



Norwegian University
of Life Sciences

Master's Thesis 2021 30 ECTS

The Faculty of Environmental and Science and natural Resource
management

Prey delivery, prey handling and circadian rhythm at two Rough-legged buzzard (*Buteo Lagopus*) nests as revealed by use of video monitoring

Byttedyr levering, byttedyr håndtering og døgnrytme ved to fjellvåk (*Buteo lagopus*) reir avslørt ved bruk av videoovervåking

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Master's degree in natural resource management

ACKNOWLEDGEMENTS

This assignment marks the end of two exciting years at the Norwegian University of Life Science in Ås, Norway. It has been interesting and there are way more subjects available at the university than what only the personal capacities set the limit. So, with an eager to learn more it is both with sadness and excitement that the time at the university has come to an end. I would like to thank my supervisors associate professor Ronny Steen and professor Geir A. Sonerud for help with statistics and being thorough when giving feedback on issues of matter. Professor Geir A. Sonerud and I have spent several hours identifying prey items delivered at the nest. Thanks to professor Vidar Selås for helping out identifying bird items that were particularly difficult to identify at the nests. Thanks to Gjøran Stenberg and Helge Grønlien for setting up the camera and maintenance during the monitoring period. Without their help there would have no data for this assignment. A huge thanks to my brother Peder, who helped me with R statistics and graphs. And finally, thanks to my wonderful fiancée Line who always has my back.

Ås, 15th May 2021

Michael Andersson

ABSTRACT

Two Rough-legged buzzard (*Buteo lagopus*) nests, were video monitored during the nestling period in 2017 in Norway. One nest was in Surnadal in Møre and Romsdal county and the other, Goppollvatnet in Innlandet county. This was to gain knowledge on the prey delivered, circadian rhythm at the nests regarding parent delivery and precise time the day and the ability of unassisted feeding as a function of nestling age. Data were collected using video recordings that were activated by sensors when movement was detected at the nest. Videoclips were reviewed on a large screen to identify all deliveries from the surveillance period. The circadian rhythm revealed that prey was delivered during daytime. The diel pattern of delivery differed between the nests, with one distinct delivery peak for Surnadal at 12.30-15.00 hours and two peaks at Goppollvatnet at 08.00-09.00 and 16.00-17.45 hours. At Goppollvatnet 349 prey items were delivered and at Surnadal 159. The most frequent prey delivered at both nests were *Microtus* voles with 28.3 % at Surnadal and 39.8 % at Goppollvatnet. Lemmings made up 29.8 % of the prey items at Goppollvatnet and none at Surnadal. Birds made up 33.8 % of the delivered estimated prey mass at Surnadal and 4.8 % at Goppollvatnet. The parent delivering pattern as a function of nestling age differed between the two nests. The single nestling in Surnadal started feeding unassisted at a younger age than the two nestlings at Goppollvatnet. This might be due to the female food allocation to increase the survival rate for siblings. Both prey type and nestling age affected the probability of female feeding at Surnadal but only prey type at Goppollvatnet. At Goppollvatnet the probability of feeding unassisted was larger for *Microtus* voles compared to Norwegian lemmings (*Lemmus lemmus*) which might explain the difference between the nests in the ability of nestlings feeding unassisted. The probability of swallowing a prey whole was affected by the prey mass at both nests. Whether prey was a shrew, or a vole has affected the probability of swallowing whole at both nests. In the future it might be an idea to set up two cameras from opposite angles to optimize the recordings. This would help getting better images when a nestling might be shielding the prey from one angle. At the same time, the sensibility on the sensors might be adjusted a bit down to avoid unnecessary recordings.

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INTRODUCTION

Knowledge about the foodwebs and species interactions across trophic levels is important in understanding the function of an ecosystem. Ecological studies have for a long time examined the predator-prey interaction (Ives et al. 2005) and these interactions can affect population dynamics and thereby affect an entire ecosystem (Lima 1998). To understand the larger picture of these interactions, one could start by monitoring the prey items that are being eaten by the predators. In the diet of raptors small rodents are important. Small rodents have multiannual cycles in their abundance and rodent peak years appears to be quite regular in Fennoscandia (Selås et al. 2021). Both the breeding density and the reproductive success of raptors that specializes on small rodent prey are often dependent on these small rodent cycles (Pokrovsky et al. 2012; Koivula & Viitala 1999). The Rough-legged buzzard is considered a small rodent specialist (Pokrovsky et al. 2013) and in some areas it may be the main avian predator of small rodents (Tast et al. 2010). However, successful breeding of the Rough-legged buzzards in years with complete absence of small rodents in the tundra ecosystem on Kolguev Island, Russia, have also been found (Pokrovsky et al. 2015). When the migrating Rough-legged buzzard arrives in April, some areas are snow-covered and vegetation is low. A study that supports the placement of the nest is the discovery done by Koivula & Viitala (1999). This study reveals that Rough-legged buzzard (*Buteo lagopus*) uses vole scent as hunting areas because they can see UV light traces from urine and faeces, that the low vegetation does not cover, making it a good placement for a nest. The tundra with low vegetation is associated with Lemmings (*Lemmus lemmus*) (Hellström et al. 2014). To gain precise knowledge on the diet of the Rough-legged buzzard the nestling period is particularly useful because the nests is a fixed place where the prey items are being delivered to. Previously, when examining prey items, the data have been restricted to controls of regurgitated pellets found in and around the nest, together with fresh prey items and other food remains. This method provides a good insight in the different prey items in family groups based upon skulls, jaws, bones etc. with a time-consuming effort in a laboratory (Tast et al. 2010). But the abundance of one prey, relative to another is not present and the method does not distinguish prey items, at the best taxonomic level. Analyzing remains and pellets can also lead to over and underestimating of large prey and small prey (Tornberg & Reif 2007) as is the case for amphibians which have been found underrepresented in nest remains for common buzzards, (*Buteo buteo*) (Selås 2001). Since many raptors are single-prey loaders (Sonerud 1992), monitoring via video creates the opportunity to a unique insight to which prey items that are delivered and might help to identify the taxonomic level in a better way, when you can actually see the prey. It

also opens to new knowledge to when prey is delivered in the circadian rhythm. Monitoring the circadian rhythm is challenging and very time-consuming if 24-hour observations is obtained in the wild (Steen 2020). And due to video monitoring with time and date logged in the recorded files it is now possible to analyze the diurnal and nocturnal activity patterns (Steen 2020). Previously a study has captured raptors and collected pellets, dried them and used it as an index to see what have been consumed between dawn and capture. These regurgitated pellets would then help to reveal prey consumed the previous day and give an estimated time of capture (Smallwood 1988). The brooding and feeding are normally carried out by the female, while the male hunts and provides prey items to nest and gradually the female also starts to provide prey items (Sonerud et al. 2014a).

Understanding the parental sex roles during the nestling period and how the prey delivering is divided between the parents through the nestling period is also easier to learn about when monitoring via video. Monitoring helps to reveals for how long time the nestlings are dependent on feeding assistance from the female and when are they able to feed for themselves or when the female still feed them regardless of their ability to feed for themselves. This could potentially indicate strategies for ensuring the survival rate of the nestlings and avoid the consequences of “parent offspring conflict” where a nestling will optimize its own success on behalf of siblings and the female parent (Szojka et al. 2020). Prey handling have been found interesting to look at in previous studies (Steen et al. 2010) and was also included as a variable in the study. Monitoring the prey handling regarding, feeding unassisted and the ability to swallow some prey whole, could help to clarify when nestlings no longer had a feeding constraint due to their gape size in accordance with the feeding constraint hypothesis (Slagsvold & Wiebe 2007). These are interesting questions that via monitoring is easier to gain knowledge on.

I aimed to investigate five aspects of the breeding ecology of the Rough-legged buzzard.

1) Identify to lowest taxonomic level of prey items delivered at the nest and 2) estimate the circadian rhythm of the prey deliveries. Furthermore, I wanted to 3) investigate who delivers the prey at the nest and does this change as a function of nestling age? 4) When are the nestlings able to feed for themselves and 5) how is the prey handled by the nestlings?

MATERIALS AND METHODS

STUDY SPECIES

The Rough-legged buzzard is a raptor that belongs to the hawk family. There is gender dimorphism and the female is larger than the male with a wingspan of up to 1.2 m - 1.5 meter (Cramp &

Simmons, 1979). It has a circumpolar distribution in Fennoscandia and parts of Russia, and with an estimated population size in rodent peak years of 4000-10000 pairs in Norway (Artsdatabanken, 2021) it is a common bird of prey. Its habitat is near the tree line and alpine tundra, where it nests on small cliffs ledges (Hellström et al. 2014). In wintertime it migrates to central Europe and the southern parts of Fennoscandia, from where it returns in April (Cramp & Simmons, 1979).

STUDY AREA

For this study, data were collected from two nests in southern Norway. One nest was located in Surnadal municipality (fig. 1a) in Møre and Romsdal county. The other nest was in Øyer municipality (fig. 1b) in Innlandet county.

Both nests were located on a small cliff ledge. The nest at Øyer is from here on referred to as Goppollvatnet. The nest at Goppollvatnet c. 1000 m a.s.l. and was surrounded by open landscapes with grass mixed with open forest of small birch trees (*Betula sp*) and small Norwegian spruce (*Picea abies*). This area makes up the upper part of the tree line and distance to alpine regions is less than 1 km. Domestic cows graze in the area in summer, as one videoclip revealed several cows passing by.

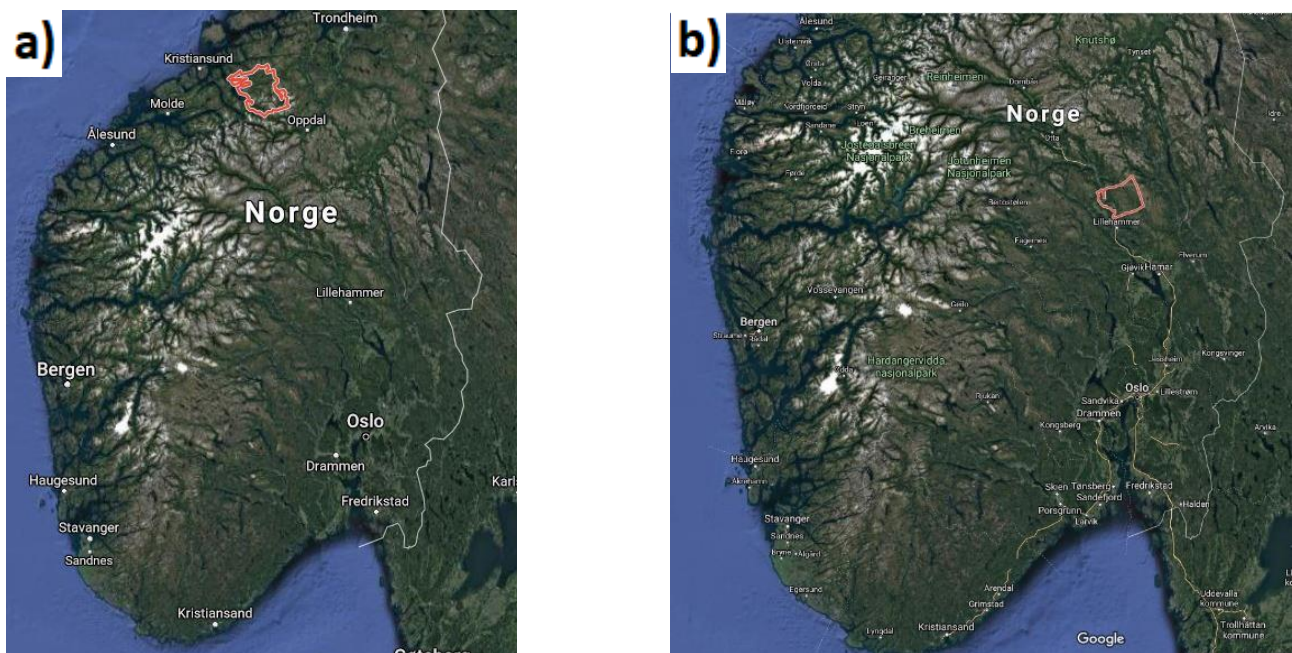


Figure 1. a) Municipality of Surnadal and b) the Municipality of Goppollvatnet.

The nest at Surnadal was located 510 m a.s.l surrounded by landscapes with grass and open birch forests with small trees. In close proximity to the nest there were open wetlands with scrubs and alpine areas.

VIDEOMONITORING

At both nests a small colour CCD (Charge-Couple Device) camera was mounted to get the best view at activity taking place at the nest.



Figure 2. The left images shows the monitoring view at a) Surnadal and b) Goppollvatnet.

An extension cord for power and an RCA cable from both cameras at the nests to a mini-DVR (Digital Video Recorder) made maintenance easier during the monitoring period. The extension cord was meant to minimize disturbances at the location when maintenance was carried out during the monitoring period. Recordings were stored on SD cards by the mini-DVR, which was placed in a waterproof box during the monitoring. The operating system was run by a 12VDC battery and solar panels. For a detailed description see Steen R. (2009). Maintenance check and the change of SD cards were carried out once a week. The system was set to record using the video motion detection within the mini-DVR. This meant that whenever movement occurred at the nest, the recordings started. These recordings lasted from 11 seconds in the shortest to 17 minutes for the longest videoclips. The sensitivity and the detection zone were adjusted to a level that was meant to capture all deliveries but leave out small movements at the nest. The sensitivity was set a little light, so it captured both. The recording made up a total of approx. 49000 videoclips to check. When going through the clips on the computer I chose the large file view in the folder and used a large screen. When the still picture of two subsequent files were different from one another I knew some activity had taken place and I started viewing a number of files to make sure I did not miss any action.

The monitoring at Surnadal (fig. 2a) started recording in the evening 10th of July and continued to early in the morning 4th August when the nestling had left the nest. This gave a total of 25 days of

monitoring. Recordings revealed that the nestling left the nest 31st July before noon, which effectively meant 20 days of monitoring. The nestling was estimated to be 20 days old when the monitoring started. During 10-17th July, the camera setup was placed in a position a bit too far from the nest to properly identify the delivered prey items at a satisfying taxonomic level. From 17th July in the evening the monitoring unit was moved to a closer position with a better view. Due to a technical error with the storage on the SD-card a few videoclips from the period 17-20th July were corrupted.

The monitoring at Goppollvatnet (fig. 2b) started in the evening 1st July and lasted until 5th August in the morning, which gave a total of 35 days. The nestlings were estimated to be 7 days old when the monitoring started. The nestlings still appeared on and off the nest when the monitoring was stopped. It was reasoned that sufficient monitoring had been acquired at that time. There was a gap in the monitoring from 21st July at 14:43 hour to 28th July at 15:27 hour due to technical difficulties.

DATA PROCESSING

In general, determining whether there had been a prey delivery or not, a conservative approach have been consistent throughout the reviewing of the video material. If a delivery had taken place outside the camera view and movement from the nestlings being excited, was consistent with receiving a prey item, it was left out because we did not see the delivery directly. This was to ensure that the data included in the statistics were as valid as possible. This also means that the number of deliveries recorded is a minimum and most likely is higher. In all other cases, when in doubt, video clips were left out.

I reviewed the collected data from each nest and every prey delivery recorded was categorized in the preliminary groups as vole, bird, amphibium, uncertain or unidentified. The time and date were recorded together with the sex of the delivering parent. When identifying the delivering parent I looked for patterns in the plumage, colors of feathers, relative size combined with the fact that the only the female feeds the nestlings (Sonerud et al. 2014a). When all deliveries were sorted into folders, they were all reviewed again in collaboration with my supervisor professor Geir A. Sonerud to determine the prey deliveries at the most precise taxonomic level as possible. Deliveries of avian prey and deliveries that needed a second opinion, were checked by professor Vidar Selås. Some deliveries where not possible to identify to a lower level than bird or small mammal. Due to the resolution on the videoclip, grey-sided voles (*Myodes rufocanus*) may have been catagorized as *Microtus* voles.

The prey handling was scored as whether the nestlings needed feeding assistance, or they could handle the prey themselves. Prey item that was delivered were scored as whole or as partly eaten or plucked prior to delivery. For mammals delivered decapitated, 16.5 % from the gross body mass was subtracted to obtain a net body mass and for birds 12.9 % (Sonerud et al. 2014a). When prey item was delivered partly eaten or plucked, a weight estimate was made in collaboration with professor Geir A. Sonerud.

STATISTICAL ANALYSIS

The statistical analysis was performed in R. Version 3.5.2 “Eggshell Igloo” (R core team 2021). The analysis of prey delivery during the circadian rhythm was calculated based on linear mixed-effects regression models using the lme4 Package, as in Steen (2017) and Steen & Barmoen (2016). “Time of prey delivery” was set as the fixed explanatory variable and by using a cosinor method that uses a fundamental period of 24 hours, that is constructed with two (12 hour) harmonic components. The sample unit (n) was the amount of observation hours and the random factor set as (ID 2) which included both locations. The activity models as in Appendix A, B and C (M1-M8) was checked using the Akaike Information Criterion (AIC) to find the best fitted model. Based on their AIC’s values where the lowest value gives the best model, model four was chosen for the combined (see appendix A). Model 3 was best for Goppollvatnet and model 2 was best for Surnadal when divided into subsets (see appendix B and C). For more information on the model specifications and best fitted models based on AIC’s values and the summary results see appendix.

In addition, some of the Logistic regression was performed in JMP version 15.0. (SAS 2019). Too few decapitated, plucked or partly eaten prey items was present in the dataset to be able to test.

RESULTS

THE DIET

During the monitoring period a total of 159 prey items at the nest in Surnadal (table 1a) and 349 prey items were delivered at the nest in Goppollvatnet (table 1b). At both nests small mammals made up the majority of the prey items with 61.6 % for Surnadal and 75.4 % for Goppollvatnet. At Surnadal 28 prey items were identified at the species level, 65 at the genus level, 36 at the family level, while three could only be identified as small mammal, and 27 could not be identified. At Goppollvatnet 129 prey items were determined at the species level, 152 at the genus level, five at the family level, and seven at the class level, i.e. bird or mammal.

The most frequent prey delivered at both nests were *Microtus* voles i.e. field voles (*Microtus agrestis*) or tundra voles (*Microtus oeconomus*). These made up 28.3 % at Surnadal and 39.8 % at Goppollvatnet. A noticeable difference between the two nests was the complete absence of Norwegian lemming at Surnadal, while lemmings were the second most important prey at Goppollvatnet with 29.8 % of the total prey numbers delivered. Birds on the other hand were very important at Surnadal with 9.4 % of the prey items delivered. Besides the absence of lemmings at Surnadal, avian prey mass was the largest difference in prey mass between the nests. Birds made up 33.8 % of the combined prey mass delivered at Surnadal compared to 4.8 % of the combined prey mass for Goppollvatnet.

Table 1. The diet of the Rough-legged buzzard based on video monitoring at two nests, one in a) Surnadal and b) Goppollvatnet

a)	Prey number		Estimated gross body mass (g)		Total % of estimated gross body mass
	N	%	Per prey	Total per prey	
Mammal:					
Field vole or Root vole (<i>Microtus sp</i>)	45	28.3	50	2250	23.2
Bank vole (<i>Myodes glareolus</i>)	1	0.6	20	20	0.2
Microtus/Bank vole	1	0.6	49.4	49.4	0.5
Vole Indet.	36	22.6	49.3	1774.8	18.3
Shrew (<i>Soricidae sp</i>)	12	7.5	10	120	1.2
Small mammal indet.	3	1.9	41.3	123.9	1.3
<i>Mammal in total</i>	98	61.6	44.3	4338.1	44.7
Amfibium:					
Frog (<i>Rana sp</i>)	16	10.1	20	320	3.3
Toad (<i>Bufo bufo</i>)	3	1.9	40	120	1.2
<i>Amfibium in total</i>	19	11.9	23.2	440	4.5
Bird:					
Black Grouse (<i>Tetrao tetrix</i>)	1	0.6	900	900	9.3
Thrush / fieldfare (<i>Turdus sp.</i>)	7	4.4	100	700	7.2
Pipit (<i>Anthus sp.</i>)	1	0.6	20	20	0.2
Willow warbler (<i>Phylloscopus trochilus</i>)	1	0.6	10	10	0.1
Willow ptarmigan (<i>Lagopus lagopus</i>)	3	1.9	500	1500	15.5
Great Spotted Woodpecker (<i>Dendrocopos major</i>)	1	0.6	90	90	0.9
Wood sandpiper (<i>Tringa glareola</i>)	1	0.6	60	60	0.6
<i>Bird in total</i>	15	9.4	218.6	3280	33.8
Unidentified:	27	17.0	61.6	1663.2	17.0
Total	159	100		9721.3	100

b)	Prey numbers		Estimated gross body mass (g)		Total % of estimated gross body mass
	N	%	Per prey	Total per prey	
Mammal:					
Field vole or Root vole (<i>Microtus sp</i>)	139	39.8	50	6950	39.3
Norwegian lemming (<i>Lemmus lemmus</i>)	104	29.8	50	5200	29.4
Bankvole (<i>Myodes glareolus</i>)	2	0.6	20	40	0.2
Microtus/Lemming	7	2.0	50	350	2.0
Birchmouse (<i>Sicista betulina</i>)	1	0.3	10	10	0.1
Stoat (<i>Mustela erminea</i>)	1	0.3	100	100	0.6
Least weasel (<i>Mustela nivalis</i>)	1	0.3	40	40	0.2
Hare (<i>Lepus timidus</i>)	1	0.3	800	800	4.5
Shrew (<i>soricidae sp</i>)	3	0.9	10	30	0.2
Small mammal indet.	4	1.1	48.6	194.4	1.1
Mammal in total	263	75.4	52.15	13714.4	77.6
Amfibium:					
Frog (<i>Rana sp</i>)	14	4.0	20	280	1.6
Amfibium in total	14	4.0	20	280	1.6
Bird:					
Thrush / fieldfare (<i>Turdus sp.</i>)	3	0.9	100	300	1.7
Passerine indet. (Passeriformes)	3	0.9	10	30	0.2
Meadow Pipit (<i>Anthus pratensis</i>)	2	0.6	20	40	0.2
Pipit (<i>Anthus sp.</i>)	2	0.6	20	40	0.2
Common Greenshank (<i>Tringa nebularia</i>)	1	0.3	200	200	1.1
Duckling indet. (Anatidae)	2	0.6	50	100	0.6
Bird indet.	3	0.9	43.8	131.4	0.7
Bird in total	16	4.6	52.59	841.4	4.8
Unidentified:	56	16	50.6	2833.6	16.0
Total	349	100		17669.4	100

CIRCADIAN RHYTHME OF PREY DELIVERIES

The following chapter deals with the circadian rhythm of prey deliveries at the nest. I investigated prey in total combined for both nest and divided into prey groups for both nests combined. Further on the dataset is split up by location to see for differences.

The probability of a prey delivery was significantly higher than randomly expected from 11 hours to 20 hours combined for both nests, and significantly lower than randomly expected from 22 hours in the evening until 5 hours in the morning (fig 3.). The activity pattern had a steep rise from sunrise until around 08.00 hours. From 19.00 hours in the evening the probability of delivery decreased fast until sunset.

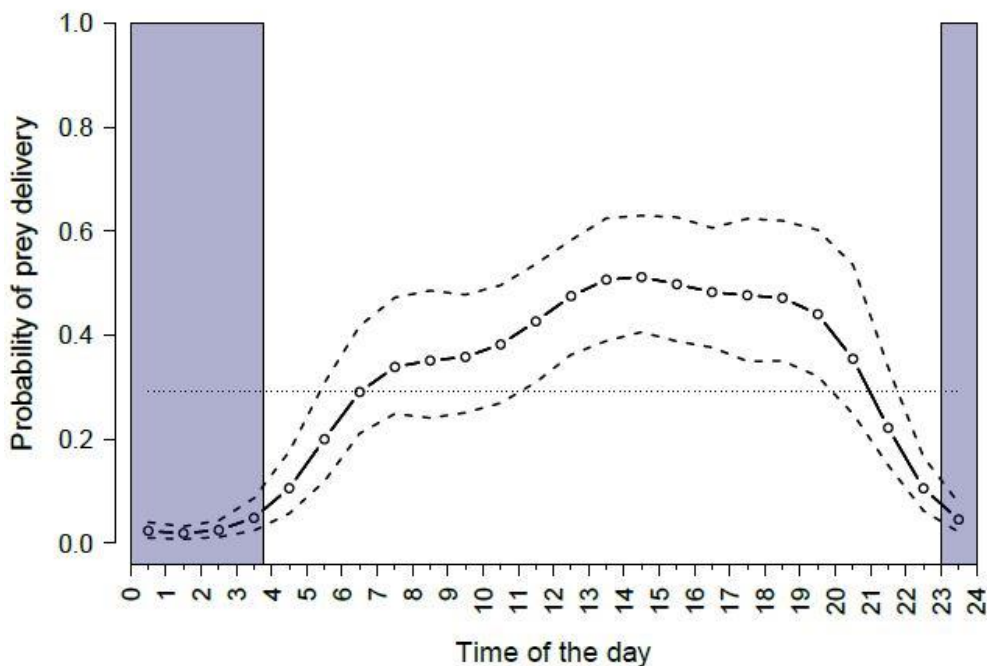


Figure 3. Probability of a prey being delivered at the nest during each hour block of the day, calculated for both nests combined. The blue toned area shows the time when the sun is under the horizon and is average for the two nests due to the east-west distance between them which would have given different sunrise and sunset times for the nests. The horizontal stippled line shows the average probability of a prey delivery during an hour block and is referred to as MESOR. The main line with the round dots is the best fitted model of the probability of a prey delivery during an hour block. The stippled lines refer to the upper and lower 95 % confidence interval. $n = 509$.

Mammals were delivered significantly more often than randomly expected from 13.00 to 19.30 hours, but the differences were marginal (fig. 4a). Mammals were delivered significantly less often than randomly expected from 22.00 hours in the evening to 5 hours in the morning (fig. 4a). Birds were delivered significantly more often than randomly expected from 11.00 to 16.00 hours, and significantly less often than randomly expected from 19.30 hours in the evening until 07.30 in the morning (fig. 4b). It should be mentioned that in fig. 4a showing circadian rhythm for mammals only, we are missing all of the unidentified in this graph ($n = 83$). It seems fair to assume that some of these would in fact be mammalian and therefore the graph could be underestimated.

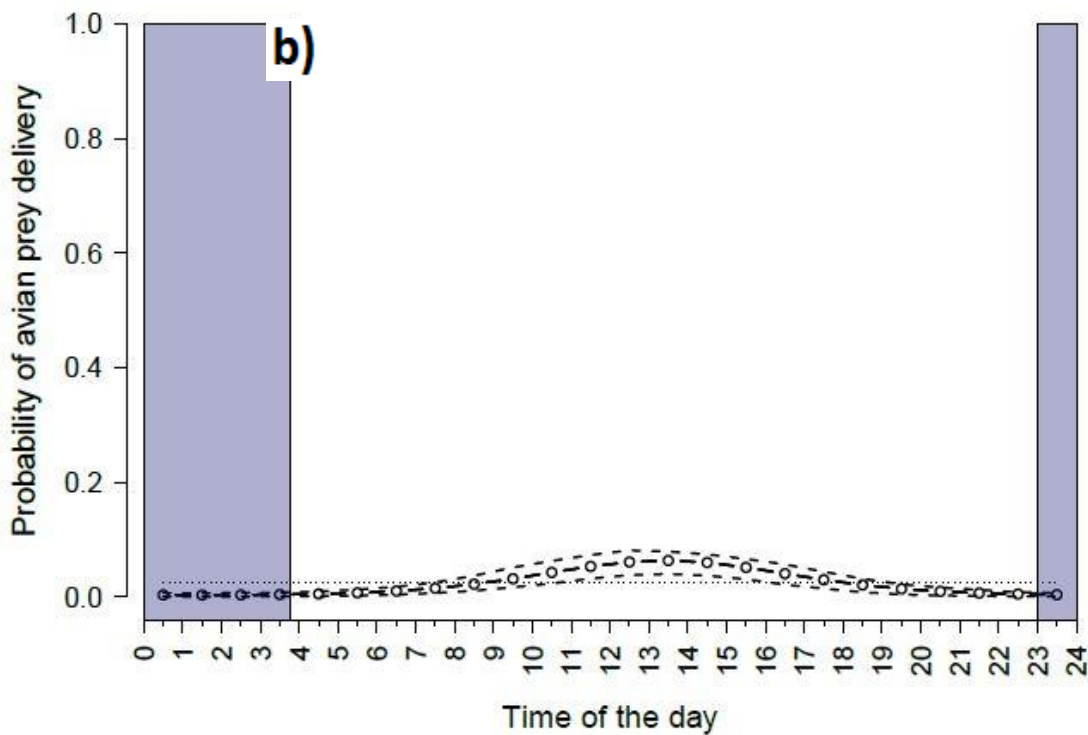
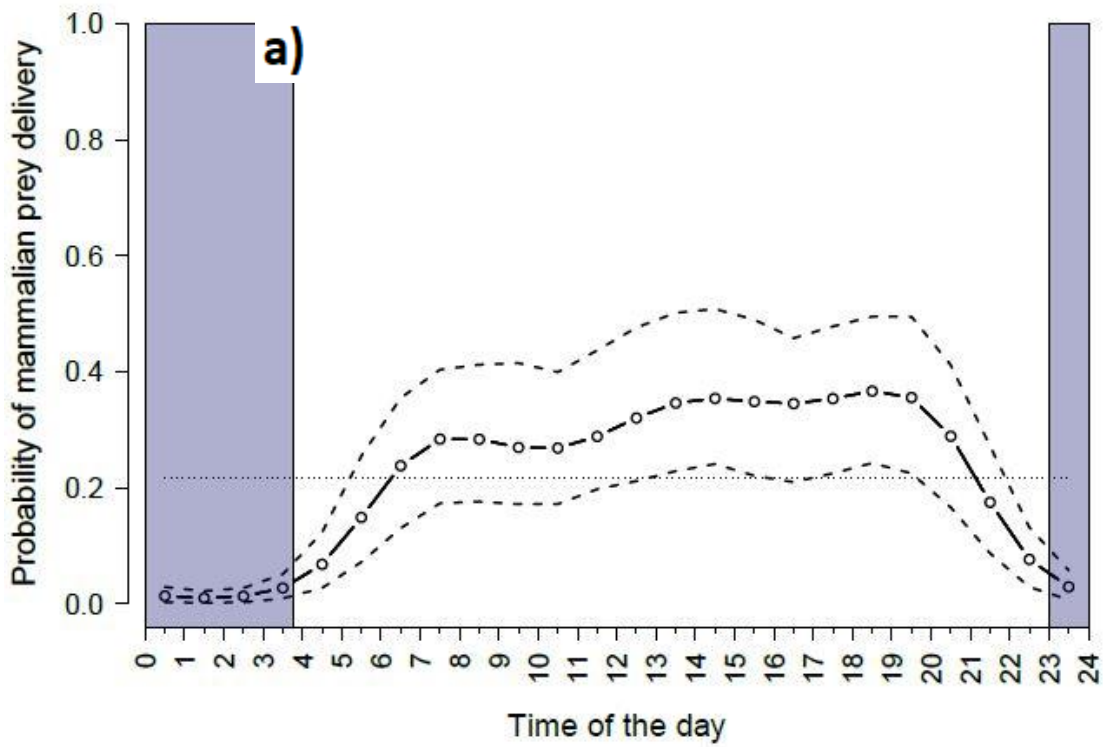


Figure 4. Probability of a) mammalian ($n = 361$) and b) avian ($n = 31$) prey being delivered at each hour block of the day. For explanation see fig. 1.

The probability of a prey delivery during each hour block of the day at the Surnadal nest was significantly higher than randomly expected between 12:30 midday and 15:00 in the afternoon (fig. 5) and significantly lower than randomly expected from 18.00 hours in the evening until 09.00 in the morning (fig. 5).

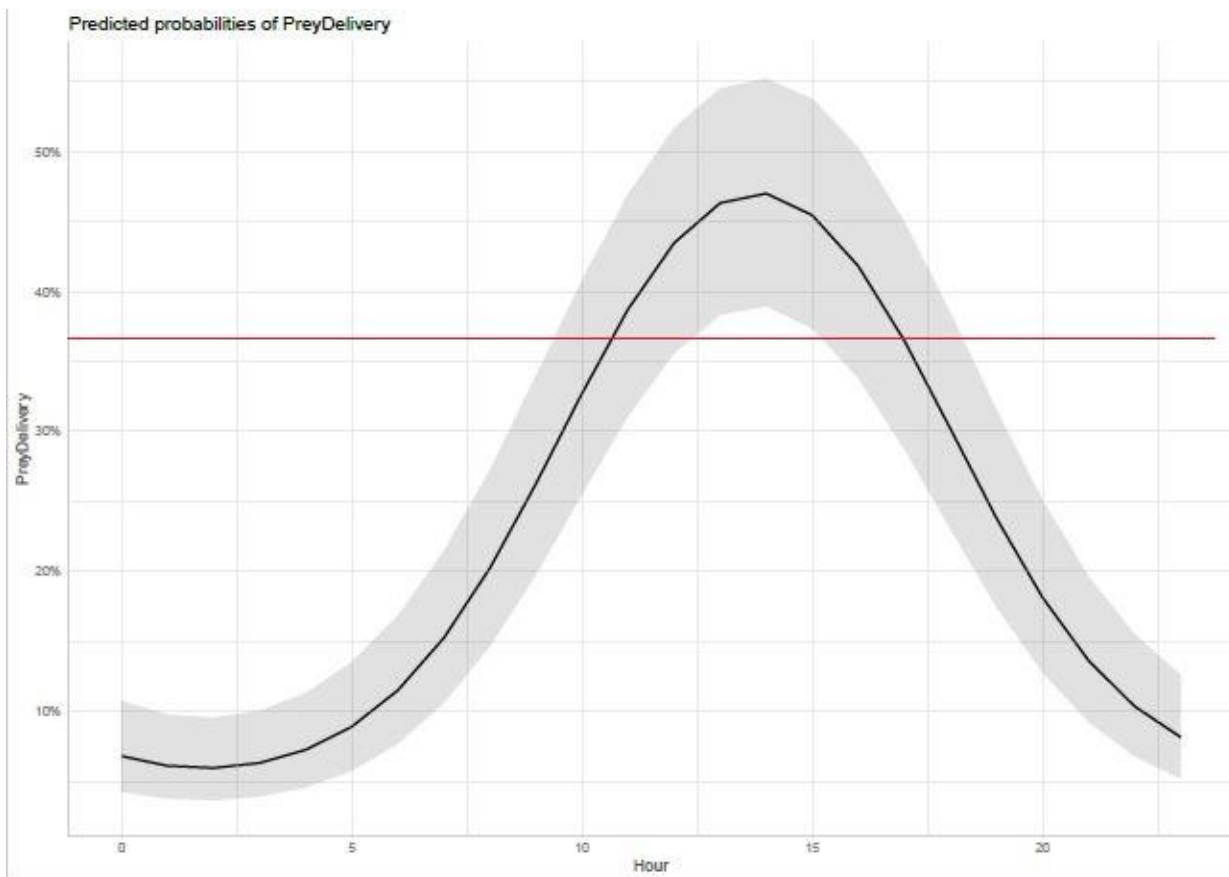


Figure 5. Predicted probability of a prey being delivered at the nest at Surnadal during each hour block of the day. The horizontal red line shows the predicted average probability of a prey delivery during each hour block of a day and is referred to as MESOR (37%). The main bold line is the best fitted model of a prey delivering during the day. The grey area refers to the upper and lower 95 % confidence interval. Average sunrise and sunset were from 04:00 to 23.00 hours at Surnadal in July 2017. $n = 159$.

The probability of a prey delivery during each hour block of the day at the nest at Goppollvatnet, was significantly higher than randomly expected between 07:00 hours to 19:30 hours with two delivery peaks between 08:00-09:00 hours and 16:00 -17:45 hours (fig.6). The probability of a prey delivery during each hour block of the day was significantly lower than randomly expected from 21.00 hours in the evening until 05.30 hours in the morning (fig. 6).

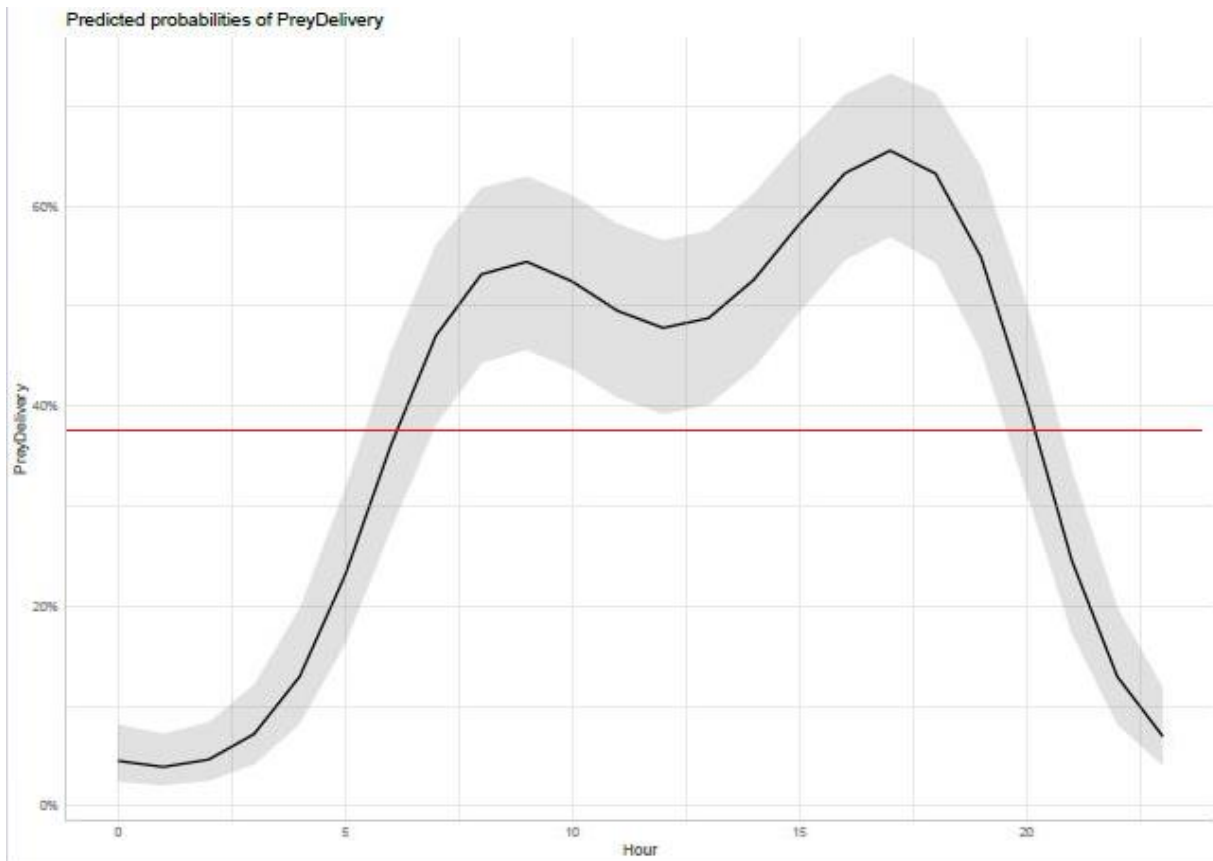


Figure 6. Predicted probability of a prey being delivered at the nest at Goppollvatnet during each hour block of the day. The horizontal red line shows the predicted average probability of a prey delivery during each hour block of a day and is referred to as MESOR (37%). The main bold line is the best fitted model of a prey delivering during the day. The grey area refers to the upper and lower 95 % confidence interval. Average sunrise and sunset were from 04:15 to 22.30 hours at Goppollvatnet in July 2017. $n = 350$

DELIVERING PARENT

When examining the parent delivering pattern combined for both locations it looked like there were no differences between the male and the female as to whom delivered the prey. This was the case from start of monitoring to the end. I decided to split the data to each nest separately and now it looked completely different. Because the 350 deliveries at Goppollvatnet against 159 at Surnadal twisted the graph combined. When divided into subsets the data showed to different trends.

Table 2. Coefficients and parameter estimates for the probability of female delivering a prey item at the nest. ($n = 442$)

Coefficients:	Estimate	SE	Z Value	P
Intercept	1.177	0.356	3.305	<0.001
Nestling_Age	-0.032	0.015	-2.077	0.037
ID_LocationSurnadal	-3.281	0.914	-3.588	<0.001
Nestling_Age:ID_LocationSurnadal	0.093	0.031	2.962	0.003

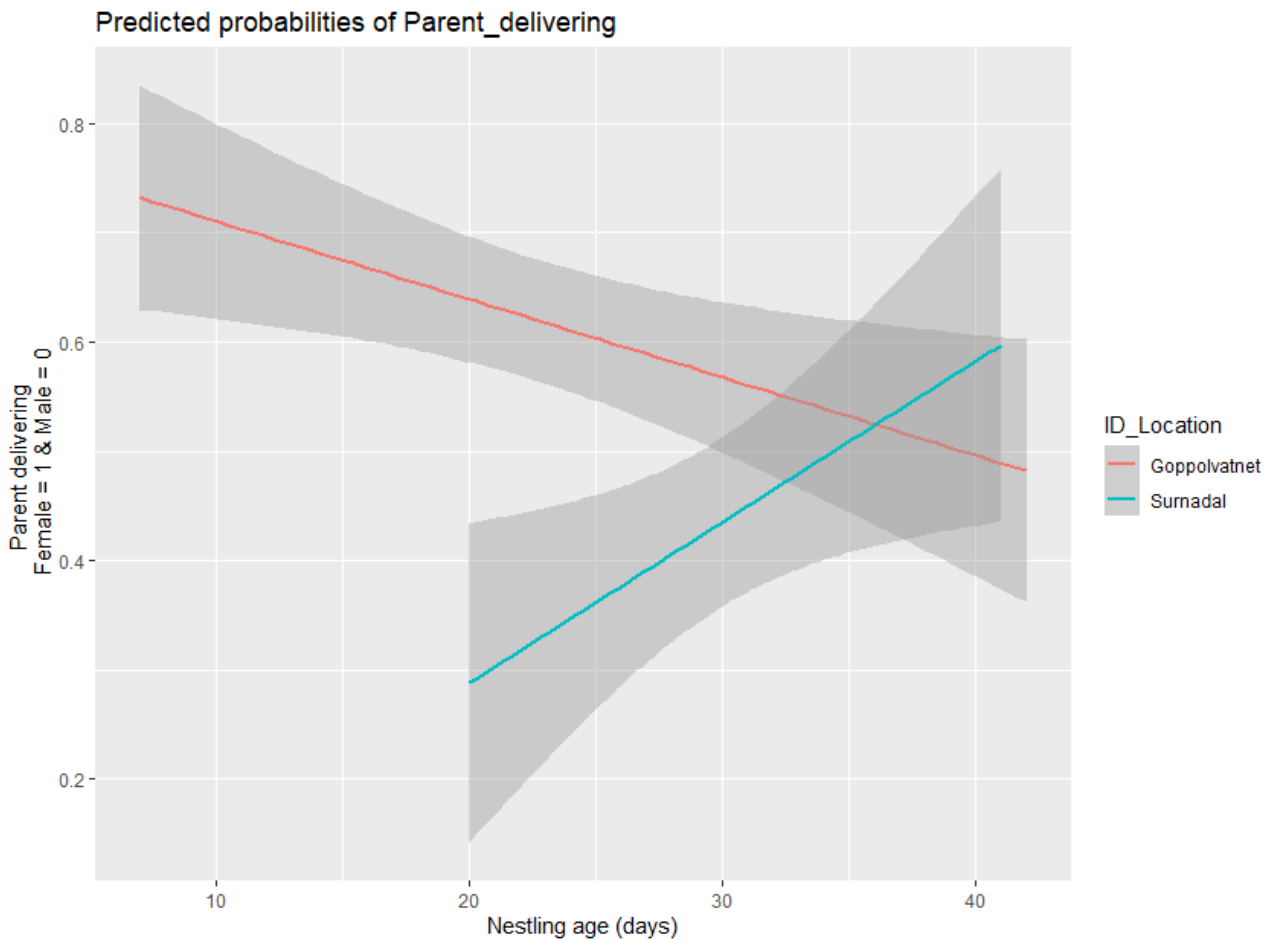


Figure 7: The graph shows the smoothed predictions within the monitoring period for each estimated nestling age, at the start of the monitoring till the end. $n = 442$.

There was a significant difference in the predicted probability of the female delivering as an effect of the nestling age between the two locations (table 2) as shown by the significant interaction between nestlings age and locality on the probability of the female delivering prey (table 2). At Surnadal the female delivered more seldom than the male when the nestlings were young and gradually the female delivered prey more frequently (fig. 7). The equal probability for either of them to deliver a prey occurred when the nestlings were about 34 days old. The trend at Goppollvatnet was opposite. Here the female delivered more when the nestlings were young, and the male gradually delivered more prey. The equal probability for either of them delivering a prey was estimated around the nestlings being 40 days old (fig. 7).

PREY HANDLING

At Surnadal (fig. 8a) at day one of monitoring, the probability of feeding unassisted was approx. 50 %. When the nestlings at Goppollvatnet (fig. 8b) were around 30 days old the probability of them feeding unassisted was approx. 50 %. At the nestling age of 30 days, the Surnadal nestling fed

unassisted more than 90 % of the cases. For Goppollvatnet at 30 days age the nestlings feed unassisted approx. 50 % of the cases. Both graphs (figs. 8a,b) shows that there is a significant effect of the nestling age regarding the probability of unassisted feeding (table 3). No significant difference was found between the locations ($z = -0.41$, $p = 0.69$) see appendix D for statistic details.

Table 3. Coefficients and parameter estimates for the probability of assisted feeding for a) Surnadal and b) Goppollvatnet.

Coefficients: a) Surnadal					Coefficients: b) Goppollvatnet				
	Estimate	SE	Z value	P		Estimate	SE	Z value	P
Intercept	5.379	1.883	2.857	0.004	Intercept	8.769	1.119	7.837	<0.001
Nestling Age	-0.279	0.077	-3.622	<0.001	Nestling Age	-0.245	0.033	-7.445	<0.001

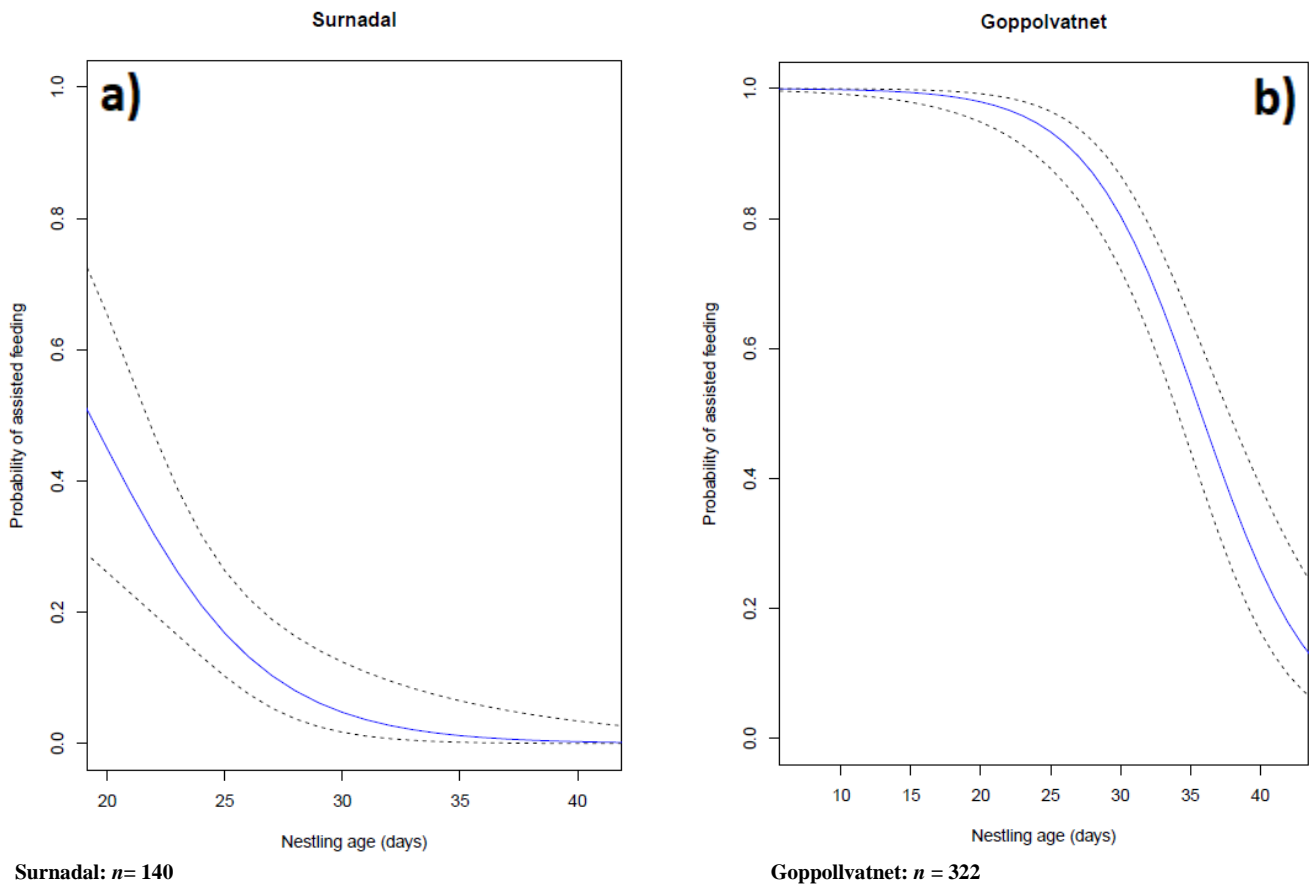


Figure 8. Probability of assisted feeding 1 = Female and 0 = Nestling, for a) Surnadal and b) Goppollvatnet

Because of the delayed unassisted feeding at Goppollvatnet I wanted to test if there was a greater probability that the nestlings would feed unassisted if the prey were a *Microtus* vole rather than a lemming. Lemmings seemed to be harder to rip apart than *Microtus* voles and due to the amount of lemmings delivered at Goppollvatnet (29.4 % of total prey mass delivered, table 1b) this was possible to investigate.

Table 4. Coefficients and parameter estimates for the probability of female feeding, rather than nestlings feeding unassisted, for lemming vs. *Microtus* voles and nestling age. Whole model test: $n = 228$, $df = 2$, $x^2 = 108.041$, $R^2 = 0.503$, $P = <0.0001$

	Estimate	SD	X²	P
Intercept	9.443	1.456	42.06	<0.001
Prey (Lemming)	0.994	0.280	12.56	<0.001
Nestling age	-0.254	0.041	37.80	<0.001

Both prey and nestling age had a significant effect on the probability of female feeding. Positive estimate (table 4) for prey (lemming) means that the probability of female feeding is larger for lemming than *Microtus* voles. The interaction between prey (lemming vs. microtus) and nestling age was not significant ($x^2 = 0.02$ and $p = 0.89$). Negative parameter estimates for nestlings age means that probability of female feeding declines with increasing nestling age when corrected for prey type (lemmings vs. *Microtus* voles). Of lemmings, 93% ($n = 100$) was fed by the female and 7 % eaten unassisted. For *Microtus* voles 73.4 % ($n = 128$) was fed by the female and 26.6 % was eaten unassisted. The prey mass was found to have no significant effect regarding the if the nestlings were able to feed unassisted ($z = -0.106$; $p = 0.915$; $n = 371$). See appendix E for statistic details.

Whether the prey was swallowed whole as a function of nestling age was not significant ($z = -0.768$; $p = 0.44$; $n = 401$). See appendix F for statistic details.

The probability of swallowing whole as a function of prey mass was significant for both nests combined (table 5). Elaborating on the swallowing whole as a function of prey type, I wanted to test if there was a larger probability of swallowing a shrew/birchmouse than of swallowing whole a vole (*Microtus* vole, bank vole and voles excluding lemming), termed shrew and vole respectively.

Table 5. Coefficients and parameters for the probability of swallowing prey whole as a function of the prey mass. ($n = 348$)

	Estimate	SD	Z value	P
Intercept	-0.353	0.933	-0.379	0.705
Prey mass net.	-0.051	0.013	-3.902	<0.001

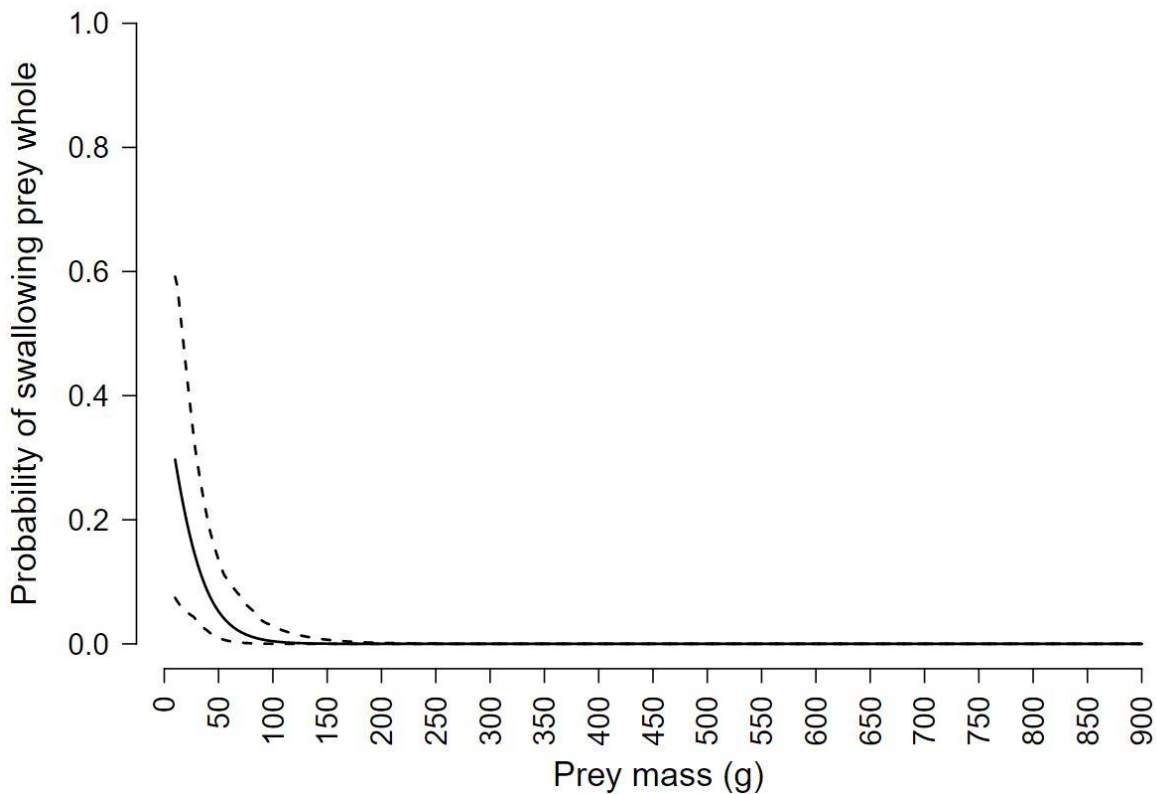


Figure 9. The probability of nestlings being able to swallow prey whole as a function of the body mass of prey delivered.

The interaction between shrew vs. vole and Nestling age was marginally significant, (table 6) meaning that the effect of nestling age on the probability of swallowing whole differed between shrew and vole. The interaction between nestling age and locality was significant, which means that the effect of nestling age on the probability of swallowing whole was dependent on locality.

Because locality was part of the interaction, a separate analysis was conducted for each location.

Table 6. Coefficients and parameter estimates for the probability of swallowing a prey whole as a function of prey type, nestlings age and locality. Whole model test: $n = 215$, $df = 5$, $X^2 = 64.89$, $R^2 = 0.41$, $P < 0.0001$. Shrew or vole = shrew and birchmouse vs. microtus, bankvole and vole excluding lemming. Locality has Goppollvatnet as vector.

Term	Estimate	SE	X ²	P
Intercept	-0.904	1.340	0.45	0.500
Shrew or vole	-2.363	0.538	19.32	<0.001
Nestling age	0.036	0.045	0.64	0.424
Locality	1.012	0.316	10.27	0.001
Shrew or vole * Nestling age	-0.084	0.046	3.25	0.072
Nestling age * Locality	-0.151	0.048	9.93	0.002

At Goppollvatnet the type of prey, (whether shrew or vole) had a significant effect on the probability of swallowing whole (table 7). At Goppollvatnet 25 % of shrews was swallowed whole while only 3 % of voles were swallowed whole.

Table 7. Coefficients and parameter estimate for the probability of swallowing whole depending on prey type and nestling age. Whole model test: $n = 135$, $df = 2$, $X^2 = 3.19$, $R^2 = 0.075$, $P = 0.20$

Term	Estimate	SE	X ²	P
Intercept	3.040	1.178	6.67	0.010
Shrew or Vole	-1.443	0.734	3.86	0.049
Nestling age	-0.039	0.048	0.66	0.42

At Surnadal there was a significant effect of both prey type and nestling age (table 8). Of shrews, 90 % were swallowed whole, compared to 17 % for voles.

Table 8. Coefficients and parameter estimate for the probability of swallowing whole depending on prey type and nestling age. Whole model test: $n = 80$, $df = 2$, $X^2 = 36.77$, $R^2 = 0.40$, $P < 0.0001$

Term	Estimate	SE	X ²	P
Intercept	-8.410	2.574	10.67	0.001
Shrew or vole	-3.050	0.741	16.94	<0.001
Nestling age	0.255	0.081	9.96	0.002

FROGS AND TOADS

At Goppollvatnet all frogs that were delivered were fed by the female to the two nestlings. This was not the case for the nest in Surnadal, where all but one was left for the single nestling to handle by itself. Here more than 20 % escaped from the nestling because often frogs and toads were not dead upon delivery and holding on to them failed in some cases. A one tailed test approach was used because of the probability of getting away was considered greater when there was only one nestling. The difference between the nests regarding eaten vs. escaped was marginally non-significant ($p=0.085$, Fischer exact test). The probability of being eaten unassisted or being fed by the female differed between the nests ($p=0.0001$, Fischer exact test).

Table 9. Handling of frogs and toads delivered at the nests

Location	Prey	Delivered	Eaten	Escaped	Unknown	Feeder	
						Female	Nestling
Goppollvatnet							
	Frog	14	14	0	0	14	0
Surnadal							
	Frog	16	13	3	0	1	12
	Toad	3	1	1	1	0	1
Total		33	28	4	1	15	13

Infanticide followed by cannibalism documented.

At the Goppollvatnet nest, brood size started out as three. One of the siblings did not manage to keep up with the other two fast-growing siblings. It was always last when it came to eating, and when the other siblings had eaten, the female tried to feed the smaller nestling. However, after some time it was obvious, that the smallest was not going to make it. After a long day of rain and few prey delivered the female changed tactic and committed infanticide (fig. 10) on the smallest nestling, followed by cannibalism, eating it alive and feeding it to the remaining two nestlings.



Figure 10. The infanticide killing of the smallest nestling. The female first ripped off a leg and then went straight to the soft parts and intestines while the nestling was still alive.

DISCUSSION

Diet composition found at the nest:

I expected a small rodent specialist diet, and for the large majority of the prey items delivered. This turned out to be true for both Goppollvatnet and Surnadal. Several studies (Dihle, 2015; Hellström et al. 2014; Pokrosky et al. 2014; Fufachev et al. 2019) found that small rodents also made up the majority of prey items delivered at the nest with. All except Dihle (2015), with lemmings as an important part of the diet, as found at Goppollvatnet. At Surnadal though, more than one third of the estimated prey mass delivered was birds and no lemming prey was recorded at all. Avian prey included black grouse, ptarmigan, juvenile hares and juvenile ducklings. Absence of Norwegian lemming was also recorded in the study conducted by Dihle (2015). This study was also with data samples from a peak rodent year in 2014 with only one lemming recorded out of 227 prey items delivered. Her data sample was collected approx. 15 km away from Goppollvatnet but at a different altitude at 640 m a.s.l. and close to a clear-cut area “associated with a high number of *Microtus voles*” (Dihle 2015) which could explain the difference in prey items recorded. The nest that Dihle (2015) monitored was also more than 3.5 km further away from the tundra than Goppollvatnet. The nest at Goppollvatnet at 1000 m a.s.l. might very well have been placed there because of its proximity to the tundra where lemmings are more present (Hellström et al. 2014). Due to lemmings colouration and patterns they might also be easier to see than a grey microtus would be. This could be the reason for the number of lemmings found at Goppollvatnet.

The majority of prey delivered at Surnadal was still small rodents, but deliveries of juvenile hare at Goppollvatnet and ducklings, ptarmigan and black grouse at Surnadal showed signs of the Rough-legged buzzard switch between the specialist and generalist approach. Pokrosky et al. (2014) mentions that in a low rodent year, it is more likely that the Rough-legged buzzards shift to alternatives in the search for prey, such as grouse, hares and juvenile ducklings. This question was also investigated by Pokrosky et al. (2015), who found continuous successful breeding in a tundra ecosystem even where small rodents were absent at Kolguev island in Russia. Here the main prey were goslings by 63 %, ptarmigan by 24 % and passerine bird, by 13 % (Pokrosky et al. 2015).

Small rodent populations have been estimated by using snap traps during 1981-2020, in Vang Almanning, Hamar municipality, approx. 65 km south-east from Goppollvatnet, at the same place and with the same method every year (G.A. Sonerud, pers. Comm. for details see Sonerud G. A. 1988). In this series, 2017 was a peak year in the small rodent cycle (Sonerud et al. 2021). A small rodent peak year in 2017 at Goppollvatnet does not necessary mean that it would also be a peak

year at Surnadal. There are no records of continuous capturing of small rodents in that area and the distance from the established snap trapping by G. A. Sonerud is around 280 km from Surnadal. The habitat type at Surnadal is also closer to the coast and the small rodent cycles can be different. So, to expect that the abundance of small rodents found at Surnadal would have been similar to what was found at Goppollvatnet could lead to a mistake.

Determining prey items delivered.

For Goppollvatnet it was easy to see if it was a lemming compared to other prey due to the distinct pattern and colors on the fur. This was the main reason for a higher number of prey items identified to species level at Goppollvatnet than at Surnadal. Norwegian lemming made up most prey identified to species at Goppollvatnet. Without lemmings it would have been around the same for the two nests with 26 at Goppollvatnet and 28 at Surnadal. In Surnadal, surveying of kestrel (*Falco tinnunculus*) has also been conducted in the same area (2016-2018, unpublished) and lemmings have not been recorded here either (G. Stenberg pers. comm). Dihle (2015) had a similar result as I found for Surnadal, when it comes to the number of lemmings recorded with only a single individual identified among 253 rodents in total, whereas six were identified at a species level (Dihle 2015). To determine this in other studies using regurgitated pellets, looking at the enamel pattern of the first lower molar is a common method (Fufachev et al. 2019).

Video monitoring makes determining the number of prey items delivered at the nest very accurate, because it eliminates over and underestimating prey items at the nest. This has been a troubling error in previous studies (Tornberg & Reif 2007; Pokrosky et al. 2014). Besides the actual number of prey delivered and the exact delivery time, video also make it possible to determine prey to species level. High level of species taxonomic recognition was due to the improved camera resolution that keeps getting better and the camera was placed close to the nest. One of the limitations with video monitoring was the distance from the camera to the actual nest. Placing the camera can be difficult on a cliff ledge, where mounting possibilities may be few without bolting the camera to the cliff and cause disturbance. The camera seemed to be lot closer in my study than in the study of Dihle (2015). This made it easier to determine prey items to a higher taxonomic level and could also explain the difference in number of identified prey items at the species level. As the nestlings grew older, they tended to grab the prey fast from the female upon delivery and turned away, shielding the prey. Unfortunately, this was also away from the camera sometimes, which made it difficult to identify prey.

So the taxonomic identification at a species level was improved for both nest in this study, which was a progression. If this was a coincident or because of lessons learned from the process resulting in better camera positioning, is difficult to say. This study showed as well as Dihle (2015) that the method for identification was improved from previous pellets and scat sorted at the lap and looking for bones, jaws, and teeth to identify prey items.

A large proportion of rodents in Surnadal was identified as mammals due to technical limitations (camera angle, delivery outside the view of the camera, and nestlings shielding the prey). Some rodents identified as *Microtus* voles might in fact have been grey-sided voles. This would support the findings by Hellström et al. (2014), who found grey-sided voles more common in diet of the Rough-legged buzzard when hunting in the birch forest than the tundra. Having the nest's location in mind, the nest in Surnadal was approximate at 510 m.a.s.l compared to Goppollvatnet with 1000 m.a.s.l. The Rough-legged buzzard in Surnadal may also have used the birch forest as its hunting grounds instead of the tundra. The fact that no Norwegian lemming at all was documented as a prey in Surnadal, supports this hypothesis. If the Rough-legged buzzards would have used the same biotope as hunting grounds maybe some lemmings would have been found in the diet. It is difficult to tell when small rodents has not been recorded in the area and maybe there were no lemmings in the area in 2017. It is a possibility that some prey categorized as "mammals" could in fact be lemmings, but none was recorded with certainty.

Circadian rhythm

Both nests showed that prey was delivered during daytime. This confirms that the Rough-Legged Buzzard is a diurnal predator. The steep curve in the morning at both nests would be expected after a night of rest and no eating resulting in hungry nestlings. The nests differed in the delivery patterns. At the nest in Surnadal there was one delivery peak during the day, while at the nest at Goppollvatnet there were two peaks. They both peaked in the afternoon when the sun was at its strongest which could explain the need for food that also contains great amount of fluids. It might also be explained by prey being most available at that time of the day. Dihle (2015) found that the Rough-legged buzzard female was likely to shield the nestlings from the sun during warm weather. This was not the case at Goppollvatnet which was the most sun-exposed nest of the two that were monitored. Videoclips from warm days revealed that the nestlings had a fast respiratory frequency in the afternoon when they were exposed to the warm sun (personal observation). In this way it would make sense that most prey were delivered when the need was greatest. At the same time prey might be easier to locate when the weather is fine, and they are not sheltering from the elements like

when it is raining, and food deliveries are scarce. Dihle (2015), Robinson et al. (2016) and Dawson and Bortolotti (2000) found that the probability of prey delivery was reduced by inclement weather and precipitation.

The different pattern between the nests regarding the circadian rhythm of prey delivery shows how important it is to monitor more than one nest when estimating effects of variables and that one should be careful about drawing conclusions based on one nest alone.

Parent delivering prey

There was a difference between the nests at Goppollvatnet and Surnadal regarding parent delivery. At Surnadal there was a pattern that is expected for the parental role of most raptors (Sonerud et al. 2013; Sonerud et al. 2014a), where the male delivers the most when the nestlings are young and while the female delivers more and more as the nestlings grow older. This pattern was also found by Dihle (2015) who did a study conducted in the same way and on the same species in the same region of Norway as I did. The trend was reversed for Goppollvatnet where the female delivered the most in the beginning and in the very end of the monitoring period the male delivered equally as much as around a nestlings age of 40 days. This shows how important it is to have multiple nests monitored with the same method to investigate and gain better knowledge on behavior of raptors during the nesting period.

By both video monitoring and physically watching a Eurasian kestrel *Falco tinnunculus* nests and the surroundings to study size-biased allocation of prey from male to offspring via female Sonerud et al. (2013) found that the male delivered his prey in close proximity to the nest and called for the female when prey were ready to be collected by her. This could explain why the female was registered more often at Goppollvatnet to begin with. Some prey items require more attention than others when preparing it for the nestlings and avian prey are often partly or completely plucked upon delivery (Sonerud et al. 2014). Most birds and larger prey had been prepared in some way before being delivered at the nest. This suggests that they were either prepared by the male in advance before he called the female or the female prepared it herself.

Another possible explanation for the female delivering most prey when they were small at Goppollvatnet could be that the brood size in the beginning of the monitoring was three, and that one of the nestlings was a lot smaller than the other two. By ensuring most deliveries of prey items, the female would always be in control of the feeding process. This would help ensuring that the smallest nestling had a better chance of surviving, as a part of a changed food provisioning strategy

due to food stealing and aggression between the siblings as in the parent offspring conflict (Szojka et al. 2020). This strategy could also help to ensure the fitness and wellbeing of the female parent as well. When the female is the delivering parent a minimum of food would end up in the nest, unattended and therefore minimizing sibling competition and food sealing which otherwise is very common (Szojka et al. 2020).

Prey handling

Unassisted feeding increased with nestling age at both nests. Sonerud et al. (2014a) found the same for eight raptor species. It is as expected that when the nestlings grow older, they should be more able to feed independently. Since no lemmings were recorded at Surnadal compared to 30 % of all prey items at Goppollvatnet being lemmings, and the nestling at Surnadal was so much sooner in being fed unassisted, I investigated if there was a connection. It seemed more difficult to process a lemming than a *Microtus* vole although they have similar weight and size. Note that the delivery of lemming vs *Microtus* voles was not independent of nestling age, which is important when comparing the probability of assisted feeding from the female. This might be due to phenology and season. The probability of female feeding was larger for lemming than for *Microtus* voles. It looked like the skin was harder to rip apart on the lemming than on the *Microtus* voles. So apart from sibling competition creating a greater need for female food allocation between the nestling, the fact that lemming was in the diet might also explain the lower probability of unassisted feeding at Goppollvatnet. Dihle (2015) found that the nestlings were assisted in feeding in most cases till they left the nest. The brood size in her study was larger (4 and later 3 nestlings) than in mine and maybe the female had to make sure that all of the nestlings were fed to avoid the “parent offspring conflict” to increase the nestlings survival rate and maintain her own fitness, instead of one or two being dominant over the others if left unattended. This is more consistent with my findings which suggests that the brood size explains the later unassisted feeding at Goppollvatnet.

I found that the need for assisted feeding did not increase with prey weight in contrast to what Dihle (2015) found for Rough-legged buzzard and Sonerud et al. (2014) found for other raptors. The Surnadal nestling fed for itself on most of the occasions from day one of monitoring, and the nestling at Goppollvatnet were likely assisted due to competition. If the nestling at Surnadal had been monitored from a younger age it might have looked different and maybe the nestling feeding unassisted had increased with decreasing prey size, as Dihle (2015) found.

Swallow whole:

At both nests, shrews were swallowed whole more often than *Microtus* voles. Numerically, a higher proportion of shrews were swallowed whole at Surnadal (90%) than at Goppollvatnet (25%). At Surnadal the probability of swallowing whole increased with the nestlings age. Food might have been shared more equally at Goppollvatnet, which was not necessary at Surnadal. Then again given the opportunity due to sibling competition and prey stealing among siblings one could assume that these prey types would be swallowed fast to “win” the competition. However, the female held on to them to avoid this. Given the opportunity to feed alone without competition the nestling swallowed prey whole rather than ripping it apart first at an earlier age and more often. I have not been able to find any other study on this matter to compare results with. The feeding constraint hypothesis (Slagsvold & Wiebe 2007) states that young nestlings are constrained from eating large prey and have a limit in prey size due to their gape size. When the nestlings get older, they become more able to swallow prey whole and the gape size limit expands as well (Steen et al. 2010). It seems that the gape size sat the limit for the capacity of swallowing whole for Surnadal in accordance with the feeding constraint hypothesis and not for the nests at Goppollvatnet. This might be because of the female’s allocation of prey between the nestlings at Goppollvatnet.

Frogs and toads

At Goppollvatnet all frogs delivered were fed assisted by the female and none escaped. At Surnadal for all frogs and toads delivered, the nestling fed unassisted and three frogs and one toad got away. To the best of my knowledge no other studies have been conducted on this specific theme. Some of these frogs were alive upon delivery and this seemed to surprise the nestling in Surnadal and some got away. As for Goppollvatnet, the probability of being fed was greater because there were two nestlings and feeding could help avoid sibling competition between the nestlings. Even though nothing can be concluded from this case review, it is worth mentioning and maybe elaborate and compare in future studies.

Infanticide and cannibalism

The female at Goppollvatnet only delivered two prey (one lemming and one frog) during the day between 07:19 to 19:14, when the killing of the smallest nestling took place. Even though infanticide was not part of my study questions, it was surprising to record this. An insight view at the activities in the nest, that most likely would have been difficult to reveal, if not for the camera monitoring. Siblicide is according to Pokrovsky et al. (2012), reported to be common in buzzard populations. But as far as I am aware there seems to be no recorded incident of infanticide

from the Rough-legged buzzards. It is recorded in populations of eagles (Markham & Watts 2007; Korňan & Macek 2011) and Franke, Galipeau, and Nikolaiczuk (2013) documented a peregrine falcon returning wet with little prey throughout the whole day and then killing one of the nestlings. This was a very similar scenario as with the infanticide recorded at the nest at Goppollvatnet.

Conclusion

My study has given an insight in the circadian rhythm at the two Rough-legged buzzard nests and a high level of taxonomic identification of prey species. This is most likely only possible using video monitoring as a modern and less time-consuming way of surveying. The monitoring revealed when the nestlings were able to feed for themselves and how the prey handling was done and evolving to the ability of swallowing some prey whole when they grew older. For Goppollvatnet I found that the probability of feeding unassisted was larger for *Microtus* voles than for Lemmings which I have not found in other studies. The importance of multiple studies on the same species, has been demonstrated in this study where both parent delivering, circadian rhythm, prey delivered differed between nests. The use of video monitoring also reveals unforeseen events like the infanticide and cannibalism that has been recorded and documented for the Rough-legged buzzard for the first time to my knowledge.

Setting the sensibility of the sensor that starts the recording is something that could be an improvement for future studies using the same method. The use of two cameras with sensibility turn down for recording might be a thing to elaborate on.

REFERENCES

- Artsdatabanken (2021): Norwegian Redlist for Species 2015, *Buteo lagopus*.
<https://artsdatabanken.no/Rodliste2015/rodliste2015/Norge/3870>
- Cramp, S. & Simmons, K E L. (eds.) (1979): The birds of Western Palearctic, Vol II. Oxford university press, Oxford.
- Dawson, R. D. and Bortolotti, G. R. (2000): Reproductive Success of American Kestrels: The role of Prey Abundance and Weather. *The Condor*, 102: 814-822.
<https://doi.org/10.1093/condor/102.4.814>
- Dihle I. (2015): *Prey selection and handling in two raptor during the breeding season as revealed by the use of video monitoring*. Master thesis, Norwegian University of Life Science, Ås.
- Franke A., Galipeau P., & Nikolaiczuk L. (2013): Brood reduction by infanticide in peregrine Falcons. *Arctic*. 66: 226-229.
<https://www.jstor.org/stable/pdf/23594688.pdf?refreqid=excelsior%3A0348cf8255757116246be9bf0d5d42c0>
- Fufachev I. A., Ehrich D., Sokolova A. N., Sokolov A. V. & Sokolov A. A. (2019): Flexibility in a changing arctic food web: Can Rough-legged buzzards cope with changing small rodent communities? *Glob Change Biol*, 25: 3669-3679
<https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.14790>
- Hellström P., Nyström J. & Angerbjörn A. (2014): Functional responses of the Rough-legged buzzard in a multi-prey system. *Oecologia* 174: 1241-1254
<https://link.springer.com/article/10.1007/s00442-013-2866-6>
- Ives, A. R., Cardinale, B. J. & Snyder, W. E. (2005): A synthesis of subdisciplines: predator–prey interactions, and biodiversity and ecosystem functioning. *Ecology Letters*, 8: 102-116.
<https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1461-0248.2004.00698.x>
- Koivula M. & Viitala J. (1999): Rough-Legged Buzzards use Vole Scent Marks to Assess Hunting Areas. *Journal of Avian Biology*, 30: 329-332.
<https://www.jstor.org/stable/pdf/3677362.pdf?refreqid=excelsior%3A45ba138d7edddbc79ecdd28a760e98e9>
- Korňan M. & Macek M. (2011): Parental Infanticide followed by Cannibalism in Golden Eagles (*Aquila chrysaetos*). *Journal of Raptor Research*, 45: 95-96. <https://doi.org/10.3356/JRR-09-77.1>
- Lima L. S., (1998): Nonlethal effects in the Ecology of Predator-Prey Interactions. *BioScience*, 48: 25-34.
<https://www.jstor.org/stable/pdf/1313225.pdf?refreqid=excelsior%3A136100102f85a78c349e34390d3495d7>
- Markham C. A. & Watts D. B. (2007): Documentation of Infanticide and Cannibalism in Bald Eagles. *Journal of Raptor Research*, 41: 41-44. [https://doi.org/10.3356/0892-1016\(2007\)41\[41:DOIACI\]2.0.CO;2](https://doi.org/10.3356/0892-1016(2007)41[41:DOIACI]2.0.CO;2)

- Pokrovsky, I., Ehrich, D., Ims, A. R., Kulikova, O., Lecomte, N., & Yoccoz, G. N. (2012): Assessing the causes of breeding failure among the Rough-legged buzzard (*Buteo lagopus*) during the nestling period. *Polar Research*, 31, 17294: 1-5. <https://doi.org/10.3402/polar.v31i0.17294>
- Pokrovsky, I., Ehrich, D., Ims, A. R., Kulikova, O., Lecomte, N., & Yoccoz, G. N. (2013): Diet, nestling density, and breeding success of Rough-legged buzzards (*Buteo lagopus*) on the Nenetsky Ridge, Arctic Russia. *Polar biology*, 37: 447-457 <https://link.springer.com/article/10.1007/s00300-013-1441-2>
- Pokrovsky, I., Ehrich, D., Ims, A. R., Kondratyev, A. V., Kruckenberg, H., Kulikova, O., Mihnevich, J., Pokrovskaya, L., & Shienok, A. (2015): Rough-Legged Buzzards, Arctic Foxes and Red Foxes in a Tundra Ecosystem without Rodents. *PLoS ONE*, 10: 1-17. doi:10.1371/journal.pone.0118740
- R Development Core Team (2021) R: A language and environment for statistical computing. R Foundation for statistical computing, Vienna, Austria. <http://www.r-project.org>
- Robinson, B. G., Franke, A. and Derocher, A. E. (2016): Weather-mediated decline in prey delivery rates causes food-limitation in a top avian predator. *Avian Biology*, 48: 748-758. <https://doi.org/10.1111/jav.01130>
- SAS (2019). JMP® version 15. SAS institute, Cary.
- Selås, V. (2001): *Predation on reptiles and birds by the common buzzard, Buteo buteo, in relation to changes in its main prey, voles*. *Canadian Journal of Zoology* Vol 79. pp. 2086-2093. <https://cdnsiencepub.com/doi/pdf/10.1139/z01-183>
- Selås, V., Framstad, E., Rolstad, J., Sonerud, G. A., Spidsø, K. T. and Wegge, P. (2021): *Bilberry seed production explains spatiotemporal synchronicity in bank vole population fluctuations in Norway*. *Ecological Research*. <https://doi.org/10.1111/1440-1703.12204>
- Slagsvold, Y. & Wiebe, K. L. (2007): Hatching asynchrony and early nestling mortality: The feeding constraint hypothesis. *Animal behaviour*, 73: 691-700. doi:10.1016/j.anbehav.2006.05.021
- Smallwood, J. A. (1988): The Relationship of Vegetative Cover To Daily Rhythms Of Prey Consumption By American Kestrels Wintering In Southcentral Florida. *Journal of raptor research*. 22: 77-80. <https://sora.unm.edu/sites/default/files/journals/jrr/v022n03/p00077-p00080.pdf>
- Sonerud, G. A. (1988): What causes Extended Lows in microtine Cycles? Analysis of fluctuations in Sympatric Shrew and Microtine Populations in Fennoscandia. *Oecologia*. 76: 37-42
- Sonerud, G. A. (1992): Functional Responses of Birds of Prey: Biases Due to the Load-Size Effect in Central Place Foragers. *Oikos*. 63: 223-232. <https://www.jstor.org/stable/3545382>
- Sonerud, G. A., Steen, R., Selås, V., Aanonsen, O. M., Aasen, G.-H., Fagerland, K. L., Fosså, A., Kristiansen, L., Løw, L. M., Rønning, M. E., Skouen, K. S., Asakskogen, E., Johansen, M. H., Johnsen, T. J., Karlsen, I. L., Røed, T. L., Skar, K., Sveen, B.-A., & Tveiten, R. (2014a): Evolution of

parental roles in provisioning birds: diet determines role asymmetry in raptors. *Behavioral Ecology* 25: 762-772. doi:10.1093/beheco/aru053

Sonerud, G. A., Solheim R., & Berg T. (2021): Age structure in a newly established and increasing population: initially high proportion of young birds among nesting Great Grey Owls. *Journal of Ornithology* 162: 109-118. <https://doi.org/10.1007/s10336-020-01809-1>

Sonerud G. A., Steen R., Løw M. L., Røed T. L., Skar K., Selås V & Slagsvold T. (2013): Size-biased allocation of prey from male to offspring via female: family conflicts, prey selection, and evolution of sexual size dimorphism in raptors. *Oecologia*. 172: 93-107. DOI 10.1007/s00442-012-2491-9

Sonerud G. A., Steen R., Løw M. L., Røed T. L., Skar K., Selås V & Slagsvold T. (2014): Evolution of parental roles in raptors: prey type determines role asymmetry in the Eurasian kestrel. *Animal Behaviour* 96: 31-38. <https://doi.org/10.1016/j.anbehav.2014.07.011>

Steen R. (2009): A portable Digital Video Surveillance System to Monitor Prey Deliveries At Raptor Nests. *Journal of Raptor Research*, 43: 69-74. <https://doi.org/10.3356/JRR-08-19.1>

Steen R. (2017): Diel activity, frequency and visit duration of pollinators in focal plants: in situ automatic camera monitoring and data processing. *Methods in Ecology and Evolution* 8: 203–213. <https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12654>

Steen R. (2020): Diel activity patterns of urban Woodchucks (*Marmota monax*) revealed by camera traps at burrows in southwestern Ontario, Canada. *Canadian Field-Naturalist*, 134: 353–360. <https://doi.org/10.22621/cfn.v134i4.2110>

Steen R. & Barmoen M. (2016): Diel activity of foraging Eurasian red squirrels (*Sciurus vulgaris*) in the winter revealed by camera traps. *Hystrix*, 28: 43-47. <http://www.italian-journal-of-mammalogy.it/Author-Ronny-Steen/66732>

Steen R., Løw L.M., Sonerud G. A., Selås V & Slagsvold T. (2010): The feeding constraint hypothesis: prey preparation as a function of nestling age and prey mass in the Eurasian kestrel. *Animal Behaviour*. 80: 147-153. <https://doi.org/10.1016/j.anbehav.2010.04.015>

Szojka, M. G., Bayne, E. M., Wellicome, T. I., Nordell, C. J. and Ng. W. Janet (2020): The role of sibling competition and parental provisioning on food distribution among ferruginous Hawk nestlings. *Journal of Raptor Research*, 54: 376-387. <https://doi.org/10.3356/0892-1016-54.4.376>

Tast J., Kaikusalo A. & Lagerström M. (2010): Breeding biology of Rough-legged Buzzards (*Buteo lagopus*) at Kilpisjärvi, NW Finnish Lapland, in relation to rodent cycles. *KILPISJÄRVI NOTES* 22, University of Helsinki
[https://helda.helsinki.fi/bitstream/handle/10138/244724/Kilpisj%C3%A4rvi_Notes%2022%20\(2010\).pdf?sequence=1](https://helda.helsinki.fi/bitstream/handle/10138/244724/Kilpisj%C3%A4rvi_Notes%2022%20(2010).pdf?sequence=1)

Tast J., Kaikusalo A. & Lagerström M. (2010): Diet composition of breeding Rough-legged Buzzards (*Buteo lagopus*) at Kilpisjärvi, NW Finnish Lapland. *KILPISJÄRVI NOTES* 22. University of Helsinki

[https://helda.helsinki.fi/bitstream/handle/10138/244724/Kilpisj%C3%A4rvi_Notes%202022%20\(2010\).pdf?sequence=1](https://helda.helsinki.fi/bitstream/handle/10138/244724/Kilpisj%C3%A4rvi_Notes%202022%20(2010).pdf?sequence=1)

Timeanddate.com (2021) *Tretten, Innlandet, Norway – Sunrise, Sunset and Daylength, July 2017* <https://www.timeanddate.com/sun/@3134016?month=7&year=2017>

Timeanddate.com (2021): *Surnadal, Møre og Romsdal fylke, Norway – Sunrise, Sunset, and Daylength, July 2017* <https://www.timeanddate.com/sun/@7626373?month=7&year=2017>

Tornberg R. & Reif V. (2007). *Assessing the diet of prey: a comparison of prey items found in the nests and images*. *Ornis Fennica*, 84: 21-31. https://www.researchgate.net/profile/Risto-Tornberg/publication/253330761_Assessing_the_diet_of_birds_of_pre_A_comparison_of_prey_items_found_in_nests_and_images/links/00b4951f89c404832e000000/Assessing-the-diet-of-birds-of-prey-A-comparison-of-prey-items-found-in-nests-and-images.pdf

APPENDIX

Appendix A:

Model specifications for both nests Combined

```
M0<-glmer(PreyDelivery~(1|ID),data=Prey_tot,family=binomial)

M1<-glmer(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+(1|ID),data=Prey_tot,family=binomial)

M2<-glmer(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
  I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+(1|ID),data=Prey_tot,family=binomial)

M3<-glmer(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
  I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
  I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+(1|ID),data=Prey_tot,family=binomial)

M4<-glmer(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
  I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
  I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
  I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+(1|ID),data=Prey_tot,family=binomial)

M5<-glmer(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
  I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
  I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
  I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
  I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+(1|ID),data=Prey_tot,family=binomial)

M6<-glmer(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
  I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
  I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
  I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
  I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+
  I(cos(6*2*pi*Hour/24))+I(sin(6*2*pi*Hour/24))+(1|ID),data=Prey_tot,family=binomial)

M7<-glmer(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
  I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
  I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
  I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
  I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+
  I(cos(6*2*pi*Hour/24))+I(sin(6*2*pi*Hour/24))+
  I(cos(7*2*pi*Hour/24))+I(sin(7*2*pi*Hour/24))+(1|ID),data=Prey_tot,family=binomial)

M8<-glmer(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
  I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
  I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
  I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
  I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+
  I(cos(6*2*pi*Hour/24))+I(sin(6*2*pi*Hour/24))+
  I(cos(7*2*pi*Hour/24))+I(sin(7*2*pi*Hour/24))+
  I(cos(8*2*pi*Hour/24))+I(sin(8*2*pi*Hour/24))+(1|ID),data=Prey_tot,family=binomial)
```

Summary of results for all prey at both nests combined.

Model selection based on AICc:

	K	AICc	Delta_AICc	AICcWt	Cum.Wt	LL
mod 4	8	1217.46	0.00	0.42	0.42	-600.67
mod 5	10	1218.86	1.41	0.21	0.62	-599.34
mod 7	14	1218.90	1.44	0.20	0.82	-595.27
mod 8	16	1221.05	3.59	0.07	0.89	-594.29
mod 6	12	1221.27	3.81	0.06	0.96	-598.50
mod 3	6	1222.64	5.18	0.03	0.99	-605.28
mod 9	18	1224.33	6.87	0.01	1.00	-593.87
mod 2	4	1251.25	33.79	0.00	1.00	-621.61
mod 1	2	1424.93	207.47	0.00	1.00	-710.46

> summary(M3), samme som mod4

Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']

Family: binomial (logit)

Formula: PreyDelivery ~ I(cos(2 * pi * Hour/24)) + I(sin(2 * pi * Hour/24)) +
 I(cos(2 * 2 * pi * Hour/24)) + I(sin(2 * 2 * pi * Hour/24)) +
 I(cos(3 * 2 * pi * Hour/24)) + I(sin(3 * 2 * pi * Hour/24)) + (1 | ID)

Data: Prey_tot

AIC	BIC	loglik	deviance	df.resid
1217.3	1257.9	-600.7	1201.3	1165

Scaled residuals:

Min	1Q	Median	3Q	Max
-1.2330	-0.7167	-0.2723	0.8593	5.5150

Random effects:

Groups	Name	Variance	Std.Dev.
ID	(Intercept)	0.1479	0.3846

Number of obs: 1173, groups: ID, 2

Fixed effects:

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-1.2053	0.2877	-4.189	2.80e-05 ***
I(cos(2 * pi * Hour/24))	-1.5471	0.1489	-10.389	< 2e-16 ***
I(sin(2 * pi * Hour/24))	-0.6002	0.1023	-5.865	4.48e-09 ***
I(cos(2 * 2 * pi * Hour/24))	-0.7025	0.1264	-5.556	2.75e-08 ***
I(sin(2 * 2 * pi * Hour/24))	-0.2858	0.1148	-2.489	0.0128 *
I(cos(3 * 2 * pi * Hour/24))	-0.2608	0.1107	-2.357	0.0184 *
I(sin(3 * 2 * pi * Hour/24))	-0.2108	0.1101	-1.916	0.0554 .

Summary of results for mammals combined for both nests:

Mammals

```
> aictab(cand.set = Cand.models, modnames = Modnames, sort = TRUE)
```

Model selection based on AICc:

	K	AICc	Delta_AICc	AICcWt	Cum.Wt	LL
mod 4	8	1128.78	0.00	0.46	0.46	-556.33
mod 5	10	1130.33	1.55	0.21	0.67	-555.07
mod 7	14	1131.75	2.97	0.10	0.78	-551.70
mod 6	12	1131.77	3.00	0.10	0.88	-553.76
mod 8	16	1132.30	3.52	0.08	0.96	-549.92
mod 3	6	1134.39	5.61	0.03	0.99	-561.16
mod 9	18	1136.19	7.41	0.01	1.00	-549.80
mod 2	4	1170.05	41.27	0.00	1.00	-581.01
mod 1	2	1278.03	149.25	0.00	1.00	-637.01

```
> summary(M3)
```

Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']

Family: binomial (logit)

Formula: PreyDelivery ~ I(cos(2 * pi * Hour/24)) + I(sin(2 * pi * Hour/24)) +
I(cos(2 * 2 * pi * Hour/24)) + I(sin(2 * 2 * pi * Hour/24)) +
I(cos(3 * 2 * pi * Hour/24)) + I(sin(3 * 2 * pi * Hour/24)) + (1 | ID)

Data: Prey_tot

AIC	BIC	loglik	deviance	df.resid
1128.7	1169.4	-556.3	1112.7	1191

Scaled residuals:

Min	1Q	Median	3Q	Max
-0.9583	-0.5889	-0.3403	-0.0801	7.2285

Random effects:

Groups	Name	Variance	Std.Dev.
ID	(Intercept)	0.2232	0.4724

Number of obs: 1199, groups: ID, 2

Fixed effects:

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	-1.6872	0.3526	-4.785	1.71e-06	***
I(cos(2 * pi * Hour/24))	-1.5030	0.1796	-8.369	< 2e-16	***
I(sin(2 * pi * Hour/24))	-0.5780	0.1133	-5.100	3.40e-07	***
I(cos(2 * 2 * pi * Hour/24))	-0.8322	0.1455	-5.721	1.06e-08	***
I(sin(2 * 2 * pi * Hour/24))	-0.4131	0.1305	-3.165	0.00155	**
I(cos(3 * 2 * pi * Hour/24))	-0.2639	0.1212	-2.178	0.02937	*
I(sin(3 * 2 * pi * Hour/24))	-0.2693	0.1210	-2.225	0.02611	*

Summary of results for birds combined for both nests:

Birds

```
> aictab(cand.set = Cand.models, modnames = Modnames, sort = TRUE)
```

Model selection based on AICc:

	K	AICc	Delta_AICc	AICcWt	Cum.Wt	LL
mod 3	6	250.62	0.00	0.44	0.44	-119.28
mod 2	4	250.73	0.11	0.41	0.85	-121.35
mod 4	8	254.32	3.70	0.07	0.92	-119.10
mod 6	12	255.05	4.43	0.05	0.96	-115.39
mod 5	10	257.23	6.61	0.02	0.98	-118.52
mod 8	16	257.77	7.15	0.01	0.99	-112.65
mod 7	14	258.84	8.22	0.01	1.00	-115.24
mod 1	2	269.18	18.55	0.00	1.00	-132.58
mod 9	18	1136.19	885.56	0.00	1.00	-549.80

```
> summary(M1)
```

Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']

Family: binomial (logit)

Formula: PreyDelivery ~ I(cos(2 * pi * Hour/24)) + I(sin(2 * pi * Hour/24)) + (1 | ID)

Data: Prey_tot

AIC	BIC	loglik	deviance	df.resid
250.7	271.0	-121.3	242.7	1183

Scaled residuals:

Min	1Q	Median	3Q	Max
-0.2603	-0.2059	-0.1198	-0.0705	14.1908

Random effects:

Groups	Name	Variance	Std.Dev.
--------	------	----------	----------

ID	(Intercept)	0	0
----	-------------	---	---

Number of obs: 1187, groups: ID, 2

Fixed effects:

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-4.2080	0.2941	-14.310	< 2e-16 ***
I(cos(2 * pi * Hour/24))	-1.4739	0.3787	-3.892	9.95e-05 ***
I(sin(2 * pi * Hour/24))	-0.3584	0.3066	-1.169	0.242

Appendix B:

Model specifications for Goppolvatnet

```
M0<-glm(PreyDelivery~1,data=Goppolvatnet,family=binomial)
M1<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24)),data=Goppolvatnet,family=binomial)
M2<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24)),data=Goppolvatnet,family=binomial)
M3<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24)),data=Goppolvatnet,family=binomial)
M4<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24)),data=Goppolvatnet,family=binomial)
M5<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
        I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24)),data=Goppolvatnet,family=binomial)
M6<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
        I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+
        I(cos(6*2*pi*Hour/24))+I(sin(6*2*pi*Hour/24)),data=Goppolvatnet,family=binomial)
M7<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
        I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+
        I(cos(6*2*pi*Hour/24))+I(sin(6*2*pi*Hour/24))+
        I(cos(7*2*pi*Hour/24))+I(sin(7*2*pi*Hour/24)),data=Goppolvatnet,family=binomial)
M8<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
        I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+
        I(cos(6*2*pi*Hour/24))+I(sin(6*2*pi*Hour/24))+
        I(cos(7*2*pi*Hour/24))+I(sin(7*2*pi*Hour/24))+
        I(cos(8*2*pi*Hour/24))+I(sin(8*2*pi*Hour/24)),data=Goppolvatnet,family=binomial)
```

Summary of results for Goppollvatnet for all prey

Model selection based on AICc:

	K	AICc	Delta_AICc	AICcWt	Cum.Wt	LL
mod 5	9	729.65	0.00	0.37	0.37	-355.68
mod 3	5	730.15	0.51	0.29	0.66	-360.03
mod 4	7	731.22	1.58	0.17	0.82	-358.53
mod 6	11	732.42	2.78	0.09	0.92	-355.01
mod 7	13	732.99	3.34	0.07	0.98	-353.21
mod 8	15	736.42	6.77	0.01	1.00	-352.84
mod 9	17	739.60	9.96	0.00	1.00	-352.33
mod 2	3	764.31	34.66	0.00	1.00	-379.14
mod 1	1	872.54	142.89	0.00	1.00	-435.27

> summary(M2)

Call:

```
glm(formula = PreyDelivery ~ I(cos(2 * pi * Hour/24)) + I(sin(2 *  
pi * Hour/24)) + I(cos(2 * 2 * pi * Hour/24)) + I(sin(2 *  
2 * pi * Hour/24)), family = binomial, data = Goppollvatnet)
```

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.460	-1.020	-0.381	1.095	2.306

Coefficients:

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	-0.7914	0.1053	-7.512	5.80e-14	***
I(cos(2 * pi * Hour/24))	-1.4790	0.1633	-9.056	< 2e-16	***
I(sin(2 * pi * Hour/24))	-0.5593	0.1258	-4.446	8.74e-06	***
I(cos(2 * 2 * pi * Hour/24))	-0.7747	0.1407	-5.505	3.69e-08	***
I(sin(2 * 2 * pi * Hour/24))	-0.3188	0.1339	-2.380	0.0173	*

Appendix C:

Model specifications Surnadal

```
M0<-glm(PreyDelivery~1,data=Surnadal,family=binomial)
M1<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24)),data=Surnadal,family=binomial)
M2<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24)),data=Surnadal,family=binomial)
M3<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24)),data=Surnadalt,family=binomial)
M4<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24)),data=Surnadal,family=binomial)
M5<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
        I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24)),data=Surnadal,family=binomial)
M6<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
        I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+
        I(cos(6*2*pi*Hour/24))+I(sin(6*2*pi*Hour/24)),data=Surnadal,family=binomial)
M7<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
        I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+
        I(cos(6*2*pi*Hour/24))+I(sin(6*2*pi*Hour/24))+
        I(cos(7*2*pi*Hour/24))+I(sin(7*2*pi*Hour/24)),data=Surnadal,family=binomial)
M8<-glm(PreyDelivery~I(cos(2*pi*Hour/24))+I(sin(2*pi*Hour/24))+
        I(cos(2*2*pi*Hour/24))+I(sin(2*2*pi*Hour/24))+
        I(cos(3*2*pi*Hour/24))+I(sin(3*2*pi*Hour/24))+
        I(cos(4*2*pi*Hour/24))+I(sin(4*2*pi*Hour/24))+
        I(cos(5*2*pi*Hour/24))+I(sin(5*2*pi*Hour/24))+
        I(cos(6*2*pi*Hour/24))+I(sin(6*2*pi*Hour/24))+
        I(cos(7*2*pi*Hour/24))+I(sin(7*2*pi*Hour/24))+
        I(cos(8*2*pi*Hour/24))+I(sin(8*2*pi*Hour/24)),data=Surnadal,family=binomial)
```

Summary of results for Surnadal for all prey:

Model selection based on AICc:

	K	AICc	Delta_AICc	AICcWt	Cum.Wt	LL
mod 2	3	483.20	0.00	0.46	0.46	-238.58
mod 5	9	484.92	1.72	0.19	0.65	-233.28
mod 3	5	485.52	2.32	0.14	0.79	-237.70
mod 6	11	486.06	2.86	0.11	0.90	-231.77
mod 7	13	486.97	3.77	0.07	0.97	-230.12
mod 8	15	489.02	5.82	0.02	1.00	-229.03
mod 9	17	492.26	9.06	0.00	1.00	-228.51
mod 1	1	544.98	61.78	0.00	1.00	-271.49
mod 4	7	731.22	248.03	0.00	1.00	-358.53

> summary(M1)

Call:

```
glm(formula = PreyDelivery ~ I(cos(2 * pi * Hour/24)) + I(sin(2 *  
  pi * Hour/24)), family = binomial, data = Surnadal)
```

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.1268	-0.7480	-0.4320	-0.3505	2.2907

Coefficients:

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	-1.4397	0.1266	-11.375	< 2e-16	***
I(cos(2 * pi * Hour/24))	-1.1769	0.1750	-6.724	1.77e-11	***
I(sin(2 * pi * Hour/24))	-0.6007	0.1650	-3.641	0.000272	***

Appendix D, E & F. Parameter estimate for the probability for assisted feeding vs. unassisted feeding. Screenshot of the output from Rstudio.

```
Call:
glm(formula = Feeder ~ Nestling_Age * ID_Location, family = binomial,
     data = Feeder_data)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.95588 -0.31270  0.06788  0.25939  2.35740

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)    8.76915    1.11897   7.837 4.62e-15 ***
Nestling_Age  -0.24518    0.03293  -7.445 9.72e-14 ***
ID_LocationSurnadal -3.38999    2.19055  -1.548  0.122
Nestling_Age:ID_LocationSurnadal -0.03391    0.08379  -0.405  0.686
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

E). Parameter estimate for the probability for assisted vs. unassisted feeding as a function of prey mass net. Screenshot of the output from Rstudio.

```
Random effects:
 Groups      Name      Variance Std.Dev.
ID_Location (Intercept) 3.996    1.999
Number of obs: 371, groups: ID_Location, 2

Fixed effects:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)  -0.3778797  1.4647444  -0.258  0.796
Prey_mass_Net -0.0007499  0.0070610  -0.106  0.915
```

F) Parameter estimate for the probability for swallowing whole as a function of nestling age for both nest combined. Screenshot of the output from Rstudio.

```
Random effects:
 Groups      Name      Variance Std.Dev.
ID_Location (Intercept) 1.909    1.382
Number of obs: 401, groups: ID_Location, 2

Fixed effects:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)  -1.98636    1.19270  -1.665  0.0958 .
Nestling_Age -0.01984    0.02583  -0.768  0.4426
```



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