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Monitoring Food Provisioning and Diel Activity of Breeding Glaucous Gulls (*Larus hyperboreus*) with Nest Cameras on Bjørnøya

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Ecology

Acknowledgements

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Emma Andrea Sørensen

Abstract

Arctic seabirds are drawn to nutrient rich areas in the breeding season, their diet reflects the availability of prey and can function as an indicator of ecosystem status. In this study, I observed food provisioning, diel activity, environmental effects and prey delivery methods of the Glaucous gull (*Larus hyperboreus*) on Bjørnøya. Camera traps and time-lapse cameras were placed at the Glaucous gull's nests at two different locations, three were placed outside large seabird colonies in 2016 (location 1) and five were placed in seabird colonies in 2020 (location 2). Prey composition for the two locations varied. Location 1 was dominated by oceanic prey, standing for 41% of prey delivered. While location 2 was dominated by avian prey, accounting for 55% of delivered prey. No diel activity pattern was observed on overall prey and avian prey, there was a 30% chance throughout the day with insignificant oscillations at 06:00 till 08:00 a.m. and 06:00 till 08:00 p.m. Diel activity pattern was observed for fish, with a slight peak in deliveries at 08:00 till 10:00 a.m. Wind and temperature had no significant effect on overall prey and fish, but did affect avian prey delivery, with a higher amount of avian prey observed in lower winds and warmer temperatures. Prey delivery method was significant, there was an 80% chance of bird prey and a 10% chance of fish prey being delivered from the crop. Little is known about food provisioning and diel activity for the Glaucous gull at Bjørnøya. The method presented shows the potential of camera traps and time-lapse cameras to monitor nesting sites, but results should be interpreted cautiously as they are based on a relatively small dataset.

Sammendrag

Arktiske sjøfugler trekker til næringsrike områder i hekketiden, dietten kan reflektere tilbudet av byttedyr og dermed fungere som en indikator på tilstanden til økosystemet. I denne oppgaven, observerte jeg matforsyning, døgnaktivitet, miljøpåvirkninger og byttedyrleveranse for polarmåken (*Larus hyperboreus*) på Bjørnøya. Viltkamera and tidsforløp kamera var plassert ved polarmåkereir ved to forskjellige lokasjoner, tre var plassert utenfor store sjøfuglkolonier i 2016 (lokasjon 1) og fem var plassert i sjøfuglkolonier i 2020 (lokasjon 2). Sammensetningen av byttedyr for de to lokasjonene varierte. Lokasjon 1 var dominert av sjømat, stående for 41% av byttedyr levert. Lokasjon 2 var dominert av fugl, stående for 55% av byttedyr levert. Ingen døgnaktivitet mønster var observert for alle byttedyr og fugl, det var en 30% sannsynlighet gjennom hele dagen med ubetydelige svingninger fra 06:00 til 08:00 a.m. og 06:00 til 08:00 p.m. Døgnaktivitet var observert hos fisk, med en topp av leveranser 08:00 til 10:00 a.m. Vind og temperatur hadde ikke signifikant effekt på alle byttedyr og fisk, men påvirket leveransen av fugl, med en høyere sannsynlighet i lav vind og varmere temperaturer. Metode for byttedyrleveranse var signifikant, det var en 80% sannsynlighet for fugl og en 10% sannsynlighet for fisk å bli levert fra kroen. Lite er kjent om matforsyning og døgnaktivitet for polarmåken på Bjørnøya. Metoden presentert viser potensialet av viltkamera og tidsforløp kamera for å overvåke reir, men resultatene burde tolkes forsiktig da de er basert på et lite datasett.

Contents

1. Introduction

The Arctic is important as a breeding ground for many endemic species and holds a great biodiversity (Gaston, 2011). The Barents Sea contains a high level of biodiversity, containing the world´s largest population of cod (*Gadus*), and is the breeding ground for several fish species (Wienerroither et al., 2011). Arctic seabird distribution is linked to areas with high nutritional value, and therefore one can find a large amount of seabirds at Bjørnøya (Fauchald, 2011). The seabird species on Bjørnøya can utilize these ecological benefits due to the abiotic factors that influence and create them, polar fronts positively affect the species' composition in the ocean by creating an abundance of nutrition on every trophic level (Theisen, 1997). Simultaneously the marginal ice zone is an important nutrient and pit stop for seabirds in the nesting period, as the melting along the zone leads to an early spring bloom of algae (Theisen, 1997).

Arctic seabirds are marine animals that are bound to land for the breeding period and spend the rest of the year at the open sea, in areas with sea ice and in coastal areas (Isaksen et al., 1995). On Bjørnøya they reside in colonies close to the sea and nests can be found high in steep cliffs or on flat, grassier areas (Fauchald, 2011). The arctic breeding season is short, and adults must accomplish rearing young in a limited amount of time. Arctic seabirds are most vulnerable to disturbances during this period due to the large resources they invest in rebuilding nests, laying eggs and caring for their young (Isaksen et al., 1995). Fluctuations in seabird populations may reflect ecosystem changes, such as food availability. This is a factor in the decline of many seabird populations as it changes their nutritional basis (Fauchald, 2011).

In this master thesis I studied the Glaucous gull (*Larus hyperboreus*), which has a circumpolar, high-arctic distribution, and can be found nesting on Svalbard, Jan Mayen and Bjørnøya, while overwintering with a nomadic life strategy (Svensson et al., 2010). The Glaucous gull lives pelagically in the partially and fully ice-free areas of the Barents Sea and migrates to the Norwegian Sea and the North Atlantic in the winter months (Isaksen et al., 1995). At my study site, Bjørnøya, there were about 650 hatching Glaucous gull pairs in 2006 and estimated to be only 427 pairs in 2013 (Fauchald et al., 2015). The population has been steadily in decline for decades, which can be related to accumulated contaminants and food shortages (Petersen et al., 2015). Like many seabirds, the Glaucous gull was affected by the crash in the capelin (*Mallotus villosus*) stock that occurred between 1985 and 1986, and experienced a population decline in the oncoming years (Erikstad, 1990).

In the breeding period, the Glaucous gull nests within or close to seabird colonies in single pairs or in small colonies, and can easily predate on eggs, chicks, and adults. The gull is landbound from about April till September/October, laying their eggs in late May/early June and incubating them for approximately four weeks (Isaksen et al., 1995). The Glaucous gull is one of the top predators in the ecosystem on Bjørnøya along with the Great skua (*Stercorarius skua*) (Erikstad, 1990). They have a strong predatory behavior and can often be observed killing and eating Little auks (*Alle alle*) and Atlantic puffins (*Fratercula arctica*) (Erikstad, 1990). The diet varies throughout the season and with their location, the gull is an opportunistic species and preys on the most abundant prey. A study by Erikstad (1990) showed that 73% of Glaucous gull stomachs contained feathers and bird remains in addition to redfish (*Sebastes marinus/S. mentella*), cod and Polar cod (*Boreogadus saida*), thus confirming the adaptiveness and flexibility of the species to fit the fluctuation of prey species. During hunting, the Glaucous gull might travel a large distance, thus many seabirds transport their prey in a specially adapted crop instead of in the bill (Furness & Monaghan, 1987). Fish carried in the bill are often attacked by other predators, making this method riskier than the crop (Hoffman et al., 1981).

Most biological processes are steered by timing, using an endogenous circadian clock that is synchronized to the 24-hour day by one or more external timing cues (for example the light-dark cycle) to time physiological processes and daily behavior (Steiger et al., 2013). Diel is a 24-hour pattern of activity that is navigated by external or endogenous timing cues (Payne et al., 2010). Bjørnøya is affected by the midnight sun for approximately three months in the summer (Yr). Studies have shown that spring migration can be set in motion by the connection between reproductive status and daylight length (Karplus, 1952, cited in Bissonnette, 1937; Benoit 1936; Wolfson 1945). The Glaucous gull is a diurnal bird, active during daytime and resting at night, and in the arctic they usually rest during the darkest hours of the night (Sjöberg, 1989).

1.1 Research question, objectives, and predictions

The hypothesis of this master thesis is to estimate the diet and food consumption of Glaucous gull nestlings on Bjørnøya by observing parental food provisioning and diel activity with the use of camera technology. I will also compare prey delivery methods and the diets at two different locations. Direct observations from a hide is time consuming and a possible disturbance for the birds and nestlings, while camera technology allows for high-resolution and remote observations of food provisioning to nestlings in the breeding period (Steen, 2009). These observations will be important for management of the Glaucous gull in the future, as fluctuating food availability is an important factor regulating their breeding success (Steen, 2009). I have compared the diet of Glaucous gulls nesting inside a large seabird colony to those outside a colony, as the gulls nesting inside commonly have a diet consisting of eggs and other nestlings, thus accumulating high levels of pollutants through their prey (Bustnes et al., 2000). Diel activity in polar zones is poorly understood with regards to animal behavior rhythms. Species usually react to the midnight sun in different ways: becoming arrhythmic, reacting to weaker light cues, relying on endogenous rhythms, or "free-running" regarding the 24-hour cycle (Steiger et al., 2013).

I hypothesize and predict that:

I. A temporary absence of diel activity during breeding under the midnight sun.

    Hence, I predict that food provisioning will occur continuously throughout the day.

II. The Glaucous gulls residing in seabird colonies will have a high number of eggs and nestlings in their diet.

    Hence, I predict that the diet will differ between localities (inside vs outside large seabird colonies).

III. The Glaucous gull will either deliver prey in the crop or by the bill.

    Hence, I predict that high value food (avian prey) will be carried safely in the crop. Further, larger prey will also be more costly to carry in the bill during flight.

To my knowledge for the Glaucous gull, no studies have been conducted observing parental food provisioning and diel activities, as well as diet and food consumption of the nestlings at Bjørnøya. However, similar studies have been completed on different species either concerning food provisioning or diel activity, seldom both.

2. Materials and methods

2.1 Study area – Bjørnøya

The study area for this master thesis is located on Bjørnøya, the southernmost island in the Svalbard archipelago, located in the Barents Sea between Spitsbergen and the coast of Finnmark, Norway at 74°30'N 19°E (Norsk Polarinstitutt, 2018). The island is characterized by its steep coastal cliffs, relatively flat surface, and few mountains. Few species have permanent residence on the island, as most are migratory species connected to the marine environment (Theisen, 1997). The island is approximately 20 kilometers long and 15 kilometers wide, with a surface area of 178 square kilometers and a highest point of 536 meters (Theisen, 1997). It is relatively flat, but the steep coastline is an ideal nesting area for several seabird species, resulting in some of the largest seabird colonies in the world being found on this island (Norsk Polarinstitutt, 2018).

The Barents Sea is also an important area for many species of fish, which the seabirds depend on, for example capelin and herring (*Clupeidae*) (Wienerroither et al., 2011). Despite being isolated, the island is affected by long-range pollution which can often be found accumulated in the top predators, such as the Glaucous gull.

In 2016, three cameras were installed at three different nests (hereafter referred to as N3, N4 and N5). These were placed at the north side of Bjørnøya (location 1). In 2020 I installed cameras at a total of five nests located close to Revdalen (location 2) (Figure 1). The five nests (hereafter referred to as N2, N3, N6, N7 and N13) were placed in two different locations, N3, N6, N7 and N13 on Kapp Kolthoff, with N2 on Lille Feitnakken. I placed the cameras where I thought I would get the best overview of the chicks as they wander and grow, one to four meters away from the nest.

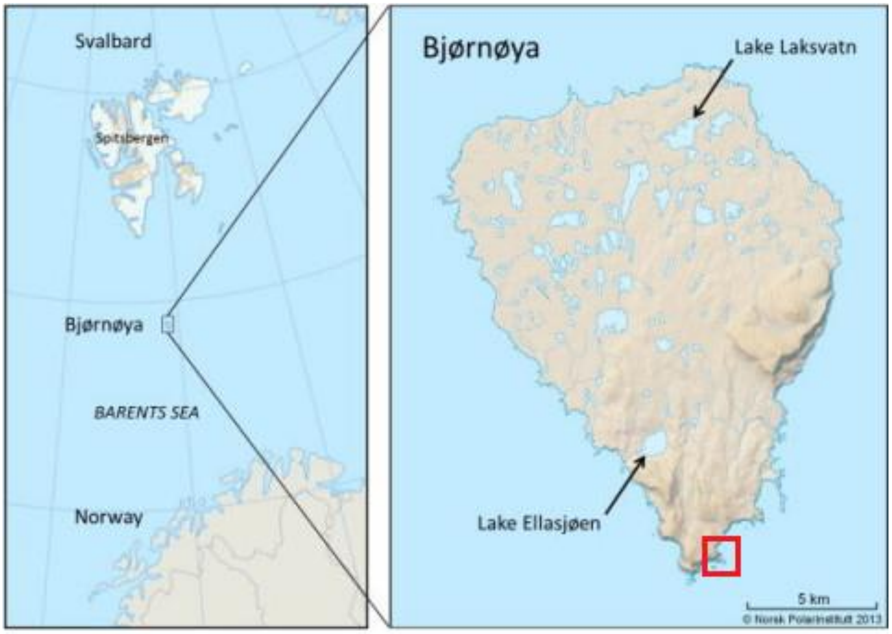

Figure 1: Study area for location 2 (2020) is marked in the red rectangle (Image (Framsenteret)).

2.2 Study species – Glaucous gull

The Glaucous gull is one of the most important flying predators on Svalbard, including Bjørnøya. Glaucous gulls that hatch close to or in seabird colonies usually specialize in providing eggs, nestlings and grown birds of other species to their chicks, and this can contribute up to 90 percent of their energy intake (Erikstad & Strøm, 2012; Weslawski et al., 1994). A study of Glaucous gulls in Canada by Gaston et al. (2009) showed that the timing of breeding was related to the timing of laying by Thick-billed guillemots (*Uria lomvia*) so they could prey on eggs and nestlings of the guillemots.

Like most seabirds, the Glaucous gull is K-selective, as it lives for up to 19 years, lays 2-3 eggs each season and has parental investment. Most arctic seabird pairs reuse their nesting spot and are territorial, defending their place by attacking intruders (Coulson et al., 2009; Thaxter et al., 2009). Since they can travel great distances to hunt, travel cost and optimal load mass is important, and the gulls can be observed carrying several prey at once (Wetterer, 1989).

2.3 Data collection

In the pilot study in 2016, three nests were monitored for five days using Reconyx model PC900 camera traps (Reconyx Inc., Holmen, WI, USA). From this pilot study I obtained 104.827 images. All images were reviewed and sorted prior to the 2020 season. In 2020 I obtained 362.911 images and 124 videos. This project used four Reconyx model PC900 camera traps, two Brinno BC2000 and two Brinno TLC200 (Brinno Inc., Taiwan) time-lapse cameras. I monitored four nests at a time, with each nest having one Reconyx and one Brinno camera. The cameras were placed at slightly different angles. The Reconyx was placed approximately one-two meters away and the Brinno approximately two-four meters away from the nest, as this was the optimal distance to receive acceptable image quality while covering a large portion of the site (Figure 2). The camera trap we used had a passive infrared sensor (PIR), detecting heat differences between the moving organism and the background (Swann et al., 2011). The batteries for the Reconyx cameras last for several months, and approximately 50 000 pictures may be stored on SD-cards (Steen & Barmoen, 2017). Thus, the nest needed to be visited only two or three times. First when mounting the camera, secondly for a midway control, and lastly for data collection after the nestlings had fledged. Since there was a limited field of view with the close-up monitoring, as observed in the pilot study, I used the time-lapse cameras to monitor the area in close vicinity of the camera-trap (Steen et al., 2017). These cameras were set up to take a picture every 10 seconds, thus the battery drained quickly and the cameras were checked every four to six days. The material from these time-lapse cameras were made into videos varying from forty-five minutes to three hours long.

Figure 2: Camera trap (left) and time-lapse (right) setup by a Glaucous gull nest.

2.4 Photo and video analysis

The material was viewed using an external hard drive connected to a computer with its standard software. While watching the videos I used my Lenovo Yoga C740 laptop, which has a touchscreen, and a compatible external pen that allowed me to precisely speed up in-between the feedings and precisely re-watch them. All prey sightings were recorded in a Microsoft Excel document, along with date, time, species, quantity, and any comments on specific feedings. In another Microsoft Excel document I recorded monitoring, noting nest ID, onset date and time, term date and time, and extra comments. This was used to get an overall view of the chicks.

If possible, prey was identified to species by Hallvard Strøm and I. There were four main prey: capelin, Lesser sand eel (*Ammodytes tobianus*), eggs and Common guillemot (*Uria aalge*) chicks. All species, except the fish species, were quite easy to distinguish. Sometimes the prey was unidentifiable due to camera angle, delivery speed, regurgitation, distance or vegetation.

2.5 Statistical analysis

The statistical analysis for this thesis was performed using version 1.2.5033 of the software R-studio and generalized linear mixed-effects models in the 'MASS' package (R Development Core Team 2021). The analysis of diel activity was based upon mixed-effects regression models (Pinheiro & Bates, 2000), in which the periodic component of the time series was presented by pairs of sine and cosine functions (Nelson et al., 1979; Pita et al., 2011). The response variable used to reflect hunting activity was the presence of prey delivery within an hour-block, which was being monitored for each breeding pair (scored as 0 vs 1, where one or more prey items within an hour-block was scored as 1). This gave a binomial outcome and logistic regression was used.

The fixed explanatory variable 'time of the day' (i.e. 0 to 24 hours) was fitted with the cosinor method (Nelson et al., 1979; Pita et al., 2011). The 24-hour period was tested first, which is the fundamental period, and then one or two harmonics was tested (i.e., 12-hour period and 8-hour period to modulate the signal). The sample unit on all tests was the observed individual hour-blocks. 'Nest ID' was included as a random factor to control for repeated measurements of the same breeding pair and any inter-pair variation (Pinheiro & Bates, 2000). The activity models were as follows:

M_0: ὰ έ ῎ΩΏΩὼ ώ̧

M_1: ὰ έ ῎ΩΏΩὼ ώ̧ ώ Ã Ï-Ǫ ώ Ó É-Î Ɛ

M_2: ὰ έ ῎ΩΏΩὼ ώ̧ ώ Ã Ï-Ǫ ώ Ó É-Î ώ Ã Ï-Ǫ ώ Ó É-Î

M_3: ὰ έ ῎ΩΏΩὼ ώ̧ ώ Ã Ï-Ǫ ώ Ó É-Î ώ Ã Ï-Ǫ ώ Ó É-Î ώ Ã Ï-Ǫ ώ Ó É-Î

x expresses 'time of the day' and Ɛ is the random effect 'nest ID'. Each model fit (M_1-M_3) was evaluated by assessing AICc values compared with a model including only the random term (M_0). The model fit was ranked in accordance with the AICc values, with a difference in AICc (ΔAICc) from the best model of 2.0 as the critical value for separating the model with the best fit

(Burnham & Anderson, 1998; Burnham, 2002). This analysis was only performed for two nests in 2020 as they had adequate monitoring coverage to capture almost all prey deliveries.

I also tested if the probability of prey delivery was affected by temperature and wind, evaluated by assessing AICc values. Finally, I tested if the probability of carrying prey type in the bill compared to the crop differed for fish and avian prey. In both tests I used logistic regression with nest ID as a random effect.

3. Results

3.1 Locations

At location 1 (in 2016), three different nests were monitored for about five and a half days, and at location 2 (in 2020) I monitored five different nests over varying time periods (Table 1). All data for location 2, except food provisioning and prey delivery method, had been cut down to 10 days, thus monitoring the Glaucous gull chicks from their youngest till they were about 10 days old. In this period, almost all activity happened within the camera view. As the chicks grew older, they start wandering out of view, resulting in uncertainties and a lack of data. In 2016, chicks were newly hatched, but precise age is unknown. 2016 had more prey deliveries per nest per day monitored than the nests in 2020 (Table 2)

Table 1: Monitoring start and end dates for Glaucous gull nests at location 1 and 2 (2016 and 2020 respectively). Total days monitored for each nest.

Location (Year)	Nest ID	Camera setup	Cameras taken down	Days monitored
Location 1 (2016)	3	Jun. 27th	Jul. 2nd	5
	4	Jun. 27th	Jul. 2nd	5
	5	Jun. 28th	Jul. 3rd	5
Location 2 (2020)	2	Jun. 26th	Jul. 27th	31
	3	Jul. 13th	Jul. 27th	14
	6	Jun. 29th	Jul. 4th	5
	7	Jun. 29th	Jul. 27th	28
	13	Jul. 4th	Jul. 27th	23

Table 2: Number of prey per nest per day monitored.

Location (Year)	Nest ID	No. of prey	Days monitored	Rate
Location 1	3	62	5	12.4
(2016)	4	47	5	9.4
	5	31	5	6.2
Location 2	2	245	31	7.9
(2020)	3	7	14	0.5
	6	32	5	6.4
	7	78	28	2.8
	13	18	23	0.8

3.2 Overall prey delivery

Of all prey deliveries at location 1, 61 (43.6%) contained unidentified prey and 53 (37.9%) fish (Table 3). At location 2, 162 contained common guillemot chicks, 54 unidentified prey, and 45 fish, standing for 42.6%, 14.2% and 11.8% of total mass respectively (Table 4). Of identified fish, capelin was the most numerous with 1.58% of total mass (N=6). Prey identification was not possible in 14.2% (N=54) of prey deliveries. For 8.7% (N=33) of prey deliveries I was uncertain if the delivery was prey, or for example, pellets or vegetation. The prey species composition differed between the two locations (Figure 3). In location 1, fish was the dominant prey with 41% (N=57). Location 2 was dominated by avian prey, with 49% (N=186) bird chicks and 6% (N=23) eggs. Location 1 only had 1% (N=1) bird chicks and 2% (N=3) eggs in comparison. While location 2 was dominated by an avian diet, 20% (N=75) of prey delivered was fish.

Table 3: Prey species composition of Glaucous gull chick diet at Bjørnøya as numbers and percentages of total prey delivered at location 1.

Prey	**No.**	**% of No.**

Bird chick	1	0.7 %
Capelin	2	1.4 %
Crab	4	2.9 %
Egg	3	2.1 %
Fish	53	37.9 %
Krill/Crayfish	2	1.4 %
Snailfish	2	1.4 %
Uncertain	12	8.6 %
Unidentified prey	61	43.6 %
Total	140	100 %

Table 4: Prey species composition of Glaucous gull chick diet at Bjørnøya as numbers and percentages of total prey delivered at location 2.

Prey	**No.**	**% of No.**
Bird chick	23	6.0 %
Capelin	6	1.6 %
Common guillemot chick	162	42.6 %
Egg	23	6.0 %
Fish	66	17.4 %
Kittiwake chick	1	0.3 %
Sand eel	3	0.8 %
Uncertain	33	8.7 %
Unidentified prey	63	16.6 %
Total	380	100 %

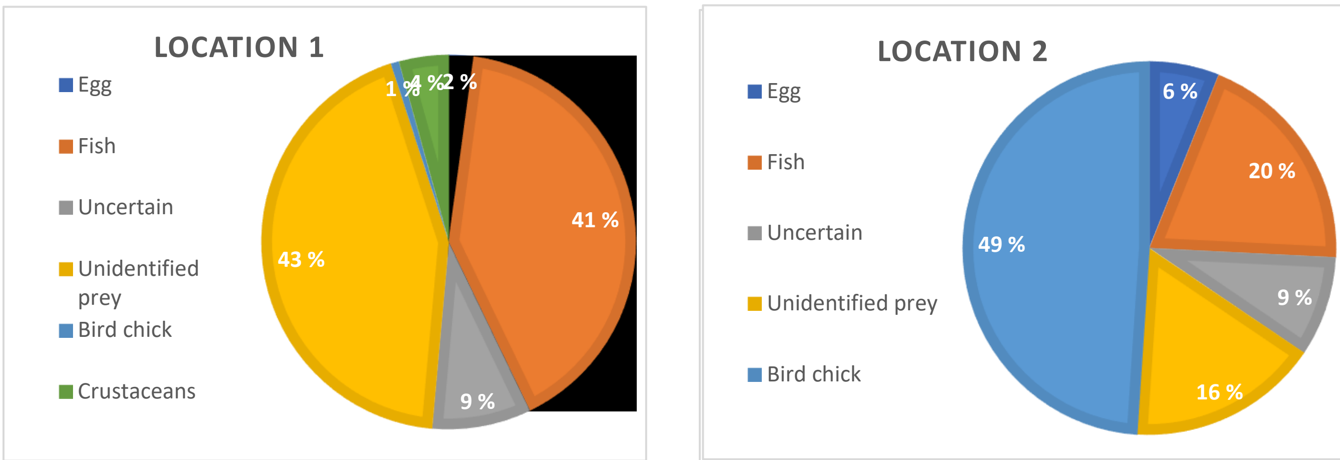

Figure 3: Prey species composition of Glaucous gull chick diet at Bjørnøya as percentage of total mass delivered at location 1 (2016) (left) and at location 2 (2020) (right).

At location 2, I analyzed diel activity for two of the nests (three nests were not included due to lack of coverage and data). There was no diel activity pattern to be observed on overall prey delivery. The possibility of prey delivery was 30% throughout the day, with a small top around 06:00-08:00 a.m. and a small dip around 06:00-08:00 p.m (Figure 4). These were not significant oscillations. The confidence interval was wide. The probability of prey delivery increased steadily with increased temperatures and was close to significant (Table 5 and Figure 4).

Table 5: Parameter estimates of the best fitted cosinor-model (n=440, random effect=2) for all prey. A=time of day and B=temperature.

	Variable	Estimate	SE	z-value	p-value
A	Intercept	-0.848	0.831	-1.021	0.307
	I(cos(2*pi*Hour/24))	-0.068	0.165	-0.413	0.680
	I(sin(2*pi*Hour/24))	0.199	0.166	1.199	0.231
B	Intercept	-1.159	0.868	-1.335	0.182
	Temperature	0.101	0.053	1.913	0.056

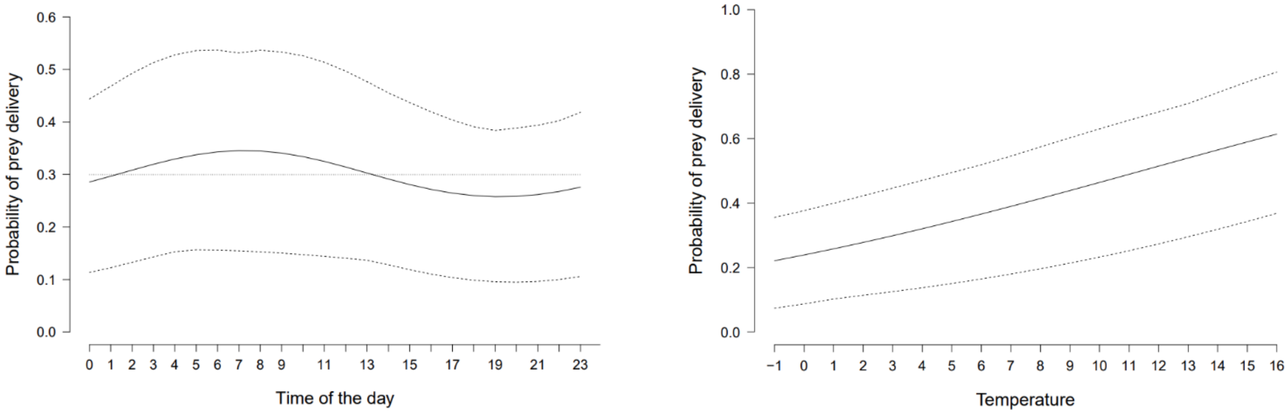

Figure 4: Probability of prey delivery in correspondence with time of day (left) and temperature (right).

3.3 Fish prey delivery

The probability of fish delivery was higher from 08:00 till 10:00 a.m. and had a small dip during the night (Figure 5). The confidence interval was wide during the high probability hours, although still significant. The probability of fish delivery was not significantly affected by temperature, although it had a negative trend (Table 6 and Figure 5).

Table 6: Parameter estimates of the best fitted cosinor-model (n=440, random effect=2) for fish prey. A=time of day and B=temperature.

	Variable	Estimate	SE	z-value	p-value
A	Intercept	-2.784	0.778	-3.580	0.000
	I(cos(2*pi*Hour/24))	-0.734	0.267	-2.752	0.006
	I(sin(2*pi*Hour/24))	0.556	0.260	2.136	0.033
B	Intercept	-2.418	0.767	-3.152	0.002
	Temperature	-0.076	0.083	-0.916	0.359

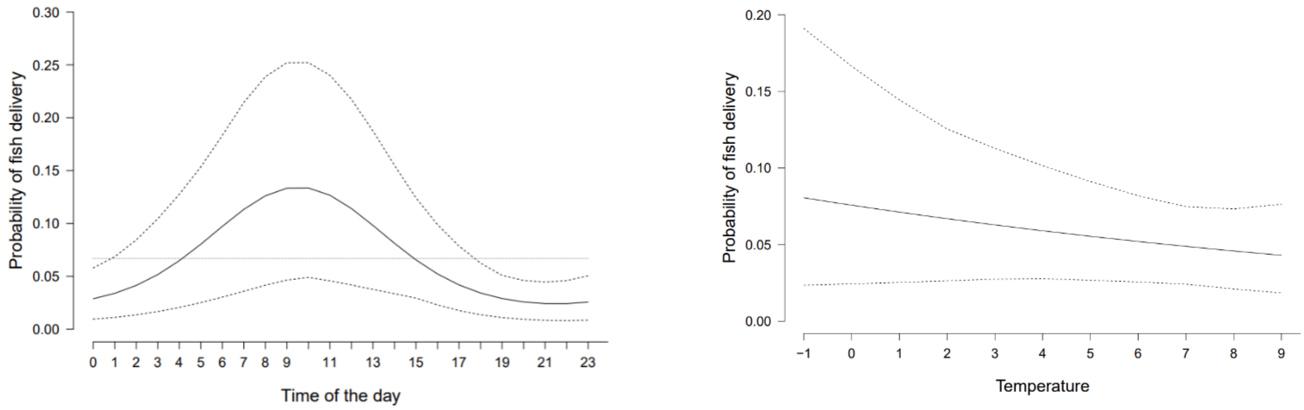

Figure 5: Probability of fish delivery in correspondence with time of day (left) and temperature (right).

3.4 Avian prey delivery

The probability of avian prey delivery was equal throughout the day. There was a small dip from 07:00 till 10:00 a.m., but this was not significant and corresponds with the top in fish prey delivery (Figure 6). Temperature and wind had a significant effect on the probability of avian prey delivery. The probability rises with rising temperatures and lowers with higher winds. Temperature had the same tendency on avian prey delivery as on overall prey delivery (Table 7 and Figure 6).

Table 7: Parameter estimates of the best fitted cosinor-model (n=440, random effect=2) for avian prey. A=time of day, B=temperature and C=wind.

	Variable	Estimate	SE	z-value	p-value
A	Intercept	-1.636	0.840	-1.047	0.052
	I(cos(2*pi*Hour/24))	0.034	0.183	0.185	0.853

	I(sin(2*pi*Hour/24))	-0.161	0.184	-0.875	0.382
B	Intercept	-2.070	0.894	-2.314	0.021
	Temperature	0.139	0.058	2.406	0.016
C	Intercept	-0.662	0.937	-0.706	0.480
	Wind	-0.135	0.047	-2.857	0.004

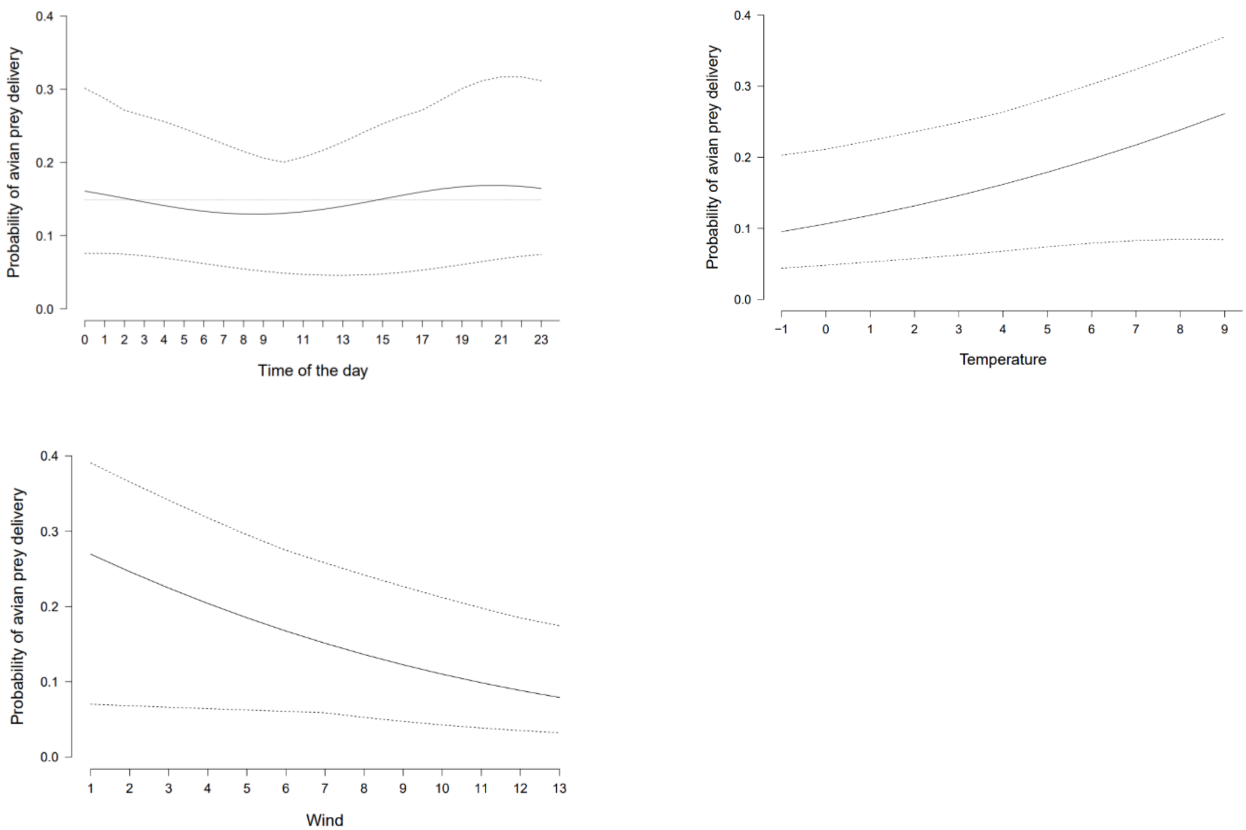

Figure 6: Probability of avian prey delivery in correspondence with time of day (top left), temperature (top right) and wind (bottom left).

3.5 Prey delivery method

The probability of prey being carried in the bill was higher if the prey was a fish compared to a bird, with approximately 80% chance for fish and 10% for birds (Figure 7). Thus, avian prey was more likely to be provided from the crop (Table 8 and Figure 7). Total number of prey delivered by the crop was overall higher than the prey delivered by the bill. The percentages of identified, unidentified and total prey was the same for prey delivery by the crop and bill (Table 9).

Table 8: Parameter estimates of the best fitted cosinor-model (n=248, random effect=5) for prey delivery method.

Variable	Estimate	SE	z-value	p-value
Intercept	-2.325	0.675	-3.448	0.001
Prey (Fish)	3.921	0.458	8.558	< 0.001

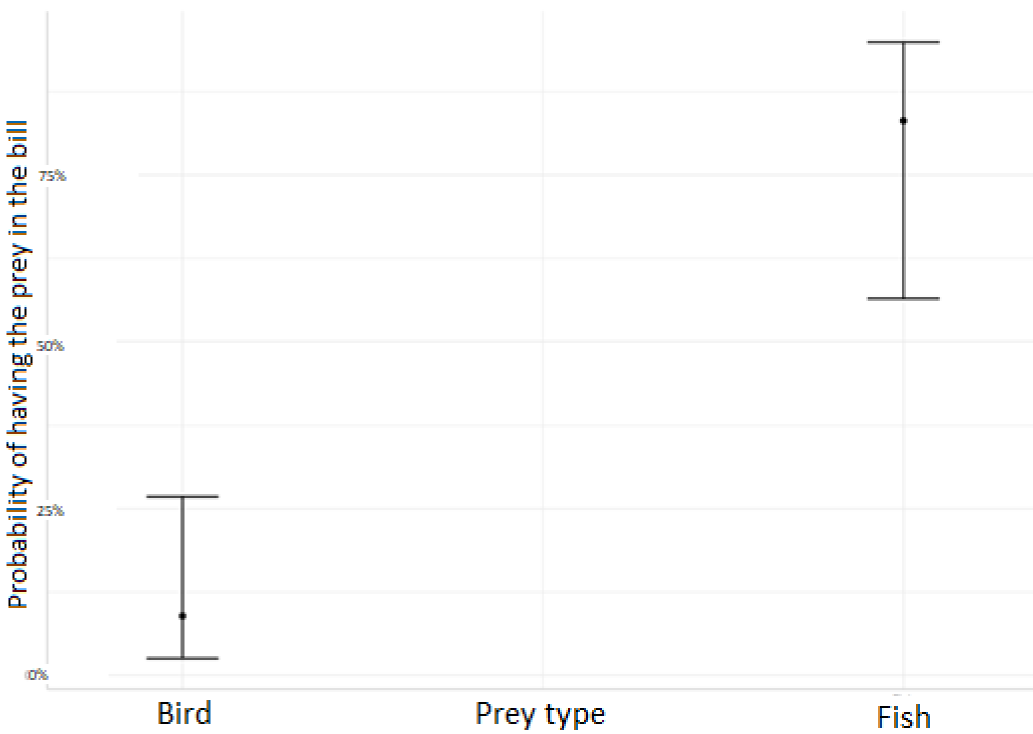

Figure 7: Probability of carrying bird (left) and fish (right) in the bill.

Table 9: Percentage of identified, unidentified, and total number of prey observed in correspondence to delivery method, with number of prey in parenthesis.

Delivery method	Percentage of identified prey	Percentage of unidentified prey	Total number of prey
Bill	65.7% (67)	34.3% (35)	102
Crop	65.3% (156)	34.7% (83)	239

4. Discussion

4.1 Prey composition

At location 2 the gulls consumed high levels of both avian prey and fish, while at location 1 they consumed mostly fish. Most of the oceanic prey is caught at the sea surface or in the intertidal zone, if not pirated from other fishing predators (Stempniewicz, 1994). The study by Stempniewicz (1994) only observed the Glaucous gulls from what can be seen at the colony, and we know little about what the gulls do out at sea (Hallvard Strøm pers. comm.). Location 1 was located further from large seabird colonies and thus there were less avian prey than at location 2, located next to their main prey, large guillemot colonies. The Glaucous gulls prioritizes prey with easy access, explaining the difference in prey we found at location 1 and location 2. Gulls nesting close to sea level and a distance from seabird colonies have a higher intake of seafood (Bustnes et al., 2000) and vice versa, thus prey composition for this study was unsurprising. It is uncommon for the Glaucous gulls to prey on healthy adult birds, but common to prey on eggs, chicks, and fledglings, as well as piracy, in all auk colonies (Stempniewicz, 1994). In late June and early July, the Glaucous gull was observed preying heavily on hatchlings in the Beaufort Sea (Barry & Barry, 1990). A study by Stempniewicz (1994) on Little auks found that there is a higher pressure of predation on large colonies compared to small ones, this could be because there was a higher chance to find vulnerable nests and chicks in large colonies.

4.2 Diel activity

For providing fish to the nestlings, time of day played a significant role. There was a higher chance of oceanic prey from 08:00 till 10:00 a.m. Aquatic organisms have a different cycle than terrestrial organisms, they function with diel vertical migrations (Neilson & Perry, 1990) to balance growth and risk of predation (Dale & Kaartvedt, 2000). Although diel vertical migration is very weak amongst zooplankton under the midnight sun (Fischer & Visbeck, 1993), weak and significant diel vertical migration was observed in young stages of *Calanus finmarchicus* (Dale & Kaartvedt, 2000). Glaucous gulls hunt fish by catching them in their bill while swimming or scavenging (Furness & Monaghan, 1987), and often hunt over small pods of oceanic mammals as they bring fish to the surface (Barry & Barry, 1990), therefore the peak in fish prey can be a result of the diel vertical migrations in zooplankton. These fish deliveries could also be fish pirated from the guillemots.

In my study I could not observe any diel activity patterns for overall prey and avian prey, the Glaucous gulls hunted equally throughout the day. The Glaucous gull is a diurnal bird, but could be affected by being located in the guillemot colonies, as large colonies do not have a noticeable activity pattern under the midnight sun (Sjöberg, 1989). Solitary nesting birds have definite resting periods and the Glaucous gull being a midway of nesting solidarity and in a colony, can display a mix between the two (Ferens, 1962). Predator-prey interactions can be steered by the diel cycle (Wojczulanis-Jakubas et al., 2020). A study by Wojczulanis-Jakubas et al. (2020) in Magdalenefjorden, Svalbard (79°35 N) showed that Little auks socialize in their colony during relatively low light conditions as shadows help them detect predators, and therefore the Glaucous gull can be observed camouflaging themselves by perching on remains of snow with their heads lowered. This study also found that the predation rate on young Little auks was low during peak fledging (22:30 p.m. to 01:30 a.m.) compared to outside this timeframe. A study by Sjöberg, (1989) in northern Sweden (64°05 N) showed that the Common gull (*Larus canus*) had a diurnal activity pattern at the beginning of the season in May, in early June they observed an activity peak in the dark periods, leading to the gulls being active the whole day in late June, when the summer solstice occurred. In July, the gulls returned to their diurnal flight activity pattern. Seeing as the *Larus* genus holds many similar traits, this could correspond with how the Glaucous gulls behave at Bjørnøya and explain the diel activity pattern we observed in oceanic prey.

4.3 Environmental effects

Wind and temperature did not have a significant effect on overall prey and fish delivered to the nestlings. Foraging methods are often influenced by environmental changes to maximize the energy and injury trade-off, which is important for avian predators since their prey executes group defenses (Gilchrist et al., 1998). Thus, their foraging decisions vary in tune with the conditions that influence this trade-off. Bjørnøya is characterized by steep cliffs and varying weather which influences the gulls' tactics. During my study, we encountered a great variation in weather with sunny days and 19 degrees Celsius, heavy rain and strong winds, and snow with 4 degrees Celsius. All of these could have varying impacts on the Glaucous gulls foraging methods.

I observed a higher chance of avian prey delivery in lower winds and warmer temperatures. In low winds and temperatures, the chick can wander and therefore be exposed to predation (Hallvard Strøm pers. comm.). Arctic ecosystems are harsh, and we can find coevolution in the predator-prey relationships (Stempniewicz, 1994). Little auks struggle in strong winds while Glaucous gulls have adapted a flight type and body construction that gives them a strong advantage (Stempniewicz, 1983; Stempniewicz, 1994). Gilchrist et al., (1998) and Stempniewicz (1983) found that foraging using aerial attacks under windy conditions is favored by the gulls as it minimizes injuries from defending guillemots and increases the effectiveness of predation. The vulnerability of guillemot nests is dependent on wind conditions at the colony; moderate wind speeds allow gulls to reach their prey without encountering parental guillemots (Gilchrist & Gaston, 1997). Low winds and warmer temperatures can thus favor the hunting method of the Glaucous gulls at Bjørnøya.

4.4 Prey delivery method

We found that birds have a higher chance of being carried in the crop compared to fish. Gulls often scavenge and steal prey from other species and fish carried in the bill are vulnerable to this (Furness & Monaghan, 1987). Barry and Barry (1990) noted the Glaucous gull as a multiple prey-load feeder, as several individuals were recorded swallowing one to four Snow geese (*Anser caerulescens*) chicks in quick succession. The gulls could also prioritize high value prey in the crop and the fish carried in the bill could be stolen from other birds, explaining the results we observed.

4.5 Methodological limitations and opportunities

Camera traps provide information on elusive wildlife and can give insight to behavior that otherwise would be difficult to collect at a site, for example a nest (O´Brien & Kinnaird, 2008).

For studying prey composition and diel activity, camera traps are preferred as they allow for minimal disturbance and an around the clock data collection that cannot be achieved by an observer (Randler & Kalb, 2018). Keeping a short distance from the camera to the nest is ideal to capture as much data as possible as well as simplifying the identification of prey (Randler & Kalb, 2018). This short distance also reduces site cover.

All images from location 1 were reviewed and sorted prior to the 2020 season to look for complications and to optimize camera set up. Still, there were difficulties in camera placement and identification of prey at location 2. At N7 the camera was placed too close to the nest, thus it did not record all feedings. Fortunately, this was corrected for and took place before hatching. At N13, I placed the cameras at a secondary nest that was not in use despite it looking inhabited during the set up. A combination of the chicks´ wandering and camera placement resulted in only two nest sides (N2 and N7) being valid in analyzing diel activity patterns.

The greatest disadvantage of using time-lapse cameras is that the analysis process is time-consuming (Weller & Derksen, 1972). To speed up the process I used a touchscreen computer and a touch pen that allowed me to fast forward the video. The time-lapse cameras also needed frequent battery changes, which could be a disturbance to the chicks and adult birds. On the other hand, time-lapse cameras allow for better documentation. These cameras had a wider angle and documented a large number of feedings that happened outside the view of the camera trap. However, identification of fish species was quite difficult due to large distance and low-quality images on the time-lapse cameras.

Using both camera traps and time-lapse cameras allowed for a better documented dataset, as well as determining the reliability of the Reconyx camera traps. The camera traps documented all feedings that occurred within its field of view, except for N7 where we miscalculated the camera´s placement. I also encountered a technical problem where the camera trap at N2 did not record any photos, luckily this was prior to hatching. Therefore, it is important to properly understand the cameras before use.

Camera traps reduce observer bias as one can re-analyze the data at a later date and by multiple people (Randler & Kalb, 2018), I had the help of my co-supervisor to analyze prey species I was uncertain about and feedings I could not decipher. Several prey deliveries ended up as uncertain or as unidentified prey. At location 1, 43.6% were unidentified, while 16.6% were unidentified at location 2. I found just as many unidentifiable prey that were delivered by the crop as were delivered by the bill. This is not uncommon as unidentified prey can account for 20-40% of all observed prey deliveries in similar studies (Robinson et al., 2015). Location 2 is well documented, and the use of two camera types could contribute to this low percentage of unidentified prey. It can be difficult to identify prey deliveries due to technical or natural issues, such as poor image quality or regurgitation. Identifying prey delivered by the crop may be difficult as prey appearance and composition can be compromised due to regurgitation (Irons, 1987). A factor contributing to the large percentage of unidentified prey at location 1 could be that the nests were observed using one camera trap, as opposed to one camera trap and one time-lapse camera at location 2. With two cameras I had the option to switch between them to find the best angle and image quality.

5. Conclusion

My study looks at using different camera traps to monitor Glaucous gulls located close to seabird colonies where traditional methods are unsuitable. This study provides information on food provisioning, environmental effects, diel activity patterns and prey delivery method to a migrating top predator located on Bjørnøya. Firstly, I found that Glaucous gulls on Bjørnøya provide food throughout the day, with a peak of fish prey in the morning. Secondly, the gulls inside seabird colonies have a higher intake of avian prey than gulls nesting outside of a colony. Lastly, there is a high chance that avian prey is delivered in the crop compared to fish prey. Further studies are needed to conclude food provisioning and diel activity patterns for the Glaucous gull at Bjørnøya due to the small sample size in this study. Future studies should ensure sufficient sample size by observing more nests and choosing these carefully to ensure chick survival and a sufficient database. It could be of use to compare diel activity patterns at both locations and compare this with the dominant prey. One might also consider using a larger battery pack or external batteries to minimize human disturbance when batteries need to be changed. Although the method presented in this study cannot substitute traditional monitoring methods, I believe it can provide valuable information to seabird research in the future.

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