Research Article

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First evidence of diverging migration and overwintering strategies in glaucous gulls (*Larus hyperboreus*) from the Canadian Arctic

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Abstract: Many seabird populations differ in their migration strategies, where individuals travel in different directions to separate wintering areas. These migratory strategies may expose individuals to different threats, thus understanding migratory connectivity is crucial to assess risks to populations. Glaucous gulls (*Larus hyperboreus*) are generalist predators with flexible migratory behaviour that may alter these behaviours in response to climate change and anthropogenic activities, such as access to landfills, yet little is known about their migration. We deployed GPS and GLS tracking devices on glaucous gulls from Coats Island, Nunavut, Canada to obtain the first insights into their migration and habitat use outside of the breeding season. Gulls used two migration strategies during the non-breeding season, where one migrated as far as the Sea of Okhotsk in the Pacific and the remainder ($n = 7$) wintered in the North Atlantic. Gulls primarily overwintered in pelagic (56%) and coastal (38%) habitats. While in coastal habitats, one gull visited one landfill once, but visits increased with a 1 km and 3 km buffer, suggesting that urban glaucous gulls primarily used non-landfill habitats. This research can be used as a baseline to explore changes in migratory behaviour and inform future conservation of Arctic-breeding gulls.

Keywords: Animal movement; Habitat use; Geolocator; Landfill; Seabirds

1 Introduction

Understanding seabird movement year-round is essential to understand life history, identify seabird hotspots and assess risks to seabird populations [1, 2]. Moreover, as migratory marine predators, seabirds can be used as indicators of biological changes in the marine environment [3]. Thus, knowledge on seabird migration and overwintering strategies can also inform conservation measures for the marine environment in which they use.

The development of miniature tracking devices, such as Global Positioning Systems (GPS) and solar Global Location Sensors (GLS), allows us to examine individual movements at finer scales to determine how seabirds use certain habitats during migration. Importantly, migration routes and habitat use can differ among individuals in a population [4–6], and populations can exhibit a migratory divide where individuals travel in different directions to multiple, distinct wintering areas [7]. Variation in migration routes and habitat use may expose seabirds to different risks, thus understanding migratory connectivity is crucial to assess threats to seabird populations.

In the Arctic, seabirds are subject to a variety of threats, including anthropogenic stressors such as fishing activities, shipping activities and landfill use, as well as climate change [8, 9]. For example, changes in sea ice concentrations can influence seabird prey [10], migration strategies and habitat use [4, 11]. Indeed, as climate change impacts increase, both fish and seabird ranges are predicted to shift northward [10, 12], however, there remains a large knowledge gap in the migration strategies and habitat use of some Arctic gulls. To assess the impacts of climate change and inform marine protected areas in the Arctic, it is essential to have a baseline of how these indicator species use these regions.

Glaucous gulls (*Larus hyperboreus*) are circumpolar, generalist predators that breed along northern coasts in open tundra and coastal cliffs [13]. These large gulls have a diverse diet that includes fish, invertebrates, small mammals, bird eggs or chicks, and also anthropo-

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genic debris [13]. This foraging behaviour may change in response to climate change and anthropogenic activities [13], such as changes in sea ice or access to landfills. Many gull species are known to forage at landfills, which can provide an easy, energy-rich prey source that may benefit populations [14], but can also result in increased contaminant loads (e.g. halogenated flame retardants) [9, 15]. Though glaucous gulls have high contaminant loads in the Arctic [16, 17], and garbage has been found in their diet [14], there is little information on their migration and habitat use [13], making it difficult to understand where these gulls may acquire contaminants and how we can mitigate potential impacts on gull populations.

As climate change continues to alter the Arctic environment [18], and anthropogenic activities continue to increase [19], understanding seabird migration and habitat use will be increasingly important. We deployed GPS and GLS tags on glaucous gulls from Coats Island, Nunavut, Canada to provide the first insights on glaucous gull migration from the Arctic. Our objectives were to: 1) examine the variability, overlap and individual repeatability in migration and overwintering strategies of glaucous gulls from the Canadian Arctic; 2) examine the non-breeding habitat use of glaucous gulls from the Canadian Arctic; and 3) investigate the relationship between glaucous gull migration and landfill sites.

2 Methods

2.1 Study area

Akpatordjuark (Coats Island) is a 5,498 km² low-lying island situated in northern Hudson Bay, Nunavut, Canada (Figure 1; Francis 2015). This island is inhabited by a variety of seabird species, including approximately 2% (60,000) of Canada's thick-billed murre (*Uria lomvia*) population near Cape Pembroke (62°57' N, 82°00' W; Figure 1), Iceland gulls (*Larus glaucoideus*; 50 pairs), glaucous gulls (30 pairs) and a variety of tundra-nesting shorebirds [21, 22]. This region has been identified as an Important Bird Area [23] and a key marine habitat site for migratory birds in Nunavut [24] and the Canadian Arctic [22].

2.2 Tag deployment and recapture

Breeding glaucous gulls from Coats Island were captured on-nest using noose poles in 2017 and 2018. In July 2017, we deployed six GLS tags (MK3005, British Antarctic Survey)

on gulls by attaching the tag to plastic leg bands using cable ties and super glue. GLS loggers collected light level data at 10-min intervals, wet/dry state was recorded at 3-sec intervals, and temperature data were recorded after 20-min of continuous wet state with repeated measurements every 4-hours. In June – August 2018, we captured gulls as above and deployed seven GPS loggers (4-Sterna and 3 Kite-M, Ecotone); devices were equipped with solar panels and UHF long-range download for retrieving data remotely. GPS loggers were attached using leg loop harnesses [25] made from Teflon ribbon (Bally Ribbon Mills). We programmed GPS devices to collect location fixes at 4-hour intervals throughout the non-breeding period. GLS-tagged gulls were recaptured on nest as above in June – July 2018/2019 (after 1 or 2 years) and tags were removed. GPS data were downloaded remotely the following breeding season. All individual glaucous gulls were numbered according to their band number.

2.3 GPS and GLS data analyses

For GLS data, we used the TwGeos package [26] to estimate twilights, with a light threshold of 15. We generated two location estimates per day using the probGLS package [27]. The probabilistic algorithm used a solar range of -10° to 3°; 3°C maximum sea surface temperature (SST) difference; 0.5°C SST standard deviation; 2,000 particles, and 100 iterations. Random latitudes were generated for 21 days around the spring and fall equinoxes. We included a movement model in location estimates based on available wet-dry sensor data with different movement rates for periods when the logger was dry (mean: 15 m/s, SD: 5 m/s, max: 25 m/s) or wet (mean: 1 m/s, SD: 1.3 m/s, max: 5 m/s). The temperature and wet/dry sensors of MK3005 loggers only recorded data for the first year of deployments; therefore, location estimates for 2018-2019 tracks were based only on light-level data.

We estimated migration timing by identifying preliminary ranges based on all locations for each individual in summer (Jun – Sep) and winter (Jan – Mar). Kernel density estimates were calculated for each individual in each winter with the kernelUD function in the adehabitatHR package [28] using a 5x5 km grid in Albers Equal Area projection and a smoothing parameter of 40 km. The 99th percentile of the utilization distribution was used to define a preliminary winter range. The start and end of fall migration period was defined as the last date each individual was within its summer range and the first date it arrived on its winter range. Likewise, timing of spring migration

was defined as the last date each bird was within its winter range and the first date it arrived on its summer range.

To examine overlap within and between individual wintering areas, we recalculated kernel density estimates based on all wintering locations, using the method described above. Winter ranges were defined by the 90th percentile of the kernel density estimate. Overlap between pairs of individual utilization distributions was calculated using the Bhattacharyya's affinity method [29] with the 'adehabitatHR' package [28]. We report the mean, min and max overlap between all individuals using the same wintering area in 2018-2019. We also examined individual consistency in wintering area by calculating overlap

between the 2017-2018 and 2018-2019 wintering areas for individuals tracked over two non-breeding seasons.

Analyses were performed using R version 3.6.3 [30]. Unless otherwise noted, summary statistics in text are means $\pm$ standard deviations.

2.4 Habitat use

To determine habitat use, we classified GPS and GLS locations as either coastal, pelagic or inland. Due to the potential error of GLS tags (approximately 200 km) [31], we did not analyze habitat use in more depth. We obtained coast-

Figure 1: Study area of Coats Island (62°57' N, 82°00' W), Nunavut, Canada where glaucous gulls (*Larus hyperboreus*) were tracked during the 2017-2018 and 2018-2019 non-breeding seasons.

line shapefiles from the National Oceanic and Atmospheric Administration National Centers for Environmental Information (version 2.3.7, intermediate resolution) [32]. Locations were classified as coastal if they were ≤ 10 km inland to ≤ 50 km from the coastline, inland if they were > 10 km from the coastline inland and pelagic if they were > 50 km from the coastline to the sea [33]. Since GPS tags record three times more locations per day than GLS tags, and three birds had two bird-years (see Results), we averaged habitat use for each individual bird-year before calculating overall proportions of habitat use.

2.5 Landfill use

To assess if gulls used landfills during the non-breeding period, we excluded GLS-tracked gulls because GLS error is too high [31] to determine exact positions. We used the Intersect tool in ArcMap v. 10.7.1 [34] to determine if GPS positions intersected with landfill sites in Canada (polygon shapefile from the Government of Canada) [35]. Other bird species have been reported to forage at landfills and rest near the landfill in between foraging bouts [36]. Thus, we also created a 1 km and 3 km buffer around each landfill site and repeated the above analyses to determine the number of times a gull falls within a landfill or landfill buffer during the non-breeding period.

3 Results

3.1 Migration and overwintering areas

We recovered GLS devices from three individuals (50% recapture rate), one in 2018 and two in 2019, for a total of 5 track years. All remaining GLS devices had either fallen off the leg bands or the individuals could not be recaptured in subsequent breeding seasons because they had moved to inaccessible breeding sites within the cliff colony. We downloaded GPS data from five individuals in 2019. The sixth gull returned to the colony in 2019 with the GPS unit still attached, but data could not be downloaded. One individual (134773232) was tracked using GLS in 2017-2018 and then GPS in 2018-2019.

Glaucous gulls used two distinct wintering areas, one in the northwest Atlantic and the second in the Sea of Okhotsk, Russia (Table 1, Figure 2). Six of the seven gulls wintered in the northwest Atlantic, ranging from the Gulf of St. Lawrence north to Davis Strait and east to southwest Greenland and the mid-Atlantic ridge. The one gull

Table 1: Migration summary for GPS- and GLS-tracked glaucous gulls (*Larus hyperboreus*) from Coats Island, Nunavut, Canada, during the 2017-2018 and 2018-2019 non-breeding seasons. Migration routes include Hudson Strait (HS), Southern Hudson Bay (SHB), and Beaufort Sea (BS). Wintering areas include the North Atlantic (NA) and the Sea of Okhotsk (SO).

Individual	Sex	Year	Tag type	Fall route	Fall start date	Fall end date	Fall duration (days)	Wintering area	Maximum distance (km)	Winter duration (days)	Spring route	Spring start	Spring end	Spring duration (days)
134773221	U	2017-2018	GLS	HS	2017-12-26	2017-12-29	3	NA	1,464	131	HS	2018-05-09	2018-05-15	6
		2018-2019	GLS	HS	2018-12-16	2018-12-27	11	NA	1,785	108	HS	2019-04-14	2019-04-22	8
134773227	M	2018-2019	GPS	SHB	2018-10-14	2018-12-27	74	NA	2,415	106	SHB	2019-04-12	2019-04-27	15
134773232	U	2017-2018	GLS	BS	2017-10-19	2017-12-17	59	SO	6,465	138	BS	2018-05-04	2018-05-31	27
		2018-2019	GPS	BS	2018-10-13	2018-11-28	46	SO	6,294	157	BS	2019-05-04	2019-05-24	20
134773235	U	2017-2018	GLS	HS	2017-12-20	2017-12-23	3	NA	1,599	124	HS	2018-04-26	2018-04-27	1
		2018-2019	GLS	HS	2018-11-10	2018-12-28	48	NA	2,430	118	HS	2019-04-25	2019-05-04	9
134773237	M	2018-2019	GPS	SHB	2018-10-06	2018-12-07	62	NA	2,324	129	SHB	2019-04-15	2019-04-23	8
134773677	M	2018-2019	GPS	HS	2018-11-16	2018-12-24	38	NA	2,588	124	HS	2019-04-27	2019-05-06	9
154752741	F	2018-2019	GPS	SHB	2018-11-13	2018-12-07	24	NA	2,457	139	HS	2019-04-25	2019-05-10	15

that wintered in the Sea of Okhotsk (134773232) returned there in both winters it was tracked.

Gulls used three migration corridors in fall and winter (Figure 2). An over land route between Southern Hudson Bay and the Gulf of Saint Lawrence was used for 30% of tracked migrations in fall and 10% in spring. Hudson Strait was used on 50% of tracked migrations in fall and 60% in spring, although one individual using this route travelled partly over land through northeastern Canada. The gull that wintered in the Sea of Okhotsk travelled west overland following rivers until reaching the Beaufort Sea, then travelled along the coast of the Beaufort Sea until reaching the Bering Sea. Fall migrations (37 ± 26 days) were longer on average longer than spring migrations (12 ± 8 days), although both were highly variable (range 3 – 74 and 1 – 27 days, respectively; Table 1). The first fall migrant

left in early October and the last migrant left at the end of December. Spring migrations began in mid-April and all birds had departed their wintering areas by the second week of May. On average, gulls spent 127 ± 15 days on their winter range (Table 1).

There was moderate overlap in wintering areas among those gulls that wintered in the North Atlantic during 2018-2019. On average, each wintering area overlapped with the wintering areas of four other gulls (range: 2 – 5). There was substantial variation in the degree of overlap across individuals; the mean amount of overlap among wintering areas was 18.4% (range: 0.0 – 70.0%). The highest overlap occurred for the three gulls that used the Gulf of St. Lawrence for part or all of the winter (Figure 3).

Three individuals were tracked over two years and showed different patterns of consistency in wintering

Figure 2: Migration routes of GPS- and GLS-tracked glaucous gulls (*Larus hyperboreus*) from Coats Island, Nunavut, Canada, during the non-breeding seasons in A) 2017-2018; and B) 2018-2019.

distribution (Figure 3). The two gulls that wintered in the North Atlantic had limited overlap in their wintering areas between the two years (134773221: 2.0% and 134773235: 5.1%). Both gulls wintered farther north in 2018-2019 than they did in the previous winter. One gull switched from spending the entire winter at sea in 2017-2018 to spending part of the winter inland in northeastern Canada in 2018-2019. The gull that wintered in the Sea of Okhotsk had significant overlap in its wintering home range between years (134773232: 78.1%). The datasets analyzed during

the current study are available in the Movebank Data Repository (<https://doi.org/10.5441/001/1.tj948m64>; Baak et al., 2021).

3.2 Habitat use

Across all individuals and bird-years, gulls were primarily associated with pelagic (56% of the non-breeding period) and coastal (38%) habitats, with limited use of

Figure 3: Wintering areas (90% utilization distributions) of GPS- and GLS-tracked glaucous gulls (*Larus hyperboreus*) from Coats Island, Nunavut, Canada, during the 2017-2018 (A and C) and 2018-2019 (B and D) non-breeding seasons.

inland areas (7%; Figure 4). The gull that wintered in the Sea of Okhotsk had the most positions in pelagic habitats, whereas the gull with the most positions inland (134773221) spent part of its overwintering period on land in northeastern Canada (see Figure 3). Finally, the three gulls with the most positions in coastal habitats (154752741, 134773237, 134773227) wintered in the Gulf of St. Lawrence (see Figure 2).

3.3 Landfill use

One gull (154752741) visited one landfill in Inukjuak (1 visit), Quebec, near the end of the non-breeding season (early May). When a 1 km buffer was created around each landfill, three individuals (154752741, 134773237, 134773227) visited a total of 16 landfill areas (229 total visits), with an average of 76.3 ± 84 visits per individual (range 21 – 173). The two most visited landfill areas (36 and 35 visits) were

in Mantane, Quebec found within 2 km of the Gulf of St. Lawrence. Finally, when a 3 km buffer was created around each landfill, the three individuals visited a total of 18 landfill areas (654 total visits), with an average of 218 ± 176 visits per individual (range 105 – 421). Again, the two most visited landfill areas (115 and 80 visits) were in Mantane, Quebec.

4 Discussion

4.1 Migration and overwintering strategies

Our study reveals that glaucous gulls from the same nesting colony do not use the same migration and overwintering strategies during the non-breeding season. Wintering areas differed greatly in location, where one gull went as far as the Sea of Okhotsk in the Pacific and the remain-

Figure 4: Habitat use of A) GLS- and B) GPS-tracked glaucous gulls (*Larus hyperboreus*) from Coats Island, Nunavut, Canada, during the 2017-2018 and 2018-2019 non-breeding seasons.

der wintered in the North Atlantic. To our knowledge, this is the first study using tracking devices to examine the migration and overwintering strategies of glaucous gulls in the Canadian Arctic. Previous knowledge was primarily obtained from aerial or at-sea seabird surveys, limited band recoveries and personal observations, which cannot be connected to a specific population and are mostly outdated or unpublished [13]. Thus, despite our small sample size, we provide key insights on the migratory connectivity of this Arctic-breeding seabird.

Gulls that wintered in the North Atlantic had two main overwintering strategies. Gulls either migrated through Hudson Strait or across Hudson Bay and north-eastern Canada to waters in the Gulf of St. Lawrence or the Labrador Sea, respectively. The most common migratory route was through Hudson Strait and into Labrador Sea, which may be the result of the higher productivity levels in the Hudson Strait compared to Hudson Bay [37]; gulls likely chose this route following prey abundance. Indeed, both the Hudson Strait and Labrador Sea have been identified as important hotspots during the breeding and non-breeding seasons for a variety of seabird species [2], including black-legged kittiwakes (*Rissa tridactyla*) [38, 39], ivory gulls (*Pagophila eburnea*) [4] and Ross' gulls (*Rhodostethia rosea*) [40]. Thus, our data reinforce the importance of both of these regions for migratory seabirds.

While we only have multi-year tracks for three glaucous gulls, the overlap of overwintering locations of individuals between years differed among them. The gull that overwintered in the Sea of Okhotsk was remarkably consistent in its overwintering home range, whereas the two gulls that wintered in the North Atlantic wintered farther north in 2017-2018 than they did in 2018-2019. This could be the result of changes in sea ice, as the 2017-2018 non-breeding season was an abnormally low year for sea ice cover in the Labrador Sea [41]. This may have caused glaucous gulls to winter in more northern regions following ice-associated prey, such as Arctic cod (*Boreogadus saida*) [13]. However, little is known about glaucous gull feeding ecology and ice association during the non-breeding season [13], thus these ideas merit further study. Collectively, these results suggest that Arctic-breeding glaucous gulls experience both inter- and intra-individual variation during the non-breeding period.

Arctic-breeding gulls can have high variation or strong fidelity in migration strategies and overwintering locations [5, 42, 43]. Davis et al. [7] recorded a similar migratory divide in Sabine's gulls (*Xema sabini*) from the Canadian High Arctic, where gulls also travelled to either the Pacific or Atlantic Ocean during migration. These divides can

occur when there are multiple, suitable wintering areas that can be reached from a breeding colony with similar energetic costs [7, 44]. Individual differences that cause these divides may be attributed to a variety of factors, such as sex [6], movement between colonies, or historical colonization from multiple populations [7]. Therefore, whether migration strategies of individual glaucous gulls are flexible, or fixed and inherited, this migratory divide suggests that this population would be more resilient to different anthropogenic risks and changing conditions than specialist species that rely on a certain diet or habitat during the non-breeding period [45]. Our limited sample size inhibits further analysis of inter- and intra-individual variation, thus additional studies at this and other eastern Arctic colonies are encouraged to further our understanding of individual variation in migration and how this may impact the survival and/or breeding propensity of these Arctic-breeding gulls.

4.2 Habitat use

Glaucous gulls spent the majority of their overwinter period in pelagic and coastal habitats during the non-breeding period, consistent with other Arctic-breeding gulls [4, 7], where some also spend time inland, including in urban areas [5, 6]. Previous records [13], citizen science observations [46], and at-sea seabird surveys [47] of glaucous gulls from these regions are also in line with our findings, where glaucous gulls are primarily recorded in pelagic and coastal areas. Specifically, data from Eastern Canada Seabirds At Sea (ECSAS) surveys [47] on glaucous gull distribution during the non-breeding season are remarkably similar to that of our findings; glaucous gulls are primarily pelagic and coastal and concentrated in the North Atlantic (Figure 5), though these data are concentrated in the western Atlantic and are not available for Russia. Additionally, while our tracking data only include adult glaucous gulls that were breeding at the time of capture, ECSAS surveys include breeders, failed breeders and immature gulls, which suggests that glaucous gulls may have similar distribution among age classes. This would have important implications for juvenile survival and recruitment, thus this idea merits further research. Importantly, our data also highlight the use of other pelagic environments, such as the Sea of Okhotsk, which is not recorded in citizen science observations of this species [46]. This demonstrates that citizen science observations alone are not sufficient to estimate seabird abundance and distribution [48] and that tracking studies

Figure 5: Comparison between A) GPS and GLS positions of glaucous gulls (*Larus hyperboreus*) from Coats Island, Nunavut, Canada, during the 2017-2018 and 2018-2019 non-breeding seasons; and B) Eastern Canada Seabirds at Sea (ECSAS) glaucous gull sightings and survey efforts during the non-breeding period (October to May) from 2006 – 2020.

play an important role to generate information in marine habitats largely absent of human observers.

4.3 Landfill use

While using coastal habitats, few glaucous gulls visited landfill sites in contrast to other gull species [15, 49, 50]. With no buffer around landfills, only one gull visited one landfill once. However, the number of gulls and visits per gull increased with the addition of both a 1 km and 3 km buffer. It is possible that the gulls foraged at a landfill and then moved outside of the landfill to rest, as bald eagles are often observed to do (*Haliaeetus leucocephalus*; Elliott et al. 2006), however, these areas also host a variety of other anthropogenic features (e.g. residential areas, wastewater basins, fish-processing plants, other sources of food waste). Ring-billed gulls (*Larus delawarensis*) from Quebec, Canada have been reported to visit landfills near their colonies, but also other anthropogenic sources in these communities, including residential and industrial areas, wastewater basins and agricultural fields [15,

49]. Thus it is more likely that gulls are associating with urban areas in general, visiting a variety of anthropogenic sources that may include, but are not limited to, landfills. The landfill sites in Mantane, Quebec in the Gulf of St. Lawrence are in coastal areas, thus it is also likely that those gulls are foraging in coastal waters near communities and/or utilizing fishing vessels [13]. Importantly, communities are the main source of anthropogenic debris to the ocean [51], thus gulls foraging in these areas may still be at risk of exposure to anthropogenic debris and associated contaminants [49, 52]. Moreover, because glaucous gulls have a high trophic position in the food web, they may be exposed to additional contaminants through their diet. The occurrence of a migratory divide could benefit this population; the gulls that spend the majority of their winter in pelagic habitats (e.g. Sea of Okhotsk) with presumably less anthropogenic pollution sources will likely have less contaminant exposure than those who primarily associate with urban, coastal areas such as the Gulf of St. Lawrence. Therefore, future research dedicated to examining the relationship between gull movements, anthropogenic sources and contaminant levels is encouraged.

5 Conclusions

Climate change is an increasing threat to Arctic wildlife. As ocean temperatures warm and sea ice decreases, the distributions of seabirds and their prey are shifting [10, 12], and impacts on seabirds and other marine mammals are now apparent (e.g. changes in phenology and reduced body condition) [53, 54]. Thus, understanding the migratory movements and overwintering patterns of seabirds is of increasing importance. This study can be used as an initial baseline for monitoring changes in the non-breeding distribution of glaucous gulls in the northern Canada, an area under significant threat to climate change [18]. This research further reinforces the importance of the Hudson Strait and Labrador Sea as biological hotspots for seabirds [2], and also highlights the importance of the Sea of Okhotsk as a wintering area for glaucous gulls breeding in the Canadian Arctic.

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