Norwegian University of Life Sciences

Master's Thesis 2024 60 ECTS
The Faculty of Environmental Sciences and Natural Resource Management (MINA)

Food provisioning, diel activity, and home range size in the glaucous gull (*Larus hyperboreus*) on Bjørnøya

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Natural resource management

Acknowledgements

This paper concludes my master's thesis in natural resource management on NMBU – Norwegian University of Life Sciences. The thesis is written in collaboration with NMBU and the Norwegian Polar Institute and is a continuation of previous master's theses from 2016 and 2021 on Bjørnøya. The project is funded by the Norwegian Polar Institute and supervised by Hallvard Strøm and Ronny Steen. I wish to express my deepest gratitude to my supervisors, Ronny and Hallvard, without whom I would never have been able to experience the awesome scenery on Bjørnøya, or the privilege of working with the amazing birds that live there. They have guided me and answered all my questions in every step of the process. I would also like to thank my colleagues on Bjørnøya, who shared their knowledge with me both while on the island and in the time after. You made the long days in the field easy and fun. I would also like to give an extra thanks to Anne Marie Austad, who volunteered to read through the entire thesis and give advice and improve upon it up until the very last minute, a big thank you! Lastly, I wish to thank my girlfriend, my family, and my friends that supported and worried about me along the way, thank you all for making this possible.

Abstract

The glaucous gull (*Larus hyperboreus*) is one of the only numerous predatory bird species on Svalbard. They are generalist feeders that hunt and scavenge for food along the coast and on the open sea. On Bjørnøya, the gulls mainly feed on carrion, avian prey, and fish. In this study, camera traps were set out on a total of nine glaucous gulls' nests to capture images of prey delivered by the parents to their young. Some of the gulls were also fitted with Pathtrack® Nanofix + RF GPS tags that tracked their movement to study their habitat use and estimate home ranges. Fish and avian prey comprised the main part of the diet. The camera trap images showed that capelin (*Mallotus villosus*), guillemot (*Uria sp*.) chicks, and guillemot eggs were the main prey brought to the chicks. The composition of prey captured varied between nests, depending on location, with fish dominating the diet at nests situated closer to sea level. The gulls were not found to display a clear diurnal cycle, as also observed in other populations and species breeding in the Arctic. An interesting find in this study was that all four gulls fitted with a GPS tag had very small home ranges, only extending a few square kilometers around their nest site. The gulls rarely ventured out to sea and were never recorded more than a few hundred meters from land. With up to 30% of fish in some of the gulls' diet, this led to the question of where and how the gulls caught the fish. Combining GPS data and prey delivery data from the camera traps, it was found that the gulls found most of the fish very close to their nest, suggesting that they mostly pirated fish from other seabirds or found shoals of fish very close to the island. To further strengthen the results in this study, more data and larger sample sizes is required, especially on the use of GPS tags in combination with camera traps, as this is still a novel data gathering method.

Content

Introduction

1 Introduction

Seabirds are a diverse group of marine fauna that vary greatly in physiology, life history and evolutionary traits. Being pelagic, seabirds are seen as good indicators of how the marine ecosystem functions, and a decline or changes in seabird populations may indicate that there are changes in the marine environment they inhabit (Parsons, 2009). In the productive waters of the Arctic, great congregation of nesting seabirds can be found in many locations. The Norwegian coastline including Svalbard, is home some of the largest seabird populations in the world, much due to the bounties of the Barents Sea (Strøm et al., 2010). Seabird colonies attracts scientists from many parts of the world and are great places to study the birds' ecology and population over time (Dias et al., 2019).

Of the 359 seabird species in the world, as much as 31% (110 species) are threatened by extinction globally and almost half of all species (47%) have declining populations (Dias et al., 2019). In Norway, the situation is much the same. Of the 54 seabird species that breed here, 24 species are threatened by extinction and another eight are considered near threatened on the national list of threatened species (Miljødirektoratet, 2023). The causes for the decline are many, and not all are that well understood. Generally, the collapse in fish stocks in the 60's-80's, the disappearance of kelp forests along the coast, bycatch, pollution, and warmer oceans that skew breeding fish stocks northward are considered the main cause for the seabird population decline (Miljødirektoratet, 2023).

Our understanding of how seabird populations change in response to anthropogenic changes in the environment has skyrocketed the past few decades, and the demand for new and updated research is increasing. Since 2005, this work has been coordinated by SEAPOP, a national seabird monitoring and mapping program that monitor seabird populations and research the factors that influence them in a set of key-sites along the Norwegian mainland coast, Svalbard, and Jan Mayen. The work in SEAPOP is also coordinated with many smaller projects on seabird populations that help highlight different species' vulnerability to environmental factors (Strøm et al., 2010; Miljødirektoratet, 2019). This master thesis falls within the latter category.

At Bjørnøya, a part of the Svalbard archipelago and the study area for this thesis, the largest bird colonies are found in the south, where the cliffs are tallest. The dominant species in these cliffs are the common guillemot (*Uria aalge*), the Brünnich's guillmot (*Uria lomvia*), the black legged kittiwake (*Rissa tridactyla*), the glaucous gull (*Larus hyperboreus*), the northern fulmar (*Fulmarus glacialis*), and in the rocky hills to the southwest, the little auk (*Alle alle*) (Theisen, 1997). Other species like the Atlantic puffin (*Fratercula arctica*), the razorbill (*Alca torda*) and the northern gannet (*Morus bassanus*) also have colonies on Bjørnøya, but in much smaller numbers. The bird colonies on Bjørnøya are some of the largest in the northern hemisphere and it is estimated that more than a million birds breed on the island in summer (Theisen, 1997). The nesting birds arrive in March-April and start laying their eggs in May-June. The chicks are fed through the summer months until they fledge in July- August. In winter, most birds leave the island and travel to other parts of the Barents Sea to overwinter (Theisen, 1997).

The glaucous gull spends the winter months living a nomadic life in the central part of the Barents Sea or along the Norwegian coast (Theisen, 1997; SEATRACK, 2024). As one of the largest avian predators in the Arctic and the only numerous predatory bird species on Svalbard, the glaucous gull plays a significant role in the Arctic ecosystem (Strøm, 2013). The gulls usually nest alone or in small colonies of 5-15 pairs, but colonies with more than 100 have also been observed (Strøm, 2013). They arrive at Bjørnøya in March-April at roughly the same time as many of the other seabird species. There they find a mate, often the same as previous years, and start building their nests on a wide ledge or in a flat grassy area where their chicks have little risk of falling off a cliff. The gulls lay 1-3 eggs that are incubated 27-28 days, and the timing often matches that of their prey, such as common- and Brünnich's guillemots (Strøm, 2013; Gaston et al. 2009). The chicks spend the first couple of days in the nest bowl but become increasingly active as they grow older (Strøm, 2006b). The chicks are reared about 42 days before fledging and take 4-5 years to become adults (Strøm et al., 2006c).

On Bjørnøya, the midnight sun is present between the 1st of May and the 10th of august (Timeanddate, 2024). This affects the birds' diurnal cycle. A study on the little auk by Wojczulanis-Jakubas et al. (2020), found that on a colony level, more birds were present in the colony during the hours when the sun was low. However, on an individual level, birds became arrhythmic and displayed little to no diurnal pattern in colony attendance

(Wojczulanis-Jakubas et al., 2020). The glaucous gull is generally regarded as a diurnal bird, however, during summer this pattern become less clear, and other ques such as prey activity and availability may become more important factors influencing the birds' diel rhythms (Sjöberg, 1989).

Research questions and objectives

The objective of this master's thesis is to continue the research done for the thesis «Monitoring Food Provisioning and Diel Activity in the Nesting Glaucous Gull (*Larus hyperboreus*) at Bjørnøya Using Camera Traps» by Sørensen E. A., (2021), estimating diet and diel activity of the Glaucous gull by use of camera traps at the gulls' nesting sites. The setup in this study has similar traits to its predecessors as two different locations will be compared to one another with regards to differences in preferred prey types. This study will however also try to estimate the gulls home range using modern, low power GPS trackers, which never have been done on glaucous gulls in Norway before, this study will serve as a pilot project in that regard. Using GPS trackers to find the gulls home range will help determine where the gulls move. Which will give a greater understanding of the overall behaviour of this gull species. The efficiency of the two camera types that were used to monitor the nests will be compared, to determine which type should be prioritized in future research. Lastly, I will explore whether the glaucous gull engages in kleptoparasitism, or mainly hunt their own prey.

In this study, the aim is to study food provisioning, diel activity, and home range size in the glaucous gull breeding on Bjørnøya, the goals are:

- Dietary analysis: Examining the typical food intake of the glaucous gull.
- Circadian activity: Investigating how perpetual daylight during the Arctic summer affects their daily activity patterns.
- Comparative observations: Assessing differences in diet and diel activity across different nests and locations.
- Technological efficiency: Determining the most effective type of camera trap for observing the glaucous gull.
- Home range determination: Defining the extent of their home range to understand where they hunt.

- Feeding behaviour: Exploring whether the glaucous gull engages in kleptoparasitism from other colonial seabirds or relies solely on its own hunting capabilities.

These investigations will help illuminate the behavioural and ecological adaptability of the glaucous gulls on Bjørnøya, providing insights into their survival strategies in a challenging environment.

2 Materials and methods

2.1 Study area

Bjørnøya is a small island situated halfway between the Norwegian mainland and Spitsbergen in the Barents Sea. It is the southernmost island of the Svalbard archipelago at 74°30'N 19°E (Theisen, 1997) and a part of Norwegian territory (Svalbardtraktaten, 1920). The island has an almost triangular shape, is about 20 km long and 15.5 km wide with an area of 178 km^2. The topography of the island differs a lot between the north and south. The northern part of the island is a mostly barren and flat lowland with more than 700 shallow lakes and ponds and are dominated by low rolling hills located around 30-50 masl (Theisen, 1997). The south is on the other hand far more mountainous, with the highest peak being Urd on Misery Mountain at 536 masl (Theisen, 1997). The most prominent feature of Bjørnøya is the steep cliffs that encircle much of the island. Reaching hights of more than four hundred meters in the south, the cliffs serve as excellent breeding ground for a variety of cliff nesting birds (Theisen, 1997).

The waters surrounding Bjørnøya are characterised by its sweeping currents, shallow plateau like seafloor and rich marine life (Sakshaug et al. 1992). Warm Atlantic currents that follow the Norwegian coast northward split in two when it passes Bjørnøya, one to the south of the island and one to the north. In turn, cold Arctic water is pushed down from the northeast, bringing the polar front down to the coastal areas surrounding Bjørnøya. The polar front is where cold brackish water from the north meets the warm salty water from the south, mixing the two and forcing the heavier southern water under the lighter polar water (Theisen, 1997). This process causes massive algal blooms in spring and summer in the areas just south of the polar front, making them extremely productive and rich in marine life. Fish species like capelin (*Mallotus villosus*), cod (*Gadus morhua*) and polar cod (*Boreogadus saida*) are important species in these waters. The capelin being of extra importance as they can be found in large numbers and are the main prey species for many species of birds, fish, and marine mammals (Theisen, 1997). The bird colonies on Bjørnøya are to a large degree supported by these marine resources during their summer stay (Theisen, 1997).

This study was conducted in its entirety in the southern end of the island, where the largest bird colonies can be found and the majority of the nesting pairs of glaucous gulls are located

(Strøm et al., 2006c). With the Norwegian Polar institute's field station in Revdalen as base, a total of nine Glaucous gull nests were monitored in two separate locations using camera traps. The two locations being "Lille Feitnakken" and Kapp Kolthoff (Figure 1).

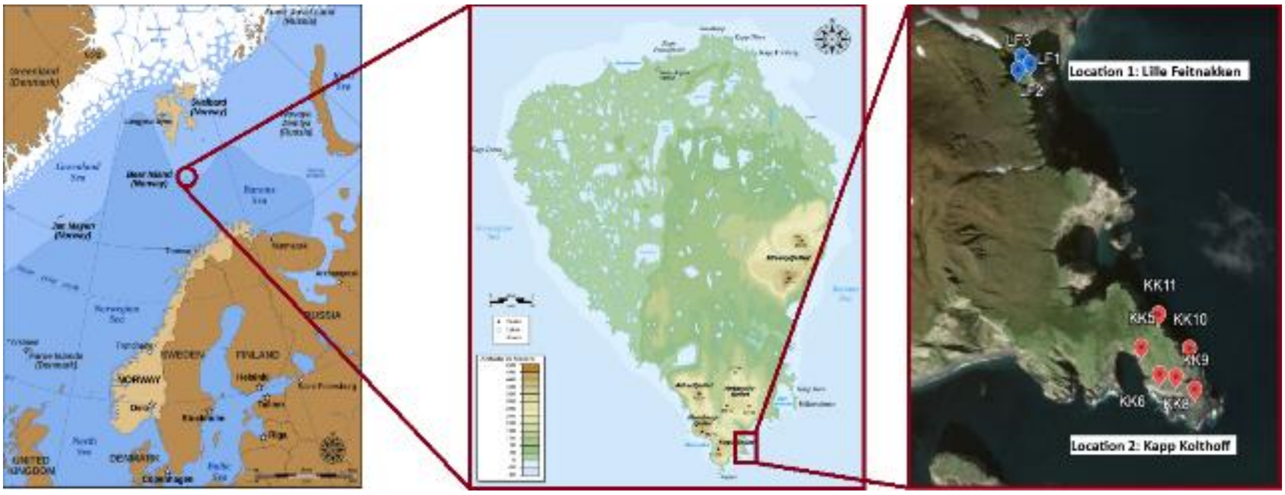


Figure 1: Overview of the study area, nest positions and locations can be seen in the image the right. Bjørnøya, 2023. (Bjørnøya meteorology station, n.d; Keyhole, Inc., 2001).

These locations were chosen due to their strategic placement, being only a short distance from basecamp and accessible and safe compared to other nest locations. The two locations also differ enough from each other to make an interesting data comparison, with "lille Feitnakken" (location 1) being considerably higher in elevation than Kapp Kolthoff (location 2).

2.2 Study Species - Glaucous gull

Image 1: The glaucous gull is a large and tough looking gull, the female (L) is slightly smaller than the male (R). Bjørnøya, 2023. (*Photo: Anders Skordal Fiskum*)

The glaucous gull is characterized by its large body size (1250–2700g), light grey back, white wingtips, pinkly coloured legs, and rough and bulky appearance (image 1). (Strøm, 2013).

Glaucous gulls breed in the Arctic and have a circumpolar distribution. There are four generally recognized subspecies, *Hyperboreus*, the subspecies inhabiting the region around Svalbard, as well as *Lauceretes, Barrovianus* and *Pallidissimus*, that live in other polar regions of the world (Petersen et al., 2015). The total population of glaucous gulls was estimated in 2013 by Petersen et al., to be somewhere between 138 600 and 218 600 breeding pairs. The Norwegian population of glaucous gulls can be found on Svalbard and Jan Mayen and was estimated in the 1980's and 1990's to be around 10 000 pairs, a newer survey from 2005-2012 by (Strom, 2006), suggested that the actual number was around 4000 pairs for Svalbard, and at least 181 pairs on Jan Mayen. On Bjørnøya, the newest survey from 2013 indicate a population size of 427 pairs, a decline form 650 in 2006 (Fauchald et al., 2015). Outside the breeding season, glaucous gulls spread throughout the polar region and can be found along the coast as well as on the open sea and is sometimes found as far south as Japan and California in the pacific, and western Europe and the Carolinas in the Atlantic (Petersen et al., 2015).

As a predator, the glaucous gull is capable of hunting and killing large prey such as adult Atlantic puffins and little auks, which they can even swallow whole (Erikstad, 1990). Gulls have also been observed stealing prey from other seabirds like bivalves from eiders (Varpe, 2009). The glaucous gull can travel large distances in search of prey (Furness & Monaghan, 1987). On Bjørnøya, guillemot species are known to have travelled up to 150-200 kilometres (Theisen, 1997) in search of good fishing grounds, although 25-60 kilometres are more common (Mehlum et al., 1997). Fishing can be a time-consuming activity for the gulls during the breeding season, especially if fish close to the island are scarce. In some areas, piracy may therefore be a more efficient method for acquiring fish (Stempniewicz, 1994).

Gulls that breed in the vicinity of other seabird colonies, often specialize in catching chicks and eggs from the colony (Strøm, 2006a). Because they often eat prey in high trophic levels, glaucous gulls are exposed to bioaccumulated organic pollutants such as PCB, DDE and OXY. (Erikstad et al., 2013). The effects of the pollutants may include weakening of the immune system, reduced hatching rates, weakening of chicks, and decreased adult survival (Bustnes et al., 2000). The diet of glaucous gulls is closely related to the level of toxins they accumulate (Bustnes et al., 2003). Gaining knowledge on the gulls’ diet and how it varies between individuals and locations can therefore be useful when studying how different population is affected by the pollutants. Populations of glaucous gulls have steadily declined on Svalbard, and especially Bjørnøya and Hopen since the 1980’s. If this trend continues, the population of gulls at these locations are likely to go extinct within a few decades (Erikstad & Strøm, 2012).

2.3 Data collection

Image 2: Downloading GPS data from a base station to a computer on Kapp Kolthoff. Bjørnøya, 2023. (Photo: Anders S. Fiskum)

Camera monitoring:

Two types of camera traps were utilized in this study, a passive trap triggered by movement and a timelapse camera capturing continuous images. To ensure the highest accuracy possible, each nest site was equipped with one of each camera type simultaneously. The passive traps consisted of two Reconyx PC900 and four Reconyx PC850 units that had similar capabilities (Reconyx Inc., Holmen, WI, USA), while six Brinno TLC300 cameras (Brinno Inc., Taiwan) were used for timelapse recording. The cameras were mounted on small tripods or placed on top of natural vantage points for the best possible view and then stabilized with rocks to prevent them from being swept away by wind or gulls toppling them when trying to land on them (image 3A and 3C). The Reconyx cameras employs passive infrared sensor technology (PIR) that respond to rapid changes in heat entering the sensors range (Steen & Barmoen, 2017). This technology, although useful, is not always accurate and the rate of successful triggers can vary strongly with factors such as distance to subject, weather, and subject size (Randler & Kalb, 2018). Placing the cameras closer to the subject can drastically increase accuracy (Randler & Kalb, 2018), but also makes the field of view smaller and therefore less dependable in cases where the subject is not constricted to a small area. The Brinno timelapse cameras on the other hand is designed to take images at fixed intervals, in this study the interval was 1 image/sec, chosen to get as detailed information from the nest sites as possible. Playback speed for the videos was also set to 1 image/sec. The Brinno cameras utilizes a wide-angle lens with 128° vision, capturing a lot more of the surrounding area and are recording 24/7. The image quality of the Brinno cameras was however lower (1080p) than in the Reconyx cameras (3.1MP - 2048×1536p) and the large field of view made it harder to see the prey deliveries clearly (Brinno Inc., Taiwan /Reconyx Inc., Holmen, WI, USA).

Where possible, the Reconyx cameras were placed 1-2 meters away from the nest, to ensure that as many prey deliveries as possible were recorded, minimalizing failed triggers while providing good quality images for prey identification. The Brinno cameras were placed a little further away at 2-4 meters from the nest to get a better overview of the nesting area, picking up the prey deliveries that would happen outside the range of the Reconyx Cameras. The cameras were also placed at different angles relative to the nest to avoid obstacles like shrubs, rocks, or the bird itself blocking the view of both cameras when delivering prey (Figure 3, A). The camera setup on each nest was based on a desire to capture as many prey deliveries as possible. This was done regardless of how it would affect the comparability of the camera types. Therefore, setups were not always paced in a similar fashion. In some cases, like on nest KK6 and KK11, the terrain was flat and clear, ideal for a comparative setup. While on for instance LF3 and KK8, the nests were placed on small ledges with a steep rockface close to the nest. Here, cameras were placed more opposite to each other and at almost the same distance from the nest. With one camera on each side of the nest with the rockface to the side, the cameras were out of view from each other. This setup was more vulnerable to random factors such as which side of the ledge the gulls preferred to feed its young. Because of the ledge sticking out in between the cameras, one camera recording a prey delivery often excluded the chance of the other picking it up on the recording, as the delivery would be hidden behind the rocks.

Reconyx had a maximum capacity of 32GB cards, and three models were used: SanDisc MicroSD 32GB with adapter, SanDisc 32GB SD card, and Kingston MicroSD 32GB with adapter. The Brinno cameras had a much higher capacity of 128 GB, and the Kingston MicroSD 128GB card with adapter was used for these cameras. Battery life in the Reconyx cameras were specified by the producers to be about 40 000 exposures (Reconyx Inc., Holmen, WI, USA), but turned out to be almost double at around 80 000 exposures after testing in the field with Lithium-ion batteries. The Brinno cameras used the same batteries but would run out after no more than a day using only the built-in batteries. To increase the battery life, twelve 20 000mp DACOTA Platinum powerbanks (Power.no. n.d), were used. Each powerbank was waterproofed using a durable plastic case with a lid and a small hole drilled into the case to run the wire trough. The wire was connected to the Brinno camera and the area around the connection area stuffed with tack-it gum to make it waterproof (image 3, D).

Image 3: (A) The finished setup with both Brinno, Reconyx and chicks in nest (and a dead kittiwake between the cameras). (B) A glaucous gull caught and tagged; GPS tag can be viewed in the bottom left at the gull's tail. (C) Brinno camera with a tripod and powerbank covered in rocks. (D) Waterproofing setup for powerbanks. Bjørnøya, 2023. (Photos: Anders S. Fisum)

Using the powerbanks with the Brinno cameras set to take 1 image/sec, the battery life increased from under a day to almost a week. While the 128GB cards would run out of space after about 72 hours. The nest sites therefore had to be visited at least every third day to avoid large gaps in Brinno data collection. Sadly, the Brinno cameras had a design flaw related to the card formatting. An issue that eventually caused large gaps in data from the Brinno cameras on some nests, since cards would stop functioning partway through the three-day recording session, ultimately reducing the quality of the results in the study.

The resulting dataset from both camera types was comprised of 316 837 images and 4 799 videos from Kapp Kolthoff and 49 586 images and 1 915 videos from Lille Feitnakken. Giving us a total of 366 423 images and 6714 videos.

GPS tracking

The use of GPS loggers that logged the position of the glaucous gulls during the nesting season was an important part of this study. The GPS loggers used were from Pathtrack of the type Nanofix® GEO + RF tag (Pathtrack, n.d). These small <8.5g solar powered tags were configured using Pathtrack software and a fixed base station (Image 2). The tags uses available satellites to plot a position and store this information in the tag until it gets in contact with a base station. The tags then unload their data, and this is stored in the base station until it is downloaded to a computer using the latest Pathtrack software. The intervals between position logging and uploading attempts, must both be configured using Pathtrack software and a base station before the tag is fitted to a subject (Pathtrack, 2023).

To fit the tags to a subject, in this case glaucous gulls, they had to be caught. This was done using a long synthetic black thread with a loop at the end. The loop was placed at vantage points close to the gulls' nests that the parents frequently used to stand watch. When a gull landed with its feet inside the loop, the thread was quickly pulled, and the loop would tighten around the gull's feet and could then be pulled in. This method was quite efficient and did not damage to the gulls. After capture, the gull was put in a cotton bag to calm down and several biometrical measurements (weight, wing length, bill length and girth, head length etc.) were taken. The GPS tags were mounted to the root of the gulls tailfeathers using tape, strips and pliers specialized for ringing birds.

The GPS tags had to be within a few hundred meters of the base stations to be able to unload data. Since the gulls spent quite a lot of time close to their nests, unloading data at the base station placed nearby was not a problem. In this study, positions were logged with an interval of 10-20 minutes, while data unloading was attempted every two hours. Configuring the GPS tags this way, we would get a detailed view of the gulls' movement, while saving battery from the data unloading process. Two base stations were deployed, one at each location (Figure 1). Data downloading from the base station to a computer was done regularly and at the same time as SD cards and batteries were changed in the Brinno and Reconyx cameras. Due to problems with the configuring of the tags, only six out of ten tags worked. Out of these six tags, four came out with enough data to create a home range before running out of battery.

The GPS trackers were active between 12 and 19 days and recorded a total of 3655 GPS positions. The distribution of positions for each individual gull can be found in appendix 2.

2.5 Photo and video analysis

Material gathered by both camera types were analysed using a Lenovo Yoga Slim 7 computer and an external hard drive from Seagate. The material from Reconyx was viewed using the computers' standard built-in software. Videos from Brinno were viewed using an open-source program called Behavioral Observation Research Interactive Software or "BORIS" for short. The Reconyx images containing prey deliveries were copied, given a unique name, and placed in another folder to avoid confusion and to make them easily accessible for future use. Information from the event like, time, date and type of prey were manually plotted into an excel sheet for further analysis. Data from the Brinno videos were collected in a similar way using BORIS and placed in a separate Excel sheet. After the data analysis was finished, the Brinno and Reconyx data was combined in a third sheet and any overlap in sightings controlled and registered. This was done so that the data from the two types of cameras would be easier to compare and, in many cases, data from both camera types were needed for the analyses. The two original data sheets were kept as to not lose any data due to mistakes in the combining process or during processing.

Prey was identified to species where this was possible and a selection of the images was controlled by Hallvard Strøm and Rob Barrett, to reduce possible misidentification errors made while determining prey. A portion of the data was unidentifiable due to obstacles like rocks and shrubs blocking the view, the lens of the cameras being covered by rain or guano, or the prey being too well digested to be identified.

2.6 GPS analyses

The raw GPS data from the Pathtrack loggers was stored in .RAW files and had to be processed using Pathtrack software. The processed data was stored in .POS files. These files could then be imported into excel following a few steps that eventually converted the file into a .CSV, which can be used in many different programs such as RStudio, QGIS and Google

Earth. The conversion from .POS files to .CSV files was automated using Rstudio.

After being converted into readable .CSV files, the GPS positions were treated in Rstudio to create a home range for each individual. I utilized kernel density estimation (KDE) using the 'adehabitatHR' package (Calenge, 2006). The 'adehabitatHR' package is a package developed specifically for ecological purposes and enables the user to estimate habitat use and home range in animals using the Rstudio software. The package is also made to be compatible with several GIS systems to allow further analysis in these types of programs (Calenge, 2006).

The program QGIS – Quantum Geographic Information System (QGIS Development Team, 2024) was used to make a visual representation of the GPS data and size of each home range. The program was also used later when calculating distances to gull positions prior to specific prey deliveries using inbuilt function *"distance matrix"*. QGIS is a free open-source program that has accumulated many powerful and useful functions since its release in 2002. The software has a user-friendly interface but can also do many advanced operations (QGIS Development Team, 2024). For the simple operations needed for this study, QGIS was therefore the optimal choice.

2.7 Statistical analyses

2.7.1 Prey delivery and chick survival

Tables containing rudimentary information of monitoring periods, prey delivery rates and prey type distribution, as well as all the cake diagrams were created using Pivot tables in excel.

The average prey delivery rate was calculated using the detailed monitoring data derived from the camera traps. Here, the "**no. of prey**" category was divided by the number of days and number of chicks in the nest to calculate the "**average rate**" of how often the chicks were fed. For instance, on nest LF2 there were three chicks alive for three days, two chicks alive for seven days, and one chick alive for another seven days, making it a total of 17 days with live chicks in the nest. The number of preys recorded at LF2 was 41, with nine preys recorded when there were three chicks, 14 prey when there were two and 18 prey recorded when there was only one remaining chick in the nest. Using LF2 as an example again:

9 prey / 3 days / 3 chicks = ***1****, 14 prey / 7 days / 2 chicks =* ***1****, 18 prey / 7 days / 1 chick =* ***2.57****. Taking the average of 1 ,1 and 2.56 is* ***1.52****.*

To check if the proportions of the three prey types: CHICK, EGG, and FISH were significantly different between the localities “Lille Feitnakken” (LF) and Kapp Kolthoff (KK), a two-proportion z-test were used. A two-proportion z-test is used when you want to determine if there is a significant difference between proportions of two categorical variables, such as for instance the “fish” and “chick” variables in the “prey type” category. The results were visually represented in a bar plot (Sakshi. n.d.).

2.7.2 Diel activity

I analysed the diel activity of Glaucous gull parents with the time of prey delivery as input. Nests with more than 100 prey observations were analysed separately and the three major prey categories shown as separate graphs as well as a graph with all prey caught included. All nests were also analysed together for a better overview and separated by their location to make it easier to compare.

To create plots showing the gulls’ diel activity, the R package *“*Activity*”* was used in Rstudio. In this package the “date” and “time” parameters are converted into radians to create an output. To ensure that the results were calculated correctly, start, and stop times for each camera on each nest was included in the datasheet. The “activity” package provides functions that enables the user to estimate and compare the activity parameters using sensor data, for instance from camera recordings (Rowcliffe, 2023). Using the Activity package is a less complicated alternative to the COSINOR-analysis used in the 2020 study by Sørensen, E. A. and fit the purpose of this study better.

2.7.3 Camera efficiency

To compare the efficiency of the cameras, I focused on incidents where both cameras were active, but only one camera succeeded in capturing a prey delivery. Therefore, deliveries that were recorded by both cameras were excluded from the analysis.

Calculating the efficiency of the two different camera types used in this study was done using the R package *“lme4”* (Bolker, 2024). The data was filtered to only contain information where both cameras were active, but only one captured a prey delivery event. A logistic regression model changed information on the camera type into binary and was adapted with "Nest_ID" as a random effect. The probability of each camera type capturing the event of a certain prey type were calculated and the resulting figure was created using the R package *"ggplot2"*.

2.7.4 Fish piracy

To investigate the likelihood of whether the glaucous gulls steal fish from other seabirds, or mainly fish for themselves, I combined camera data on prey deliveries and GPS data from the same individuals. Of the four gulls with sufficient GPS data, a selection of only 87 observations were confirmed to be from tagged individuals. 19 observations were for the gull with GPS-tag 44559 on KK8. For nest LF3, 48 observations came for the gull with GPS- tag 44598 and 20 observations for the gull with GPS- tag 44623. From this selection of confirmed prey deliveries, all GPS locations within 180 min before the delivery for each gull were split into separate time frames. The time frame consists of six colour coded categories that went from red, closest to delivery, to bright yellow, longest until delivery. The categories were: "less than 30 min" "30-60 min" "60-90 min", "90-120 min", "12-150 min" and "150-180 min", all other observations were coloured grey.

A 0–180-minute interval was chosen based on calculations of the mean time spent hunting by the gulls. To calculate this, the mean and median time between consecutive deliveries of either fish, chicks or eggs was calculated. This means that time between instances where a certain prey type was recorded two or more times in a row was calculated to give an estimate of how long the gulls on average spent hunting for that prey type. While not infallible, this method gave a rough estimate that could be used for the purpose of this study. To calculate the mean distances from the positions within the 180-minute mark with standard deviations, the QGIS function *"distance matrix"* was used.

3 Results

3.1 Prey delivery rates and chick survival

Image 4: Newly hatched glaucous gull chicks (L), dead chick in the same nest, now abandoned, LF2 (R). Bjørnøya, 2023. (Photos: Anders S. Fiskum)

In this study, six nests were monitored simultaneously over the course of 34 days from the start of the chick rearing period. Because three of the initial nests failed early, they were exchanged for three new nests, hence a total number of nine nests were monitored. The 2023 season was rather poor with very few chicks fledging (image 4). Only four nests were monitored for more than 20 days. At the end of the monitoring period (19.07.2023) only two of the six original nest sites, KK6 and KK11, had surviving chicks. No prey deliveries were recorded on camera at nest KK9, as the chicks died in a storm only two days after the cameras were deployed and will not be included any further in this study. The monitoring period for each nest can be found in table 1.

Table 1: Overview of monitoring period and total number of days monitored for each nest. The six initial nest sites is marked with **bold** text. Bjørnøya, 2023.

Location/year	Nest ID	Camera set up	Camera removed	Days monitored
Lille Feitnakken 2023	**LF1**	16.06.2023	24.06.2023	9
	LF2	16.06.2023	04.07.2023	19
	LF3	24.06.2023	19.07.2023	26
Kapp Kolthoff 2023	**KK5**	16.06.2023	28.06.2023	13
	KK6	18.06.2023	17.07.2023	30
	KK8	18.06.2023	19.07.2023	32
	KK9	29.06.2023	05.07.2023	7
	KK10	06.07.2023	19.07.2023	14
	KK11	18.06.2023	19.07.2023	32
Sum	9			182

The nests that were monitored the longest also had the highest prey delivery rates. KK6 had the highest prey delivery rate at 3.9 prey per chick per day, followed by KK8 and KK11 with prey delivery rates at 2.88 and 2.73 respectively (Table 2). The lowest prey delivery rates were observed at LF1, with only 0.5 deliveries per chick per day. The topography of the LF1 nest site may have contributed to the low number of prey delivery events, as some events may have been hidden by the terrain. Only 5 out of 22 chicks were confirmed alive at the end of the monitoring period (table 3), with two chicks dying just a day or two before cameras were removed. This gave a survival rate of 0.227 for all the monitored nests.

Table 2: The distribution of prey delivery rates at the glaucous gull nests monitored on Bjørnøya. At LF1 there were 2 chicks alive in the nest for 5 days, and 1 chick alive for 2 days, a total of 7 days with live chicks. The Average rate was calculated taking the distribution of prey deliveries, days monitored and the number of chicks in the nest into account, further detail about the calculations is provided in the methods chapter.

Location/Year	nest ID	No. of prey	Days monitored total	Chicks in nest	Days chicks in nest	Average Rate
Lille Feitnakken 2023	LF1	6	7	2 1	5 2	0.5
	LF2	41	17	3 2 1	3 7 7	1.52
	LF3	102	24	3 2 1	9 2 13	1.88
Kapp Kolthoff 2023	KK5	21	10	3 2 1	4 4 2	1.07
	KK6	277	30	3 2 1	10.5 10.5 9	3.92
	KK8	244	32	3 2 1	12.5 11 8.5	2.88
	KK10	30	12	2 1	12 0	1.25
	KK11	175	32	2 1	32 0	2.73
Sum	**8**	**896**	**164**		**182**	**1.88**

Table 3: number of chicks alive at the start and end of the season. Bjørnøya, 2023.

Location/Year	Nest ID	Chicks at start of monitoring	Chicks at end of monitoring
Lille Feitnakken 2023	LF1	3	0
	LF2	3	0
	LF3	3	1
Kapp Kolthoff	KK5	3	0
	KK6	3	1
	KK8	3	1
	KK10	2	1
	KK11	2	1
Sum		**22**	**5**

3.2 Prey delivery

The total number of prey deliveries in the 2023 season was 896. Of these, 253 (28.2%) were fish, 247 (27.6%) were chicks of different species, and 174 (19.4%) of prey were uncertain. Eggs, tissue, and adult birds each stood for 98 (10.9%), 71 (7.9%), and 3 (0.3%) of observations respectively. The “egg uncertain”, “fish uncertain” and “chick uncertain” categories only stood for a minor part of the observations (50 all together) (Table 4). Of the identifiable avian prey, 274 (30.6%) were either chicks or eggs from guillemots, while only 15 (1.7%) came from Kittiwakes. Of the identified fish, 142 (15.9%) were capelin, there were also 3 (0.3%) sand lances (*Ammodytidae*) and one unidentified species of Sculpin (*Cottoidea*) (0.1%). The rest of the observations were either not possible to determine to species 388 (43.3%), or one of several categories of tissue that may have come from carrion or prey broken into pieces before being transported back to the nest (table 5).

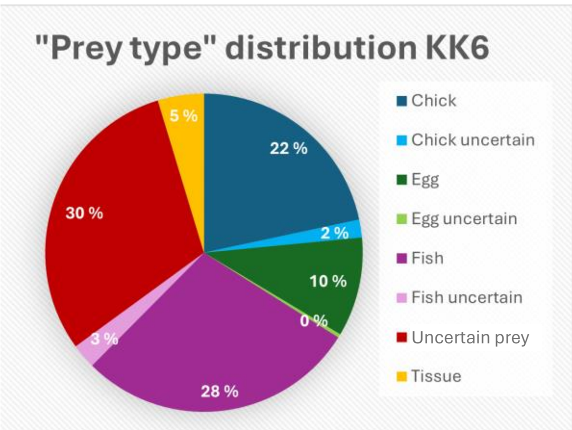
Table x4: Summary of the amount of different prey types in Glaucous gull deliveries as numbers and percentage of total. Bjørnøya, 2023.

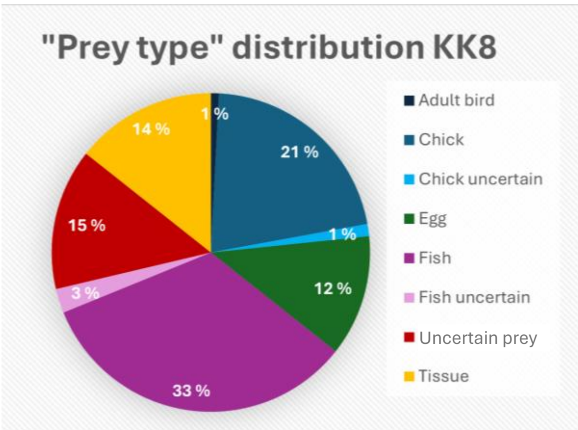
Prey type	Number of preys	% of total
Adult bird (only kittiwakes)	3	0.3%
Chick	247	27.6%
Chick Uncertain	24	2.7%
Egg	98	10.9%
Egg Uncertain	6	0.7%
Fish	253	28.2%
Fish Uncertain	20	2.2%
Tissue	71	7.9%
Uncertain prey	174	19.4%
Sum	**896**	**100%**

Table 5: Summary of the amount of different prey species in Glaucous gull deliveries as numbers and percentage of total. Bjørnøya, 2023.

Prey species	Number of preys	% of total
Guillemot sp.	274	30.6%
Kittiwake	15	1.7%
Kittiwake uncertain	7	0.8%
Capelin	142	15.9%
Capelin uncertain	1	0.1%
Sand lance	3	0.3%
Sand lance uncertain	1	0.1%
Sculpins sp.	1	0.1%
Black tissue	15	1.7%
Grey tissue	5	0.6%
Red tissue	44	4.9%
Uncertain prey	388	43.3%
Sum	**899**	**100%**

Of the four nests with more than 100 observations, the three nests in Kapp Kolthoff, KK6, KK8 and KK11, had very similar results in terms of prey deliveries (figure 2, 3, 4). All three nests had chick delivery rates between 21-22%, while fish delivery rates varied between 28% and 34%. Egg deliveries was 7% for KK11, 10% for KK6 and 12% for KK8. The uncertain category was larger for KK6 and KK11 as prey was often delivered further away from the cameras than at KK 8. This was because the nest at KK8 were located on a very small cliff with steep sides, restricting the chicks' movement at the nest site.





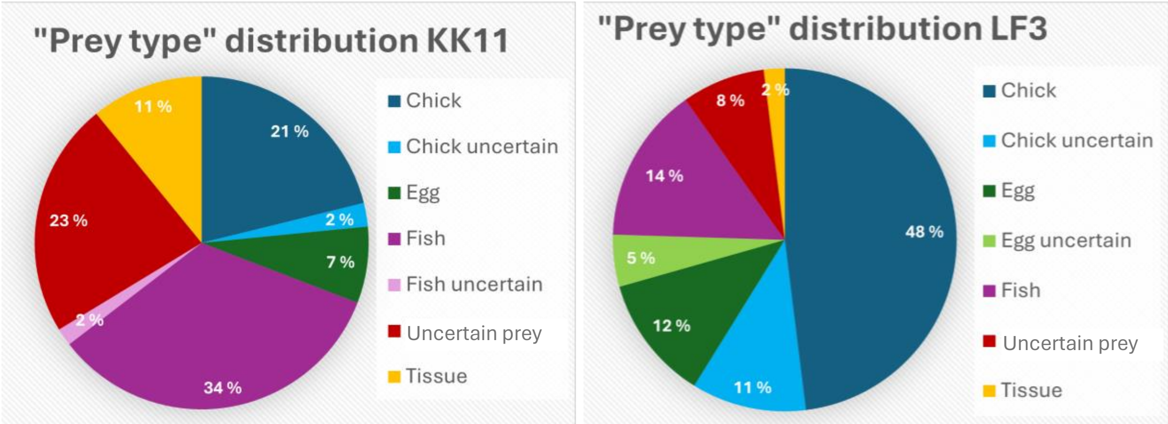


Figure 2, 3, 4, 5: Prey type distribution for the four nests with more than 100 prey observations. Nest KK6, KK8, KK11 and LF3 on Kapp Kolthoff and "Lille Feitnakken". Bjørnøya, 2023.

LF3, being located on "Lille Feitnakken", had a prey type distribution very different form the nests on Kapp Kolthoff and was largely dominated by chicks (48%), standing for more than half of all deliveries if including the uncertain chick category (11%). The number of uncertain prey type deliveries on LF3 were the smallest of all the four nests that were monitored for more than 20 days (6%). Again, due to the topography of the nest site which naturally restricted the chicks' movement.

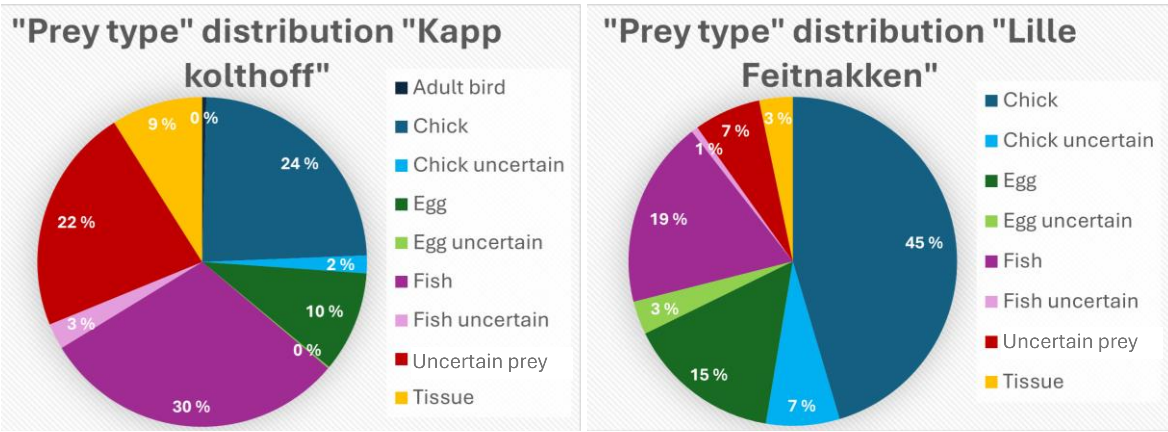


Figure 6, 7: Prey type distribution for locations "Lille Feitnakken" and Kapp Kolthoff. Bjørnøya, 2023.

There was significant difference in the proportions of "Chick" prey between the LF and KK localities when comparing all eight nests ($Z=4.96$, $p<0.001$). There was almost a significant difference in proportions of "Egg" deliveries between the LF and KK sites ($Z=1.94$, $p = 0.053$) and there was a significant difference in the proportions of "Fish" deliveries between the LF and KK localities ($Z=-3.13$, $p=0.002$) (Figure 8). The gulls at "Lille Feitnakken" had a significantly higher consumption of avian prey, standing for 72% of all deliveries. Chicks stood for 46% and eggs 16% at “Lille Feitnakken” while at Kapp Kolthoff these categories only amounted to 24% and 10% respectively (Figure 6-7). The fish consumption on Kapp Kolthoff was in turn significantly higher at 30%, compared to “Lille Feitnakken” who only had 19% fish in their diet. Lastly, the number of unidentified prey were overall higher on Kapp Kolthoff than on “Lille Feitnakken” due to the general difference in topography.

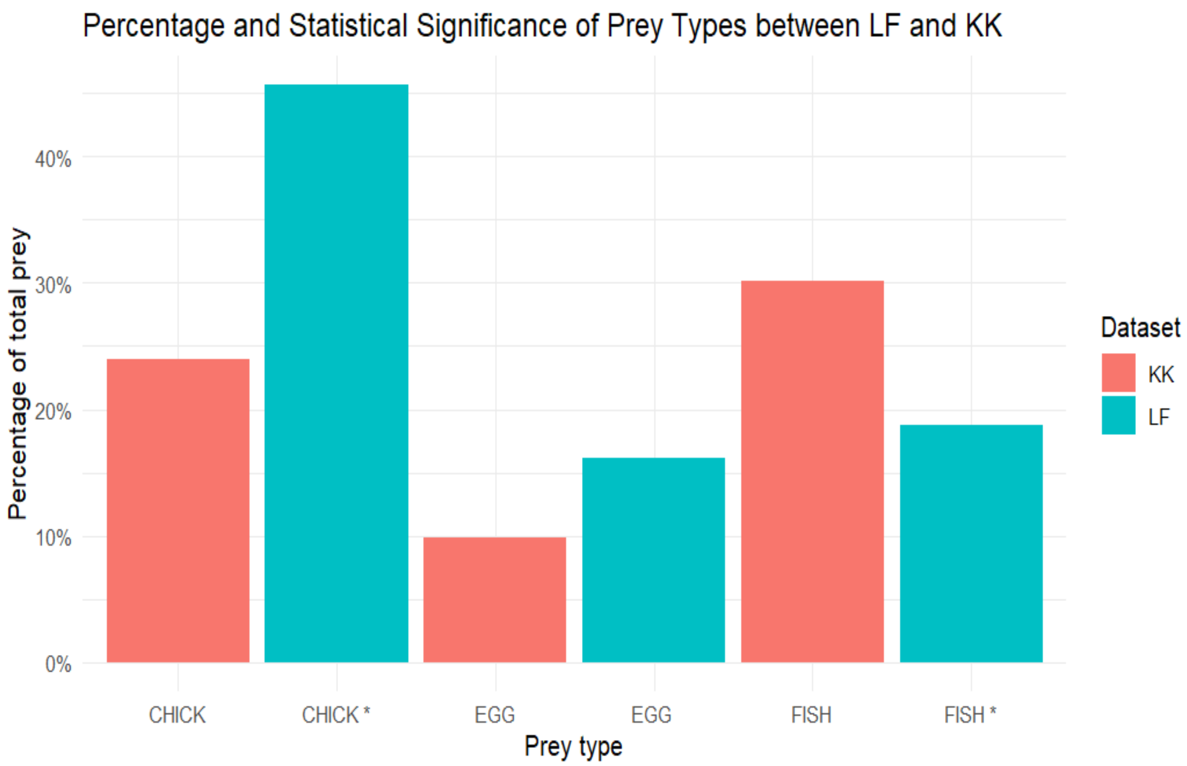


Figure 8: Percentage and Statistical significance of prey types between LF and KK. Proportions are calculated as the number of occurrences of each prey type divided by the total number of occurrences. Asterisks (*) indicate a significant difference in proportions between the datasets (p-value < 0.05). Bjørnøya, 2023.

3.4 Diel activity

The glaucous gulls were active throughout the 24-hour cycle and the chicks at all the nests were continuously fed during the entire study period. Prey deliveries were however not evenly distributed for all the nests and the data does show certain patterns in the gulls' activity.

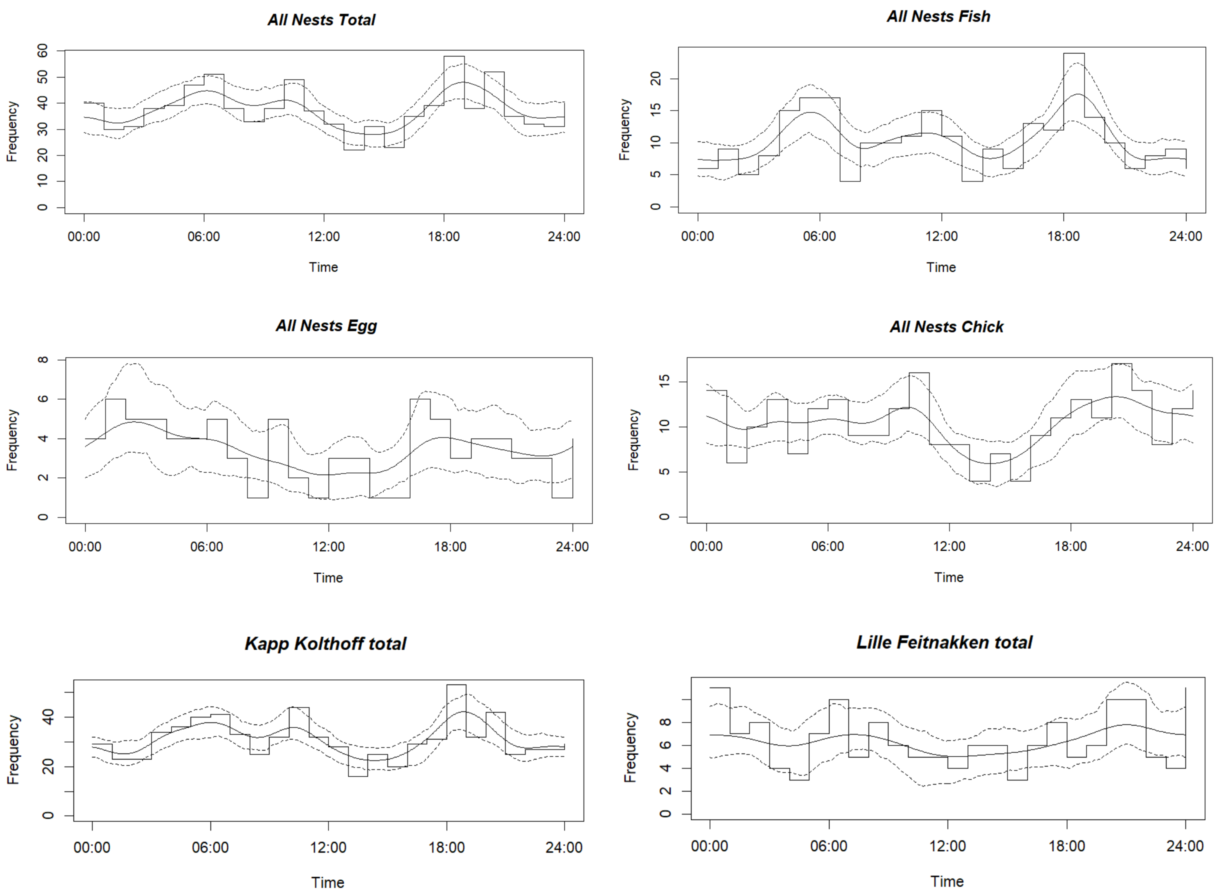


Figure 9: Overview of diel activity data combined from all nests investigated. The solid line represents the mean, and the dashed lines the standard deviation. The categories were separated into "Total", "Fish", "Egg", and "Chicks". An overview of the nests differentiated by location was also included to compare diel activity differences between them. Bjørnøya, 2023.

For all pairs, there was a dip in activity between 12 and 18 o'clock with 15 o'clock as the lowest point, followed by a peak around 18-20 o'clock. The pattern was overall weaker in the nests at "Lille Feitnakken" but can be seen in the "Fish" and "Chick" category in figure 13. The trend can also be seen in the "All nests total" graph in figure 9, which represents the average of all the investigated nests. A less apparent, but also noticeable trend was the peak in the morning hours between 6 and 10 o'clock, which can be seen especially well in "Total" graph for nest KK6 and KK8 in figure 10 and 11, and the "Fish" category for KK11 in figure

12. Comparing Kapp Kolthoff to “Lille Feitnakken” the structure of the graphs show that hunting was more evenly distributed throughout the day at “Lille Feitnakken”.

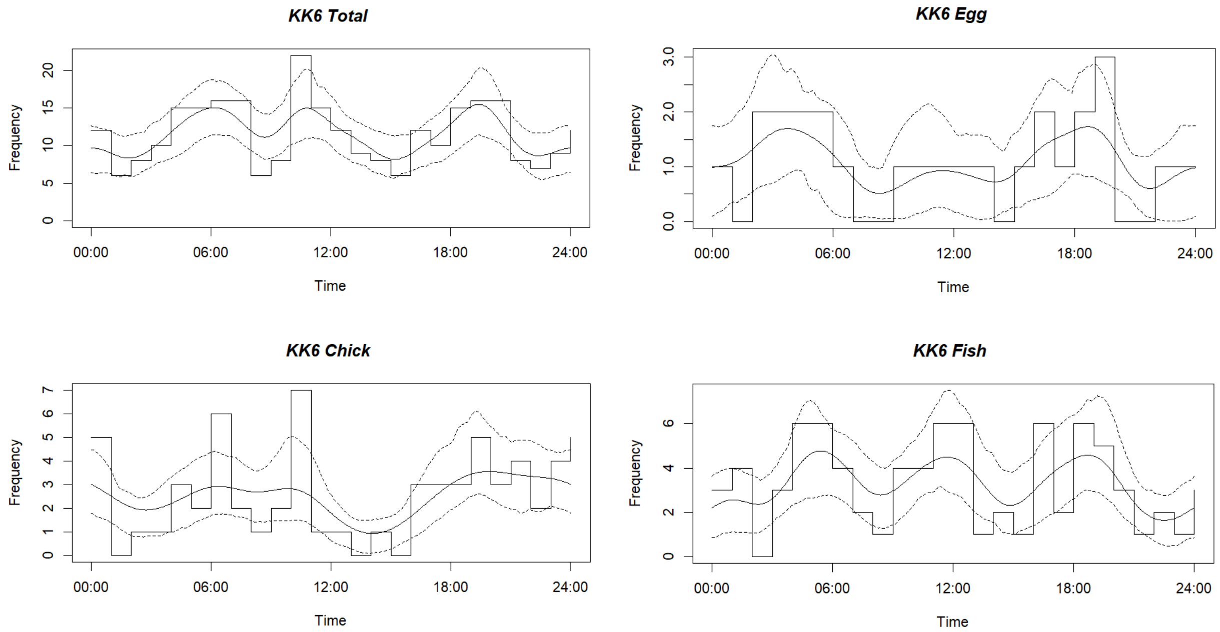


Figure 10: Diel activity data from nest KK6, separated into categories “Total”, “Egg”, “Chick”, and “Fish”. Bjørnøya, 2023.

KK8

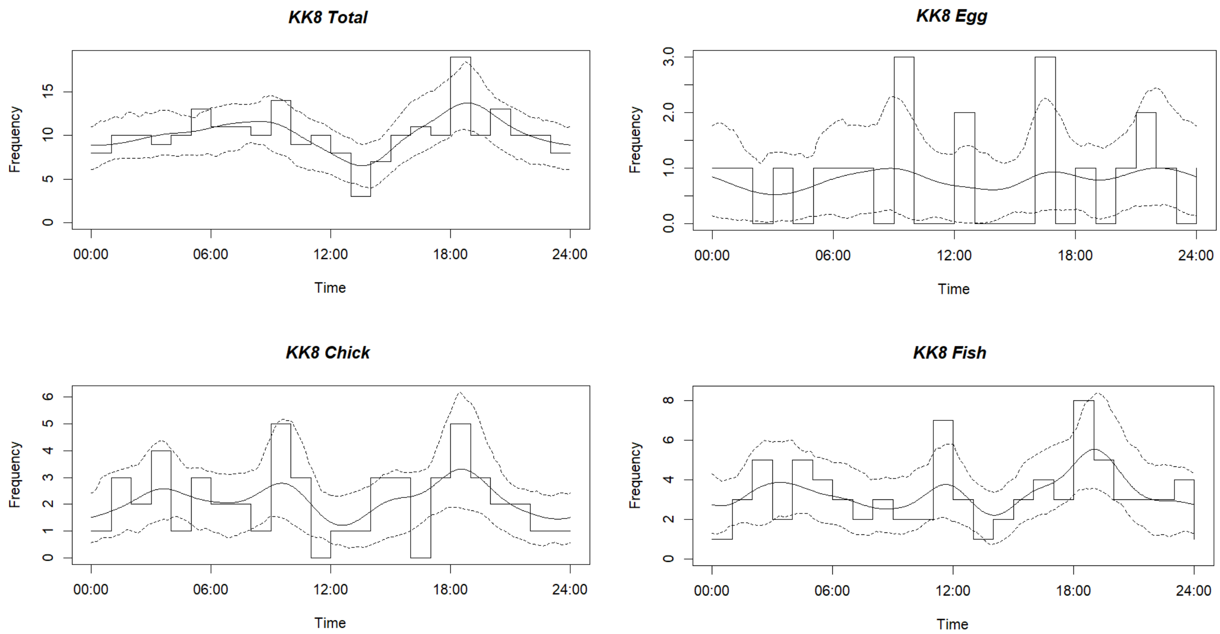


Figure 11: Diel activity data from nest KK8, separated into categories “Total”, “Egg”, “Chick”, and “Fish”. Bjørnøya, 2023.

KK11

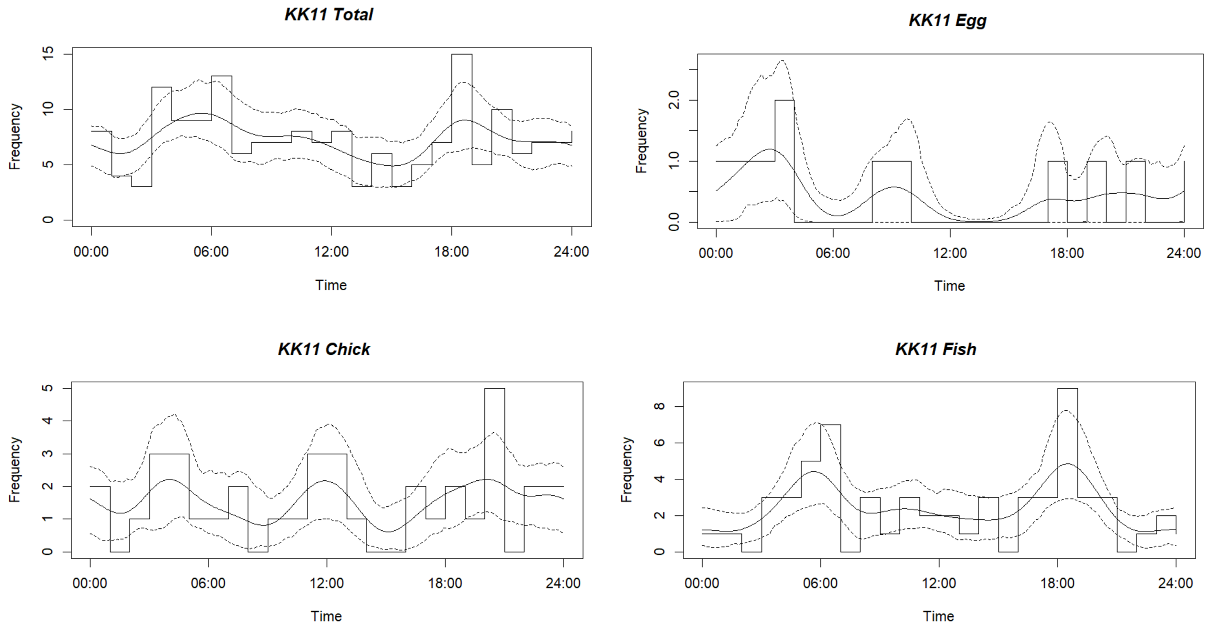


Figure 12: Diel activity data from nest KK11, separated into categories "Total", "Egg", "Chick", and "Fish". Bjørnøya, 2023.

LF3

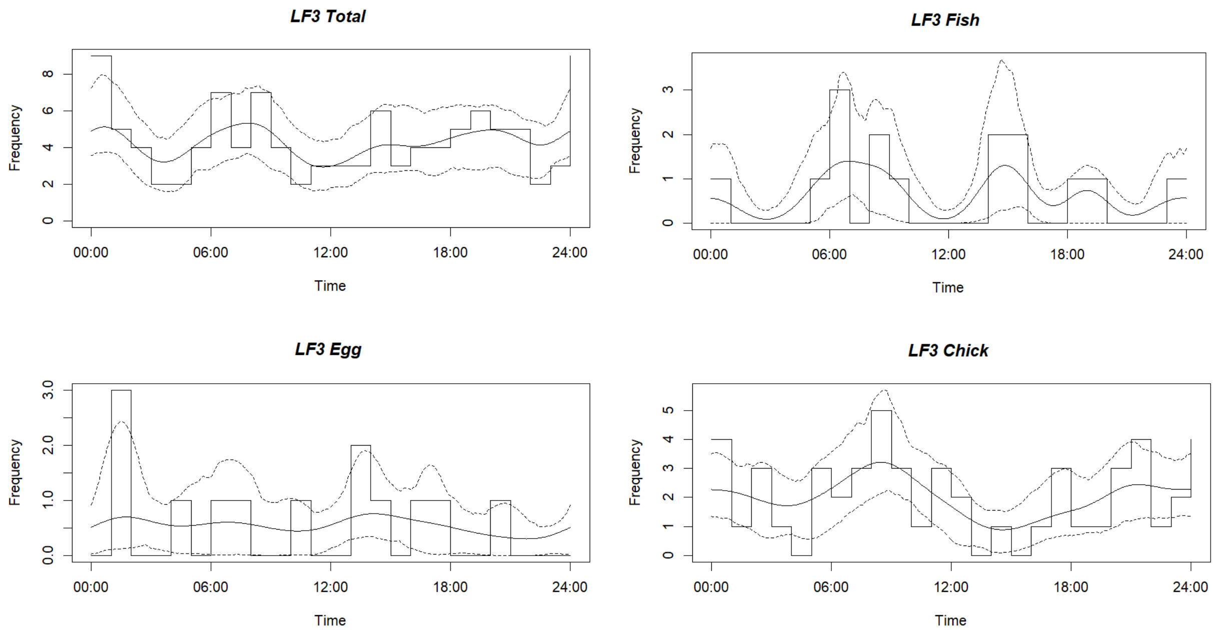


Figure 13: Diel activity data from nest LF3, separated into categories "Total", "Egg", "Chick", and "Fish". Bjørnøya, 2023.

3.5 Camera efficiency

Brinno captured 304 observations that Reconyx did not record, mainly prey deliveries out of view from the Reconyx camera. The Reconyx on the other hand captured 83 prey deliveries that the Brinno did not, mainly in cases where the delivery was hidden behind a bush or rock that hindered the view of the Brinno. The probability that only the Brinno camera captured images of a prey delivery was overall higher as shown in figure 14, however only the tissue category was significant (more than 50% probability). Brinno was also less likely (41%) to capture prey deliveries categorised as "uncertain" compared to Reconyx, but this result was not significant. These results mean that the Brinno cameras in general were more effective than the Reconyx cameras and more of the prey recorded with the Brinno cameras were identified to prey category.

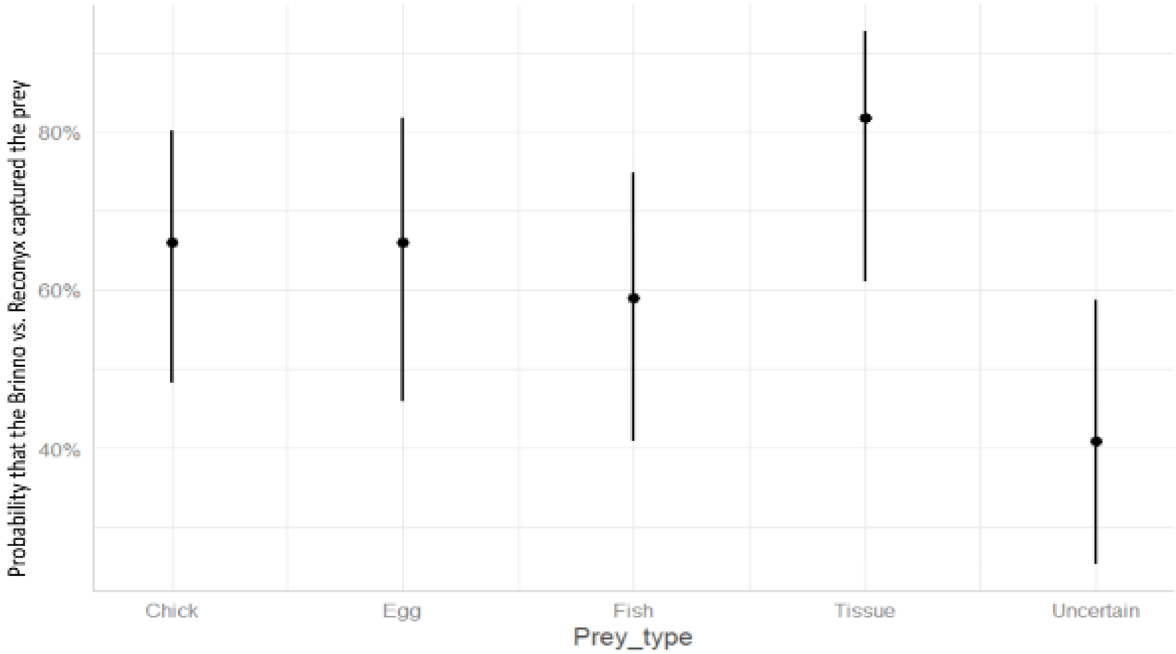


Figure 14: Probability that the Brinno camera vs Reconyx captured a prey delivery of a certain prey type category. Higher values favour Brinno. Bjørnøya 2023.

3.6 GPS data

The GPS data collected from the glaucous gulls during their nesting season have been used to create a home range for the four individuals with the most available data. In figure 15 we see that the tagged glaucous gulls mainly used the costal southern parts of the island and were rarely more than a few hundred meters out at sea or inland towards the north of the island. The pair on LF3, which were both tagged, had very similar habitat use and home ranges, with a size of 0.31 km^2 for the female and 0.85 km^2 for the male. The male gull on KK8 had a home range size of 1.28 km^2 while the female gull on KK1 had the largest home range of 4.73 km^2 (Table 6).

Table 6: Area of home range in km^2 for each individual bird with sufficient GPS data. Bjørnøya, 2023.

Nest_ID	GPS_id	Sex	Km^2 ≈ of home range
KK8	44559	Male	1.28 km^2
KK1	44585	Female	4.73 km^2
LF3	44598	Female	0.31 km^2
LF3	44623	Male	0.85 km^2
Total			**7.17 km^2**

The majority of the GPS positions were registered very close to the gulls' nest site, but there were also some exceptions. These exceptions, which can be seen in figure 15, are known key locations where the gulls have been observed to perch and bathe by scientists throughout the years. Both Russehamna, Kvalrossbukta, the outlet of Røyevatnet, and the local pool above the nest sites locally called "Krykjedamdalen" are among these spots. The male from LF3 also seemed to be partial to perching on a small group of islets known as Flaskeskjæra.

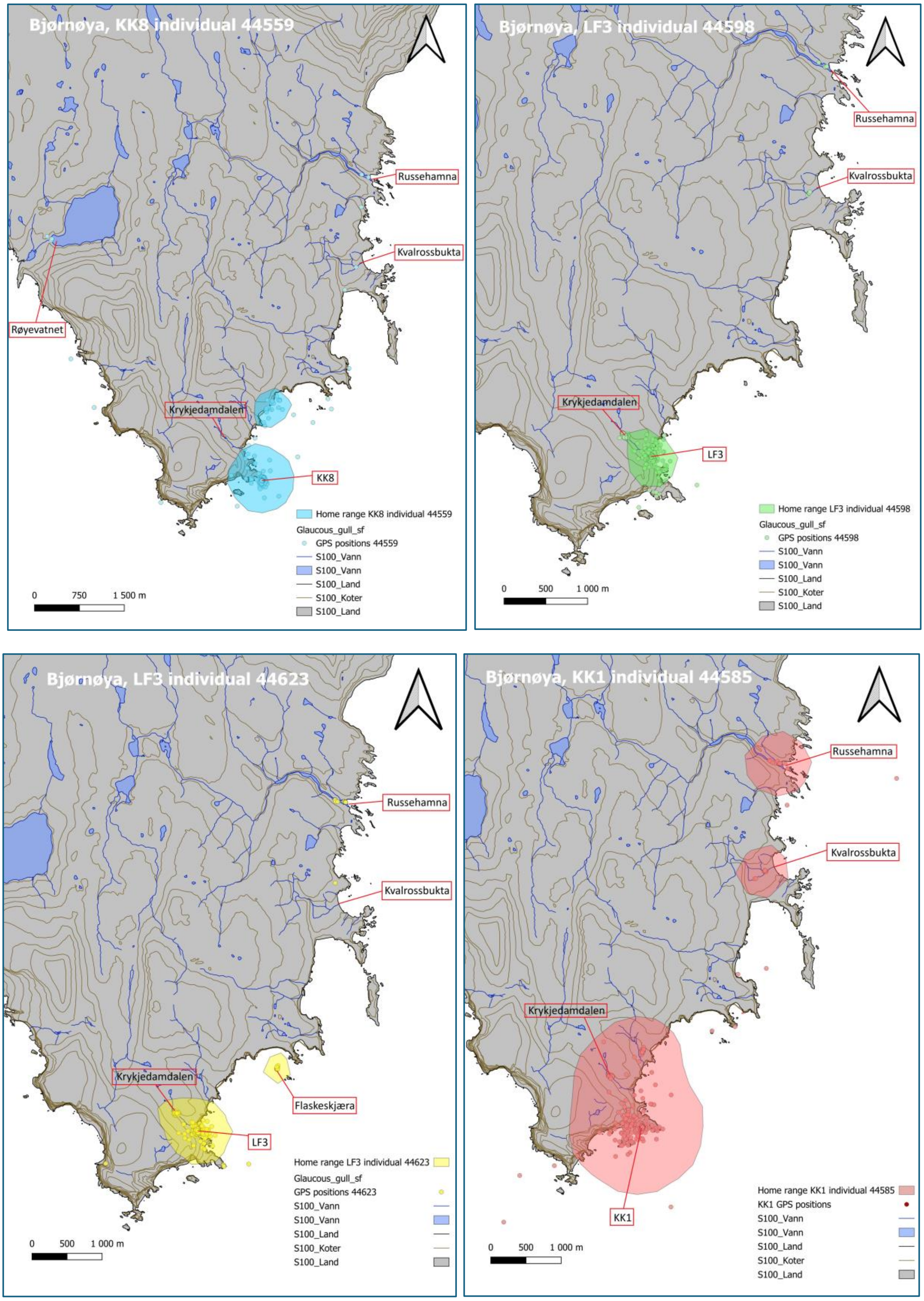


Figure 15: Maps of the four tagged individuals with enough data to create a home range. The maps also have the names of some key locations often used by the glaucous gulls to bathe and socialise based on observations by scientists in the field. Bjørnøya, 2023.

3.7 Fish piracy

Combining camera data on prey deliveries and GPS data from the same individuals. The 87 observations that were confirmed to be from tagged individuals were used to estimate the mean and median time and distance gulls spent and travelled from their nest sites to capture fish. To get a better idea of how the distance travelled hunting fish compared to other prey, the "chick" and "Egg" categories were also included.

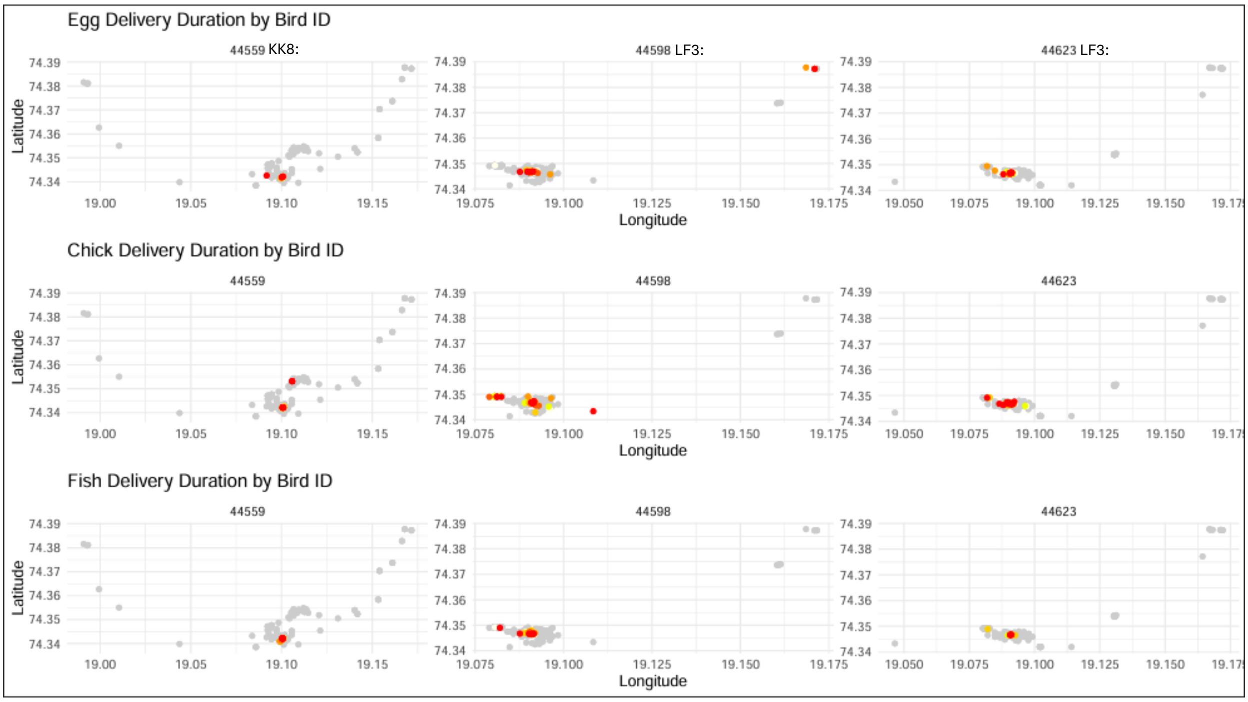


Figure 16: The chart gives a visual representation of the gulls' positions before prey delivery, on KK8 only the male was tagged with a GPS, while on LF3, both gulls were monitored. Bjørnøya, 2023.

Excluding the cases where the N value was too low, we see that the mean time spent hunting fish ranged between 67 minutes and 109 minutes, and the median between 49 and 63 minutes (Table 7).

In figure 16 we see that most observations were very close together, and close to the gulls' nest, the only exception is the egg delivery for 44598 on LF3, that also included a few observations at one of the known bathing spots shortly before prey delivery. The resulting distances seen in the bar chart in figure 17, show that the mean distance of the fixes from the nest for the "fish" category was only 30.9 meters for the male "44559" on KK8. For the female "44598" on LF3 it was 60.8 meters and for the male "44623" on LF3 it was 33.5 meters. The mean distance of the "fish" category was less than the mean distances for the other major prey categories. Eliminating the chance that time spent perching close to the nests before a prey delivery would drag the average distance down, mean, and median time spent hunting was also calculated. The results which can be seen in table 7, show that the mean time spent hunting fish ranged from 67 to 109 minutes and the median time between 49 and 63 minutes. Calculating the mean distance from the nest only using positions in the categories "30-60 min" prior to a prey delivery gave the mean distances of 42, 53 and 9 meters. While for the "60-90 min" gave the mean distance of 109, 33 and 6 meters. Both results were thus very similar to the full 180 min range. For both categories N was very small.

Table 7: Average time between consecutive prey deliveries of either Fish, Chicks, or Eggs. Bjørnøya, 2023.

NestID	Prey	Average (min)	Median (min)	N	SE	Comments
KK11	Chick	881.6	78.5	10	2421.3	
KK11	Egg	5.5	5,5	2	4.95	N too low
KK11	**Fish**	**67.92**	**49.5**	**26**	**89.37**	
KK6	Chick	92.24	61	17	100.13	
KK6	Egg	2609	2609	2	3634.53	N too low
KK6	**Fish**	**109.23**	**61**	**31**	**151.32**	
KK8	Chick	228.78	83	23	397.97	
KK8	Egg	119	52.5	6	195.36	N too low
KK8	**Fish**	**99.26**	**63**	**35**	**129.17**	
LF3	Chick	206.8	160	25	201.51	
LF3	Egg	203	203	1	NA	N too low
LF3	Fish	171	171	2	214.96	N too low

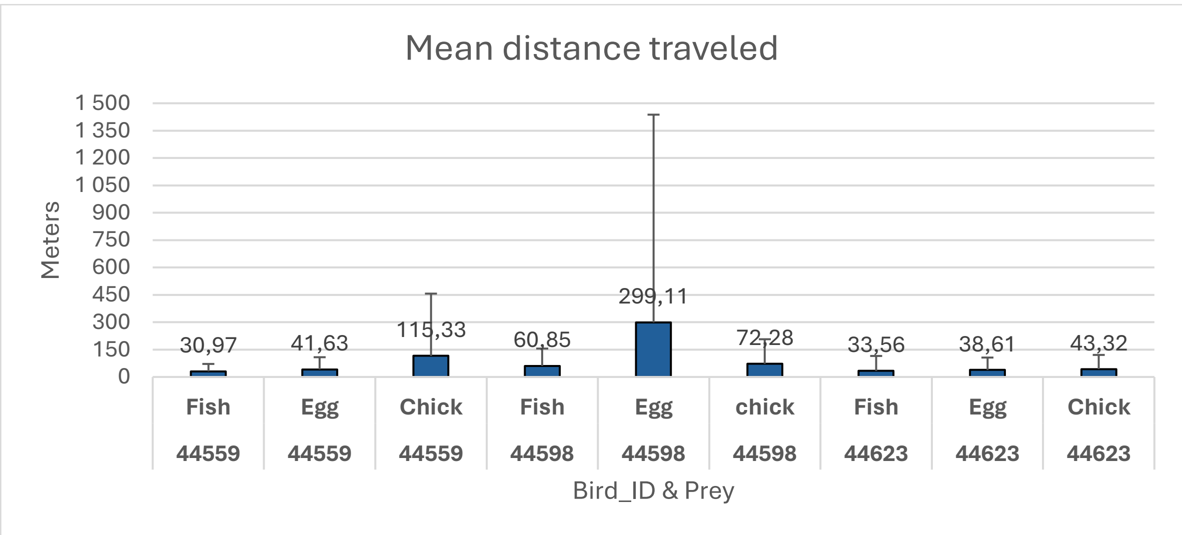


Figure 17: Mean distance and standard deviation in GPS positions within 180 min of the delivery of a fish, chick, or egg for the three gulls with available data. Bjørnøya, 2023.

4 Discussion

4.1 Prey delivery rates and chick survival

Prey delivery rates varied greatly between nests with only 0.5 prey deliveries per chick per day at LF1 and as much as 3.9 prey per chick per day at KK6. Some of the differences might have been caused by the topography at the nest site which could have affected the likelihood of the cameras recording prey deliveries. Many of the gulls had regular spots for feeding the chicks, and if the camera angle was even slightly off, many prey deliveries could be missed until the camera was adjusted correctly. Despite not capturing all prey deliveries, the majority of events was still recorded, and the data should be considered viable.

Comparing prey delivery rates with chick mortality in the nests, we see that the nests with the lowest prey delivery rates had high chick mortality rates. This suggests that a lack of food resources may have been one of the factors contributing to the low survival rates for the monitored chicks, and the poor nesting season in 2023 in general (Fayet et al., 2023 in prep.). However, also in the two nests with the highest prey delivery rates, two out of three chicks had died by the end of the monitoring period. The prey delivery rates in this study were similar to the prey delivery rates in the study by, Sørensen, E.A (2020). Overall chick survival rate for the nests included in this study was 0.227, while data from the northern part of Bjørnøya showed a chick survival rate of 0.48 (Unpublished). These are both very low numbers considering Gaston et. al. (2009) found average survival rates for glaucous gull chicks to be 1.6 per year at Coast Island in Canada, with survival rates ranging between 0.9 and 2.2. Looking at chick survival from previous years on Bjørnøya, which was 1.64 in 2022 (Fayet, et al., in prep.), 0.82 in 2021 (Anker-Nilssen, et al., 2022), and 0.94 in 2020 (Anker-Nilssen, et al., 2021), we see that the 2023 season had a very low chick survival compared to what has been normal in recent years. We also see that the chick survival rate from 2020 was higher than in the 2023 season, even though prey delivery rates were similar in both years. The fact that even nests with relatively high prey delivery rates in 2023 lost 2/3 of their chicks suggests that other factors may have contributed to the poor nesting season. Whether this was due to anthropogenic disturbances, bad weather, bird flu, mismatch in hatching dates between the glaucous gulls and their prey, accumulative pollution, or other factors, is not certain (Strøm, 2006b; Fayet et al., 2023, in prep).

4.2 Prey delivery

Overall prey delivery showed an even distribution between fish and chick catches in the gulls' diet, but when comparing "Lille Feitnakken" (LF) to Kapp Kolthoff (KK) there were a drastic increase in chick and egg deliveries at LF compared to KK. Being low in elevation it was within expectation that KK had a high percentage of fish deliveries (Bustnes et al., 2000). LF was on the other hand much higher in elevation and had easy access to the large guillemot colony in the cliffs surrounding the nests, making these ideal hunting grounds. Whether the difference in elevation alone was the key factor leading to the significant difference in prey deliveries, or if other factors contributed to this as well is hard to know. Although Sørensen, 2020 had the same study area, a comparison between locations was never done. An interesting anecdote in this regard is the male glaucous gull on LF3 who was observed several times stealing chicks and eggs from common guillemots on the ledge closest to their nest through the timelapse camera. Hunting and catching prey less than 20 meters from the nest site. An observation that is rare to see in gull (Strøm H., personal communication, May 14, 2024). Predatory birds prioritize catching more of the type of prey that is most readily available to them and cost the least amount of energy (Burke & Montevecchi, 2009). All three nests with large quantities of data on KK had remarkably similar distribution in prey types, meaning that there was little degree of specialization on and individual scale. The gulls' diet seemed to be steered mainly by prey availability in their immediate vicinity. Since gulls that eat a large amount of prey from high in the food chain are more exposed to organic contaminants (Strøm et al., 2006c), we would expect the gulls from LF to have higher concentrations of contaminants in their bodies. Although blood samples of the gulls from LF have been sampled, analysis of the samples are yet to be executed. However, the fact that all chicks but one died at LF before the end of the monitoring period suggests that this could be the case, although mortality rates were high also for KK.

Comparing the results of the prey delivery composition in this study to the results of the previous study by Sørensen (2020), we saw a larger proportion of chick prey in the 2020 study, standing for almost 50% of all deliveries. Both fish and eggs stood for smaller portions of the birds' diet in 2020 at 20% and 6% respectively. With the study are for both studies being the same, the reason for the large difference in prey delivery composition may come from smaller differences in nest placing, chicks being more easily available in 2020 or fish being more scarce and harder to come by. Looking at chick survival rates for the common guillemot and black legged kittiwake from the last couple of years, which can be seen in appendix 1. We see that the 2020 season was above average for guillemots, and about on average for the kittiwakes. The high number of chicks in the glaucous gulls' diet in 2020 may therefore be a result of chicks being more abundant this year.

A final interesting anecdote was the surprisingly low number of adult Kittiwakes in the gulls' diet in 2023, only being observed three times throughout the season. Glaucous gulls do not normally eat many adult kittiwakes, as there is usually easier prey to be found at the colony (Stempniewicz, 1994), but with the bird flu heavily affecting the kittiwake population on the island, dead or dying kittiwakes was a common sight throughout the 2023 season (Fayet et al., 2023, in prep). It is possible that some of the "red tissue" observations stemmed from kittiwakes being disassembled away from the nest before being brought back in pieces to the chicks, but this is just a speculation.

4.3 Diel activity

Analysing the diel activity of all nests and observations this season, we found that the glaucous gulls hunted continuously throughout the day, making use of the high light levels. As shown in Wojczulanis-Jakubas et al., (2020) study on the little auk, the presence of the midnight sun made the seabirds activity arrhythmic. Even so, several patterns could be observed from the data in this study. The most pronounced pattern in the data was the dip in activity at mid-day between 12 and 18 o'clock. Although the general pattern in the data showed that the gulls' activity fluctuated, this dip in activity was more pronounced than the other fluctuations. There may have been several causes for this fluctuation, but the most probable cause may be that this was the time batteries and SD cards were exchanged on all the cameras. Other fieldwork on the gulls like capturing and measuring them was also done during this period, causing enough disturbance at the nest site to make the gulls temporarily postpone feeding their chicks. This would also explain why the nests on LF did not show the same pronounced dip in activity. LF is a much smaller location with fewer nests and was harder to work on due to steep hills, leading to much less of a footprint from the researchers there.

As the gulls' activity may have been "artificially" low during midday due to disturbance, they seemed to make up for it by delivering more prey from 18 till 20 o'clock. There was also a second peak in prey delivery usually occurring in the morning hours around 6 o'clock. This morning and evening peak in activity was especially visible in fish deliveries across all nests, suggesting that fish, or the marine animals hunting the fish, were more active and closer to the surface at these times, making them easier to hunt for the glaucous gulls. In 2008, Falk et al., studied the foraging behaviour of the Brünnich's Guillemot in a high Arctic setting. They found that trip start and diving initiation in the Brünnich's Guillemots peaked in the morning and evening, despite the midnight sun being present (Falk et al., 2008). These finds support the theory that fish may have been more active and easier to catch for the gulls at these times, or that the birds prefer to hunt at these times. Another theory is that the gulls stole fish from the seabirds as they returned to their nests, which will be discussed in greater detail later in the discussion. The most common fish prey species in this study, the capelin, is a small pelagic zooplankton feeder that perform seasonal migrations and are commonly found in the productive waters around Bjørnøya (Gjøsæter, 1998). Zooplankton perform a daily diel migration called the Diel Vertical Migration or DVM. This migration usually takes place in the night when zooplankton rise from the deep sea closer to the surface to feed on the phytoplankton that live there, safe from day active predators (Storrie et al., 2022). However, during the artic summer, the lack of darkness and clear light cues causes the plankton to become more arhythmic, or react to weaker light ques (Storrie et al., 2022). It is uncertain whether this influences when the glaucous gulls time their foraging trips, or if other factors is more important, but the activity peaks during morning and evening may have a connection to the activity pattern of the prey species they search for.

4.4 Camera efficiency

Only the “Tissue” category had a significant higher chance of being recorded by the Brinno cameras rather than the Reconyx cameras. The graph did however show overall higher probability for all categories except for the “Uncertain category”. But more data will be needed before drawing an absolute conclusion. As mentioned in the introduction, the camera setup on each nest was based on a desire to capture as many prey deliveries as possible, not considering how this would affect the comparability of the camera types. Not having a standard setup for the cameras and similar conditions at the nest sites made comparison between the camera types less than ideal, since the results could get skewed in one camera type’s favour. If the gulls preferred to feed their chicks at any particular side of the nest, especially in the instances where the cameras were placed opposite to each other, the camera closest to this side would be favoured in the comparison. Still, the total number of prey deliveries exclusively recorded by Brinno exceeded Reconyx by more than 2/3 of the observations, making it the most efficient camera. In an ideal setup, the continuously recording Brinno cameras should in theory have been able to record all the same prey deliveries as the Reconyx cameras. With a larger field of view and continuous recording, all deliveries in the view of the Reconyx, would also be within in the Brinno camera's field of view. The high amount of exclusive Reconyx recordings was therefore a result of the terrain, or the birds themselves, hindering the Brinno's view of the delivery.

When evaluating the overall usability of the two camera types in the field, the results become very different from just looking at the numbers. In the next couple of paragraphs, I will discuss my personal experience using the two camera types and the conclusion should be interpreted thereafter. Starting with the Reconyx PC850 and PC900 cameras, I found them to be easy to use and reliable in the field. The battery life exceeded the numbers given by the producers, and only had to be exchanged once during the entire 34-day long monitoring period. The PIR-sensors responsible for firing the camera were located underneath the camera lens, meaning that the camera itself had to be raised to a level where the sensor was not obstructed by any small bushes, leaves, or rocks. Using small tripods on all cameras may be a solution for future research, as this gives the user more options for placing and tweaking the camera's position and avoid potential obstructions. The PIR sensors did however occasionally fail to trigger a release even without anything obstructing the sensors' view. The Reconyx cameras could only handle 32 GB SD cards, but this was enough to store more than 80 000 images and cards could be changed at the same time as the batteries. Overall, the Reconyx cameras were easy to use, required very little maintenance and never had any technical issues except for the occasional missed trigger, making them ideal to reduce disturbance when monitoring nesting birds.

The large 118° field of view offered by the Brinno cameras was very useful for getting a good overview of the nesting area, although prey delivered far from the camera became harder to identify since they appeared very small on the screen. This was also noted in the study by Sørensen E.A. (2020), which used another Brinno camera model. As the nesting season progressed, chicks became more active and start wandering around the nest site (Strøm, 2013), giving the wide angled Brinno cameras an advantage. By recording one image every second, which is what was done in this study, the Brinno cameras would only last about 8-12 hours using the built in battery capacity. Using 20 000mp powerbanks the battery would last about a week. The Brinno TLC300 was compatible with 128GB cards, enough to record for about 72 hours at 1 image/sec (personal observation). This meant that even with powerbanks and a large capacity card, cameras had to be maintained at least once every three days, a drastic increase from the Reconyx cameras. Furthermore, the Brinno cameras had a software bug, causing the Kingston SD cards to fail over time. The core of the problem had to do with the cards formatting. At the end of the season only 4-5 cards out of 12 were still functioning. As previously mentioned, this issue caused large gaps in data from the Brinno cameras on some of the nests, reducing the overall quality of the results. Another problem was the fact that the powerbanks sometimes turned off automatically during recordings because of the low battery consumption of the Brinno. This problem was already described in the Brinno manual, where they recommended using powerbanks that would not turn of automatically. By the time this was discovered however, it was too late for anything to be done, as there are no practical ways to get new gear while on Bjørnøya. Overall, the numerous challenges using the Brinno cameras caused a lot of frustration and unnecessary disturbance at the nest sites. Maintaining a single camera could take up to 15-20 minutes, greatly disturbing the birds at that site. The maintenance work would usually consist of testing various SD cards and trying to get the camera to stay on for long enough so that the power bank did not turn of automatically, all while being struck in the head by angry parent gulls, which was not a pleasant experience for either party.

The Brinno TLC300 recorded more prey deliveries when active than the Reconyx PC850 and PC900 cameras, thanks to its large field of view, good image quality, and continuous recording. In terms of user friendliness, the passive Reconyx was the clear winner with very little maintenance, good image quality and very high reliability. Reconyx cameras are well tested in the field and have been used in a variety of studies and on many species' groups (Urbanek et al., 2019). The Brinno cameras on the other hand had a lot of technical issues, causing it to be highly unreliable in the field, and very bad for gathering continuous data. Using timelapse cameras to gather data has been tested in a few studies such as a nest monitoring of a pair of parrot crossbills (Steen et al., 2017), and even estimating the activity and abundance of leaf litter arthropods (Collett & Fisher, 2017). The use of timelapse cameras as a supplement or even a substitute for other methods of recording animal behaviour and abundance is however still a relatively novel method of data gathering. I believe that the use of timelapse cameras in field research on gulls and other bird species has the potential to be a better alternative to the classical passive camera types, yielding more data of better quality and giving scientists the opportunity to study the birds' behaviour in greater detail with continuous imagery. But for this to happen, several technical issues need to be improved upon. Most of all, making the systems durable and reliable in the field will make all the difference for how well they can be implemented into future research.

4.5 GPS and home range

The use of GPS tags on the glaucous gull to determine habitat use and home range had never been done in Norway before and was a pilot project. Similar tags has been deployed on other species such as herring gulls (*Larus argentatus*) and kittiwakes in the UK, (Pathtrack, 2024; Rock et al., 2016) so the technology is well tested.

As little has been done to study the home range of the glaucous gull before, it was hard to know what to expect, but based on previous diet studies it was expected that the gulls would hunt along the cliffs at the bird colony as well as travel out on the open sea to search for fish and other marine life. What was found was that all four gulls with functioning GPS-tags were extremely local, mainly using the area in the immediate vicinity of the nest in addition to a few spots used for bathing and socializing with other gulls. No GPS position was found more than a couple of hundred meters out at sea, which was surprising. In one of the few studies on the subject using similar technology, a study on herring gulls from the UK, Rock et al. (2016) discovered that the urban herring gulls had highly variable home ranges. Whereas one individual roamed far and wide, often more than 50 kilometres offshore, others kept within the radius of a few kilometres, much like the gulls on Bjørnøya. Seeing as the sample size in this study was very small, future studies may reveal a similar pattern for the glaucous gulls as for the herring gulls.

Comparing diet to habitat use, LF3 had a high percentage of chicks and eggs in their diet, which matched the small home ranges of the parent gulls well. As mentioned, the male gull on LF3 was observed hunting very close to the nest site. Combined with the GPS data this suggested that the gulls found almost all the food they needed very close to the nest, or that there was a lack of marine food sources causing them to only hunt locally in the bird colony. Looking at KK1 and KK8, they had larger home ranges and more positions out at sea, although not far from the shoreline. As KK1 was not monitored with camera traps, no information about diet is available, but KK8 had a higher proportion of fish in the diet compared to LF3, which may explain the higher number of offshore observations.

Perhaps the most interesting aspect of these results, was the lack of observations far out at sea. The GPS tags in question should have had no problem registering positions far offshore, as they use satellites to pinpoint locations and should be well within the limitations of the technology (Pathtrack, 2024). With over 80 observations of fish delivered to KK8, this raised the question of where and how the glaucous gull caught fish to feed their young.

4.6 Fish Piracy

Glaucous gulls were observed hunting and successfully catching both chicks and eggs from the bird colony directly from the Brinno cameras. They were, however, never observed catching or stealing fish, neither on the cameras nor by scientists in the field. Hallvard Strøm, the team leader on Bjørnøya and seabird ecologist also said that he had never in his 25 years on Bjørnøya observed glaucous gulls steal fish from other seabirds (Strøm H., personal communication, March 05, 2024). Gulls of many species are well known to steal fish from other seabirds (Hatch, 1970), and the glaucous gulls have been documented to be a kleptoparasite on common eiders in Svalbard, stealing bivalves in spring (Varpe, 2010). There are however few studies on the glaucous gull documenting the extent of kleptoparasitism of fish on colonial seabirds. Stempniewicz, 1994, mentioned that glaucous gulls sometimes pick up fish dropped by kittiwakes that were harassed by skuas. But few explain the phenomenon of kleptoparasitism in greater detail or try to document its extent.

The chart showing the position of the gulls 180 minutes prior to prey delivery showed that the gulls only travelled a mean distance of about 30-60 meters away from the nest to catch fish, less than they did for both eggs and chicks. Even when only including the positions 30-60 minutes and 60-90 minutes before a delivery, which was the estimated mean time between prey deliveries of fish, the results did not change much. Although the sample size was very low, this result was interesting as it suggested that many of the fish delivered by the gulls was stolen from other seabirds, making them a kleptoparasite in the Bjørnøya colonies. Alternatively, the gulls must have been able to find fish very close to the shore, which was not very likely as there were usually tens of thousands of birds resting on the water close to the colony and there is no evidence that the birds feed on shoals of capelin near the island (Strøm, 2024). Furthermore, the composition of fish in the gulls’ diet was mostly capelin, a fish species that both fulmars and guillemots on average have been found to travel 25-60 kilometres to hunt for, along the edge of the polar front (Mehlum et al., 1997; Cherel et al., 2001). The Northern fulmars in particular, have been found to travel for 8 hours at a time in search of fish and other marine food sources to bring back to their chicks (Cherel, 2001). If fish could easily be found closer to shore, these long trips should not have been necessary.

In the end, the hypothesis that the glaucous gulls on Bjørnøya are kleptoparasites was based on a small number of observations and GPS locations, but with the short time intervals between deliveries in the dataset, and the complete lack of GPS positions far out at sea, it may be a hypothesis worth pursuing in future research. More accurate data is needed to support the hypothesis. The direct observation of a gull stealing a fish would be best, as it would be direct proof of it happening, as well as give insight into the gulls preferred hunting place and method, making further research on the subject easier.

5 Conclusion

In this study, I recorded food provisioning and diel activity using two types of camera traps and mounted GPS tags on the gulls to estimate their home range. I also studied the efficiency of each camera type and combined data from the cameras and GPS tags to examine the extent of fish piracy by the glaucous gulls. I found that the glaucous gulls mainly eat fish, chicks, and eggs. The most numerous species in each category were capelin and guillemot eggs and chicks. The nests closer to sea level had higher intake of fish than those that were located higher up in the colony. The gulls fed their young throughout the day and only had a temporary pause at mid day, probably due to disturbances caused by scientists working in the field. The overall most effective camera trap was the timelapse cameras, but due to malfunctions in the software and poor external battery solutions, they were often turned off and became a liability in the field. An important finding in this study was that the gulls had exceedingly small home ranges that only extended a few square kilometres at most, and the fact that they barely went out to sea to fish. With high percentages of fish in some of the gulls' diets, this suggested that the gulls pirated fish from other seabirds, making them kleptoparasites in the bird colonies on Bjørnøya. Further studies are needed to draw definitive conclusions, especially in the field of GPS tracking. Increasing sample size and marking gulls to easily identify them using cameras, combining GPS data and camera data with a high level of accuracy may give insight into many exciting parts of the glaucous gulls' life and ecology.

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Appendix 1

Chick rearing success for common guillemots and black legged kittiwakes:

Common guillemot:

2020	0,75
2021	0,66
2022	0,45
2023	0,62

Black legged kittiwake:

2018	0,74
2019	0,74
2020	0,82
2021	0,80
2022	0,80
2023	0,69

Appendix 2

GPS- position distribution between gull individuals:

Nest ID	GPS ID	Number of GPS positions
LF3	44598	1081
LF3	44623	991
KK1	44585	599
KK8	44559	984

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