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Tracking Diel Activity and Foraging Patterns of Breeding Glaucous Gull *Larus hyperboreus* on Bjørnøya

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Natural Resource Management

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Abstract

Knowledge on diel activity, habitat use, and foraging patterns are fundamental to understanding a species' ecological role. Especially for species in decline such ecological knowledge is key when managing populations. Glaucous gulls *Larus hyperboreus* at Bjørnøya have been exposed to high levels of persistent organic pollutants for more than 50 years, resulting in dramatic effects on the population. Though this is likely a result of diet and role as apex predator, detailed insight into diet and, especially, foraging patterns remains limited. In an attempt to close this knowledge gap, 12 breeding glaucous gulls were monitored with nest cameras and GPS at Bjørnøya in the Barents Sea in 2024. By combining data on food provisioning from nest cameras with fine-scale GPS tracking we aimed to document both temporal and spatial trends in foraging behaviour. The glaucous gulls did not display any clear diurnal activity patterns in food provisioning, with foraging occurring continuously throughout the polar day. GPS data revealed exclusive use of the coastal habitat, with minimal behavioural plasticity in terms of both general area use and foraging patterns. Social aggregation sites were frequently used. However, nest attendance was prioritized, with approximately 80% of the time spent at the nest. Prey was sourced locally, averaging only 87 meters way from the nest, and no trips exceeded 5.5 km from the nest site. Guillemot chicks and capelin were the most common identified preys, with the latter most likely being obtained through kleptoparasitism. The results found foraging to occur continuously throughout the polar day and predominantly near the nest site, aligning with the initial hypotheses and predictions. Through small home ranges, breeding glaucous gulls at Bjørnøya exhibit a high degree of site fidelity. The results provide a valuable foundation for knowledge-based management.

Samandrag

Å forstå døgnaktivitet, habitatbruk og næringssøksmønster er grunnleggjande for å forstå ein arts økologiske rolle. Særleg for artar i tilbakegang er slik økologisk kunnskap avgjerande for kunnskapsbasert forvaltning. Polarmåse *Larus hyperboreus* på Bjørnøya har vore utsett for høge nivå av persistente organiske miljøgifter i meir enn 50 år, noko som har hatt dramatiske effektar på bestanden. Dette kjem truleg av dietten og artens funksjon som toppredator i eit arktisk marint næringsnett. Trass dette, er inngåande kunnskap om diett, og spesielt, furasjeringsmønster under hekking noko avgrensa. I eit forsøk på å tette dette kunnskapsgapet vart 12 hekkande polarmåsar overvaka med reirkamera og GPS loggarar på Bjørnøya i Barentshavet, under hekkesesongen 2024. Ved å kombinere data på byttedyrleveringar frå viltkamera med GPS-sporing på individnivå, var målet å dokumentere diett samt tidsmessige og romelege trendar for næringssøk. Polarmåsane viste ingen tydelege døgnmønster, der både byttedyrleveringar og generelt aktivitet fann stad kontinuerleg under det polare døgnet. GPS-sporing viste at polarmåsane utelukkande nytta seg av kysthabitatet, med minimal intraspesifikk åtferdsmessig plastisitet. Dei oppsøkte regelmessig sosiale samlingsplassar, men reirtilhald vart prioritert, med om lag 80% av tida brukt i ro ved reiret. Byttedyr vart predatert lokalt, i gjennomsnitt berre 87 meter frå reirlokaliteten, og ingen meir enn 5,5 km frå reiret. Ungar av lomvi og lodde var dei vanlegaste identifiserte bytta, der lodde truleg vart tileigna gjennom kleptoparasittisme. Resultata viser at næringssøk skjer kontinuerleg gjennom det polare døgnet og nært reirplassen. Gjennom særs små kjerneområde utviser hekkande polarmåsar på Bjørnøya høg grad av stadtruheit. Resultata dannar eit verdifullt grunnlag for framtidig kunnskapsbasert forvaltning.

Contents

1. Introduction

The Arctic region is home to a wide range of endemic species (Lydersen & Kovacs, 2006; Meltofte et al., 2013). The Barents Sea is especially rich in biodiversity and serves as a key habitat for numerous seabirds (Mehlum et al., 1994). Seabirds are commonly used as indicator species for the marine environment (Parsons et al., 2008; Gill et al., 2011). They hold a variety of different foraging strategies, engaging in important predator-prey interactions across food webs, making them suitable as indicators of the environment (Barrett, 2002; Natsukawa & Sergio, 2022). Population decline in seabirds can therefore reveal larger ecosystem change.

Since the 1950s, seabird populations have been in globally decline (Paleczny et al., 2015). Negative population trends are evident for species breeding in the Norwegian Arctic (Fauchald et al., 2015; Hanssen, 2023). Changes in climate and food availability are key factors to this decline (Grémillet & Boulinier, 2009; Fauchald et al., 2015; Capuzzo et al., 2018; Dias et al., 2019; Descamps & Strøm, 2021). The glaucous gull *Larus hyperboreus* is part of this trend (Petersen et al., 2015), particularly the population on Bjørnøya. Since initial monitoring began in 1987, the breeding population has declined by more than 80% (Descamps & Strøm, 2021).

Contaminants, particularly persistent organic pollutants (POPs), have been implicated as one of the main drivers behind this decline (Erikstad & Strøm, 2012). As top predators, glaucous gulls are especially vulnerable to bioaccumulation of heavy metals and POPs, which has been linked to lower survival, fecundity, body condition and even death during chick rearing (Gabrielsen et al., 1995; Bustnes et al., 2000; Bustnes et al., 2003; Sagerup et al., 2009). These impacts ultimately compromise population viability (Erikstad & Strøm, 2012). To understand how glaucous gulls are exposed to these pollutants and to develop effective management strategies, it is essential to study their foraging patterns – specifically what they consume, when they feed, and where they forage.

Predation on eggs and chicks is a prevalent foraging strategy among glaucous gulls that nest in proximity of other seabird colonies (Stempniewicz, 1994; Gaston et al., 2009). At the southern tip of Bjørnøya, guillemots *Uria spp.* constitute a large part of the glaucous gulls diet (Sørensen, 2021; Fiskum, 2024), contributing to elevated levels of POPs (Bustnes et al., 2000). Additionally, the diet consists of a variety of fish and crustaceans *Crustacea*, particularly capelin *Mallotus villosus* and sandeel *Ammodytidae* (Strøm, 2006; Sørensen, 2021; Fiskum, 2024). Composition of diet is influenced by prey availability, which in turn can be affected by environmental conditions and the diurnal activity patterns (Gilchrist et al., 1998; Sørensen, 2021). Availability of prey is especially important during breeding when energy demands are elevated (Martin, 1987).

Arctic breeders face a short and intense breeding season, dictated by the short summer characteristics of high latitude environments. The brief breeding window can be partially offset by continuous daylight, contributing to shorter nestling periods observed in arctic breeders (Karplus, 1952). The environmental timing cues of light and dark are strongly associated with the circadian clock and thus activity patterns (Roenneberg & Foster, 1997; Devlin & Kay, 2001). As the difference between dark and light becomes less pronounced in Arctic conditions, diel activity in arctic breeders differ from that of boreal species. This results in continuous arrhythmic or weakly rhythmic activity patterns (Karplus, 1952; Steiger et al., 2013; Wojczulanis-Jakubas et al., 2020).

Studies on the glaucous gull have found overall diel activity to be continuous, with no clear diurnal rhythm (Sørensen, 2021; Fiskum, 2024). However, certain prey types appear to be associated with specific parts of the day, likely reflecting availability. Sørensen (2021) reported that fish had a higher chance of being delivered between 08:00-10:00. In contrast, avian prey did not display any significant diurnal pattern, implying relatively consistent availability.

The absence of a defined diurnal activity pattern implies a constant energy demand, which during breeding can strain parental resources (Drent & Daan, 1980). This is in turn made worse by stressors such as POPs, as the mobilization of fat reserves results in the release of high concentrations into the bloodstream (Sagerup et al., 2009). To reveal if prey-diel-activity is directly linked to predator-prey interactions, information on habitat use is essential. Understanding not only when, but also where the glaucous gulls forage is crucial to assess these interactions and their potential role in population decline. Knowledge of habitat use during breeding remains limited for the glaucous gull.

The rapid advancement of global positioning system (GPS) technology with smaller and less intrusive devices, has expanded the opportunities for fine scale tracking and behavioural studies (Strøm et al., 2021). Tracking data supported by home range analysis is a useful tool in terms of conservation efforts (Hays et al., 2019). Effective conservation actions are also reliant on identifying key areas and habitat use throughout all life stages (Strøm et al., 2021). Furthermore, understanding a species habitat use is essential when assessing a species ecological function (Krausman, 1999), and crucial when managing populations undergoing declines (Norris, 2004). Gaining further insight into the glaucous gull's ecological role is thus essential for providing a good knowledge basis for future management.

A pilot study by Fiskum (2024) documented small home ranges for the glaucous gulls, with individuals rarely venturing more than a few hundred meters from land. The integration of GPS data and camera trap observations suggested that prey was acquired close to the nests site, and that fish prey likely was stolen from other seabirds. In general, the gulls operated on a very local scale. However, the study was constrained by a limited amount of data (Fiskum, 2024). The present study builds on the work initiated by Sørensen (2021), and aims to verify and expand on the preliminary findings of Fiskum (2024). By doing so, it aims to advance our understanding of glaucous gull foraging ecology – knowledge essential for effective species management and conservation.

During the 2024 breeding season, six nests and 12 individual glaucous gulls were monitored at the southern tip of Bjørnøya. Nests were equipped with camera traps to monitor prey deliveries and diel activity. To study habitat use, individuals were tagged with light weight high resolution GPS loggers throughout the nestling period.

The primary objective for this thesis was to combine temporal data on prey and prey deliveries with spatial GPS tracking data. This approach provides a more nuanced understanding of the gulls foraging patterns and behaviour. By enabling analysis of where prey items likely are collected, deeper insight into the temporal and spatial dynamics of glaucous gull foraging ecology is gained.

The combined use of GPS data and camera trap data is a novel approach, and to my knowledge applied to the glaucous gull only once; in the pilot study by Fiskum (2024). Building on this, this thesis further refines and expands the methodology. Similar approaches have been applied to other seabirds such as Atlantic puffins *Fratercula arctica* (Fayet et al., 2021) and Sandwich Terns *Thalasseus sandvicensis* (Fijn et al., 2024).

Additionally, the thesis reports breeding successes between monitored and non-monitored nests. Though becoming less and less invasive, the biological interference loggers pose may still have negative effect (Symons & Diamond, 2019).

Aiming to monitor food provisioning, diel activity and area use in breeding Svalbard glaucous gull *Larus hyperboreus Gunnerus*, I hypothesize that:

1.2 Hypothesis

1. Glaucous gulls forage in relative closeness to nest site.
    - ➢ Predicting guillemots from nearby colonies to be a common prey and that kleptoparasitism occur, causing fish to appear in diet.
    - ➢ Predicting foraging to occur in the coastal habitat and no offshore feeding.
    - ➢ Predicting habitat use to be limited, and that the extent of GPS positions are limited to nest area, socializing areas and in between. In line with what previous research indicated.
2. Glaucous gulls show temporary absence of diel activity during continuous daylight
    - ➢ Predicting food provisioning to occur continuously throughout the polar day. In line with previous studies.
3. Monitored nests do not have lower breeding success.
    - ➢ Predicting that the use of camera traps and GPS-loggers are low invasive methods that do not affect breeding success.

2. Materials and Methods

2.1 Study Area

Data collection was conducted on the southern tip of Bjørnøya, the southernmost island of the Svalbard archipelago (Figure 1). Located at 74°26 N 19°02 E, in the western part of the Barents Sea, daylight is continuous from May 1st until August 10th (Meterologisk Institutt, n.d.). Mean July temperatures are that of the high arctic: <7°C (Meltofte et al., 2013; Norsk klimaservicesenter, 2025). Despite its Arctic location, the climate is relatively mild. This is due to the island's proximity to the Polar front, i.e. zone where warm Atlantic water mixes with colder Arctic water (see Figure 1) (Loeng, 1991; Sakshaug et al., 1994).

The mixing creates a highly productive area in terms of primary production and fish stocks (Loeng, 1989; Sakshaug et al., 1994; Nøst Hegseth, 1998). An average of 70% of the total biomass of capelin *Mallotus villosus*, cod *Gadus morhua*, haddock *Melanogrammus aeglefinus* and herring *Clupea harengus* can be found is this part of the Barents Sea (Eriksen et al., 2011). Combined with its strategic location in a high productive environment, Bjørnøya also offers suitable breeding habitat including steep cliffs, thus becoming one of the largest breeding areas for Arctic seabirds in the North Atlantic (Gabrielsen, 2009).

For the glaucous gull, Bjørnøya constitutes the southernmost part of its breeding range in Svalbard (Strøm, 2006). It also holds the largest breeding concentration, with an estimated population size of 700 breeding pairs (Erikstad & Strøm, 2012). Breeding pairs can be found all around the island (Artsdatabanken, n.d.). This study was conducted on the southernmost part of the island, in Evjebukta and at Kapp Kolthoff (Figure 2). The landscape is here characterized by steep cliffs and large dense colonies of common guillemots *Uria aalge*, Brünnich's guillemots *Uria lomvia* and black legged kittiwakes *Rissa tridactyla* (Bakken & Mehlum, 1988; Theisen, 1997).

The gulls at Kapp Kolthoff have been subject to long term population and contaminant monitoring since 1986 (Descamps & Strøm, 2021). In 2020 a project using automated camera traps were initiated. This study is the third season of camera monitoring on Kapp Kolthoff.

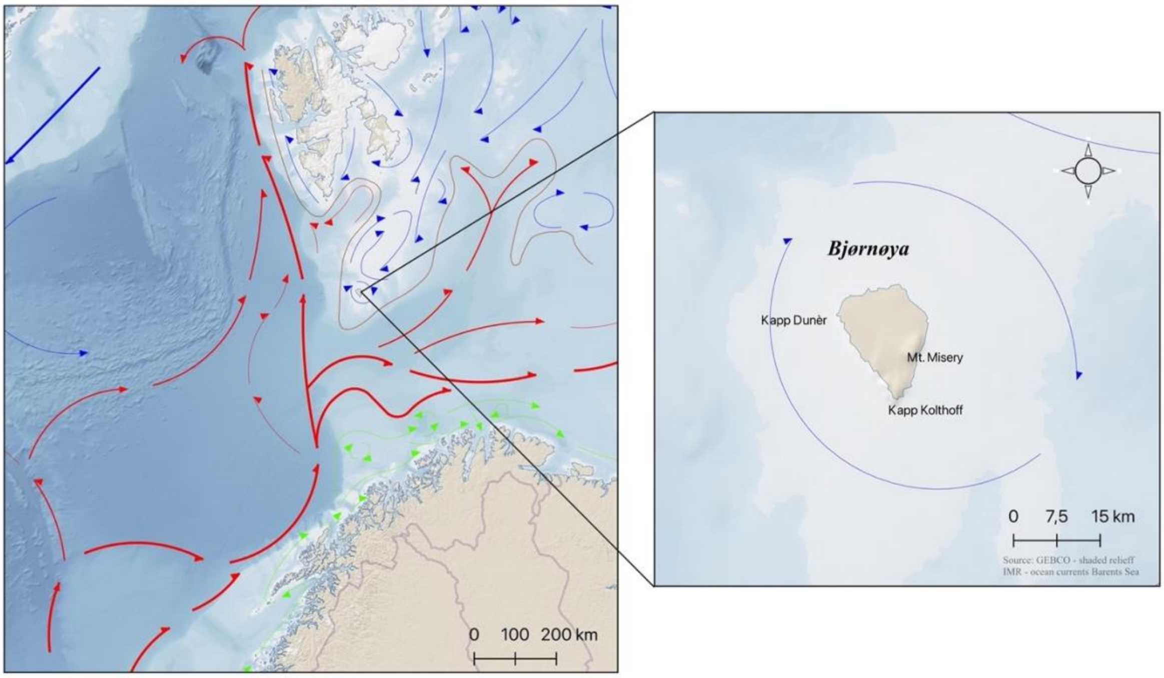


Figure 1. Map showing the western Barents Sea and northern part of the Norwegian Sea. Bjørnøya is situated on the polar front (brown line) were warm Atlantic water masses (red) meets cold Arctic water masses (blue).

2.2 Study Species

The glaucous gull in Svalbard *Larus hyperboreus Gunnerus* is one of four recognised subspecies in its circumpolar distribution areas (Burfield & van Bommel, 2004; Petersen et al., 2015). As a K-selective species it lives up to 20 years, with a generation time at 11 years (Erikstad & Strøm, 2012; Stokke et al., 2021). It breeds in pairs with shared parental investment. Two to three eggs are usually laid, and incubated for ~27-28 days (Strøm, 2006). Pairs return to same nesting location each year around April-May and are protective of it. Nests are placed either isolated or in small colonies, often close to other bird colonies (Samelius & Alisauskas, 1999; Strøm, 2006; Gaston et al., 2009). Birds breeding on Bjørnøya winter in the open waters of the Barents Sea and North Atlantic as far south as Iceland and northern parts of the Norwegian coast (SEATRACK, 2025).

Alongside the great skua, the glaucous gull is considered one of the aerial predators of importance in Svalbard (Strøm, 2006). It is an opportunistic forager, consuming a wide range of prey including fish, crustaceans and eggs or chicks from other seabirds (Strøm, 2006; Sørensen, 2021). Kleptoparasitism is also a reported strategy (Stempniewicz & Iliszko, 2010; Varpe, 2010; Fiskum, 2024). Especially gulls that breed close to other seabird colonies specialize in preying eggs, hatchlings and kleptoparasitism (Hatch, 1970; Stempniewicz, 1994; Bustnes et al., 2000; Gaston et al., 2009).

As a top predator, the glaucous gull is highly susceptible to bioaccumulation of persistent organic pollutants. Already in 1972, were individuals on Bjørnøya found to contain high levels of these contaminants (Bogan & Bourne, 1972). Given that organochlorines are considered a key driver of population decline (Erikstad & Strøm, 2012), the species has become a bioindicator for the European Arctic (Verreault et al., 2010). In addition to contaminant exposure, the Bjørnøya population is also subject to predation by arctic foxes *Vulpes lagopus* (Strøm, 2006).

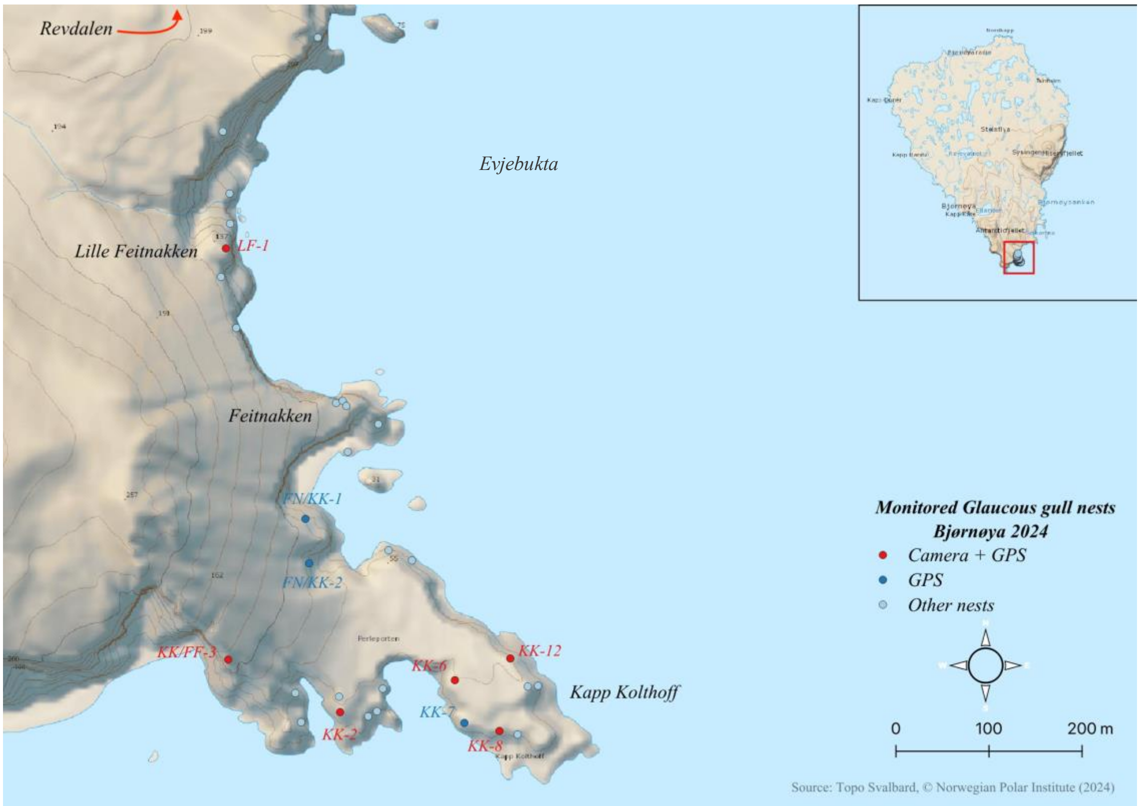
2.3 Study Design

In June-July 2024, six nests ranging from Lille Feitnakken (LF) to Kapp Kolthoff (KK) were monitored using camera traps (Figure 2). All nest locations were located on the outskirts of guillemot colonies. Several of them only 1-2 meters from breeding common guillemots *Uria aalge*, and no nests were more than 20 meters away. At each monitored nest at least one adult was equipped with a GPS-logger. At two nests, both adults were equipped. In addition, four adults from three other nests, that were not camera monitored, between Feitnakken (FN) and KK were equipped with GPS loggers (Figure 2).

Camera sets used for monitoring consisted of two camera types (sec. 2.4.1). The cameras were placed within one to four meters of the nest bowl, with one camera closer than the other, as this was believed to give a more detailed view of the different prey types delivered (Figure 3). The placements and distance of camera to nests was determined by the accessibility to the nest and local topography. As a result, some placements were better than others in terms of field of view, feeding places and area for chicks to wander. Placements methodology from previous studies, Sørensen (2021) and Fiskum (2024), was reviewed and replicated for result comparability.

Data on prey deliveries were analysed and combined with GPS tracking data to reveal the gull’s foraging patterns, specifically where prey was obtained compared to nest site.

Based on indications that the gulls are very local, it would be difficult to determine foraging trips solely from GPS-tracks. The GPS data therefore had to be interpreted in relation to confirmed food provisioning events. By combining information on food provisioning and GPS-tracks, foraging patterns could be more reliably analysed.



Source: Topo Svalbard, © Norwegian Polar Institute (2024)

Figure 2. Study area and location of glaucous gull nests.

2.4 Data Collection

2.4.1 Camera monitoring

For recording prey deliveries, two different complementary camera traps were used. Reconyx Hyperfire PC850 and PC900 cameras (Reconyx Inc., Holmen, WI, USA) with a passive infrared motion sensor for event triggered images and Brinno TLC300 time lapse cameras (Brinno Inc., Taipei, Taiwan) for continuous footage. Reconyx cameras were used for determining prey species as the images were of higher resolution. They were placed one to two meters from where chicks were assumed to be fed; nest bowl or designated feeding areas (Figures A1, A2, Appendix A).

Brinno cameras were used with the intention of capturing a broader overview of the gull's activity pattern due to its superior field of view (118°), and capture deliveries Reconyx would not. Therefore, they were placed two to four meters from the nest bowl. Combining the two cameras facilitated for data collection of prey composition and diel activity.

The motion sensor on the Reconyx was set to high and took images in series of three with no delay, stored as JPG-image files. Brinno cameras were set to take one pic/sec, recording independently of movement and stored as AVI-video files (time-lapse video). Both camera types used Panasonic eneloop pro NiMH (model BK-3HCDE) rechargeable AA-batteries, and SanDisk Extreme SDXC (32-128 GB) memory cards (SanDisk, 2025).

Demanding constant power supply when recording over longer periods of time (>1 day, with given settings (1 pic/sec)), Brinno cameras were connected to an additional lithium-ion battery (Biltema lithium-ion performance safety long life, 12 V 3-5 Ah), via a USB socket (12V Kayoba marine, Jula art.nr. 650454) (Figure A3, Appendix A). This was done to avoid larger gaps in the time series, as experienced by Fiskum (2024). Lithium-ion batteries were packed in plastic zip-loc bags to avoid short circuiting and providing some waterproofness. Preliminary testing resulted in battery change every $3^{1/2}$-4th day. Testing was done in foggy conditions with low temperatures (<4 °C). This however turned out not to be the case during the sampling period. Due to memory card limitations on Brinno cameras, these needed to be changed every second day. Image size varied greatly and is thought to have a connection with weather and image complexity. Sunny days and clear skies increased image complexity compared to foggy and rainy days with poor visibility. Some periods could accumulate 100 GB over the course of two days but usually 75-80 GB (memory card capacity was 128 GB). To avoid larger gaps in time series, memory cards where therefor changed every second day, giving the gulls 48 hours of no direct disturbance. Some nests were visited every day in the start to adjust camera angle and check that everything was running as expected.

Camera checks every other day also proved necessary as the lens of Brinno cameras tended to fog up causing very poor image/focus quality. Rain droplets on the lens also caused challenges. Changing memory cards every other day however allowed these challenges to be dealt with at an early stage.

Some gaps in the monitoring occurred, but never both cameras at the same time. I experienced this with both Brinno and Reconyx. Overall, the Reconyx were deemed more reliable, as were they in Fiskum (2024).

Chicks start to wander around the nest site with older age (>10 days) (Sørensen, 2021). Prey deliveries can therefore become hard to record. Not all camera placements were ideal, and nest varied in susceptibility to camera monitoring. Especially KK-2 was challenging due to limited space and variable topography, unlike LF-1 (Figures A1, A2, Appendix A). This resulted in less photos on Reconyx camera, and the view was more often blocked during potential feeding events.

The camera setups were concealed to blend in with environments and to minimize disturbance (Figure 3).

Figure 3. Camera setup at nest KK/FF-3. Reconyx to the left, Brinno to the right (in waterproof casings). Photo: Author.

2.4.2 GPS tracking

In this study we used PathTrack nanoFix®GEO + RF tags designed for glaucous gulls with remote download to a base station (PathTrack Ltd., Otley, UK). The nanoFix® have an internal lithium battery and integrated solar panel, enabling long term monitoring (depending on settings). Weighing 7.70-8.12 grams, the tags account for ~0.52% of the gull's weight (mean tag weight: 7.93 g, mean bird weight: 1537 g, Table B1, Appendix B).

Tags gather data on the bird's position according to predetermined settings. To minimize usage of storage space, data is stored as *.raw* files containing unprocessed data. When in range of a base station the data is downloaded at given intervals. Two fixed base stations were placed within 200 meters (with a clear view) of the tagged individual's nest.

In Fiskum (2024), the download rate from tag to base station was set to every second hour. Based on the small home ranges found then, this rate was set to every fourth hour to achieve longer battery life in tags and hence a longer sampling period. Before deployment, the tags were configured to take positions every 10th minute (as a minimum sampling interval) when battery life was sufficient. To extend sampling period, the interval between each position increased as the battery level decreased. This setting gave approximately two days of positions every 10th minute. At the end of the sampling period (>20 days) the tags would take one position every 40th minute before running out of battery.

Birds were caught with foot snares adjacent to the nest. GPS tags were fitted to the birds four middle tail feathers using white tesa® 4651 (tesa SE, 2024) tape and 115 mm cable ties (Figure C1, Appendix C). The cable ties lock was super glued shut using LOCTITE® super glue precision (Loctite, Henkel Ltd., 2024). This method seemed to secure the tags well. Handling time, which also included biometric measurements and biological (blood and feather) sampling, was on average 20 minutes. All GPS tagged individuals had previously been ringed (both metal and plastic ring with engraved code), and sex was known.

Tagged individuals were marked with black wax paint to distinguish which of the parents was tagged when viewing camera material. When both adults were equipped, only one was marked with wax.

During nest visits, base stations were also visited and data downloaded. *.raw* files were downloaded via USB to mac, using parallels desktop as the PathTrack software is only compatible with Windows operative systems. *.raw* files were later processed through the PathTrack Host software (version 3.17) and full GPS data was obtained as *.pos* files and used for further analysis.

2.5 Photo and Video Analysis

2.5.1 Initial data handling

All video and photo material were stored on an external hard drive (SEAGATE Expansion SW 4TB). The total material from camera monitoring was 3.27 TB. This was all analysed on a 2020 MacBook Air with 8 GB RAM. Photos from Reconyx cameras were viewed using the photo and video viewer app Apollo One (version 3.6.9 (2600)) (Anogeissus Ltd.). Time lapse videos from Brinno cameras was viewed using Behavioural Observation Research Interactive Software (BORIS) (version 8.27.7 – 2024-08-23). BORIS is an open source program designed for behavioural observations and event logging (Friard et al., 2016).

To ensure accurate prey identification, prey species were identified together with Hallvard Strøm in the early stages of photo analysis. Later, to ensure continuity, a selection of images representing all the prey categories was controlled by the aforementioned.

Prey deliveries were logged as a delivery when photos confirmed feeding of chick. (i.e. I could visually see that chick consumed food), or when this was believed to happen without reasonable doubt (i.e., parent came flying in with prey in bill). A delivery was also logged when it was clear that the parent came flying in, carrying prey in bill. This is a subjective approach, and not without limitations and flaws, but allows for flexibility. Using this approach, I could to some extent avoid logging regurgitation of pellets as a prey delivery, hence avoid false deliveries.

Prey species were classified and identified as, e.g., guillemot chicks, fish unknown or capelin. Many of the deliveries was categorized as unknown. Items within this category include tissue in different sizes and colour making it hard to determine the original form. Contributing factors were regurgitation, topography of nest site, distance, camera angle, rain and dew on lens. It is plausible that most of these deliveries are in fact pieces of for example guillemot chicks or adults dismembered elsewhere. To get the most precise prey composition possible I chose a conservative approach when identifying prey species.

As not all placements were ideal, and nest varied greatly in susceptibility to camera monitoring, a comparison between nests was difficult and not done in this study.

2.5.2 Reconyx

When viewing Reconyx images the first photo in the sequence of a prey delivery was copied to a specific folder depending on prey species and *nest ID*. If there was reasonable doubt about potential delivery it was logged as possible delivery. This was later filtered out and not included in the analysis.

Each nest was given folders for the different prey species recorded, i.e. capelin, sandeel, guillemot chick/foetus etc. In the images meta data, date and timestamps are stored. Using R these were extracted, and later manually controlled. An excel sheet on prey deliveries were then generated based on *nest ID* and sorted by time, date and prey species.

With photos triggered by motion sensor, and limited to three pictures per motion, there is a risk of logging the same delivery several times. To avoid this prey handling within ~30 minutes of another were treated on a discretionary basis. This problem was mostly related to delivery of chick prey, as they are larger than fish and egg and require more handling time for the chick to consume. Whilst fish prey was consumed directly after delivery, one chick prey could be fed multiple times.

2.5.3 Brinno

Analysing time lapse videos allowed for a deeper understanding of the overall activity pattern and usage of area around the nest site. Time lapse videos were viewed in 20x speed in BORIS. When a prey delivery occurred, the video was stopped and the event logged. The event was logged with prey species, if possible, if it was a GPS bird, or whether the delivery was by regurgitation or by bill. As with the Reconyx analysis, the ~30 minutes rule was considered, unless the delivery was without doubt a new one.

Time lapse videos would reveal that parents didn't feed directly after return to the nest site. Parents would for example lay in nest bowl for some time before moving to a feeding place and deliver prey from the crop. Often taking some time to regurgitate it. As some preys are larger than other, parents could swallow bits that the chick couldn't eat and regurgitate it at later time. This behaviour makes it difficult to sort out individual preys. Number of preys in especially chick categories should thus be treated with discretion.

Data from Reconyx and Brinno were later combined and overlapping sightings controlled to avoid double counting of prey deliveries.

Overall, the identification of prey species followed a conservative approach to minimize the number of false or uncertain. When species determination was hard, the event was just simply logged as a delivery. The Brinno cameras record more prey deliveries than the Reconyx, (Fiskum, 2024), and being harder to determine identity of prey the unknown category consequently becomes larger.

2.6 Statistical Analysis

Statistical analysis was done using R version 4.4.2 (R Core Team, 2024), with α-level 0.05. Excel was used to visualize prey composition with pie charts. QGIS version 3.34.13-Prizren (QGIS Development Team, 2025) was used to visualize results in maps. QGIS is an open-source program used to edit, view and analyse geospatial data.

2.6.1 Breeding success

Breeding success was estimated for all monitored and non-monitored nests at the colony (from Revdalen to Kapp Kolthoff), when data was sufficient (Figure 2 and Table 1). Breeding success was estimated by dividing number of assumed fledglings on number of eggs (Nice, 1957; Murray, 2000). Number of real fledglings is unknown as the field season ended prior to fledgling, which usually happen seven weeks after hatching (Strøm, 2006). Assumed fledglings, based on last nest visit, was therefor used. Difference between the two groups were then compared and analysed for statistical significance.

Three of the monitored nests were only monitored with GPS (Figure 2). Though not as disturbed as camera & GPS nests, they seemed fit to be included in the monitored category. A Welch's t-test was used to compare mean breeding success between the two groups (Lu & Yuan, 2010). A *Hedges' g* estimate was used for measuring effect size, due to small and unequal sample sizes (Hedges, 1981).

Exact breeding success is difficult to calculate for all nests from Revdalen to Kapp Kolthoff. This is mainly due to the inaccessibility of some nests, resulting in uncertain counts. Additionally, non-monitored nests were visited infrequently to check for incubation, hatching or attending chicks (ringing chicks).

2.6.2 Prey composition

When possible, prey delivered was determined to species. Prey compositions for each nest were analysed using excel and visualized with pie charts.

Prey species were later grouped into overall categories: *Aves* – all avian prey ("egg", "chick", "chick-unknown"), *Fish* – all fish prey ("capelin", "sandeel", "fish unknown"), *Other* ("unknown", "other"). The overall categories were analysed for significance through proportion testing using both a two-sided z-test with pooled proportions (Gimond, 2022) and the *prop.test ()* function from the R base package (R Core Team, 2024). The latter being a more conservative approach including continuity correction and chi-square approximation. Proportions were calculated as number of occurrences within prey category, divided by total occurrences in dataset. All prey deliveries from all nests were used as input.

2.6.3 Prey delivery

Prey delivery rate was calculated by dividing number of prey deliveries on days monitored, per nest. From this a mean was calculated.

2.6.4 Diel activity

For analysing diel activity, the *activity* package in R was used (Rowcliffe, 2023). The package is designed to analyse animal activity data from e.g. camera traps. Using time data in radians and plotting the distribution, it allows for a visualisation of overall diel activity patterns (Rowcliffe, 2023).

Timestamps from prey deliveries, both Reconyx and Brinno, were converted to time decimals (Radians: $\left(\frac{hour}{24}\right) * 2\pi$) for analysis. The analysis was run separately for four of the six nests - those monitored for more than seven days and presumed to provide high-quality data (Table 1). Additionally, diel activity across all nests was analysed by pooling prey deliveries from all nests.

Diel activity was also analysed using the GPS data. *adehabitatLT* was used to extract movement trajectories and calculate speed (distance travelled per time unit) (Calenge, 2024b). Elbow method was used to determine a threshold for identifying at-nest positions. Thresholds from 10-300 meters were tested to determine the optimal cut-off. The threshold was set at the distance where low-speed home points stabilized (at ~50 meters). This way we could classify away-from-nest events, providing data on activity. This was then fitted into the *activity* package (Rowcliffe, 2023). To examine any intraspecific plasticity, diel activity patterns were overlapped using the *overlap* package (Meredith, Ridout and Campbell, 2024) and visualized with a heatmap using *ggplot2* (Wickham, 2016).

2.6.5 Home range and habitat use

Home range was calculated using the *adehabitatHR* package (Calenge, 2024a). Traditional methods for calculating home range are both minimum convex polygon (MCP) (Mohr, 1947) and kernel density estimation (KDE) (Worton, 1989). MCP creates the smallest possible convex polygon, wrapping around all the given GPS positions. From this a home range area can be calculated. MCPs can be drawn based on percentages of the positions, were 95% of the centroids are commonly used to obtain a more precise measure by excluding outliers. KDE is a more complicated way of estimating home range size, focusing on point density. This method is helpful when identifying areas of low and high activity and thus give a more nuanced view on home range and area use. For both methods 95% and 50% are commonly used for home range and core area, respectively.

We utilized the *kernelbb* function, which accounts for autocorrelation by combining traditional kernel density estimation with Brownian bridge method (Calenge, 2024a). PathTrack reports the horizontal position error of nanoFix® to be 20 meters at the 95th percentile. This was used as the sig2-value in the analysis. We calculated 95- and 50% MCP and KDE, and results were visualized using *ggplot2* (Wickham, 2016) in R studio and QGIS (QGIS Development Team, 2025).

Moreover, the GPS data was also used to analyse the bird's relative attachment to the nest site, measured as time spent away and the number of trips taken. As for diel activity, *adehabitatLT* (Calenge, 2024b) was used to process movement and trajectory data. By combining trajectories and movement data we could estimate no. trips taken from nest and determine whether birds where in motion when GPS-positions were obtained. We applied elbow method to determine an optimal threshold for "at nest" behaviour (see chap. 2.6.4). The analysis included all GPS tracked individuals during the active nesting period (i.e. before any breeding failure). The latter was not conducted for home range analysis, as we aimed to use the most complete dataset and assess potential difference (potentially) caused by breeding failure.

2.6.6 Camera traps & GPS

Spatial Analysis – Prey-catch locations

Combining GPS-fixes and observations of prey deliveries at nest allows for temporal and spatial analysis of foraging behaviour. By doing so we could investigate where and when different prey potentially was apprehended.

The pilot study by Fiskum (2024) used a method were identified prey deliveries were seen in relation to GPS fixes within a set time interval (from 0-180 minutes prior to delivery). In this study the method has been refined and further developed.

Before combing the two dataset, different thresholds were set. Firstly, all GPS fixes outside camera-monitoring period were excluded. Secondly, deliveries from unidentified birds were excluded, keeping only deliveries that were confirmed to be from GPS birds. We then filtered out all GPS fixes that was not within a 10–40-minute time interval prior to a specific prey delivery. (Low (0-30) and high (40-70) thresholds were also tested). This was all done individually based on *bird ID* and *nest ID*. GPS fixes within the time interval was then set to represent the connected prey delivery of a certain prey, and the distance from the nest calculated. Additionally, GPS fixes within 25 meters of the nest site was filtered out to avoid assigning prey deliveries to non-hunting behaviour.

The remaining positions after filtering was categorized based on grouped prey (differently than for diet). By doing so we aimed to investigate plasticity in behavioral traits related to foraging strategies, e.g., if fish was collected differently from chicks. Prey was grouped as follows: *Fish* - “Capelin”, “Sandeel” and “Fish unknown”. *Chick* - “Guillemot chick foetus”, “Kittiwake chick foetus” and “Foetus unknown”. *Egg* - “Guillemot egg”, “Kittiwake egg” and “Egg unknown”. *Other* - “Other” and “Unknown”. The results were visualized using *ggmap* (Wickham, 2013).

Predicted distance travelled

To investigate what explained distance travelled to potential prey locations, four different models were tested. Using logistic regression and GLMM, four different models were tested with two different datasets: aggregated and with random effect.

Since each prey delivery could be linked to several GPS positions, distances from nest to potential prey location were analysed using two distinct approaches. Firstly, the dataset was aggregated by calculating the mean distances from all GPS positions recorded within the time interval of a given prey delivery. Linear mixed effects models (LME) were then used to analyse the variation in distance travelled from nest to prey location (Pinheiro & Bates, 2000). Using the *lme4* package in R, four models were tested and evaluated based on ΔAkaike Information Criterion (AIC) values (Akaike, 1974; Bates et al., 2015).

Secondly, the multiple distance measurements were treated as a random effect. The same models were tested to analyse variation and assessed based on ΔAIC values. Graphic results were made using *ggplot2* (Wickham, 2016).

Prey hotspots

To analyse spatial density distribution of the grouped prey, two different methods in R were used: *Hexbin* and Gaussian mixture model (GMM) from the *mclust* package. A Hexbin analysis divides a map into hexagonal cells and count the number of datapoints in each cell (Carr et al., 2024), enabling a visual representation of where certain prey types are collected from. A GMM uses a statistical model to estimate the density of data points and group them probalistically (Scrucca et al., 2023).

Hexbin is a quick grid-based visualisation, while GMM utilizes more advanced modelling for density estimation. Both Hexbin and GMM were conducted separately for each grouped prey category and the results visualised using ggplot2 (Wickham, 2016).

2.7 Use of AI

This thesis has utilised the artificial intelligences (AI) ChatGPT-4 (OpenAI, 2025) and Copilot (Microsoft, 2025). AI has been used to troubleshoot error codes in R, for streamlining R-scripts and as a sparring partner in critical thinking. It has also been used as a tool for language editing, primarily to improve grammar, vocabulary, and overall clarity. Under no circumstances has AI been used to solely generate content or results.

3. Results

Between the period 25th June and 20th July, a total of six glaucous gull nests were monitored with cameras (Table 1). Cameras recorded parental food provisioning during the initial stages of chick rearing, supplying data for dietary and diel activity analysis. Monitoring periods ranged from 5-23 days, mainly due to breeding success. Three out of six nests failed. Reconyx cameras took a total of 427 968 images, whilst the Brinno cameras recorded ~110 000 minutes.

Table 1. Overview of camera and GPS monitored nest. Including data on the different breeding stages.

Nest	***GPS Parent(s)***	***Monitor period***	***Original clutch***	***Hatching date***	***Hatched***	***Survived***	***Breeding failed***
KK-2	3EP	28.06-20.07	3	22-24.06	2	1	
KK-6	BU3	22.06-27.06	3	21.06	2	0	27.06
KK-8	3ES AB3	22.06-01.07	3	21-22.06	3	0	30.06
KK-12	3ER BT3	27.06-09.07	3	23.06	3	2	
KK/FF-3	CH3	25.06-02.07	3	25-26.06	2	0	02.07
LF-1	3EM	27.06-20.07	3	29.06	1	1	
KK-7	CE3* 3ET*		3	16.07	1	1	
FN/KK-1	3EN*		3	26.06	2	1	
FN/KK-2	3EO*		2	25.06	2	1	
x̄			**2.9**	**24.06****	**2**	**0.8**	

*only GPS monitored. **mean hatching date for camera monitored nests.

3.1 Breeding success

Breeding success (see Table D1, Appendix D) was compared between monitored and non-monitored nests to assess potential impacts of monitoring on reproductive outcomes. Monitored nest (n=9) had a mean breeding success of 27.67% (Figure D1, Appendix D), SD = 23.60. Non-monitored nests (n=15, originally 22 but nest without sufficient data was left out) had higher mean breeding success at 56.67%, SD = 38.79. Mean breeding success for all nest (n=24) was 45.79%. Welch's t-test revealed the difference to be significant (t (21.97) = -2.28, p = 0.033). *Hedges g* estimate was -0.822. This suggests a large negative effect between the two groups, with monitored nests having lower breeding success. However, the 95% CI (-1.699-0.055) included zero meaning there is uncertainty, and the effect might not be as strong as the point estimate suggests.

When only including camera monitored nests, difference in breeding success was still significant (t (13.27) = -2.304, p = 0.038). (Mean breeding success only camera monitored, (n=6), was 22.17%, SD = 27.27). There was a significant difference in breeding success between monitored and non-monitored groups.

3.2 Diet

3.2.1 Across all nests

Prey deliveries was collected from six different nests, amounting to 558 individual prey deliveries (Table 2). When possible, prey species was determined and registered to the event.

Table 2. All prey deliveries filtered by prey species.

Prey	***Count***	***% of count***
Guillemot *spp.* chick/foetus	129	23.12%
Kittiwake chick/foetus	4	0.72%
Chick/foetus unknown	9	1.61%
Guillemot egg	22	3.94%
Kittiwake egg	1	0.18%
Egg unknown	1	0.18%
Capelin	31	5.56%
Sandeel	2	0.36%
Fish unknown	61	10.93%
Unknown	297	53.23%
Other	1	0.18%
Total	**558**	**100%**

The following results are based on data from all nests, regardless of number of days monitored. Guillemot chicks were the most common prey delivered (23%), followed by fish unknown (11%) (Table 2). Capelin was the most common fish prey, 5.5% of the total. Guillemot eggs only amounted to 3.9% of the diet.

The unknown category was very high (>50%). Mainly due to most of the prey deliveries being delivered by regurgitation (Figure E1, Appendix E), and hence hard to identify. In addition, cameras were sensitive to rain and dew on lens, making identification of prey hard. When species determination was this hard, the event was just simply logged as a delivery.

When excluding unknown prey, guillemot chick/foetus was the most common at 49% (Figure 4). Fish unknown was 23%, followed by capelin at 12%. Guillemot egg accounted for 9%, chick/foetus unknown 4%, and kittiwake chick/foetus 2%. Sandeel was only 1% of the total. Kittiwake egg, egg unknown and other were all under 1%.

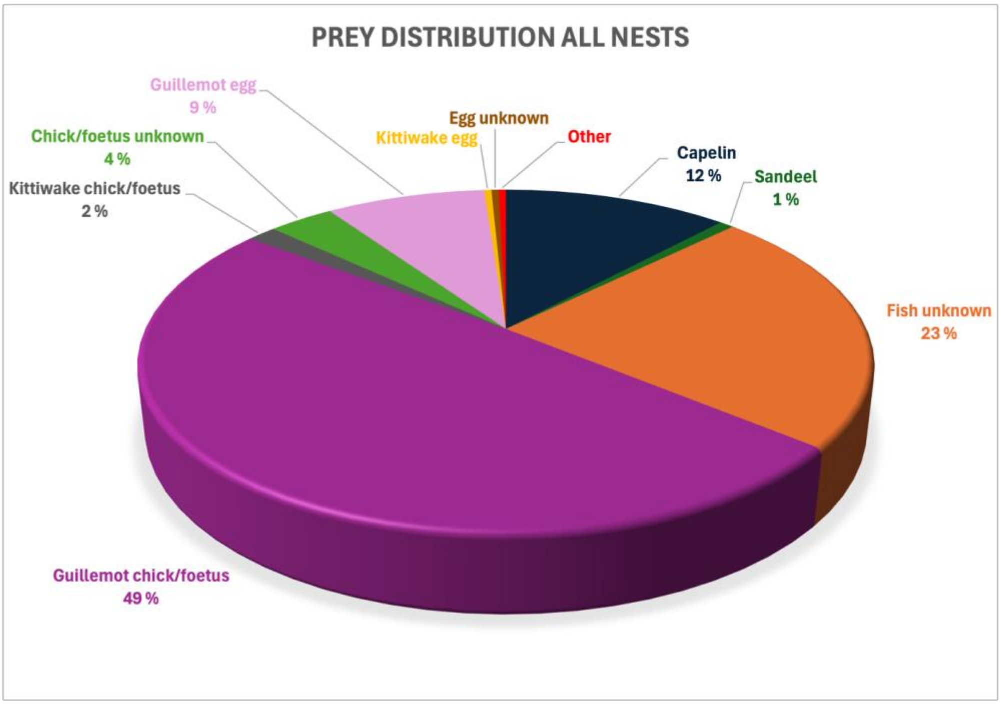


Figure 4. Distribution of identified prey species across all nests. Unknown category is left out.

3.2.2 Between nests

Four nests were analysed for prey composition, individually. These nests were considered to provide sufficient data, as they were monitored for more than seven days.

Of all prey deliveries at LF-1, 50% were categorized as unknown (Figure E2, Appendix E). Guillemot chicks (or foetuses) were the most common identified prey at 25%. Fish unknown was 15% of all prey deliveries. When determined to species, capelin was the most common fish prey, 5% of the total. Fish total was then 20%. Guillemot egg and chick/foetus unknown were both 2%. Kittiwake egg and chick/foetus were the least common, 0.5% each.

Of all prey deliveries at KK-2, 54% were categorized as unknown (Figure E2). Guillemot chicks were the most common identified prey species at 32%. Guillemot egg was 6% and fish unknown was 4% of all prey deliveries. Identification of fish prey was not possible due to local topography and cameras distance to nest and feeding places. Kittiwake chick was 2%, egg unknown 1% and other 1%. The latter was infanticide, where one parent killed the weaker chick.

Of all prey deliveries at KK-12, 64% were categorized as unknown (Figure E2). Guillemot chick/foetus was the most common identified prey species at 15%. Capelin was the most common fish, 13% of all deliveries. Fish unknown was 8%. Fish total was then 21% of all prey deliveries.

Of all prey deliveries at KK-8, 54% were categorized as unknown (Figure E2). Fish unknown was the most common prey category at 18%. Guillemot chick/foetus was 15%, and capelin 10% of all prey deliveries. Fish total was then 28%. Guillemot egg accounted for 2% of all prey deliveries, while chick/foetus unknown was 1%.

3.2.3 Preferred prey

To determine the preferred prey, overall prey categories, *Aves, Fish, and Other* (n=558), were used and analysed for statistical significance based on proportions. The proportion of *Aves* prey (n=166) was 0.297 and 0.168 for *Fish* (n=94). The difference between the two was significant (Table 3), though only just with the z-test. *Aves*-prey was a significantly larger part of the gull's diet.

Table 3. Results on proportion testing for preferred prey. A two-sided t-test and the prop.test in Rs core package was used.

Test	***Statistics***	***SE***	***95% CI***	***df***	***p-value***
z-test	Z = 2.004	0.064	0.003-0.255	-	0.045
prop.test	$x^2 = 25.277$	-	0.078-0.180	1	<0.001

3.3 Prey delivery rate

Prey delivery rate varied greatly between nests, with KK-8 having the highest rate at 9.3 prey per day and KK-12 with the lowest at 3.8 prey per day (Table 4). Mean prey rate across all nests was 6.9 prey per day.

Table 4. Monitoring periods and prey rates for camera monitored nests.

Nest	***Monitor period***	***Days monitored***	***No. prey***	***Prey rate***
KK-2	28.06-20.07	23 (22*)	163	7.08
KK-6	22.06-27.06	5 (4*)	42	8.40
KK-8	22.06-01.07	10 (8*)	93	9.30
KK-12	27.06-09.07	12 (10*)	46	3.83
KK/FF-3	25.06-02.07	6 (4*)	29	4.83
LF-1	27.06-20.07	23 (22*)	185	8.04
x̄		**13 (12*)**	**93**	**6.91**

*days monitored from first to last observed prey delivery.

3.4 Diel activity

Individual diel activity was analysed for nests KK-2, KK-8, KK-12 and LF-1, as these were considered to provide sufficient data for individual analysis (specified above). Additionally, diel activity across all camera monitored nests and all GPS tracked individuals was analysed. Neither displayed a clear diurnal activity pattern, though there were some recognisable patterns.

Based on 185 prey deliveries, LF-1 showed stable continuous diel activity (Figure 5). The least active period was early morning, just before 06:00. From heron the activity level stably increased towards a top at late evening, around 23:00, before the trend decreased again.

For aves-prey (n=56) the overall activity pattern was like the total (Figure F1, Appendix F). However, there were some highs and lows. Least activity was seen at 06:00, a slight top around noon (12:00) followed by a slight decrease, before the top was reached at 23:00. Diel activity for fish-prey (n=37) shows a pronounced peak in the afternoon (~15:00) (Figure F1). The trend increased from a low at 06:00 and decreased towards another low at midnight.

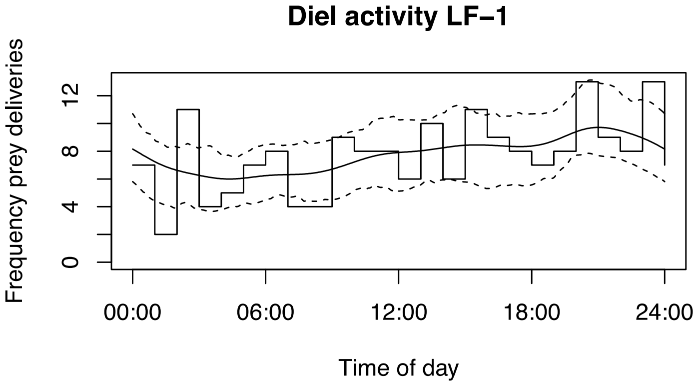


Figure 5. Diurnal activity level for nest LF-1, with 185 prey deliveries over 22 days used as input. Solid line represents mean with dashed line showing standard deviation.

Diel activity plot for KK-2 was based on 163 prey deliveries (Figure 6). Least activity was just past 12:00. Prior to this, activity level was relatively stable, with lowest activity between 00:00 and 06:00. A peak in activity was seen around 17:00. After this the trend decreased.

Aves-prey (n=66) activity level showed a marked dip from midnight towards 06:00 (Figure F1). As for the total, the peak was around 17:00. Diel activity for fish-prey (n=7) showed weak diurnal activity, likely due to low n (Figure F1). Despite this a distinctive bottom was seen at 06:00.

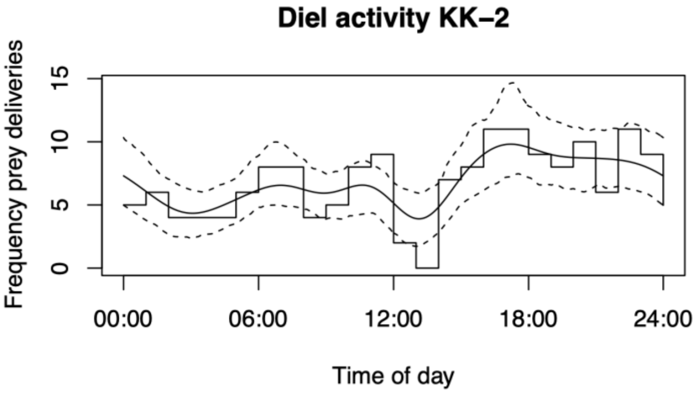


Figure 6. Diurnal activity level for nest KK-2, with 163 prey deliveries over 22 days used as input. Solid line represents mean with dashed line showing standard deviation.

Diel activity plot for KK-8 was based on 93 prey deliveries (Figure 7). The diurnal activity pattern was strikingly stable. A slight dip in the trend was just after 12:00 and before 24:00.

Aves-prey (n=17) activity level peaked around midnight and 06:00 (Figure F1). From 06:00 the trend declined towards a remaining bottom from ~13:00-18:00. Fish-prey (n=26) activity peaked at 12:00 (Figure F1).

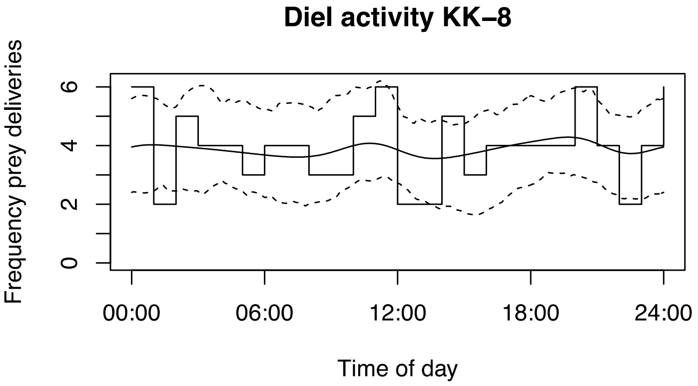


Figure 7. Diurnal activity level for nest KK-8, with 93 prey deliveries over eight days used as input. Solid line represents mean with dashed line showing standard deviation.

Diel activity plot for KK-12 was based on 46 prey deliveries (Figure 8). Activity level was stably increasing from a bottom at midnight towards a top around 07-08:00. The level then decreased towards a bottom again at 13-14:00. Another top was seen around 19-20:00. After this, the decline was marked.

Aves-prey (n=7) activity level peaked at 07:00 and 19-20:00 (Figure F1). Fish-prey (n=10) activity level peaked at 03:00, 9-10:00 and 16-17:00 (Figure F1). Lowest activity level was from around 19-24:00.

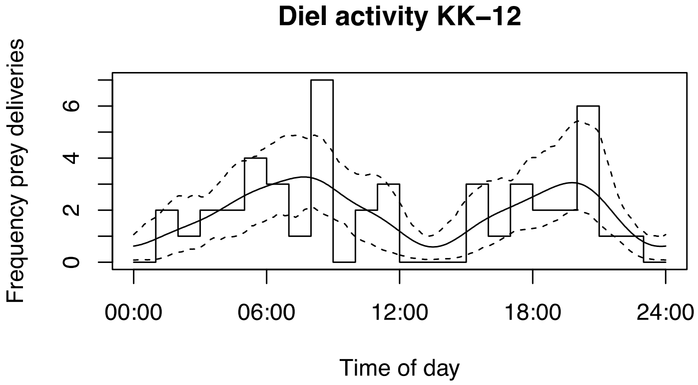


Figure 8. Diurnal activity level for nest KK-12, with 47 prey deliveries over ten days used as input. Solid line represents mean with dashed line showing standard deviation.

Diel activity for all nests was based on 558 prey deliveries from six nests (Table 2). A peak in activity level was seen late evening around 18:00-20:00 (Figure 9). A pronounced bottom was around 12:00-14:00. Overall, the activity pattern was relatively consistent.

Total aves-prey (n=166) activity level peaked towards midnight (Figure F1). Lowest activity level was early morning, 04-06:00, and 13:00. Fish-prey (n=94) activity level peaked from 12:00 until 15:00 (Figure F1). Lowest level of activity was at midnight. The trend was steadily declining from 15:00, with a distinct low is at 06:00.

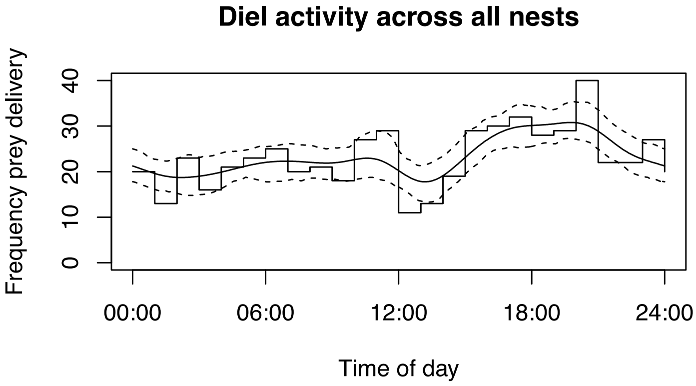


Figure 9. Diurnal activity level for all nest, with 558 prey deliveries as input. Solid line represents mean with dashed line showing standard deviation.

Diel activity by GPS revealed notable individual differences, although the overall pattern was continuous activity throughout the 24-hour cycle (Figure 10). In most cases, lowest activity occurred around midnight. BT3 (KK-12) showed a dip (among multiple dips) in activity at 12:00, aligning with the food provisioning pattern. Similarly, 3EM (LF-1) followed a pattern closely resembling that of food provisioning. AB3 (KK-8) deviated somewhat from this trend, while 3ES (KK-8) showed a more similar pattern to the food provisioning. 3EP (KK-2) also deviates from that of the food provisioning, with somewhat opposite patterns.

The consistent patterns were confirmed with a high degree of overlap (Figure F2, Appendix F), revealing little intraspecific plasticity in diel activity.

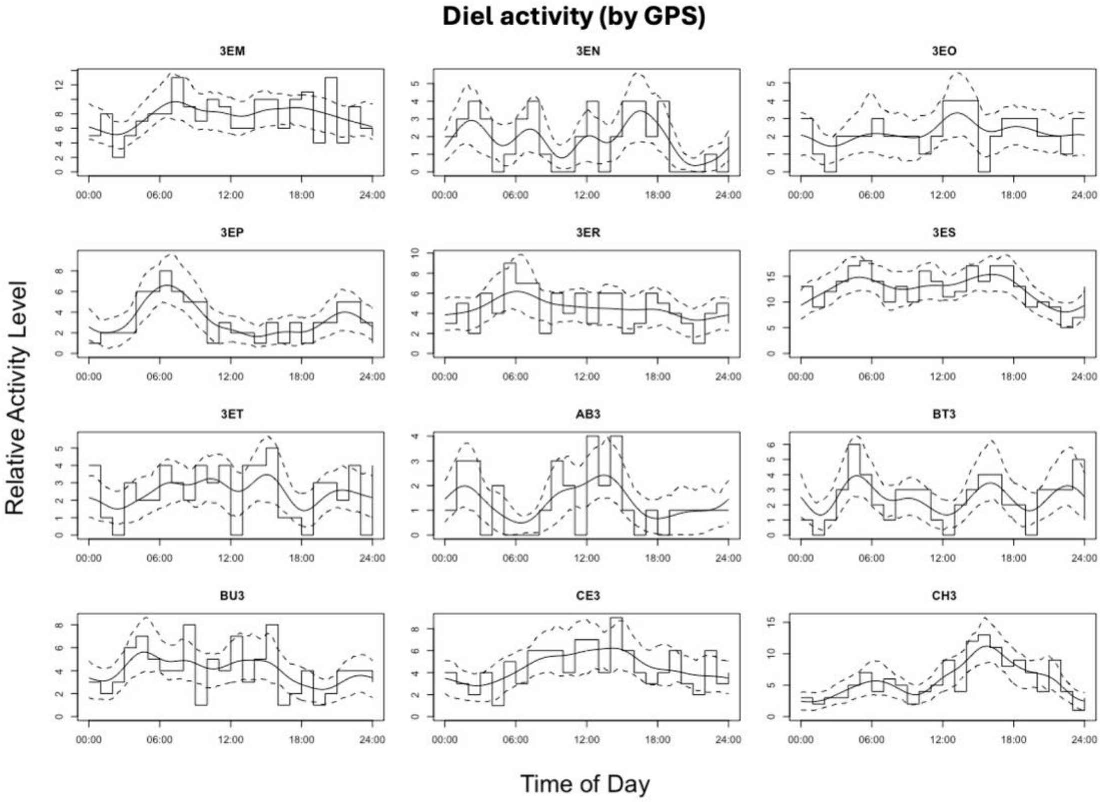


Figure 10. Diel activity across individuals, based on GPS data and away-from-nest events. Positions away from nest was calculated to ~50 meters (based on speed and trajectory).

3.5 GPS tracking

A total of 11 520 GPS positions were obtained from 12 different glaucous gulls, seven females and five males, in the period 22nd June to 25th July (Table 5). On average, GPS tags remained active for 16 days. The 95% utilization areas per individual ranged from 0.96 km^2 to 12.52 km^2, with an average of 3.78 km^2.

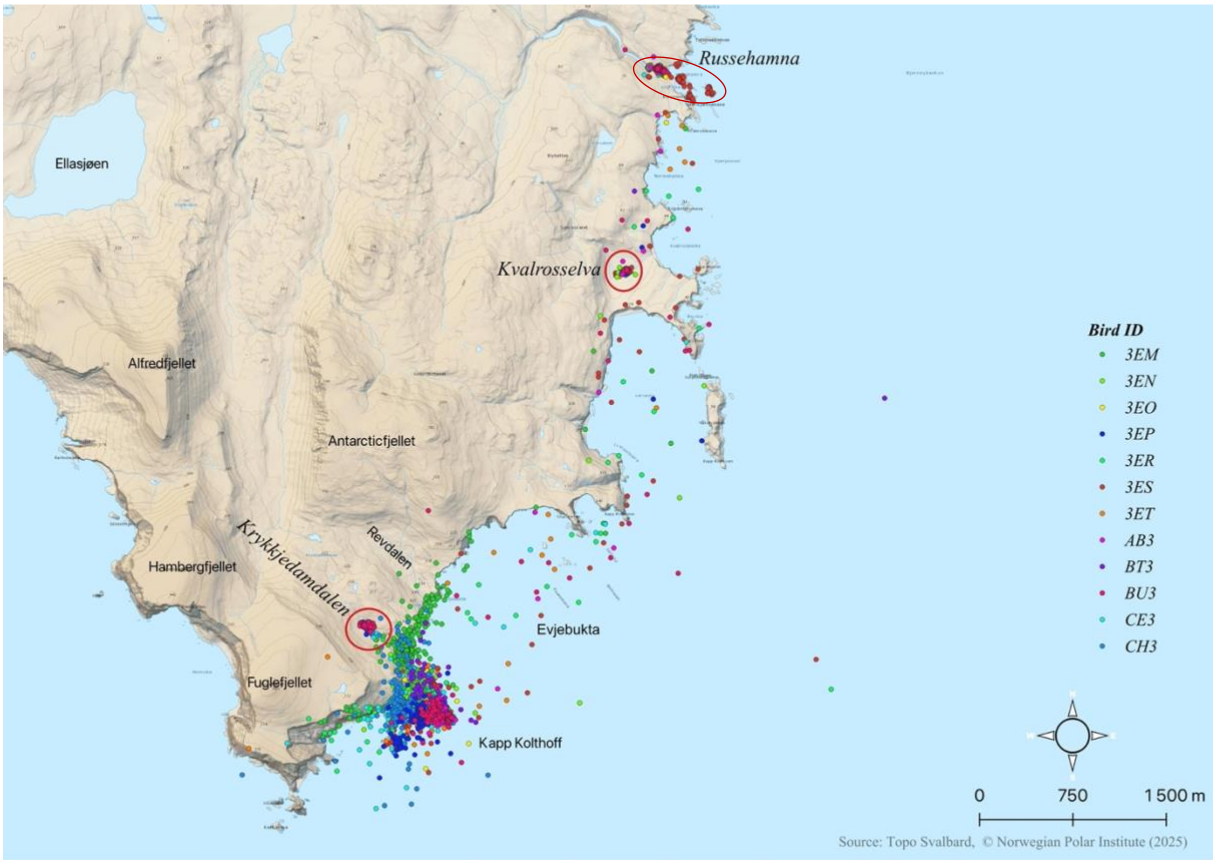
Table 5. Overview of GPS tracked individuals and their calculated home ranges.

Individual	***Tag ID***	***Sex***	***Nest***	***Deployed***	***Disabled***	***Days tracked***	***No. positions***	***MCP km^2 95% (50%)***	***kernelUD km^2 95%***	***kernelBB km^2 95% (50%)***
3EP	46046	Male	KK-2	28.06 *18:10*	13.07 *05:57*	14.5	894	0.24 (0.01)	0.78	0.96 (0.03)
BU3	46043	Female	KK-6	22.06 *19:00*	08.07 *14:48*	15.8	893	8.20 (0.21)	6.66	8.24 (0.58)
CE3	46049	Female	KK-7	28.06 *18:40*	19.07 *10:31*	20.7	1249	0.72 (0.004)	0.41	1.16 (0.06)
3ET	46036	Male	KK-7	01.07 *19:10*	18.07 *18:41*	17	962	1.50 (0.04)	2.19	4.72 (0.38)
3ES	46179	Female	KK-8	29.06 *19:10*	23.07 *12:18*	23.7	1220	7.03 (2.75)	13.49	12.52 (1.50)
AB3	46044	Male	KK-8	22.06 *19:10*	27.06 *03:06*	4.3	408	1.86 (0.01)	2.64	3.51 (0.24)
BT3	46045	Female	KK-12	27.06 *18:00*	03.07 *09:55*	5.7	569	0.09 (0.0006)	1.04	0.64 (0.02)
3ER	46051	Male	KK-12	28.06 *18:50*	23.07 *18:34*	25	1458	1.32 (0.02)	2.00	5.57 (0.48)
CH3	46048	Female	KK/FF-3	23.06 *18:40*	05.07 *18:31*	12	750	1.65 (0.09)	2.59	1.31 (0.05)
3EN	46017	Male	FN/KK-1	26.06 *20:20*	03.07 *04:15*	6.3	477	0.34 (0.02)	1.80	4.10 (0.17)
3EO	46029	Female	FN/KK-2	26.06 *20:30*	10.07 *20:20*	14	870	0.04 (0.004)	0.34	1.30 (0.10)
3EM	46050	Female	LF-1	23.06 *20:06*	25.07 *15:41*	31.8	1770	0.40 (0.007)	0.82*	1.37 (0.13)
$\bar{x}$		**7:5**				**15.8**	**11 520**			**3.78** **(0.31)**

*90% kernelUD (unable to process 95%).

3.5.1 General habitat use

The GPS-tracking revealed a relatively limited activity area. Positions obtained stretched from Kapp Kolthoff in south to Russehamna in the north (~5.5 km), exclusively in the coastal habitat (Figure 11). Most positions were concentrated near the gulls' nest sites. The locations Russehamna, Kvalrosselva and Krykkjedamdalen (red circles in Figure 13) are all known as resting and preening sites (Hallvard Strøm, personal communication, June 2024).



Source: Topo Svalbard, © Norwegian Polar Institute (2025)

Figure 11. All GPS positions obtained from the 12 glaucous gulls. Obtained in the period 22nd June – 25th July 2024. The glaucous gulls remained exclusively in the coastal habitat, travelling no further than 5.5 km from their breeding sites.

3.5.2 Home range and movement patterns

The gulls displayed relatively small home ranges and core areas (Table 5, Figure 12). Both MCP and KDE show some variation in home range size across individuals. Mean 95% home range was 3.78 km^2 (range: 0.64-12.52 km^2). Mean 50% core area was 0.31 km^2 (range: 0.02-

1.50 km^2). Despite differences in breeding success, tracking period (onset and offset) and sex, the variation was small (Table 5).

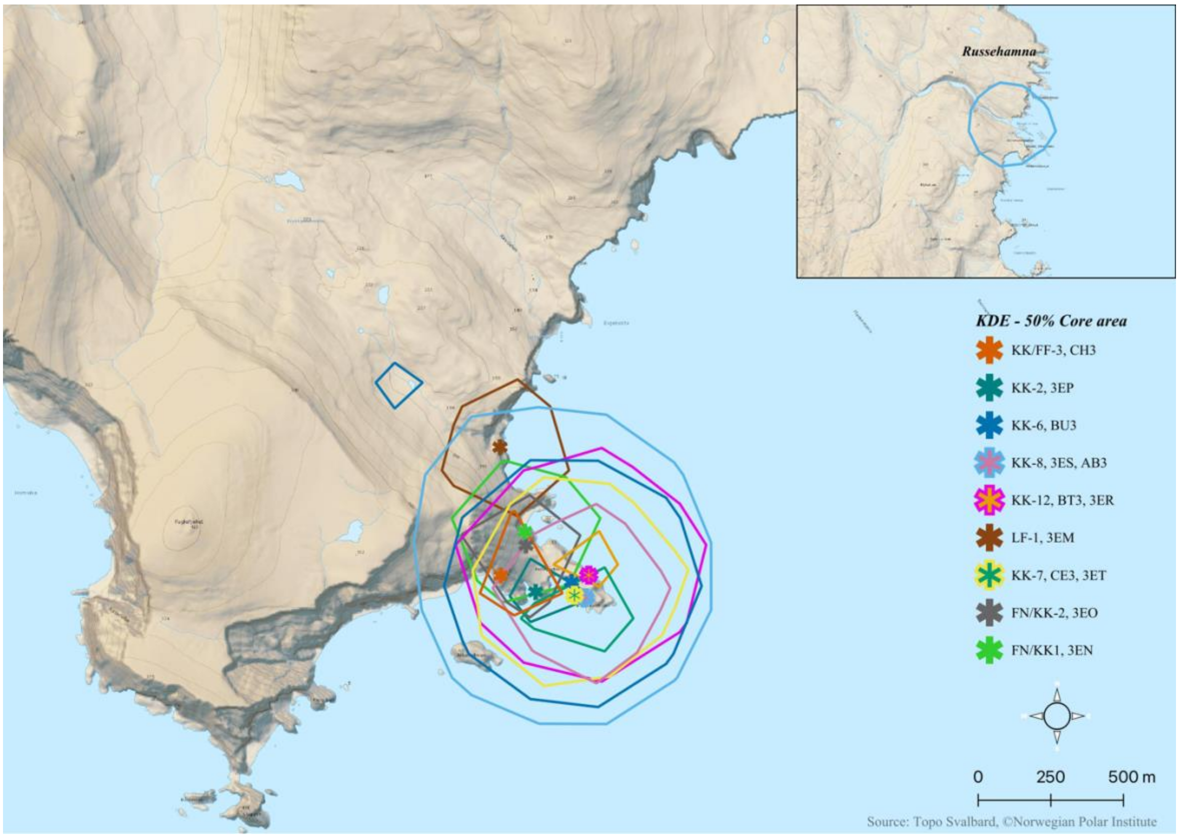
Two individuals stand out in terms of 95 % kernel density estimation. 3ES (KK-8) with the largest at 12.52 km^2 and BU3 (KK-6) with the second largest at 8.24 km^2. In both cases, breeding failed. 3ES was tagged after nesting had failed, whilst at KK-6 all chicks died shortly after initial tracking and monitoring had begun (see Table 1 and 5). The average 95- and 50% home range without these individuals was 2.46 km^2 and 0.17 km^2, respectively.

KK-7 hatched the latest (16.07.24) and CE3 was tagged 18 days prior to this, displaying a low home range of 1.16 km^2, likely linked to due to incubation of eggs. At KK-8 AB3 had a home range of 3.51 km^2, tagged at the time of hatching. This individual was only tracked for 4.5 days (picked tag off), nonetheless within chick rearing as opposed to 3ES, whose positions are less concentrated around nest site, and more at social sites, especially Russehamna.

At KK-12 BT3 and 3ER had a home range of 0.64 km^2 and 5.57 km^2, respectively. Being tracked the longest, 25 vs. 6 days, 3ER had larger home range than BT3. 3EN (FN/KK-1) had a home range of 4.10 km^2 and was tagged at the time of hatching, 26.06.24. Tracking stopped 03.07.24. 3EN did not yield positions in Russehamna, as the only one not to. At this nest the other mate (female) was found dead in Krykkjedamdalen 06.07.24. 3EO (FN/KK-2) had a home range of 1.30 km^2. This individual was perceived as particularly protective of its nest site.

Situated further away from the rest of the colony and with fewer neighbours (see Figure 2) 3EM had a home range of 1.37 km^2. This individual was tracked the longest (32 days), from before hatching until chicks were >15 days old.

Individual mapping with 50-95% KDE and trajectories can be found in Appendix G (Figures G1, G2 and G3).



Source: Topo Svalbard, ©Norwegian Polar Institute

Figure 12. Visualization of 50% core areas for all the tracked individuals.

Movement and activity patterns also revealed limited behavioural plasticity. The optimal threshold distance from nest in terms of speed and movement was 50 meters. Analysis revealed that the glaucous gulls spent little of their time in motion during different breeding stages (Figure 13). On average, only 14% of the day was spent moving. The retaining period of the day was spent standstill, mostly at nest site (Figure 14A) but also away (Figure 14B).

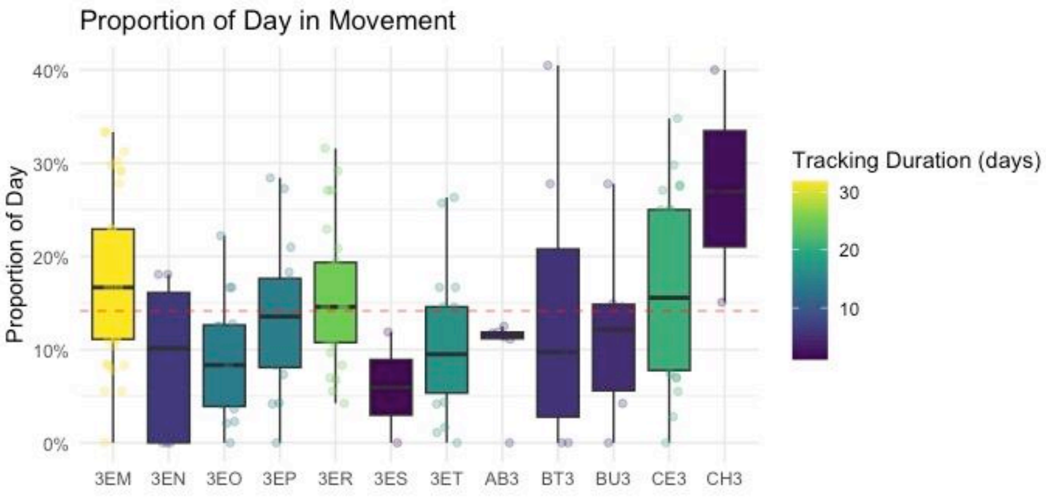


Figure 13. Proportion of day in movement, based on speed, trajectories and distance threshold from nest. Red dashed line is overall average. Dots are daily proportions of movement. Shaded relief based on tracking duration.

Just below 80% of the day was spent standstill at the nest (Figure 14A), while <10% was spent standstill away from the nest (Figure 14B), on average. The patterns are consistent, except for CH3, which stands out as being more active.

The average number of trips made per day was six (Figure 14C). The duration of these trips was on average ~20 minutes when standstill behaviour is adjusted for (Figure 14D).

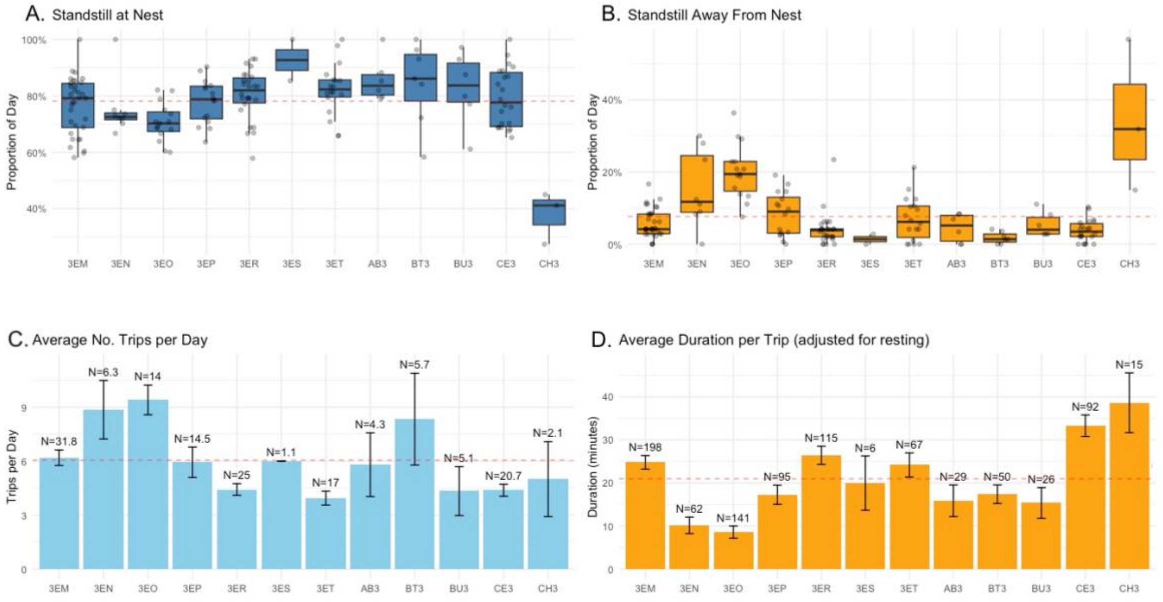


Figure 14. A: Proportion of the day standstill at nest site (approximately within 50 meters of the nest as this was the optimal cut-off threshold when applying elbow method), boxes are the interquartile range (IQR) with lines displaying range of data. B: Proportion of the day standstill away from nests (for example at social aggregation sites), with IQR and lines displaying range. C: Average no. of trips per day with error bars (+/- SE). N = number of days tracked (before any failed breeding). D: Average duration per trip with error bars (+/- SE) adjusted for standstill behaviour. N = number of trips made (before any failed breeding). Red dashed lines are overall averages.

3.6 Prey deliveries & GPS

3.6.1 Prey catch locations

175 prey deliveries were confirmed to be from seven different GPS tagged individuals. CH3 was excluded from the analysis due to only one observed delivery.

All individuals with confirmed prey deliveries showed similar trends towards potential prey locations being near nest sites (even with 25 meter threshold; Figure 15). AB3 and 3EM displayed spatially dispersed prey locations, though most were centred around the nest. 3EP, BT3 and BU3 prey locations were all closely concentrated near nest site. 3ER stand out to some extent, being very concentrated at the nest.

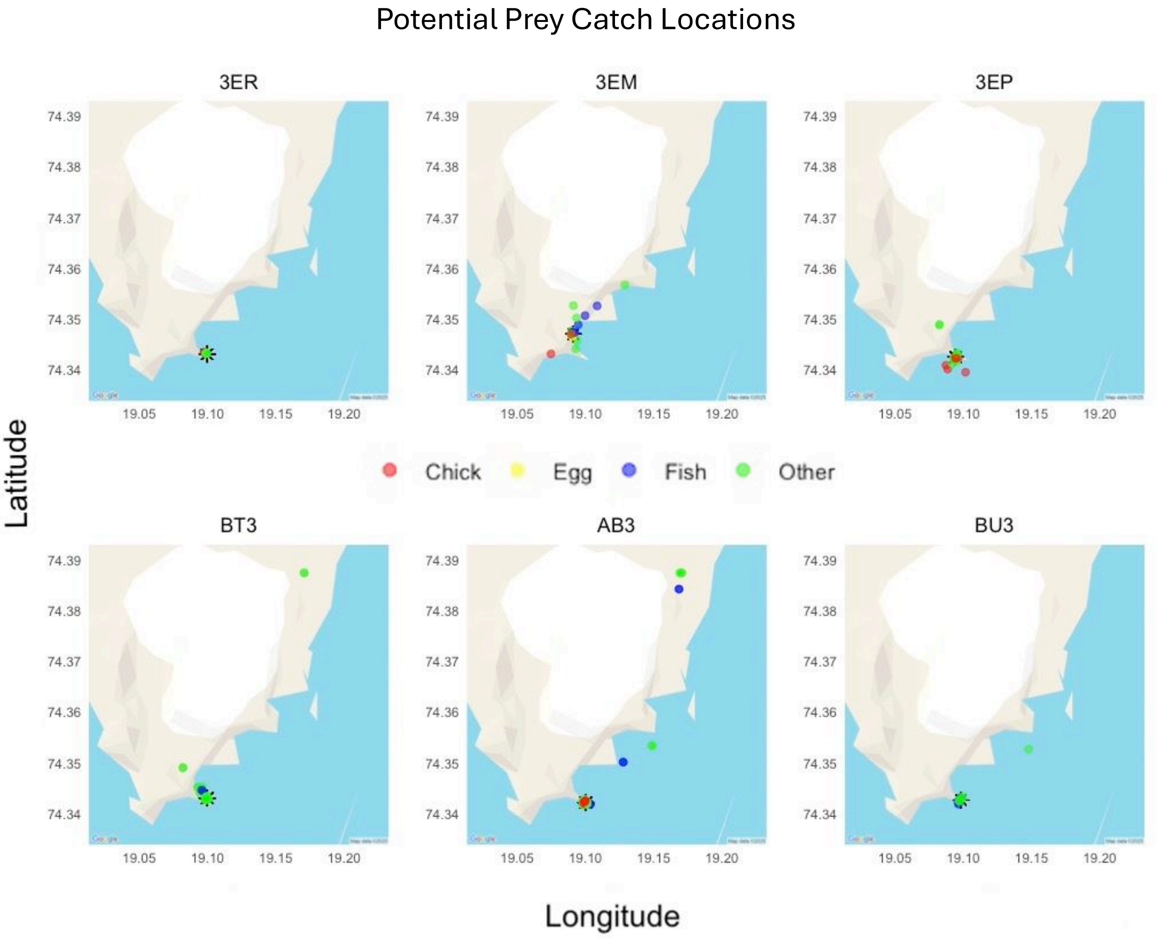


Figure 15. Spatial foraging trends of glaucous gulls related to different prey types. With 10-40-25 threshold. Black stars symbolize nest site. Colour dots are the respective birds GPS position prior a specific prey delivery. All plots show most prey catches to happen close to the nest site.

It is important to interpret the GPS positions as likely catch locations rather than definite locations where a prey was caught. The dots do not show where a specific prey was obtained, it shows positions of the gull prior to delivery of a specific prey, within the given time frame and 25 meter outside nest. The points therefor give an idea of where specific prey may have been collected, rather than definite locations.

Trajectories reveal that positions just of land (at sea) most likely are during flight, i.e. during travel from core area to social aggregation sites (Figure G3, Appendix G).

3.6.2 Predicted distance to potential prey locations

Models were tested to see what best explained the distance travelled (i.e. the potential prey locations distance to the nest) (Table 7), using two different datasets. Firstly, as there are multiple measurements (distances) allocated to single prey deliveries (one delivery but many GPS positions within time threshold), these distances were aggregated by calculating the mean distance per prey delivery. This way all prey deliveries contributed the same, independently of number of GPS positions. Secondly, the multiple measurements were treated as a random effect within *bird ID*. This way we could control for variation between and within *bird ID*, giving a more precise estimate of the effects.

Table 6. Models tested. Multiple measurements as random effect (aggregated dataset in parentheses). Threshold 10-40-25 (more and less conservative thresholds: Figure H1 and Tables H1 and H2, Appendix H). Intercept-only was the best based on ΔAIC values.

Model	***df***	***AIC***	***ΔAIC***	***Weight***
Intercept-only	4 (3)	237.951 (204.195)	0.000	0.974 (0.979)
Only grouped prey	7 (6)	245.277 (211.892)	7.326 (7.697)	0.025 (0.021)
No interaction	8 (7)	255.502 (221.548)	17.552 (17.353)	<0.001 (<0.001)
Full model (interaction)	11 (10)	270.913 (242.601)	32.962 (38.406)	<0.001 (<0.001)

Both datasets yielded equal results, where the model with only intercept fitted the data best (Table 6). As the final model only included *Bird ID* as random factor, the variation in predicted distance was best explained by individual differences, and that consistent distances are maintained throughout the foraging grounds, unrelated to i.e. prey type.

Mean predicted distance from nest to potential prey catch was 87 metres (Table 7). There are deviations from the global average in both directions (Figure 16), resulting in some individuals travelling further than others (Figure 17).

3EM and BT3 flew the furthest, above the global average (Table 7). AB3 and 3EP are closest to the global average (slightly negative). BU3 and 3ER was also below global average, with the latter flying the shortest.

Table 7. Results from the best fitted model (Intercept only), showing predicted distances from nest to potential prey catch locations. Based on average distance from nest to potential prey sites, with multiple measurements as random effect (aggregated dataset in parentheses).

Individual (nest)	***Predicted distance in meter***	***Intercept***
3EM (LF-1)	110 (104)	~ 0.1 (0.091)
BT3 (KK-12)	95 (85)	~ 0.04 (0.010)
AB3 (KK-8)	83 (87)	~ -0.01 (0.021)
3EP (KK-2)	82 (80)	~ -0.02 (-0.005)
BU3 (KK-6)	81 (77)	~ -0.03 (-0.037)
3ER (KK-12)	70 (69)	~ -0.08 (-0.081)
	$\bar{x}$ = 87	

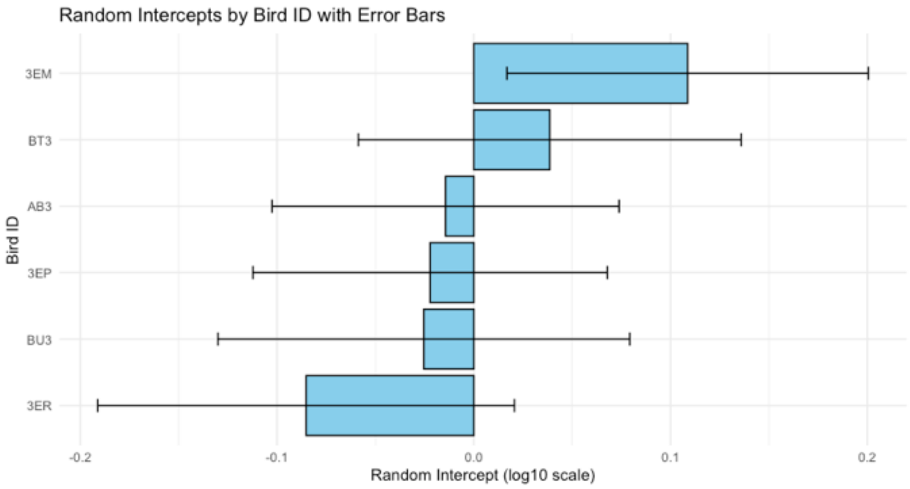


Figure 16. Random intercepts based on bird ID. With error bars indicating uncertainty of estimates. With multiple measurement as random effect. Low (0-30-35) and high (40-7-25) threshold were also tested, with similar results (see Figure H1 and Tables H1 and H2, Appendix H).

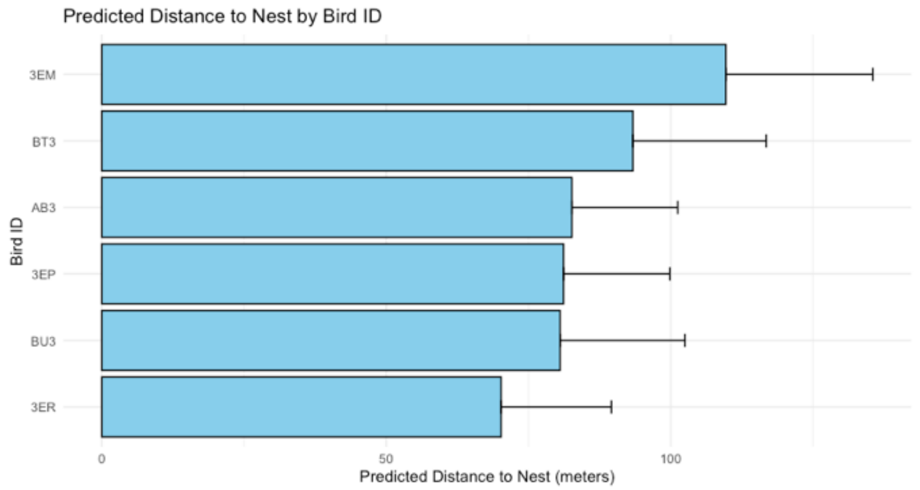


Figure 17. Predicted distance from nest to potential prey catch locations. Error bars represent the variation between prey deliveries. Low (0-30-35) and high (40-7-25) threshold were also tested, with similar results (see Figure H1 and tables H1-H2, Appendix H).

3.6.3 Prey location hotspots

To determine if the gulls visit the same, or certain, areas to obtain prey a GMM and Hexbin analysis was done. Both methods indicated that prey hotspots were concentrated near nest sites (Figure 18 and H2 (Appendix H)). The GMM plot reveals more pronounced hotspots compared to the Hexbin plot. The clearest hotspots for all the different grouped prey are observed on Kapp Kolthoff, where most nests (and consequently where most prey deliveries are recorded) are located. The hotspots are clearly centred in the immediate vicinity of the nests.

Egg prey is left out when threshold is 10-40-25; not enough datapoints.

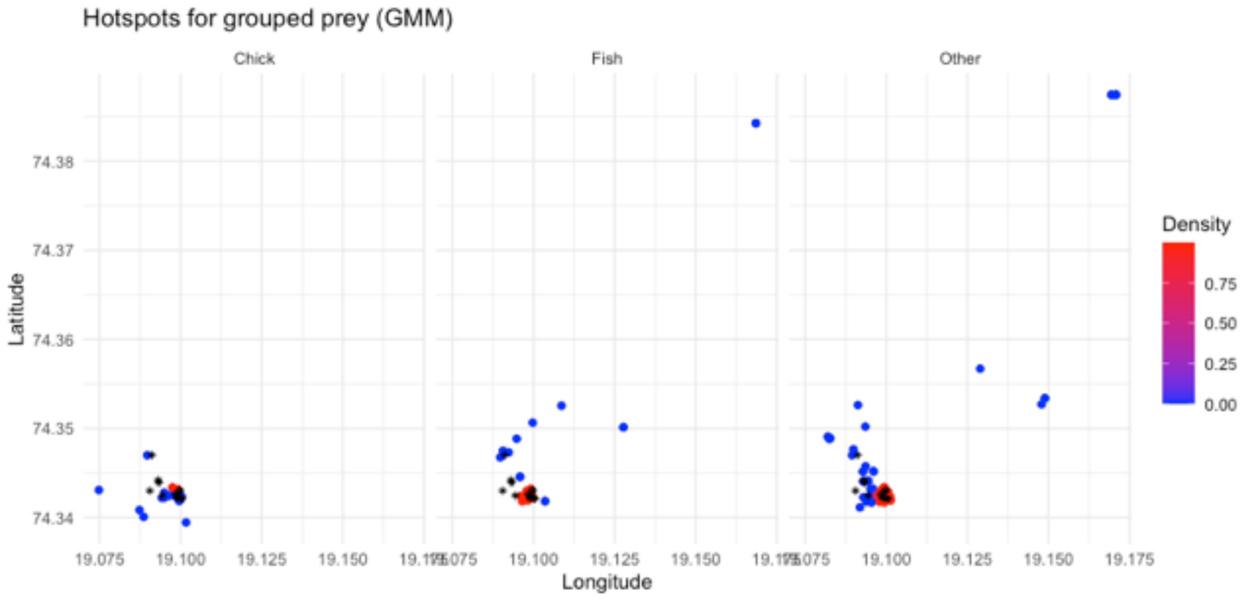


Figure 18. GMM analysis, showing areas of high and low density for grouped prey. Black dots symbolize nests. Prey are clearly concentrated near the nest sites, correlating with the surrounding seabird colonies.

4. Discussion

4.1 Overall

The gull's diet was found to mainly consist of guillemot chicks and fish, where capelin was the most common identified. Most prey were delivered by regurgitation, but bill deliveries were also frequent. Temporal analysis of prey deliveries and GPS-data did not reveal any clear diurnal activity patterns, although activity levels were generally lowest around midnight and early morning, peaking at approximately 18:00. GPS tracking revealed that the individual gulls maintained relatively small home ranges, whilst exhibiting consistent movement patterns. Furthermore, foraging was largely confined to areas near the nest site, with average distance to potential prey locations estimated at 87 meters. The short distances and prevalence of fish in the diet suggest that kleptoparasitism is a common foraging strategy. Kleptoparasitism refers to the acquisition of prey from one predator by another, occurring both intra- and interspecifically (Brockmann & Barnard, 1979) and is a common strategy adopted by gulls (Monaghan, 1988). The fish-based diet coincides with that of breeding guillemots making it likely that guillemots are the primary victims of this parasitism.

4.2 Diet

The diet of breeding glaucous gulls in this study aligned with findings from previous studies in the same area, consisting primarily of guillemot chicks and capelin (Sørensen, 2021; Fiskum, 2024). Whilst other studies have reported crustaceans and cod as part of the diet, these were not observed in 2024. Sørensen (2021) documented a more diverse diet, but this study included nests north on the island, where large, dense guillemot colonies are lacking. The discrepancy in diet is therefore likely attributable to difference in glaucous gull colony location. Furthermore, the diet may be attributed to interannual differences in prey availability, causing favoured prey to differ.

The reason guillemot chicks were the most common prey, is likely due to their high availability. As the gulls nest near the large guillemot colonies, they have an abundant supply of high energy prey. Travel costs and search times are thus minimal, making the strategy of targeting guillemots highly profitable (MacArthur & Pianka, 1966). Other prey, such as e.g. fish was less common, likely due to lower availability. With low availability, search time increases. It would therefore be more favourable to target the more available guillemot chick, even if handling time is slightly higher (MacArthur & Pianka, 1966). This then becomes the optimal foraging strategy, where fish prey may be taken opportunistically when encountered by chance (Brockmann & Barnard, 1979).

Relatively few egg deliveries were recorded in the 2024-season. A possible explanation for this is related the phenology of guillemot hatching. Gaston et al. (2009) found that timing of breeding seemed to be related to timing of laying by guillemots. Timing of hatching would therefore influence the proportion of eggs versus chicks in the diet. Mean hatching date for common guillemots at Bjørnøya in 2024 was July 5th (Strøm, 2025b), while the mean hatching date for the monitored glaucous gulls was June 24th, with monitoring on average beginning June 25th (Table 1). This provides an ~11-day window for potential egg deliveries and thus be expected to constitute a larger part of the diet. However, as this is not the case, it is possible that some prey registered as a foetus/chick were initially taken as eggs but registered as the former due to the nature of the regurgitation.

A common observed behaviour was that parent gulls regurgitated guillemot chicks, which were partially eaten by the chicks before the parents re-swallowed the remains and fed them again later. Consequently, the same chick prey could have been recorded multiple times (skewing the prey composition). Capelin was on the other hand perceived as easier to consume (swallowed whole by the chick), making the delivery count for fish more accurate. The prey composition could therefore in reality be more evenly distributed than perceived. Another explanation for the lower apparent frequency of capelin in the diet could relate to its availability within the gulls foraging range.

Capelin, usually found at the polar front (60-100 km from the coast), is a key prey species for both common and Brünnich's guillemots on Bjørnøya (Barrett et al., 1997; Mehlum et al., 1998). This was also the most common prey for breeding guillemots in 2024 (Strøm, 2025a), coinciding with the glaucous gulls' fish diet. Since the gulls are restricted to the local coastal habitat and not present in the pelagic zone where capelin is typically found, fish prey must therefore be acquired close to, or on, land through scavenging, stealing or retrieving discarded fish, and guillemots are presumably the main source. This creates a dietary mirroring between the two species, which can be particularly noticeable in good years.

Guillemots experienced a strong breeding season on Bjørnøya in 2024 (Hallvard Strøm, personal communication, 15 April 2025). As a result, the observed overlap in diet is likely driven by kleptoparasitism, with the fish availability governed by guillemot provisioning.

García et al. (2010) found that more profitable prey triggered kleptoparasitism in gulls. From an optimal foraging perspective, this suggests that fish-prey may be highly favourable for the glaucous gulls, but its relative scarcity limits how often it can be targeted. Prey availability therefore becomes a key constraint in kleptoparasitism (Brockmann & Barnard, 1979). This form of parasitism is commonly applied in predatory and opportunistic feeders, and when it consistently yields a net energetic benefit, it can evolve into an evolutionary stable strategy (ESS) (Brockmann & Barnard, 1979).

At Bjørnøya and within the large seabird colonies, glaucous gulls seemingly benefit from the kleptoparasitism strategy as it reduces the need for energetic costly hunting flight offshore. Guillemots are likely targeted as they can provide a relatively large prey, such as capelin, and therefore be easily exploited (Brockmann & Barnard, 1979). In contrast, kittiwakes typically regurgitate smaller and more diverse preys (Mehlum & Gabrielsen, 1993), and being more agile flyers, are less vulnerable to such parasitism. Targeting guillemots has therefor likely evolved as the most viable strategy. However, as kleptoparasitism becomes more common, guillemots may adapt defensively, reducing the gulls success in the strategy. This forces the gulls to diversify their foraging strategy, and not solely rely on fish from the parasitism (Brockmann & Barnard, 1979).

The context dependant use of kleptoparasitism is further reflected in the spatial and dietary data. Habitat use and movement patterns showed limited variation among individuals (Figure 14), and diet composition was consistent across nests (Figure E2, Appendix E). Both predatory and kleptoparasitic strategies exploit the guillemots parental provisioning. Consequently, the distinction between foraging behaviour becomes blurred, making the two strategies somewhat indistinguishable. The kleptoparasitism is therefore suggested to be part of an opportunistic feeding strategy, where it is flexible and dependent on conditions (e.g. prey encounter rates) (Brockmann & Barnard, 1979; Ydenberg et al., 1994).

In addition to being context-dependent, kleptoparasitism is also influenced by frequency-dependant dynamics, making the strategy less profitable the more common it is (Brockmann

& Barnard, 1979). Despite this, all monitored gulls appear to adopt similar foraging strategies, including parasitism. This raises the question as to why the strategy is still viable. Negative frequency dependency typically applies to intraspecific interactions, i.e. when individuals compete directly with one another (Brockmann & Barnard, 1979). However, the glaucous gulls at KK more often engage in interspecific kleptoparasitism, resulting in indirect competition for an external resource and thus altering the typical frequency-dependant dynamic. Reduced direct competition allows the strategy to remain profitable for many individuals simultaneously, but only when the gull population is small and host population relatively large (Brockmann & Barnard, 1979). Both these conditions seem to apply for the study area. Whilst the guillemot population is large (Norwegian Polar Institute, 2024a), the glaucous gull population is at a historical low (Norwegian Polar Institute, 2024b), making interspecific kleptoparasitism a viable strategy for all participating individuals.

Finally, and notably some of the GPS positions recorded are over sea (Figure 13). These could possibly be related to foraging on other fish species than recorded in this study. The habitat use could also have been related to preying on newly fledged guillemots. However, the monitoring period ended prior to this fledging. (Fledging usually happen ~20 days after hatching, mean hatching date was July 5th (Strøm, 2025b). Monitoring ended prior to July 25th). Positions over sea could then simply be related to travel to social aggregation sites.

4.3 Prey delivery rate

Prey rate among nests ranged from 3.8-9.3 prey per day. The wide range is most likely due to nests susceptibility to camera monitoring. Some nest sites were easier to capture all deliveries simply due to local topography. Nesting success, together with difference in monitoring periods, may also have contributed to the observed variation. However, their influence appears limited, as both high and low prey rates were recorded regardless of nesting outcome or the number of days monitored. Additionally, random events such as dew and other unforeseen events may have negatively impacted the delivery rate. Some nest sites were also more prone to fox predation (due to in the terrain), causing parents relocate energy towards nest defence, thus affecting prey rate (Lima & Dill, 1990). Despite variation, the mean observed prey rate (6.9) coincides with the two previous studies. Sørensen (2021), who used the same method, found a mean prey rate of 5.8.

KK-12 had the lowest prey rate. This nest laid openly in the landscape and multiple fox predation attempts were recorded. Following the risk allocation hypothesis, predation risk and antipredator behaviour is an important factor shaping foraging strategy (Lima et al., 1999). In this case, time spent away from nest elevates the likelihood of chick loss, thereby reducing reproductive success and overall fitness (Magnhagen, 1991; Zanette et al., 2011). The risk is however outweighed in terms of low search time for high energy prey (guillemot chicks) with little handling time (swallowed whole) that the breeding habitat facilitates, consistent with optimal foraging theory (OFT) (MacArthur & Pianka, 1966).

Smaller and more easily consumable prey, such as fish, could influence prey rates and help explain the observed variation. Nests with a higher intake of fish could exhibit higher prey rates. However, this cannot be confirmed, as diet composition was largely consistent across nests (Figure E2, Appendix E).

When combining average prey rate (6.9) and average number of trips made per day (6), the results are remarkably similar. Specific nests prey rate and no. trips made deviate in some cases, whilst being remarkably accurate at others. Deviations seen here are likely due to a combination of nest susceptibility (as mentioned above) and the nature of the gulls parental food provisioning where regurgitation of food after standstill at nest was common - thus not being reflected in the movement data. The similarity across the two methods is a solid indication of robust results.

An interesting observation worth mentioning is that one gull was observed carrying multiple fish prey in the crop (Figure I1, Appendix I). Similar multi-prey loading was also observed by Barry and Barry (1990). The decision to carry single or multiple prey is influenced by factors such as travel time, handling time and prey encountered rate, making it a flexible and context-dependant strategy (Houston, 1985; Ydenberg & Hurd, 1998). Since fish is not the most frequently encountered prey, individuals may benefit from collecting multiple items when the opportunity arises. However, such opportunities may be rare, as guillemots (primary targets of the kleptoparasitism) are single-prey loaders. This makes it unlikely that the gulls can obtain more than one fish in a single kleptoparasitic event, which could help explain why the multi-prey loading behaviour only was observed once, and that it is context dependant rather than fixed (Ydenberg & Hurd, 1998).

Although multi-prey loading was documented in 2024, most deliveries consisted of single prey. Given the proximity of the central place, it is generally more efficient to return promptly with a single prey than to prolong the search or travel time to obtain an additional prey item (Orians & Pearson, 1979; Houston, 1985). One possible explanation of the observed behaviour is that the prey may have been obtained farther from the colony, e.g. at sea, where increased travel cost would favour multi-prey loading (Ydenberg & Hurd, 1998). However, GPS tracking suggests that long-distance foraging is unlikely in this case.

The kleptoparasitism is assumed to occur opportunistically, however, the multi-prey loading observation might suggest a more facultative approach. Given that the gull hunt close to their central place, obtaining multiple fish may only be worthwhile under conditions of exceptionally low search and handling time. This could occur if the gulls are highly specialised and have optimized their search strategy for targeting multiple guillemots carrying fish.

4.4 Diel activity

A clear diurnal activity pattern was not identified for the glaucous gulls. Food provisioning occurred continuously throughout the polar day, indicating an arrhythmic activity pattern during breeding. Activity based on GPS data indicated the same continuous pattern, though with some more variation. The results coincides both with the findings in Sørensen (2021) and Fiskum (2024), and the initial predictions and hypotheses. Some nests (e.g. LF-1) showed a peak in activity around midnight and lower activity in the early morning. However, overall activity levels appeared to be lowest around midnight (Figure 12), coinciding with low light intensity when resting is most common (Karplus, 1952). Other factors however, e.g. wind (Gilchrist et al., 1998), are likely more important as foraging constraint than light is. Rather than a constraint, light presumably facilitates for maximum utilization the environmental conditions during a short polar summer (Reierth & Stokkan, 2002).

Existing literature on diel activity in breeders under continuous daylight show diversity in activity patterns. Steiger et al. (2013) found that semipalmated sandpipers *Calidris pusilla* showed arrhythmic activity patterns, whilst Lapland longspur *Calcarius lapponicus* had an entrained pattern. Both monogamous species like the glaucous gull. Little auks have shown highest colony attendance at low sun elevation (midnight-early morning), but the apparent rhythmicity diminishes at individual levels (Wojczulanis-Jakubas et al., 2020). Overall chick feeding was equally distributed throughout the 24-hour period. Furthermore, the Svalbard ptarmigan *Lagopus muta hyperborea*, a year-round polar resident, also displays seasonal absence of rhythmicity in diel activity (Reierth & Stokkan, 2002). Both food provisioning, and least activity at lowest light coincides with that found in the glaucous gulls here, also the individual variation.

Though the overall pattern showed absence of diurnal rhythmicity, a notable dip in food provisioning activity was observed around midday for several nests (Figure 9, 11, and 12). This pattern was also reported in Fiskum (2024) and is likely linked to human disturbance. Battery and memory card changes typically occurred around midday every other day, and additional research activities in the area may have contributed this effect. Human disturbance is therefore thought to be the primary cause of the observed discrepancy in activity patterns. This underscores that even low-invasive monitoring methods can have an impact, though primarily due to the human aspect of it (which here was large due to camera limitations).

For some nest this mid-day trend was less pronounced. A reasonable explanation to this is nest positioning in the terrain. Nests that are more sheltered may be less prone to disturbance compared to those in more exposed locations (as with potential fox predation). Additionally, individual behaviour likely plays a role. Some gulls were perceived as more aggressive than others, possibly influencing the observed activity pattern.

When separating for aves and fish prey, the activity pattern was more rhythmic. Sørensen (2021) found fish delivery to be most likely between 08:00 and 10:00 am. Fiskum (2024) found the same trend for one nest. In this study fish delivery occurred most often around 12:00 am, whereas aves prey tended to peak from 18:00 towards midnight. Given the overall consistency in diel activity, theses pattern may reflect a temporal availability of the different prey. In Sjöberg (1989) prey availability governed birds diel activity during continuous daylight. Fish availability should be considered in relation to guillemot foraging patterns, and particularly so considering the kleptoparasitic interactions, as previously highlighted. However, establishing such interactions is challenging. Large colonies like those on Bjørnøya do not exhibit distinct activity patterns during the continuous daylight (Mehlum et al., 2001).

Nonetheless, due to nest location and closeness to foraging areas, prey is arguably always available for the glaucous gulls, thus the arrhythmic activity pattern.

When comparing diel activity by food provisioning with GPS, it is important to address the fundamental differences. Nest cameras measure activity from both parents, GPS only from one. The differences seen in diel activity within nests and individuals may therefore be caused by the fact that food provisioning is a shared task. Furthermore, conflicting patterns can be due to how the parents feed their young. As previously pointed out, parents provided food without leaving the nest (keeping prey in the crop for some time). This behaviour can explain the opposite patterns seen in AB3 (KK-8) and 3EP (KK-2).

The dip in food provisioning at 12:00 was only found to be evident in one of the birds (BT3, KK-12). BT3 was only sampled for a short time (logger was picked off, see Appendix I), though within camera monitoring period, in contrast to 3ER. As the GPS sampling period was within food provisioning, it might have caused the trend to be more prevalent for BT3. Furthermore, as tracking period increased, the amount of (human) disturbance decreased. (Tracking period was longer than camera monitoring period). Causing the human induced stress to potentially diminish from the overall activity pattern, hence the 12:00 dip is not seen in any other birds. If this is the case, the findings indicate that the human aspect of monitoring disrupts food provisioning.

Finally, as for prey rate, predation risk is also applicable to diel activity patterns (Lima et al., 1999; Bonter et al., 2013), and a factor to consider here. However, little is known about Bjørnøya’s fox population and their ecological impacts on the glaucous gulls. This should be addressed in future research.

4.5 Home range, habitat use and movement patterns

GPS data revealed the gulls to operate on a very local scale, with relatively small home ranges. The home range sizes found here coincides with what found by Fiskum (2024), and are consistent with initial predictions and hypotheses. During the sampling period, the gulls remained exclusively in the coastal habitat, and did not utilize inland or pelagic habitats. This contrasts with their habitat use outside the breeding season, when they typically use pelagic areas (Baak et al., 2021; SEATRACK, 2025). The habitat use also differs significantly from that of the great skua, a co-predator on Bjørnøya, which utilizes both coastal and pelagic habitats (Jakubas et al., 2018). Within the *Larus* genus, breeding glaucous gulls are among the most site faithful.

Several studies are done on breeding *Larus spp.* and their foraging patterns, showing both intra- and interspecific plasticity in foraging behaviour and home range (Corman et al., 2016; Isaksson et al., 2016; Rock et al., 2016; Shaffer et al., 2017; Petracci et al., 2024). Shaffer et al. (2017) found foraging trips to range from 9-27 km in western gulls *Larus occidentalis*, over sea and land. Corman et al. 2016 pointed at intraspecific competition as driver for the variation in behaviour, and thus variation in home range, among colonies of lesser black-backed gulls *Larus fuscus*. Xu et al. (2021) found the home range of two individuals of Saunders's gulls *Larus saundersi* to be 85- and 69 km^2. Rock et al. (2016) found that urban herring gulls *Larus argentatus* varied greatly in home range, ranging from <10km^2 to 560km^2 (90% estimation). Petracci et al. (2024) found mean home range (100% MCP) for female and male orlog's gulls *Larus atlanticus* to be 31- and 12 km^2, respectively. These studies exemplify the variation of habitat use in breeding *Larus* gulls.

Compared to their congeners, the glaucous gulls show very little plasticity in home range and habitat use. All tracked individuals displayed the same pattern, and habitat use remained the same even when breeding failed. Mean 95% utilization area was only 3.78 km^2, and no gulls travelled further than ~5.5 km from the colony.

Core areas (50% utilization area) were typically less than 0.5 km^2 (see Table 5), with only two exceptions (3ES and BU3). These deviations are likely attributable to failed breeding, which may result in reduced nest attendance and increased roaming behaviour, thereby expanding the core area estimates. Nonetheless, many positions were still recorded near the nest, underscoring its continued relative importance despite breeding failure.

At KK-8, breeding failure resulted in a particularly notable case. The male (AB3) was tagged during chick rearing, while the female (3ES) was tagged shortly before breeding failure occurred. Erikstad et al. (2013) proposed a non-exclusive explanation for such failures, suggesting that males abandon nesting to ensure own survival, when under stress from POPs. This hypothesis may apply to the KK-8 pair. The male's final recorded location was on June

27th, and he was not observed near the nest site for the remainder of the season. Results from blood sample analysis would be particularly interesting in this case.

A reasonable explanation for KK-7 (3ET) low home range (compared to average) is likely incubation behaviour. Tagging occurred 18 days prior to hatching, causing incubation to the dominant behaviour, rather than foraging.

Some difference in home range was observed between sexes and within nests, with variations occurring in both directions. In some cases, females had larger home ranges, while in others, males did. The differences are likely linked to individual behavioural traits, nestling stage (ref. KK-7) and varying sampling periods. Overall, females tended to have smaller home ranges than males (when cases were breeding failed early are excluded). Nevertheless, the differences are minimal and likely of limited importance.

All home ranges overlapped to a varying extent. Raw positions revealed that individuals maintained a degree of “personal space” (Figure 13). In general, gulls that did not nest on Kapp Kolthoff tended to avoid the area. For instance, 3EM (LF-1) did not seem to frequent on KK at all. Social aggregation sites, however, served as common gathering points for all tagged individuals, regardless of nest location. (Some visited these sites more frequent than other, likely due to differences in nestling status). While the gulls are territorial and protective of their nest site (Strøm, 2006), they engage in social interactions outside of nesting areas. Nest attendance is however prioritized (Figure 14A).

The glaucous gulls spent most of their time standstill at the nest. Combined with the fact that prey is obtained relatively close to the nest (Figure 15 and Table 8), foraging costs are likely low, as highlighted previously. This allows the gulls to reduce time spent hunting in favour of nest attendance, consistent with central place foraging (CPF) (Orians & Pearson, 1979) and parental provisioning models (Houston, 1987). Ydenberg et al. (1994) showed that when provisioning costs are low, foragers tend to adopt efficiency-maximizing strategies that favour short foraging trips and prolonged nest attendance. The latter is especially favourable considering the imminent threat of fox predation at some nests (e.g. KK-12) (Lima & Dill, 1990). Nest were never observed without at least one parent in immediate vicinity.

As with diel activity, the movement patterns were consistent, suggesting limited behavioural plasticity with a high degree of nest attendance. Behavioural plasticity is unnecessary when a stable strategy already effectively maximizes daily energy delivery and offspring survival (Houston, 1987). The glaucous gulls thus seem have adopted an optimal strategy where foraging cost are low, allowing them to "afford" increased nest attendance, and even social aggregation, during the critical chick rearing period.

Figure 14 shows days with no recorded movement; however, this is likely misleading. As battery levels dropped, GPS tags recorded fewer positions (as infrequently as every 40 minute). Given the high degree of site faithfulness and the amount of standstill behaviour, it is likely that activity was simply not captured at the end of monitoring due to long GPS intervals, resulting in apparent 0% movement days. This interpretation is further supported by the duration of trips away from the nest, where all averages were below 40 minutes (Figure 17). It is also possible that, given the central placement of the nest, the gulls use the immediate surroundings as a scouting area. Foraging within the nest vicinity may therefore cause 0% movement days to appear.

Why CH3 stands out in all movement and standstill plots is somewhat hard to explain. Its nest (KK/FF-3) lays close to an experimental plot for guillemot demography, which is frequently visited throughout the season. This could cause the parent to spend more time overlooking threats "away" from the nest.

4.6 Potential prey catch locations

The nesting and foraging grounds of glaucous gulls on Bjørnøya are closely linked and spatially inseparable. This aligns with the initial predictions and hypothesis. Foraging occurred exclusively within the coastal habitat (over or near land), with no indication of offshore activity, in contrast to species such as guillemots and great skuas (Mehlum et al., 1998; Jakubas et al., 2018). While GPS data may suggest foraging in the intertidal zone, this is not supported by dietary analysis. Instead, the glaucous gulls appear to exploit nearby energy sources by hunting within the larger seabird colonies.

Consistent with CPF theory – where ample resources negate the need for long-distance-travel – the results suggests that food availability near the nest site is abundant (Orians & Pearson, 1979). Consequently, long-distance foraging for high value food appears unnecessary. Instead, the longest travels (~5.5 km) seem to be primarily driven by social behaviour. Support for CPF is further strengthened by the fact that glaucous gulls primarily operate as single-prey loaders. As a result, travel costs are low, and there is no apparent need to carry multiple prey items to justify long trips. Notably, the glaucous gulls exhibit the shortest travel distances compared to other breeding *Larus* species documented in the literature (Shaffer et al., 2017; Xu et al., 2021; Petracci et al., 2024).

Another factor contributing to localized area use is the nest-site behaviour. Defending the nest from conspecifics limits flight and foraging time (Shaffer et al., 2017), and attacks from neighbours can play a significant role in increasing chick mortality among gulls (Gillett et al., 1975). This behaviour was observed through camera monitoring, though only on two occasions, and was seemingly aimed towards the parent's prey rather than chick (Figure I2, Appendix I). (Thus, the kleptoparasitism occurs not only interspecifically, but also intraspecifically). Additional in-field observations indicated minimal aggression toward neighbouring nests, possibly as a response to high availability of other prey.

Contrarily, the artic fox was perceived as a bigger threat to chicks, with multiple (unsuccessful) attacks being recorded and observed (Figure I3, Appendix I). An increasing population of arctic foxes is believed to be a contributing factor to population decline (Strøm, 2006). With this predation risk comes a predation-starvation trade-off between nest attendance and foraging (Lima & Dill, 1990; Bonter et al., 2013). Short distance to foraging ground is advantageous, enabling reduced prey search times. This can also be seen in relation to single prey loading and CPF theory, where multi-prey loading is beneficial in longer foraging trips (Ydenberg & Hurd, 1998). Additionally, proximity to large guillemot colonies may offer a dilution effect, whereby the risk of predation decreases as group size increases (Krause, 2002).

Isaksson et al. (2016) identified within-colony plasticity in *Larus fuscus* foraging patterns, mediated by prey availability. In contrast, the glaucous gulls here exhibit highly similar patterns across all individuals. Predicted distance travelled from nest prior to a prey delivery ranged only from 70-110 meters. The distances were relatively short and consistent, with hotspot analysis indicating certain hotspots for prey (see Figure 18). This aligns with the surrounding guillemot colonies, highlighting their importance as foraging areas and that all monitored glaucous gulls hunt within the same patch. This is made possible under the assumption of high prey availability.

The variation in predicted distance to potential prey catch location was best explained by *bird ID*. Foraging grounds were therefore consistent regardless of prey type. This suggests an opportunistic feeding strategy where the gulls capture prey as they encounter it rather than actively searching for specific prey. The arrhythmic diel activity can further suggest that they are continuously vigilant and ready to seize feeding opportunities.

Furthermore, the significance of *bird ID* can be explained by the temporal distribution of prey types. Eggs and chicks were found the same places, even fish, as they are likely stolen. The predicted distances are therefore a result of the nests distances to the guillemot colony, rather than prey being located at different sites. When nests are placed close by, long distance flight is more costly and unnecessary, and thus not optimal (MacArthur & Pianka, 1966). In other words, the glaucous gull's nest in the centre of their food supply.

Corman et al. (2016) pointed at competition as driver of variation in foraging patterns for *Larus fuscus*. As previously highlighted, glaucous gulls at Bjørnøya have undergone extensive population decline. When monitoring began in 1987, 150 nests were present at KK (Bakken & Mehlum, 1988). In 2024 this number was 14, and the population has remained this low for more than 15 years (Norwegian Polar Institute, 2024b). In contrast, the common guillemot population has regained much of its former size following the collapse in 1986/87 (Hallvard Strøm, personal communication, June 2024). It is therefore plausible that resource competition is of less importance when it comes to choosing foraging strategy for the monitored gulls. Again, this is possible under the assumption of food being abundant (Brockmann & Barnard, 1979), and population size constrained by other factors (i.e. POPs).

The results further suggest that the gulls' foraging activity is confined to a single patch surrounding the nest site (see e.g. Figure 12 and 15). The theory of area-restricted search, suggest that movement is concentrated in areas with higher resource availability (Kareiva & Odell, 1987). This is likely the case for the glaucous gulls. In contrast, the occasional long-distance travel to Russehamna, and sporadic potential prey catches along the way (Figure 15), appears unrelated to foraging behaviour despite the presence of nesting seabirds in the intervening area. Instead, such movements are likely driven by social interactions rather than efforts to locate or exploit high-value prey.

4.7 Methodical limitations

4.7.1 25-meter exclusion zone

A 25-meter exclusion zone was introduced to reduce the influence of nest activities, such as brooding or resting, which could otherwise skew the results. Without this exclusion, positions very close to the nest could be mistaken for potential prey-catch locations. Nonetheless, nest location characteristics may still introduce biases in the analysis. Differences in topography mean some nest sites naturally offer larger roaming areas. Likewise, can nest density reduce roaming areas, influencing movement patterns. Since nests are more clustered on Kapp Kolthoff than on Lille Feitnakken, the 25-meter exclusion zone may be too large or small in certain areas. Resulting in potential foraging areas to be excluded from the analysis.

Fiskum (2024) reported events of gulls targeting neighbouring common guillemots (<20 meters from nest bowl). Consequently, the strict 25-meter exclusion zone might have omitted some prey-positions from this analysis. While it’s difficult to determine the effect of this, it is believed to be of little importance. Without the use of the exclusion zone, the large number of positions obtained from the nest would likely have overshadowed other potential prey locations. The exclusion zone was therefore considered necessary to obtain a more realistic picture of the gulls foraging behaviour.

4.7.2 Time threshold

The threshold for including positions within a 10–40-minute interval was chosen as moderately conservative approach. Given the dynamic setting of the GPS loggers, where positions were recorded based on battery levels, it seemed appropriate to use a broad time window. When using this threshold, hunting events were assumed to last between 10-40 minutes, though they could be longer or shorter (most likely shorter rather than longer - again due to the small home ranges and relative short distances travelled). To account for this variability, we tested both larger and smaller thresholds but found no changes to the results (see Appendix H). A shorter GPS interval, ideally every minute, would have provided a more detailed picture but would have considerably reduced the sampling period.

Another limitation is the complex feeding behaviour. Parents were commonly observed feeding chicks (by regurgitation) after some time brooding at the nest. As a result, many feeding events occurred well after the parents' return from foraging, making it difficult to directly associate prey delivery with the location of prey capture within the given time frame.

However, despite these limitations, the method used and presented results provide valuable insight in glaucous gull foraging behaviour. The limited variation in results across methods and thresholds suggests that the findings are robust and representative.

4.7.3 Logger and camera interference

Though becoming less and less invasive, the biological interference loggers pose may still have negative effect and should be considered in research (Symons & Diamond, 2019). Even camera traps are intrusive to some extent (Figure I4, Appendix I). This thesis therefore reported breeding successes between monitored and non-monitored nests, hypothesizing that there would be no significant difference, but finding the opposite.

Chivers et al. (2016) investigated the impact of logger intrusiveness on kittiwakes, finding no significant effects when loggers weighed 1% of body mass. Larger tags (5.2% of body mass) however, reduced flight time by 30%. In this study, loggers accounted for approximately 0.5% of the bird's body weight (Table B1, Appendix B). While intrusiveness was likely minimal, the loggers used may still have contributed to reduced flight and foraging time, primarily due to the birds' attention to the equipment (Figure I5, I6 and I7, Appendix I). BT3 (KK-12) successfully removed its tag which was later retrieved during a nest visit. This highlights the intrusiveness even small loggers can have.

The significant difference (though with some uncertainty) in breeding success is more likely attributable to camera monitoring than to the use of GPS-loggers. While time spent changing battery and memory card were kept to a minimum, the frequent visits to the nest site still caused stress. For an aggressive and protective species like the glaucous gull (Strøm, 2006), such disturbances would likely have led to high energy expenditure. Arguably, the induced stress can be compared to, or even serve as a substitute for, interactions with the arctic fox. The KK-12 nest was relocated mid-breeding, possibly in response to repeated nest visits and predation attempts by foxes. Moreover, the unmonitored nests are naturally more protected from disturbance (i.e., inaccessible to monitoring, and hard for foxes to get to). (Contrarily, cameras could offer some shelter for chicks (Figure I4, Appendix I)). Location of nest could thus influence breeding success.

Human disturbance was in Gillett et al. (1975) the indirect cause of increased chick mortality in glaucous-winged gulls *Larus glaucescens*. When disturbed, chicks were scattered into adjacent territories and attacked by neighbouring adults. Similar chick behaviour was observed on KK, however attacks from neighbours was not.

Notably, results on breeding success are not based on flawless data and remain to some extent uncertain. Monitoring could be a contributing factor to lower breeding success, though primarily mediated by contaminants (Erikstad & Strøm, 2012) and possibly increased predation from arctic foxes (Strøm, 2006).

4.6.4 Historical foraging patterns

According to Votier et al. (2004) some great skuas specialize exclusively on depredating other seabirds, with only the "best" individuals in the colony engaging in this strategy. Other individuals in the colony tended to adopt more generalist or fish-feeding strategies. A similar pattern was observed by Jakubas et al. (2018), on Bjørnøya. Where glaucous gulls have undergone significant population decline, great skuas have experienced population growth on Bjørnøya (Descamps & Strøm, 2021).

Although intracolonial plasticity in foraging traits is common among several other *Lari* species (Corman et al., 2016; Isaksson et al., 2016; Shaffer et al., 2017), this does not appear to be the case for the glaucous gulls on Bjørnøya. Constrained and consistent movement patterns suggest a more specialized foraging strategy within this colony. It is plausible that the population decline has resulted in a smaller, more specialized group where a single foraging strategy is favoured. While a larger population may have supported greater plasticity in foraging traits, reduced intraspecific competition in the remaining group likely diminishes the need for such flexibility. This low competition is likely mediated and constrained by contaminant exposure and shifting prey availability – particularly of guillemots.

The strong association with guillemots, as shown in the results, further supports the guillemot collapse in 1986-87 (see Bakken & Mehlum, 1988) as a contributing factor to the initial population decline, alongside contaminants (see Erikstad & Strøm, 2012). Given the species long generation time and reproductive strategy, the effects of these pressures remain evident, and the population has not recuperated.

Given that great skuas and glaucous gulls have similar ecological roles as top predators, and that great skuas are favoured in the "borealization" of the arctic (Descamps & Strøm, 2021), it seems plausible that greater population health in great skuas allows for a broader range of foraging strategies.

Alternatively, one could argue that the glaucous gulls are simply more endemic and adapted to the region, having evolved more specialized and optimal foraging strategies over time. However, this specialization paradoxically increases vulnerability to environmental toxins, as specialized diets may expose them to higher levels of bioaccumulated toxins (Bustnes et al., 2000). Similarly, Votier et al. (2004) found that specialized skuas exhibited lower-than-predicted breeding success, suggesting that such a strategy may only be advantageous for a small subset of the population. The glaucous gulls from LF to KK may represent such a subset.

Predation risk is another key factor in understanding historical foraging patterns. The Arctic fox was almost absent from Bjørnøya for many years, but in recent years the population has increased (Fuglei, 2006). It is, however, unclear how this has affected the glaucous gulls (Strøm, 2006), and doing so would require further research. However, a historically larger gull population may have been less vulnerable to fox predation due to the protective benefits of colonial nesting behaviour (Alexander, 1974).

The suppositions presented in this section are based on limited evidence and should be interpreted with caution.

5. Conclusion

In conclusion, the glaucous gulls monitored on Bjørnøya in 2024 exhibited diet and diel activity patterns similar to those recorded in previous years. The results align with the initial hypothesis and predictions, indicating that diet was strongly influenced by the immediate surroundings. The abundant supply of local prey reduced the need for long-distance foraging. Prey, primarily consisting of guillemot chicks and fish, was generally obtained close to the nest site, with a mean predicted distance of just 87 meters and limited intracolonial plasticity.

The diel activity patterns revealed that food provisioning occurred arrhythmic and continuous throughout the 24-hour cycle, a common trait among Arctic breeders. Tracking data revealed that during the early stages of chick rearing, the gulls operated on a highly localized scale, demonstrating strong nest-site fidelity while actively using socializing sites. Consequently, their constrained movement patterns resulted in small home ranges.

Three key behavioural traits related to area use were identified: resting and nestling at nest site, foraging at nearby guillemot colonies and socializing at specific locations. Offshore foraging is not a strategy adopted by the gulls during breeding, likely due to the ample prey available nearby. With a sample size of 12 individuals, the data provide robust evidence that glaucous gulls on Bjørnøya forage on a much more local scale than many other *Larus* species. This thesis contributes valuable insight into the diversity of foraging strategies within the *Larus* genus and supports the characterization of *Larus hyperboreus* as an opportunistic predator.

An unexpected finding was the significant difference in breeding success. However, the outcome may be influenced by multiple factors, and it is unlikely that monitoring alone was responsible. Nonetheless, even low-invasive methods can affect behaviour and outcomes – a consideration that should continue to be addressed in future research.

Overall, the findings underscore a close ecological relationship between guillemots and glaucous gulls within the Arctic food web, emphasizing their interdependence. This relationship should be considered in future management strategies to ensure stability of the predator-prey dynamics in the region. Additionally, the evidence of concentrated home ranges may have important implications for future conservation and management.

6. References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19 (6): 716-723. doi: 10.1109/TAC.1974.1100705.

Alexander, R. D. (1974). The evolution of social behavior. *Annual review of ecology and systematics*, 5: 325-383.

Anogeissus Ltd. (n.d.). *Introducing ApolloOne - The Fastest Mac Image Viewer*. Available at: https://www.apollooneapp.com (accessed: 14.11.2024).

Artsdatabanken. (n.d.). *Polarmåke (Larus hyperboreus), Bjørnøya med kystnære øyer, Svalbard*. Artskart. Available at: https://artskart.artsdatabanken.no/#map/619664,8263629/9/background/greyMap/filter/%7B%22TaxonIds%22%3A%5B203554%5D%2C%22AreaIds%22%3A%5B2451%5D%2C%22IncludeSubTaxonIds%22%3Atrue%2C%22Found%22%3A%5B2%5D%2C%22NotRecovered%22%3A%5B2%5D%2C%22Style%22%3A1%7D (accessed: 30.04.2024).

Bakken, V. & Mehlum, F. (1988). *Sjøfuglundersøkelser nord for N 74 Bjørnøya : AKUP sluttrapport*. Rapportserie, 44: Norwegian Polar Institute.

Barrett, R. T., Bakken, V. & Krasnov, J. V. (1997). The diets of common and Brünnich's guillemots Uria aalge and U. lomvia in the Barents Sea region. *Polar Research*, 16 (2): 73-84. doi: 10.3402/polar.v16i2.6626.

Barrett, R. T. (2002). Atlantic puffin Fratercula arctica and common guillemot Uria aalge chick diet and growth as indicators of fish stocks in the Barents Sea. *Marine Ecology Progress Series*, 230: 275-287. doi: 10.3354/meps230275.

Barry, S. J. & Barry, T. W. (1990). Food Habits of Glaucous Gulls in the Beaufort Sea. *Arctic*, 43 (1): 43-49.

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, 67 (1): 1-48. doi: 10.18637/jss.v067.i01.

Bogan, J. A. & Bourne, W. R. P. (1972). Organochlorine Levels in Atlantic Seabirds. *Nature*, 240 (5380): 358-358. doi: 10.1038/240358a0.

Bonter, D. N., Zuckerberg, B., Sedgwick, C. W. & Hochachka, W. M. (2013). Daily foraging patterns in free-living birds: exploring the predation-starvation trade-off. *Proc Biol Sci*, 280 (1760): 20123087. doi: 10.1098/rspb.2012.3087.

Brockmann, H. J. & Barnard, C. J. (1979). Kleptoparasitism in birds. *Animal Behaviour*, 27: 487-514. doi: 10.1016/0003-3472(79)90185-4.

Burfield, I. & van Bommel, F. (2004). *Birds in Europe: Population estimates, trends and conservation status*. BirdLife Conservation Series 12. Cambridge: BirdLife International.

Bustnes, J. O., Erikstad, K. E., Bakken, V., Mehlum, F. & Skaare, J. U. (2000). Feeding Ecology and the Concentration of Organochlorines in Glaucous Gulls. *Ecotoxicology (London)*, 9 (3): 179-179. doi: 10.1023/A:1008938603257.

Bustnes, J. O., Erikstad, K. E., Skaare, J. U., Bakken, V. & Mehlum, F. (2003). Ecological Effects of Organochlorine Pollutants in the Arctic: A Study of the Glaucous Gull. *Ecological applications*, 13 (2): 504-515. doi: 10.1890/1051-0761(2003)013[0504:EEOOPI]2.0.CO2.

Baak, J. E., Patterson, A., Gilchrist, H. G. & Elliott, K. H. (2021). First evidence of diverging migration and overwintering strategies in glaucous gulls (Larus hyperboreus) from the Canadian Arctic. *Animal Migration*, 8 (1): 98-109. doi: 10.1515/ami-2020-0107.

Calenge, C. (2024a). *adehabitatHR: Home Range Estimation*. Available at: https://CRAN.R-project.org/package=adehabitatHR (accessed: 03.03.2025).

Calenge, C. (2024b). *adehabitatLT: Analysis of Animal Movements*. Available at: https://CRAN.R-project.org/package=adehabitatLT (accessed: 03.03.2025).

Capuzzo, E., Lynam, C. P., Barry, J., Stephens, D., Forster, R. M., Greenwood, N., McQuatters-Gollop, A., Silva, T., Leeuwen, S. M. & Engelhard, G. H. (2018). A decline in primary production in the North Sea over 25 years, associated with reductions in zooplankton abundance and fish stock recruitment. *Global Change Biology*, 24 (1): 352-364. doi: 10.1111/gcb.13916.

Carr, D., Lewin-Koh, N., Maechler, M. & Sarkar, D. (2024). *hexbin: Hexagonal Binning Routines*. Available at: https://CRAN.R-project.org/package=hexbin (accessed: 07.01.2025).

Chivers, L., Hatch, S. & Elliott, K. (2016). Accelerometry reveals an impact of short-term tagging on seabird activity budgets. *The Condor*, 118: 159-168. doi: 10.1650/CONDOR-15-66.1.

Corman, A. M., Mendel, B., Voigt, C. C. & Garthe, S. (2016). Varying foraging patterns in response to competition? A multicolony approach in a generalist seabird. *Ecology and evolution*, 6 (4): 974-986. doi: 10.1002/ece3.1884.

Descamps, S. & Strøm, H. (2021). As the Arctic becomes boreal: ongoing shifts in a high-Arctic seabird community. *Ecology (Durham)*, 102 (11): 1-9. doi: 10.1002/ecy.3485.

Devlin, P. F. & Kay, S. A. (2001). Circadian photoperception. *Annu Rev Physiol*, 63: 677-94. doi: 10.1146/annurev.physiol.63.1.677.

Dias, M. P., Martin, R., Pearmain, E. J., Burfield, I. J., Small, C., Yates, O., Phillips, R. A., Lascelles, B., Borboroglu, P. G. & Croxall, J. P. (2019). Threats to seabirds: A global assessment. *Biological Conservation*, 237: 525-537. doi: 10.1016/j.biocon.2019.06.033.

Drent, R. H. & Daan, S. (1980). The Prudent Parent: Energetic Adjustments in Avian Breeding. *Ardea*, 55 (1–2): 225-252. doi: 10.5253/arde.v68.p225.

Eriksen, E., Bogstad, B. & Nakken, O. (2011). Ecological significance of 0-group fish in the Barents Sea ecosystem. *Polar Biology*, 34 (5): 647-657. doi: 10.1007/s00300-010-0920-y.

Erikstad, K. E. & Strøm, H. (2012). *Effekter av miljøgifter på bestanden av polarmåke på Bjørnøya: sluttrapport til Svalbards miljøvernfond*. Kortrapport, 25: Norsk Polarinstitutt.

Erikstad, K. E., Sandvik, H., Reiertsen, T. K., Bustnes, J. O. & Strøm, H. (2013). Persistent organic pollution in a high-Arctic top predator: sex-dependent thresholds in adult survival. *Proceedings of the Royal Society B: Biological Sciences*, 280 (1769): 20131483. doi: 10.1098/rspb.2013.1483.

Fauchald, P., Anker-Nilssen, T., Barrett, R., Bustnes, J. O., Bårdsen, B.-J., Christensen-Dalsgaard, S., Descamps, S., Engen, S., Erikstad, K. E., Hanssen, S. A., et al. (2015). *The status and trends of seabirds breeding in Norway and Svalbard*. NINA Report, 2135: Norsk institutt for naturforskning.

Fayet, A., Clucas, G., Anker-Nilssen, T., Syposz, M. & Hansen, E. (2021). Local prey shortages drive foraging costs and breeding success in a declining seabird, the Atlantic puffin. *Journal of Animal Ecology*, 90. doi: 10.1111/1365-2656.13442.

Fijn, R. C., Courtens, W., Engels, B. W. R., van Loon, E. E. & Shamoun-Baranes, J. (2024). Combining video and GPS-tracking to study the spatial foraging distribution of a single-prey loading seabird. *Avian Research*, 15. doi: 10.1016/j.avrs.2024.100196.

Fiskum, A. S. (2024). *Food provisioning, diel activity, and home range size in the glaucous gull (Larus hyperboreus) on Bjørnøya*. Master thesis: Norwegian University of Life Sciences. Available at: https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/3148340 (accessed: 13.11.2024).

Friard, O., Gamba, M. & Fitzjohn, R. (2016). BORIS: a free, versatile open-source event-logging software for video/audio coding and live observations. *Methods in ecology and evolution*, 7 (11): 1325-1330. doi: 10.1111/2041-210X.12584.

Fuglei, E. (2006). Arctic Fox (Alopex lagopus) In Kovacs, K. M. & Lydersen, C. (eds) *Birds and Mammals of Svalbard*, pp. 77-80. Tromsø, Norway: Norwegian Polar Institute.

Gabrielsen, G. (2009). Seabirds in the Barents Sea. In *Ecosystem Barents Sea*, pp. 415-452.

Gabrielsen, G. W., Skaare, J. U., Polder, A. & Bakken, V. (1995). Chlorinated hydrocarbons in glaucous gulls (Larus hyperboreus) in the southern part of Svalbard. *Science of The Total Environment*, 160-161: 337-346. doi: 10.1016/0048-9697(95)04367-A.

García, G., Favero, M. & Vassallo, A. (2010). Factors Affecting Kleptoparasitism by Gulls in a Multi-Species Seabird Colony (Factores que Afectan el Cleptoparasitismo por Gaviotas en una Colonia Multiespecífica de Aves Marinas). *The Condor*, 112: 521-529. doi: 10.1525/cond.2010.090117.

Gaston, A. J., Descamps, S. & Gilchrist, H. G. (2009). Reproduction and Survival of Glaucous Gulls Breeding in an Arctic Seabird Colony. *Journal of Field Ornithology*, 80 (2): 135-145. doi: 10.1111/j.1557-9263.2009.00215.x.

Gilchrist, H. G., Gaston, A. J. & James, N. M. S. (1998). Wind and Prey Nest Sites as Foraging Constraints on an Avian Predator, the Glaucous Gull. *Ecology (Durham)*, 79 (7): 2403-2414. doi: 10.1890/0012-9658(1998)079[2403:WAPNSA]2.0.CO2.

Gill, M., Crane, K., Hindrum, R., Arneberg, P., Bysveen, I., Denisenko, N., Gofman, V., Grant-Friedman, A., Guðmundsson, G., Hopcroft, R., et al. (2011). *Arctic Marine Biodiversity Monitoring Plan (CBMP-MARINE PLAN)*.

Gillett, W. H., Hayward, J. L. & Stout, J. F. (1975). Effects of Human Activity on Egg and Chick Mortality in a Glaucous-Winged Gull Colony. *The Condor*, 77 (4): 492-495. doi: 10.2307/1366102.

Gimond, M. (2022). *Z and T tests*. Basic stats explained (in R). Available at: https://mgimond.github.io/Stats-in-R/z_t_tests.html (accessed: 27.03.2025).

Grémillet, D. & Boulinier, T. (2009). Spatial ecology and conservation of seabirds facing global climate change, a review. *Marine Ecology Progress Series*, 391: 121-138. doi: 10.3354/meps08212.

Hanssen, S. A., Descamps, S., Anker-Nilssen, T., Setsaas, E. (eds), Bærum, K.M., Christensen-Dalsgaard, S., Dehnhard, N., Erikstad, K.E., Fauchald, P., Fayet, A., Layton-Matthews, K., Lorentsen, S.-H., Moe, B., Reiertsen, T.K., Strøm, H., Systad, G.H. (2023). *Sjøfugl i Norge 2022*. Resultater fra SEAPOP-programmet. Årsbrosjyre SEAPOP.

Hatch, J. J. (1970). Predation and Piracy by Gulls at a Ternery in Maine. *The Auk*, 87 (2): 244-254. doi: 10.2307/4083918.

Hays, G. C., Bailey, H., Bograd, S. J., Bowen, W. D., Campagna, C., Carmichael, R. H., Casale, P., Chiaradia, A., Costa, D. P., Cuevas, E., et al. (2019). Translating Marine Animal Tracking Data into Conservation Policy and Management. *Trends Ecol Evol*, 34 (5): 459-473. doi: 10.1016/j.tree.2019.01.009.

Hedges, L. V. (1981). Distribution Theory for Glass's Estimator of Effect Size and Related Estimators. *Journal of Educational Statistics*, 6 (2): 107-128. doi: 10.2307/1164588.

Henkel Ltd. (2024). *LOCTITE SUPERGLUE Precision product page*. Available at: https://www.loctite-consumer.co.uk/products/central-pdp.html/loctite-superglue-precision-max/SAP_0201DCLSGZ77.html (accessed: 08.01.2025).

Houston, A. (1985). Central-Place Foraging: Some Aspects of Prey Choice for Multiple-Prey Loaders. *The American Naturalist*, 125 (6): 811-826. doi: 10.1086/284381.

Houston, A. I. (1987). Optimal foraging by parent birds feeding dependent young. *Journal of Theoretical Biology*, 124 (3): 251-274. doi: 10.1016/S0022-5193(87)80115-7.

Isaksson, N., Evans, T. J., Shamoun-Baranes, J. & Åkesson, S. (2016). Land or sea? Foraging area choice during breeding by an omnivorous gull. *Movement Ecology*, 4 (1): 11. doi: 10.1186/s40462-016-0078-5.

Jakubas, D., Iliszko, L. M., Strøm, H., Helgason, H. H. & Stempniewicz, L. (2018). Flexibility of foraging strategies of the great skua Stercorarius skua breeding in the largest colony in the Barents Sea region. *Front Zool*, 15 (1): 9-9. doi: 10.1186/s12983-018-0257-x.

Kareiva, P. & Odell, G. (1987). Swarms of Predators Exhibit "Preytaxis" if Individual Predators Use Area-Restricted Search. *The American Naturalist*, 130 (2): 233-270. doi: 10.1086/284707.

Karplus, M. (1952). Bird Activity in the Continuous Daylight of Arctic Summer. *Ecology (Durham)*, 33 (1): 129-134. doi: 10.2307/1931264.

Krause, J. a. R., G.D. (2002). *Living in groups*. Oxford: Oxford University Press.

Krausman, P. R. (1999). Some basic principles of habitat use. In Launchbaugh, K. L., Sanders, K. D. & Mosley, J. L. (eds) vol. 70 *Grazing behavior of livestock and wildlife*, pp. 85-90. Moscow: University of Idaho.

Lima, S. & Dill, L. (1990). Behavioral Decisions Made under the Risk of Predation: A Review and Prospectus. *Canadian Journal of Zoology-revue Canadienne De Zoologie - CAN J ZOOL*, 68: 619-640. doi: 10.1139/z90-092.

Lima, S. L., Bednekoff, P. A. & Andrew, S. (1999). Temporal Variation in Danger Drives Antipredator Behavior: The Predation Risk Allocation Hypothesis. *Am Nat*, 153 (6): 649-659. doi: 10.1086/303202.

Loeng, H. (1989). *Ecological features of the Barents Sea*. Proceedings of the 6th conference of the Comité Arctique International. Brill, Leiden.

Loeng, H. (1991). Features of the physical oceanographic conditions of the Barents Sea. *Polar Research*, 10. doi: 10.3402/polar.v10i1.6723.

Lu, Z. & Yuan, K.-H. (2010). Welch's t test. In Salkind, N. J. (ed.) *Encyclopedia of research design*, pp. 1620-1623. CA: Thousand Oaks.

Lydersen, C. & Kovacs, K. M. (2006). *Svalbards fugler og pattedyr*. Polarhåndbok (trykt utg.), vol. nr 13. Tromsø: Norsk polarinstitutt.

MacArthur, R. H. & Pianka, E. R. (1966). On Optimal Use of a Patchy Environment. *The American Naturalist*, 100 (916): 603-609. doi: 10.1086/282454.

Magnhagen, C. (1991). Predation risk as a cost of reproduction. *Trends in Ecology & Evolution*, 6 (6): 183-186. doi: 10.1016/0169-5347(91)90210-O.

Martin, T. E. (1987). Food as a Limit on Breeding Birds: A Life-History Perspective. *Annual Review of Ecology and Systematics*, 18: 453-487. doi: 10.1146/annurev.es.18.110187.002321.

Mehlum, F. & Gabrielsen, G. W. (1993). The diet of high-arctic seabirds in coastal and ice-covered, pelagic areas near the Svalbard archipelago. *Polar research*, 12 (1): 1-20. doi: 10.1111/j.1751-8369.1993.tb00417.x.

Mehlum, F., Gulliksen, B., Sakshaug, E., Norges, f. & Pro, M. (1994). *Økosystem Barentshavet*. Revidert opplag ed. Oslo: Norges forskningsråd: Universitetsforlaget.

Mehlum, F., Nordlund, N. & Isaksen, K. (1998). The importance of the “Polar Front” as a foraging habitat for guillemots Uria spp. breeding at Bjørnøya, Barents Sea. *Journal of Marine Systems*, 14 (1): 27-43. doi: 10.1016/S0924-7963(98)00017-7.

Mehlum, F., Watanuki, Y. & Takahashi, A. (2001). Diving behaviour and foraging habitats of Brünnich's guillemots (Uria lomvia) breeding in the High-Arctic. *Journal of Zoology*, 255 (3): 413-423. doi: 10.1017/S0952836901001509.

Meltofte, H., Barry, T., Berteaux, D., Bültmann, H., Christiansen, J., Cook, J., Dahlberg, A., Daniëls, F., Ehrich, D. & Fjeldså, J. (2013). Arctic biodiversity assessment: Synthesis. *Conservation of Arctic Flora and Fauna (CAFF), Akureyri*.

Meredith, M., Ridout, M. & Campbell, L. A. D. (2024). *overlap: Estimates of Coefficient of Overlapping for Animal Activity Patterns*. Available at: https://CRAN.R-project.org/package=overlap.

Meterologisk Institutt. (n.d.). *Polar nights and midnight sun*. yr.no. Available at: https://hjelp.yr.no/hc/en-us/articles/360008027114-Polar-nights-and-midnight-sun (accessed: 24.01.2025).

Microsoft. (2025). *Copilot [Large language model]*. Available at: https://copilot.microsoft.com (accessed: 03.04.2025).

Mohr, C. O. (1947). Table of Equivalent Populations of North American Small Mammals. *The American Midland Naturalist*, 37 (1): 223-249. doi: 10.2307/2421652.

Monaghan, P. (1988). *J.P. Croxall Seabirds. Feeding Ecology and Role in Marine Ecosystems 1987 Cambridge University Press Cambridge viii*, 36: Elsevier Ltd. pp. 631-632.

Murray, B. (2000). Measuring Annual Reproductive Success in Birds. *Condor*, 102. doi: 10.1650/0010-5422(2000)102[0470:MARSIB]2.0.CO;2.

Natsukawa, H. & Sergio, F. (2022). Top predators as biodiversity indicators: A meta-analysis. *Ecol Lett*, 25 (9): 2062-2075. doi: 10.1111/ele.14077.

Nice, M. M. (1957). Nesting Success in Altricial Birds. *The Auk*, 74 (3): 305-321. doi: 10.2307/4081922.

Norris, K. (2004). Managing threatened species: the ecological toolbox, evolutionary theory and declining-population paradigm. *Journal of Applied Ecology*, 41 (3): 413-426. doi: 10.1111/j.0021-8901.2004.00910.x.

Norsk klimaservicesenter. (2025). *Mean July temperatures - Bjørnøya* Seklima - Observasjoner og værstatistikk Available at: https://seklima.met.no/observations/ (accessed: 08.03.2025).

Norwegian Polar Institute. (2024a). *Breeding population of common guillemot, as percentage of the average in the colony.* Environmental monitoring of Svalbard and Jan Mayen (MOSJ). Available at: https://mosj.no/en/indikator/fauna/marine-fauna/common-guillemot/ (accessed: 12.05.2025).

Norwegian Polar Institute. (2024b). *Glaucous gull population, as percentage of the average in the colony*. Environmental monitoring of Svalbard and Jan Mayen (MOSJ). Available at: https://mosj.no/en/indikator/fauna/marine-fauna/glaucous-gull/ (accessed: 23.01.2025).

Nøst Hegseth, E. (1998). Primary production of the northern Barents Sea. *Polar Research*, 17 (2): 113-123. doi: 10.3402/polar.v17i2.6611.

OpenAI. (2025). *ChatGPT (March 14 version) [Large language model]*. Available at: https://chat.openai.com/chat (accessed: 03.04.2025).

Orians, G. H. & Pearson, N. E. (1979). On the theory of central place foraging. In *Analysis of Ecological Systems*, pp. 154-177: Columbus: Ohio State University Press.

Paleczny, M., Hammill, E., Karpouzi, V. & Pauly, D. (2015). Population Trend of the World's Monitored Seabirds, 1950-2010. *PLOS ONE*, 10 (6): e0129342. doi: 10.1371/journal.pone.0129342.

Parsons, M., Mitchell, I., Butler, A., Ratcliffe, N., Frederiksen, M., Foster, S. & Reid, J. B. (2008). Seabirds as indicators of the marine environment. *ICES Journal of Marine Science*, 65 (8): 1520-1526. doi: 10.1093/icesjms/fsn155.

PathTrack Ltd. (2024). *nanoFix® GEO+RF*. Available at: https://www.pathtrack.co.uk/product/nanofix-georf/ (accessed: 14.11.2024).

Petersen, A., Irons, D., Gilchrist, H., Robertson, G., Boertmann, D., Strøm, H., Gavrilo, M., Artukhin, Y., Clausen, D., Kuletz, K., et al. (2015). The Status of Glaucous Gulls Larus hyperboreus in the Circumpolar Arctic. *Arctic*, 68: 107-120. doi: 10.14430/arctic4462.

Petracci, P., Caruso, N., La Sala, L. F., Marbán, L., Sotelo, M., Carrizo, M. & Sarria, R. (2024). Foraging areas of Orlog's gulls in an estuarine ecosystem of Argentina: are they underprotected? *Marine Biology*, 171 (4): 96. doi: 10.1007/s00227-024-04404-7.

Pinheiro, J. & Bates, D. (2000). Theory and computational methods for linear mixed-effects models, mixed-effects models in S and S-PLUS. *Statistics and Computing*: 57-96. doi: 10.1007/978-1-4419-0318-1_2.

QGIS Development Team. (2025). *QGIS Geographic Information System* (Version 3.34.13-Prizren): Open Source Geospatial Foundation Project. Available at: http://qgis.org (accessed: 07.01.2024).

R Core Team. (2024). *R: A Language and Environment for Statistical Computing* (Version 4.4.2). Vienna, Austria: R Foundation for Statistical Computing. Available at: https://www.R-project.org/.

Reierth, E. & Stokkan, K. A. (2002). Biological Rhythms in Arctic Animals. In Kumar, V. (ed.) *Biological Rhythms*, pp. 216-223. Berlin, Heidelberg: Springer Berlin Heidelberg.

Rock, P., Camphuysen, C. J., Shamoun-Baranes, J., Ross-Smith, V. H. & Vaughan, I. P. (2016). Results from the first GPS tracking of roof-nesting Herring Gulls Larus argentatus in the UK. *Ringing & Migration*, 31 (1): 47-62. doi: 10.1080/03078698.2016.1197698.

Roenneberg, T. & Foster, R. G. (1997). Twilight Times: Light and the Circadian System. *Photochem Photobiol*, 66 (5): 549-561. doi: 10.1111/j.1751-1097.1997.tb03188.x.

Rowcliffe, J. M. (2023). *activity: Animal Activity Statistics*. Available at: https://CRAN.R-project.org/package=activity.

Sagerup, K., Helgason, L. B., Polder, A., Strøm, H., Josefsen, T. D., Skåre, J. U. & Gabrielsen, G. W. (2009). Persistent organic pollutants and mercury in dead and dying glaucous gulls (Larus hyperboreus) at Bjørnøya (Svalbard). *Science of The Total Environment*, 407 (23): 6009-6016. doi: 10.1016/j.scitotenv.2009.08.020.

Sakshaug, E., Bjørge, A., Gulliksen, B., Loeng, H. & Mehlum, F. (1994). *Økosystem Barentshavet*. Revidert opplag ed. Oslo: Norges forskningsråd: Universitetsforlaget.

Samelius, G. & Alisauskas, R. (1999). Diet and growth of Glaucous Gulls at a large Arctic goose colony. *Canadian Journal of Zoology-revue Canadienne De Zoologie - CAN J ZOOL*, 77: 1327-1331. doi: 10.1139/cjz-77-8-1327.

SanDisk. (2025). *SanDisk Extreme SDXC product page*. Memory card: Western Digital Available at: https://shop.sandisk.com/product-portfolio/memory-cards/sd-cards (accessed: 09.05.2025).

Scrucca, L., Fraley, C., Murphy, T. B. & Raftery, A. E. (2023). *Model-Based Clustering, Classification, and Density Estimation Using mclust in R*: Chapman and Hall/CRC.

SEATRACK. (2025). *Wintering Glaucous gull - Bjørnøya colony*. Distribution map. Available at: https://experience.arcgis.com/experience/435f2df809324f858fc5e437cd035973 (accessed: 31.01.2025).

Shaffer, S. A., Cockerham, S., Warzybok, P., Bradley, R. W., Jahncke, J., Clatterbuck, C. A., Lucia, M., Jelincic, J. A., Cassell, A. L., Kelsey, E. C., et al. (2017). Population-level plasticity in foraging behavior of western gulls (Larus occidentalis). *Movement Ecology*, 5 (1): 27. doi: 10.1186/s40462-017-0118-9.

Sjöberg, K. (1989). Time-related predator/prey interactions between birds and fish in a northern Swedish river. *Oecologia*, 80 (1): 1-10. doi: 10.1007/BF00789924.

Steiger, S. S., Valcu, M., Spoelstra, K., Helm, B., Wikelski, M. & Kempenaers, B. (2013). When the sun never sets: diverse activity rhythms under continuous daylight in free-living arctic-breeding birds. *Proceedings of the Royal Society. B, Biological sciences*, 280 (1764): 1-10. doi: 10.1098/rspb.2013.1016.

Stempniewicz, L. (1994). Predator-prey interactions between Glaucous Gull Larus hyperboreus and Little Auk Alle alle on Spitsbergen. *Acta Ornithologica*, 29: 155-170.

Stempniewicz, L. & Iliszko, L. (2010). Glaucous Gulls Kleptoparasiting Arctic Foxes in Magdalenefjorden, NW Spitsbergen. *Arctic*, 63 (1): 107-111. doi: 10.14430/arctic651.

Stokke, B., Dale, S., Jacobsen, K.-O., Lislevand, T., Solvang, R. & Strøm, H. (2021). *Fugler: Vurdering av polarmåke Larus hyperboreus for Svalbard*. Rødlista for arter 2021: Artsdatabanken.

Strøm, H. (2006). Glaucous gull. In Kovacs, K. M. & Lydersen, C. (eds) *Birds and Mammals of Svalbard*, pp. 141-143. Tromsø, Norway: Norwegian Polar Institute.

Strøm, H., Descamps, S., Ekker, M., Fauchald, P. & Moe, B. (2021). Tracking the movements of North Atlantic seabirds: Steps towards a better understanding of population dynamics and marine ecosystem conservation. *Marine Ecology Progress Series*, 676: 97-116. doi: 10.3354/meps13801.

Strøm, H. (2025a). *Food items (deliveries) common and Brûnnichs guillemot - Bjørnøya 2024*: Norwegian Polar Institute. Unpublished manuscript.

Strøm, H. (2025b). *Hatching dates common guillemot Bjørnøya 2024*: Norwegian Polar Institute. Unpublished manuscript.

Symons, S. & Diamond, T. (2019). Short-term tracking tag attachment disrupts chick provisioning by Atlantic Puffins Fratercula arctica and Razorbills Alca torda. *Bird Study*, 66: 1-11. doi: 10.1080/00063657.2019.1612850.

Sørensen, E. A. (2021). *Monitoring food provisioning and diel activity of breeding glaucous gulls (Larus hyperboreus) with nest cameras on Bjørnøya*. Master thesis. Ås: Norwegian University of Life Sciences. Available at: https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/2831673 (accessed: 11.12.2023).

tesa SE. (2024). *tesa® 4651 product page*. Available at: https://www.tesa.com/en-gb/craftsmen/tesa-4651.html (accessed: 08.01.2025).

Theisen, F. (1997). *Dokumentasjon og vurdering av verneverdier på Bjørnøya*. In Theisen, F. (ed.). Meddelelser, 143: Norsk Polarinstitutt.

Varpe, Ø. (2010). Stealing bivalves from common eiders: kleptoparasitism by glaucous gulls in spring. *Polar biology*, 33 (3): 359-365. doi: 10.1007/s00300-009-0712-4.

Verreault, J., Gabrielsen, G. & Bustnes, J. (2010). The Svalbard Glaucous Gull as Bioindicator Species in the European Arctic: Insight from 35 Years of Contaminants Research. *Reviews of environmental contamination and toxicology*, 205: 77-116. doi: 10.1007/978-1-4419-5623-1_2.

Votier, S. C., Bearhop, S., Ratcliffe, N. & Furness, R. W. (2004). Reproductive Consequences for Great Skuas Specializing as Seabird Predators. *The Condor*, 106 (2): 275-287. doi: 10.1093/condor/106.2.275.

Wickham, D. K. a. H. (2013). ggmap: Spatial Visualization with ggplot2. *The R Journal*, 5 (1): 144-161.

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. New York: Springer-Verlag.

Wojczulanis-Jakubas, K., Wąż, P. & Jakubas, D. (2020). Little auks under the midnight sun: diel activity rhythm of a small diving seabird during the Arctic summer. *Polar research*, 39: 1-9. doi: 10.33265/polar.v39.3309.

Worton, B. J. (1989). Kernel Methods for Estimating the Utilization Distribution in Home-Range Studies. *Ecology*, 70 (1): 164-168. doi: 10.2307/1938423.

Xu, H., Li, D., Hou, X., Yu, X., Liu, Y., Li, X., Li, B., Chen, L., Wang, X. & Xia, S. (2021). Home Range and Habitat Disturbance Identification for a Vulnerable Shorebird Species *Larus saundersi* in the Yellow River Delta, China. *Journal of Coastal Research*, 37 (4): 737-748.

Ydenberg, R. & Hurd, P. (1998). Simple models of feeding with time and energy constraints. *Behavioral Ecology*, 9: 49-53. doi: 10.1093/beheco/9.1.49.

Ydenberg, R. C., Welham, C. V. J., Schmid-Hempel, R., Schmid-Hempel, P. & Beauchamp, G. (1994). Time and energy constraints and the relationships between currencies in foraging theory. *Behavioral Ecology*, 5 (1): 28-34. doi: 10.1093/beheco/5.1.28.

Zanette, L. Y., White, A. F., Allen, M. C. & Clinchy, M. (2011). Perceived Predation Risk Reduces the Number of Offspring Songbirds Produce per Year. *Science*, 334 (6061): 1398-1401.

7. Appendix

Appendix A – Camera Setup

Figure A1: Camera placement at KK-2. Reconyx camera (red circle) was placed by feeding place, aiming towards nest bowls. Small area to wander around. Photo: Author.

Figure A2: LF-1. Large area to roam around, compared to KK-2. Brinno camera was partially concealed with camouflage tape and rocks. Reconyx camera (red circle) by nest bowl. Photo: Author.

Figure A3: Additional lithium battery with USB socket for Brinno cameras. Photo: Author.

Appendix B – ID and Biometrics

Table B1: Identification, biometric measurements and logger weight.

Ring ID	ID	Sex	Wing	Culmen	Gonys	Total head	Weight (g)	Tarsus	Nest	Tag weight
NOS 3086527	3EP	M	464	65,88	23,13	155,75	1620	71.57	KK-2	7.99
NOS 3045661	BU3	F	461	57,16	20,01	139,35	1290	64.11	KK-6	7.70
NOS 3046221	CE3	F	472	56,87	20,75	141,79	1460	69.05	KK-7	8.12
NOS 3046214	3ET	M	449	68,76	24,16	152,84	1850	75.97	KK7	7.81
NOS 3051254	3ES	F	460	58,37	22,09	142,65	1320	71.60	KK-8	8.09
NOS 3051258	AB3	M	491	65,11	23,87	149,27	1780	75.22	KK-8	7.94
NOS 3086505	BT3	F	471	57,35	21,03	142,87	1450	71.42	KK-12	-
NOS 3030795	3ER	M	485	66,53	23,12	157,4	1710	74.56	KK-12	8.04
NOS 3086509	CH3	F	466	58,28	21,27	141,73	1510	69.56	KK/FF-3	7.99
NOS 3051301	3EN	M	470	63,5	23,55	147,11	1610	67.60	FN/KK-1	7.72
NOS 3007161	3EO	F	470	57,73	20,35	141,97	1380	68.65	FN/KK-2	8.11
NOS 3065062	3EM	F	444	55,55	20,75	134,27	1460	68.17	LF-1	7.69
$\bar{x}$ =							***1537***			**7.93**

Appendix C – GPS Logger

Figure C1: PathTrack nanoFix®GEO + RF tag. Secured with cable tie at the base of the four middle tail feathers and tesa tape at the end. Photo: Author.

Appendix D – Breeding Success

Table D1: Breeding successes for nest between Revdalen and Kapp Kolthoff with sufficient data. *camera and GPS monitored nests.

Nest	*Clutch size*	*Eggs hatched*	*Chicks dead*	*Potential fledgers*	*Breeding success*
KK-1	3	2	1	1	0.33
KK-2*	3	2	1	1	0.33
KK-3	3	2		2	0.67
KK-4	3	3	2	1	0.33
KK-5	1	0			0
KK-6*	3	2	2	0	0
KK-7*	3	1		1	0.33
KK-8*	3	3	3	0	0
KK-9	3	2		2	0.67
KK-10	2	2	1	1	0.5
KK-11	3	2	2	0	0
KK-12*	3	3	1	2	0.67
KK-13	3	3		3	1
KK-14	3	2	1	1	0.33
KK/FF-1	1	1		1	1
KK/FF-3*	3	2	2	0	0

FN/KK-1*	3	2	1	1	0.33
FN/KK-2*	2	2	1	1	0.5
FN-1	3	3		3	1
FN-2	1	1		1	1
FN-3	3	2		2	0.67
LF-1*	3	1		1	0.33
LF-2	3	3		3	1
LH-1	1	0			0
9:15					**45.79%**

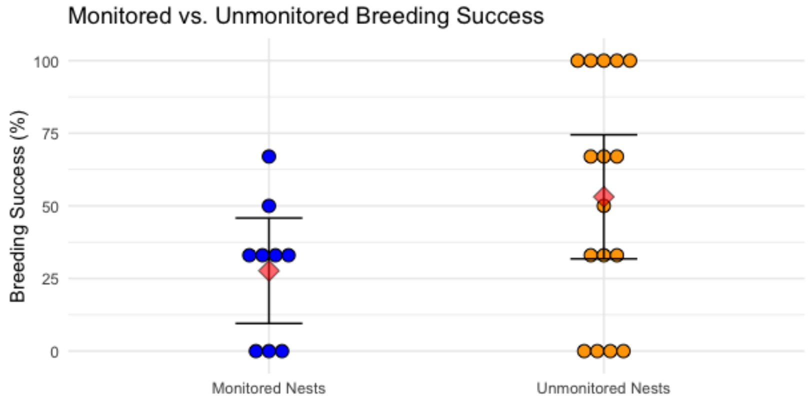


Figure D1: Breeding success between monitored and unmonitored nests. Point shows individual breeding success for nests. Red point is mean for each group. Bars show the 95% CI.

Appendix E – Prey Composition

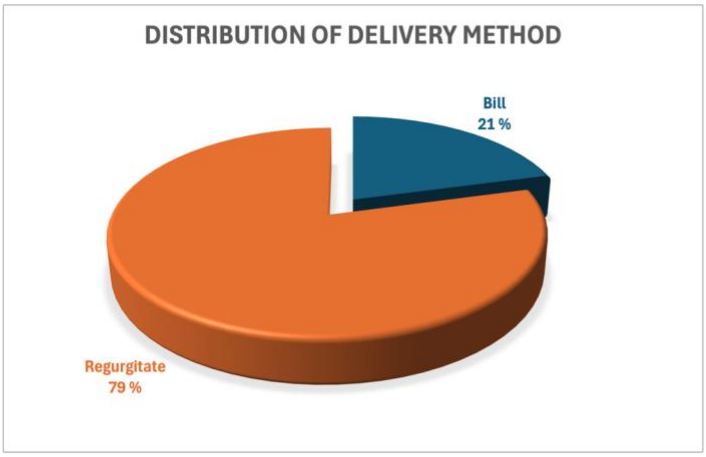


Figure E1: Distribution of prey delivery. For 389 prey deliveries, method of delivery was also registered.

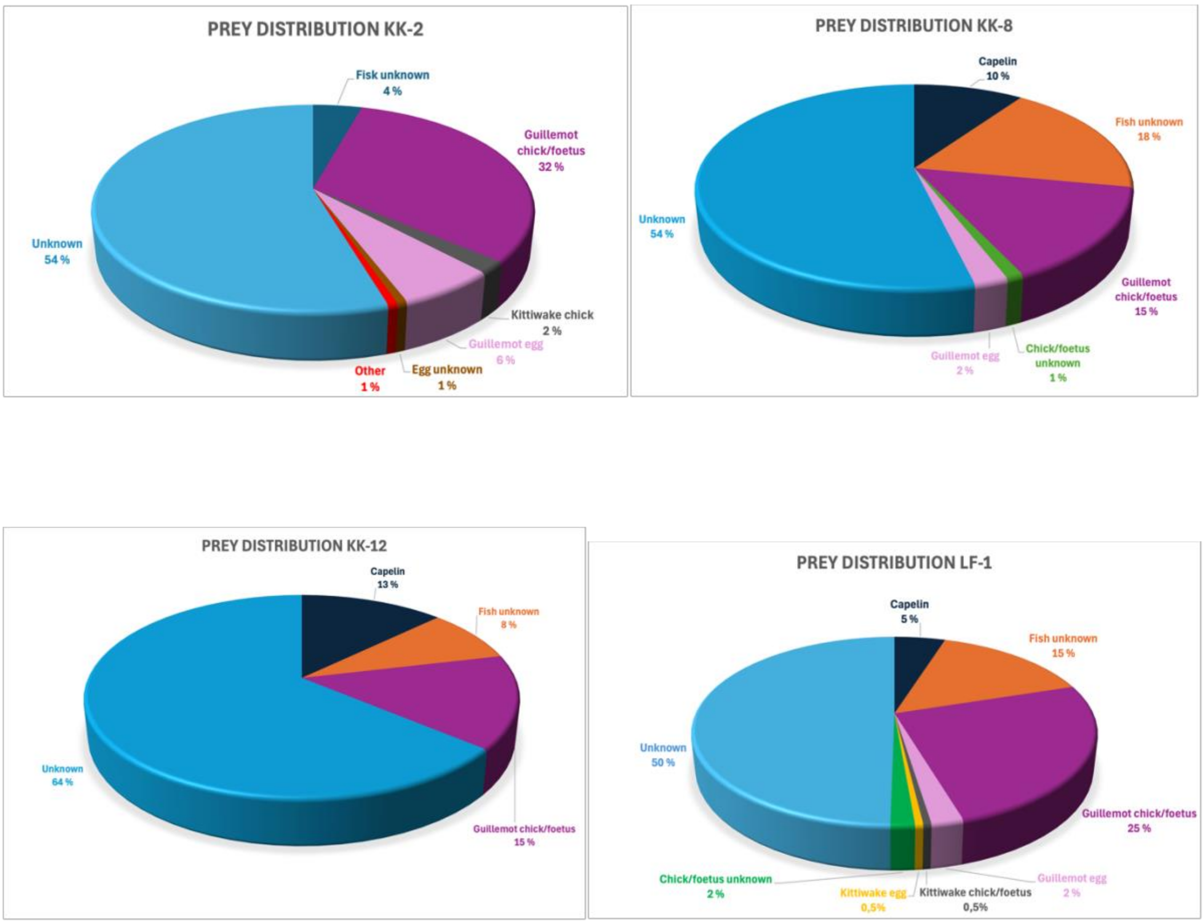
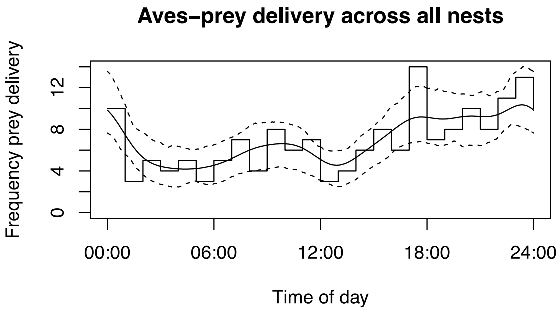
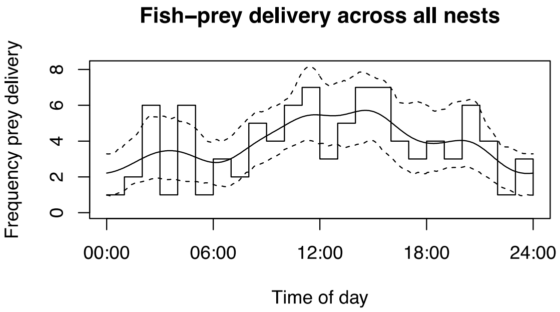


Figure E2: Prey distribution per nests.

Appendix F – Diel Activity





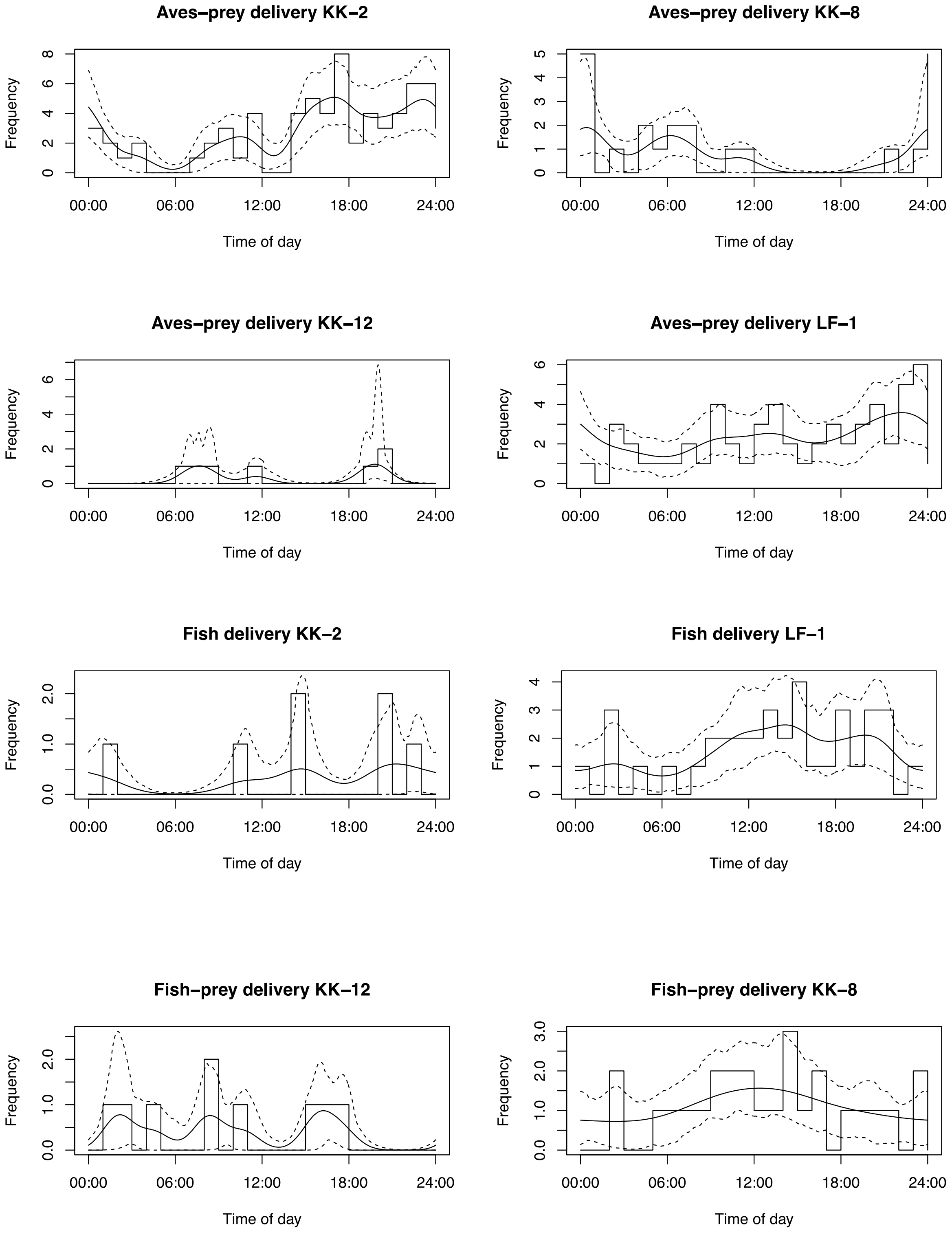


Figure F1: Diel activity for different nests and prey groups. For KK-12 n is low (<8) for both prey groups (many of the prey deliveries were of unidentified prey). For KK-2 n is low for the fish group.

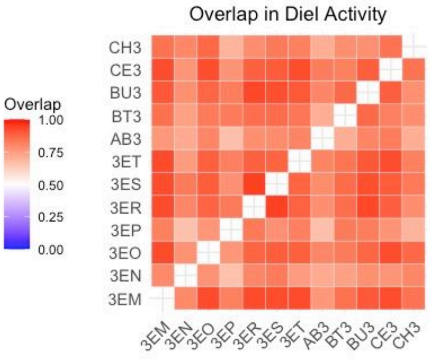
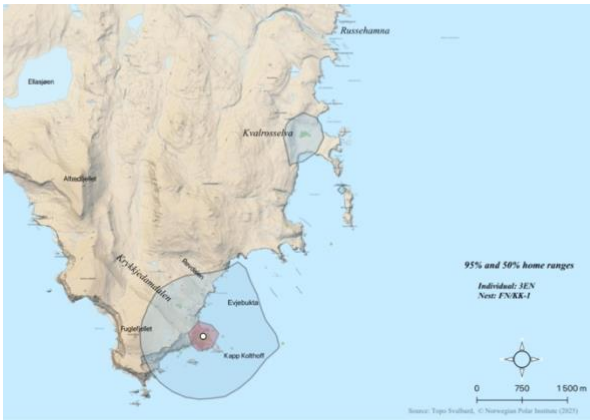
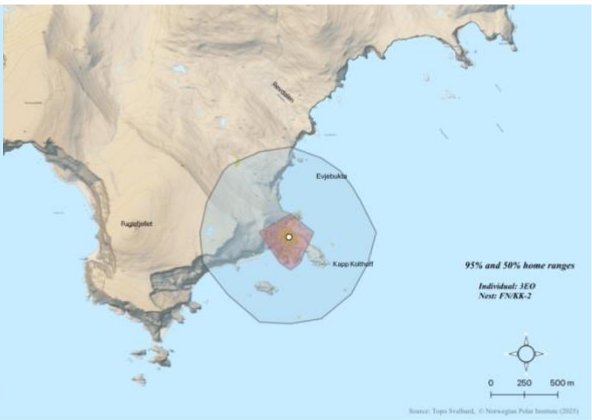
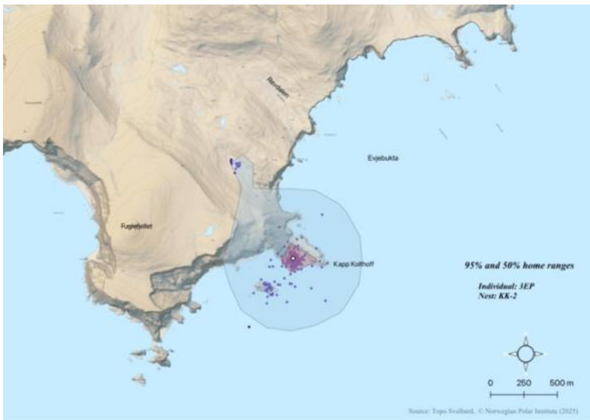


Figure F2: Overlap in diel activity.

Appendix G – Home Range







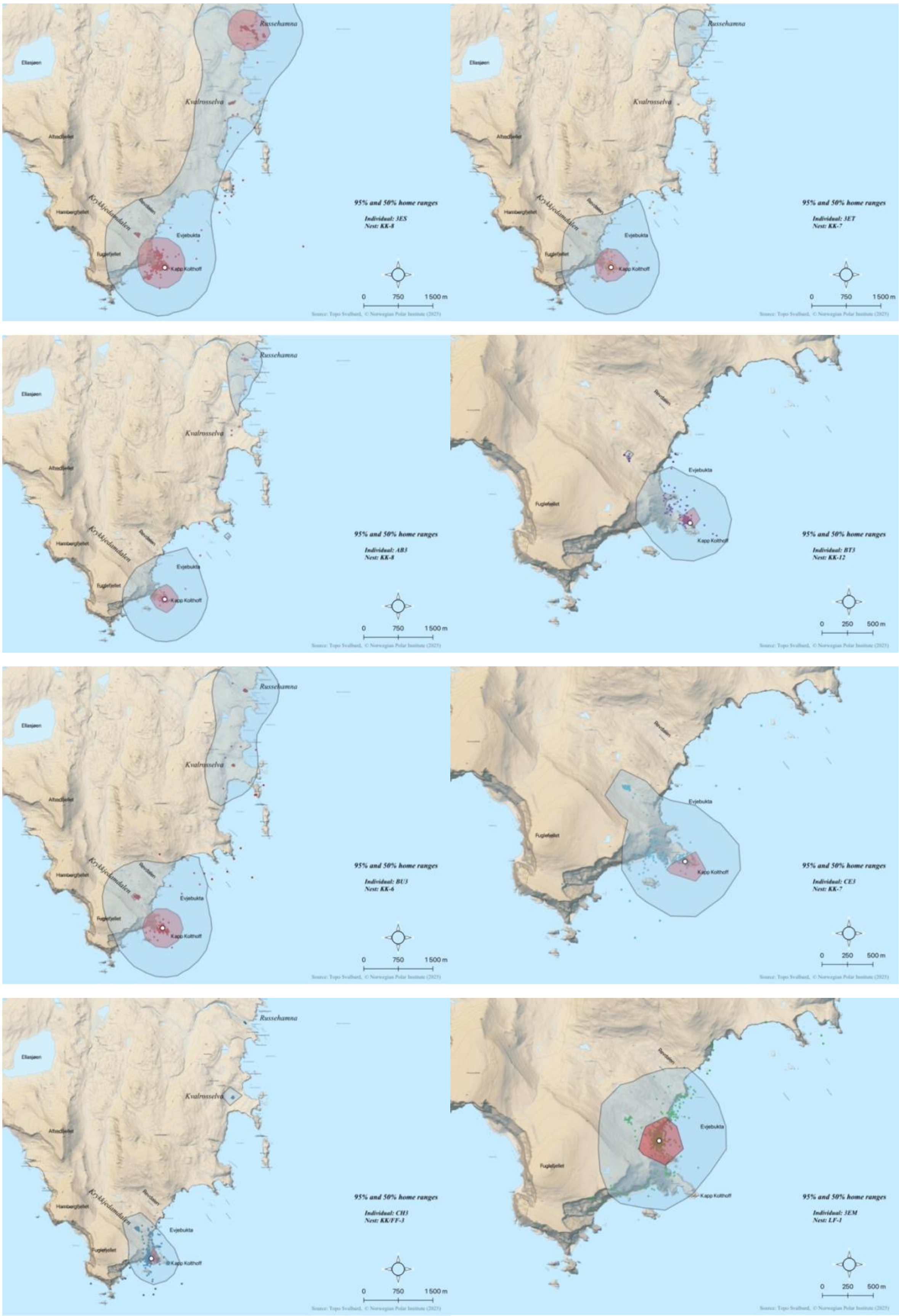


Figure G1: 95% home ranges and 50% core areas, filtered by *bird ID*. White dot is the allocated nest.

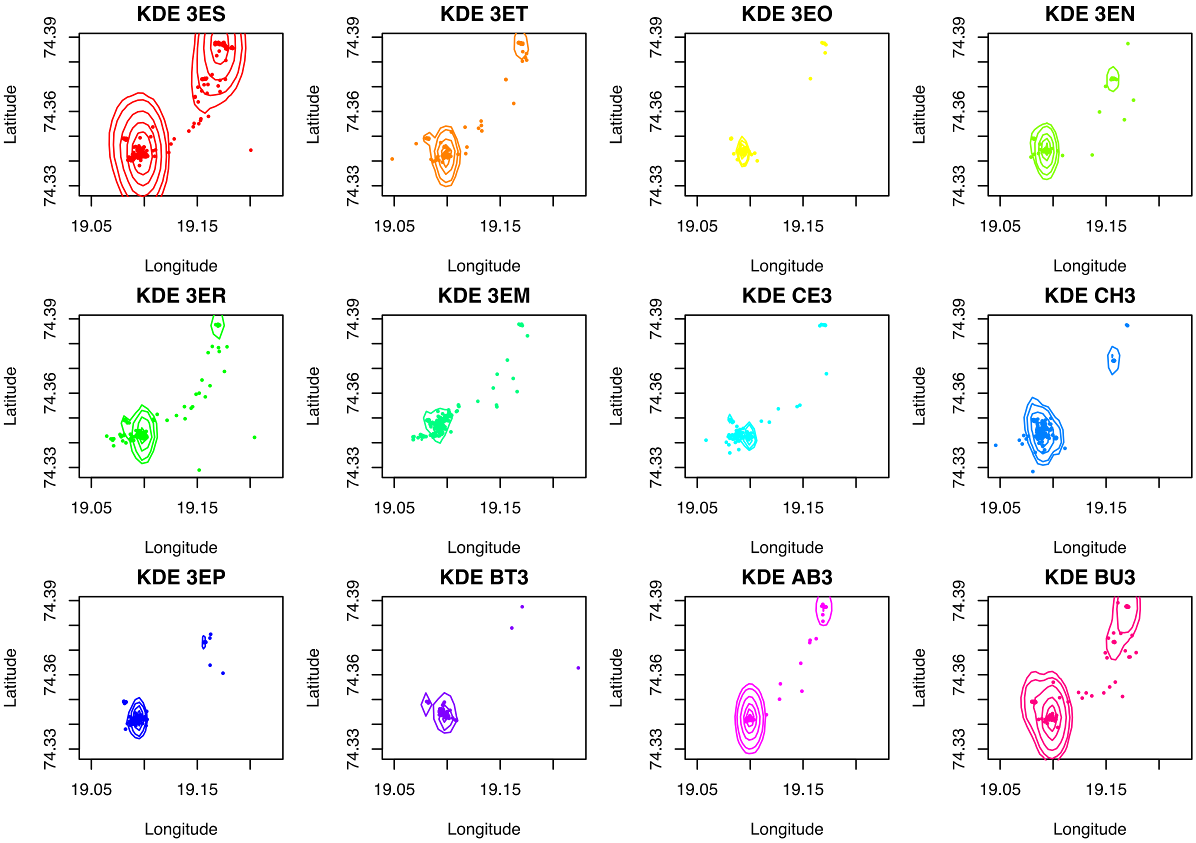
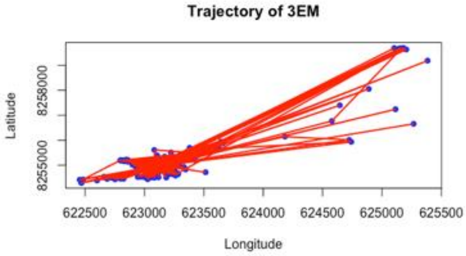
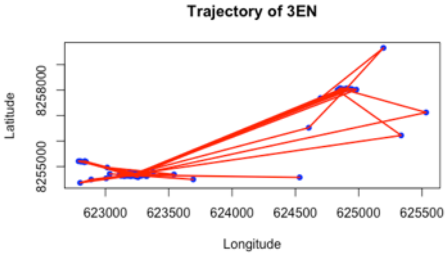
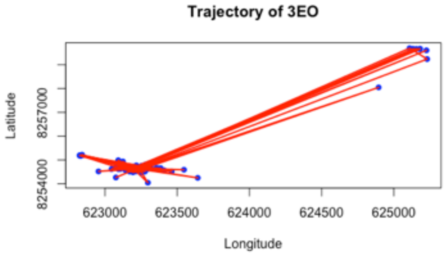
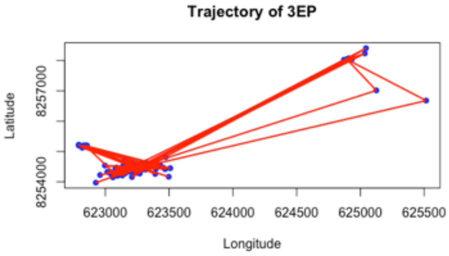


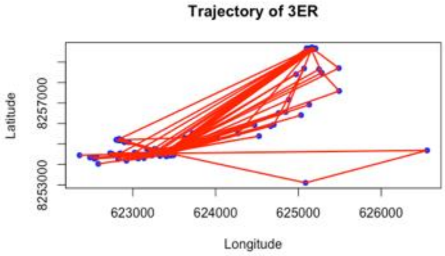
Figure G2: KernelUD home ranges, from 20-95%.

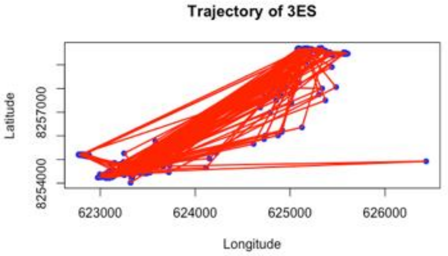

Trajectory of 3EM


Trajectory of 3EN


Trajectory of 3EO


Trajectory of 3EP


Trajectory of 3ER


Trajectory of 3ES

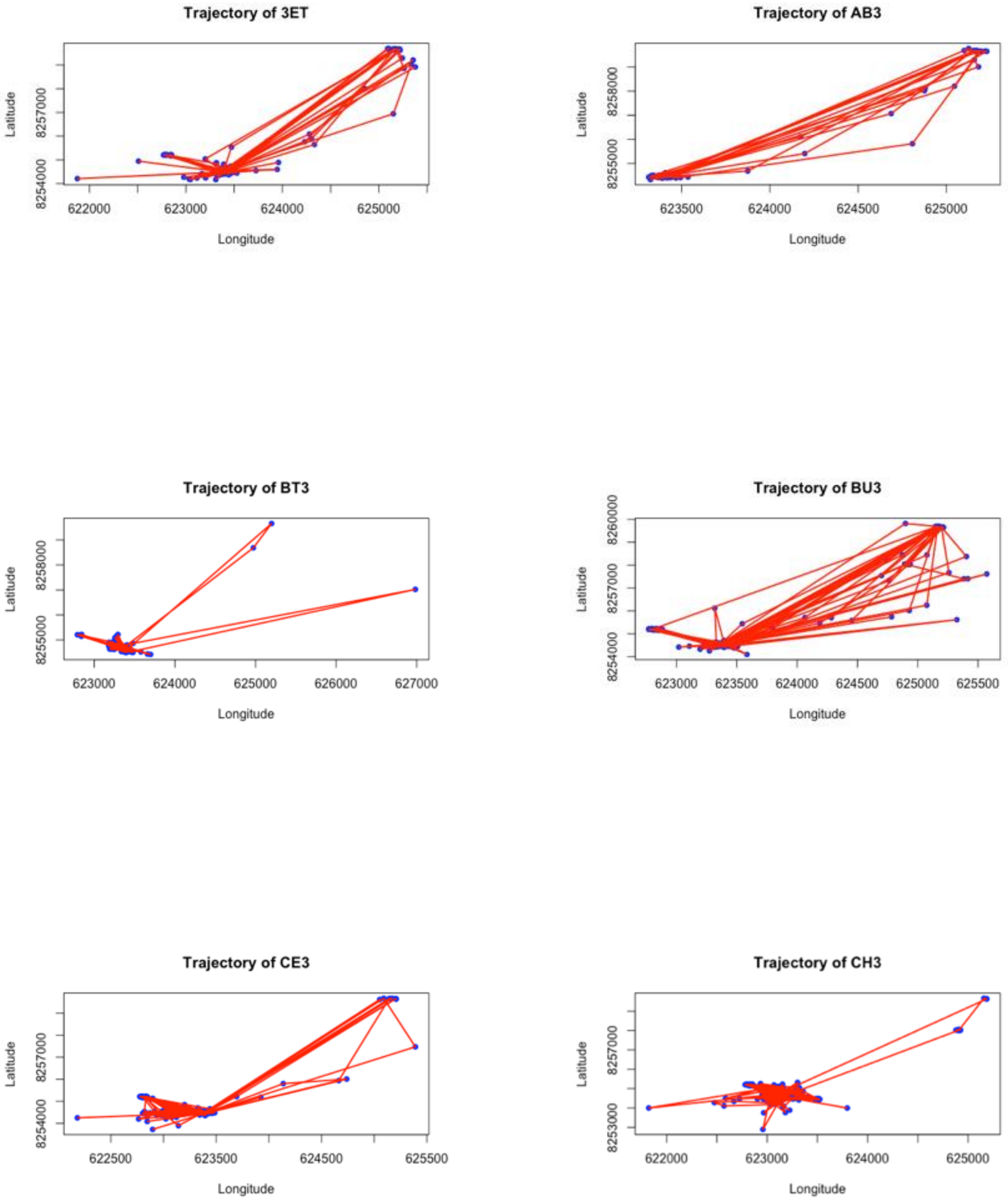


Figure G3: Individual trajectories. Displaying the connectivity of positions.

Appendix H – Prey Catch Locations

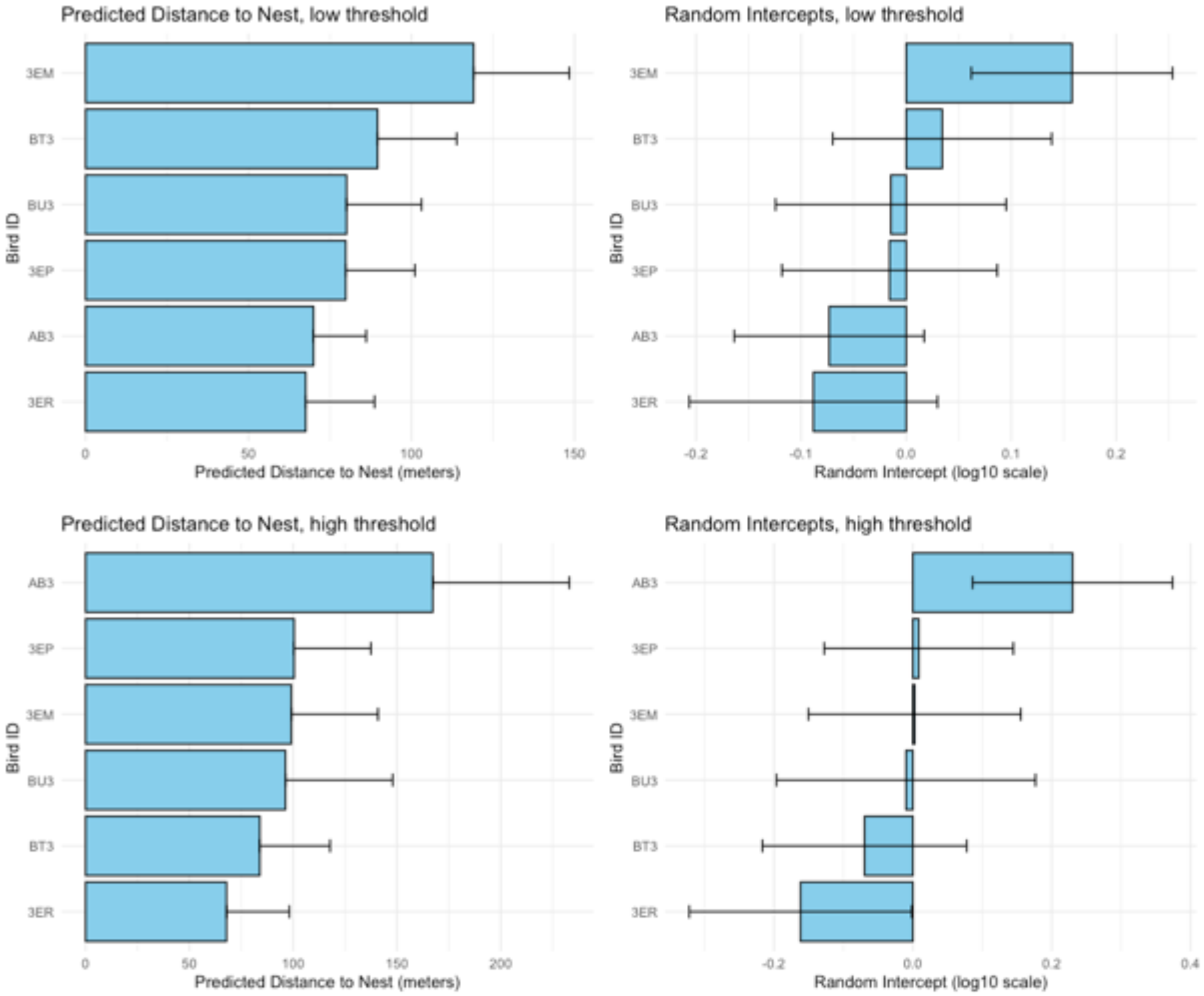


Figure H1: Low (0-30-25) and high (40-70-25) thresholds (model with only intercept still the best fitted). The different thresholds change individual distance travelled. Overall distance travelled is still consistent. With multiple measurements as random effect.

Table H1: Low-threshold model testing. Multiple measurements as random effect.

Model	*df*	*AIC*	*ΔAIC*	*Weight*
Intercept-only	4	240.841	0.000	0.962
Only grouped prey	7	247.534	6.693	0.034
No interaction	8	251.631	10.790	0.004
Full model (interaction)	11	258.437	17.597	<0.001

Table H2: High-threshold model testing. Multiple measurements as random effect.

Model	***df***	***AIC***	***ΔAIC***	***Weight***
Intercept-only	4	186.308	0.000	0.909
Only grouped prey	7	190.937	4.629	0.090
No interaction	8	200.801	14.493	<0.001
Full model (interaction)	11	217.379	31.071	<0.001

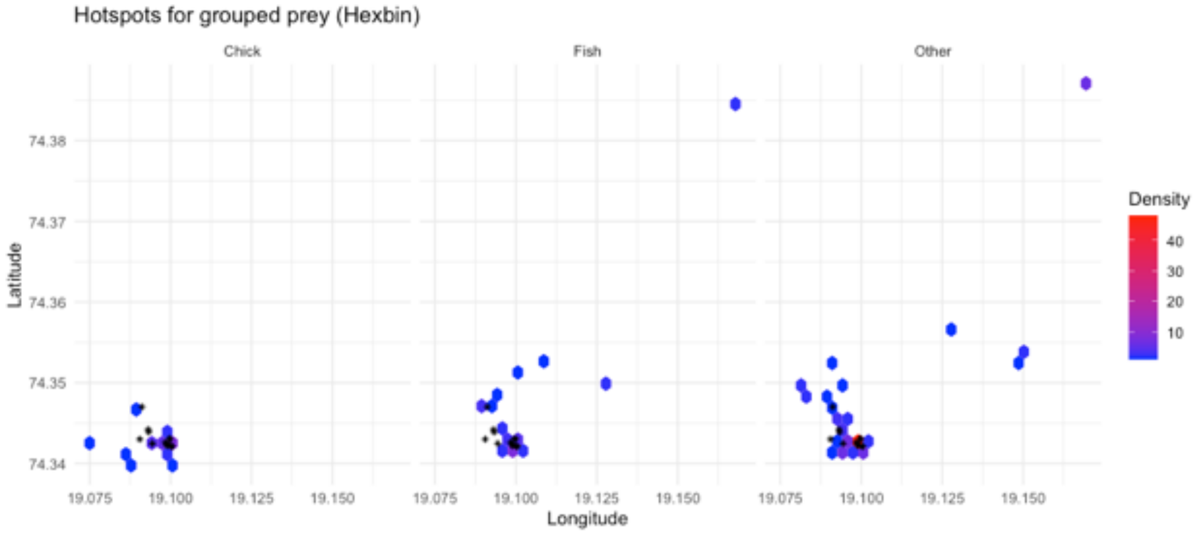


Figure H2: Hexbin hotspot analysis. Showing areas of high and low density for grouped prey. Black dots symbolize nests. Prey are concentrated near the nest sites, however not as pronounced as the GMM plot, but still corresponding with the surrounding seabird colonies.

Appendix I – Specified Nest Events

Still images from camera monitoring. All images: Author.

Figure I1: Evidence of glaucous gull as a multi-prey loader. Two fish in one regurgitation.

Figure I2: Intraspecific kleptoparasitism. An egg is targeted by conspecifics at KK-2.

Figure I3: Fox – predation attempt at KK-12.

Figure I4: Camera “intrusiveness”, LF-1.

Figure I5: Logger intrusiveness – BT3, KK-12.

Figure I6: Logger intrusiveness – BT3, KK-12

Figure I7: Logger intrusiveness – 3EM, LF-1

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