Dietary preferences of Golden eagles (*Aquila chrysaetos*) in Sweden

– A camera trap approach

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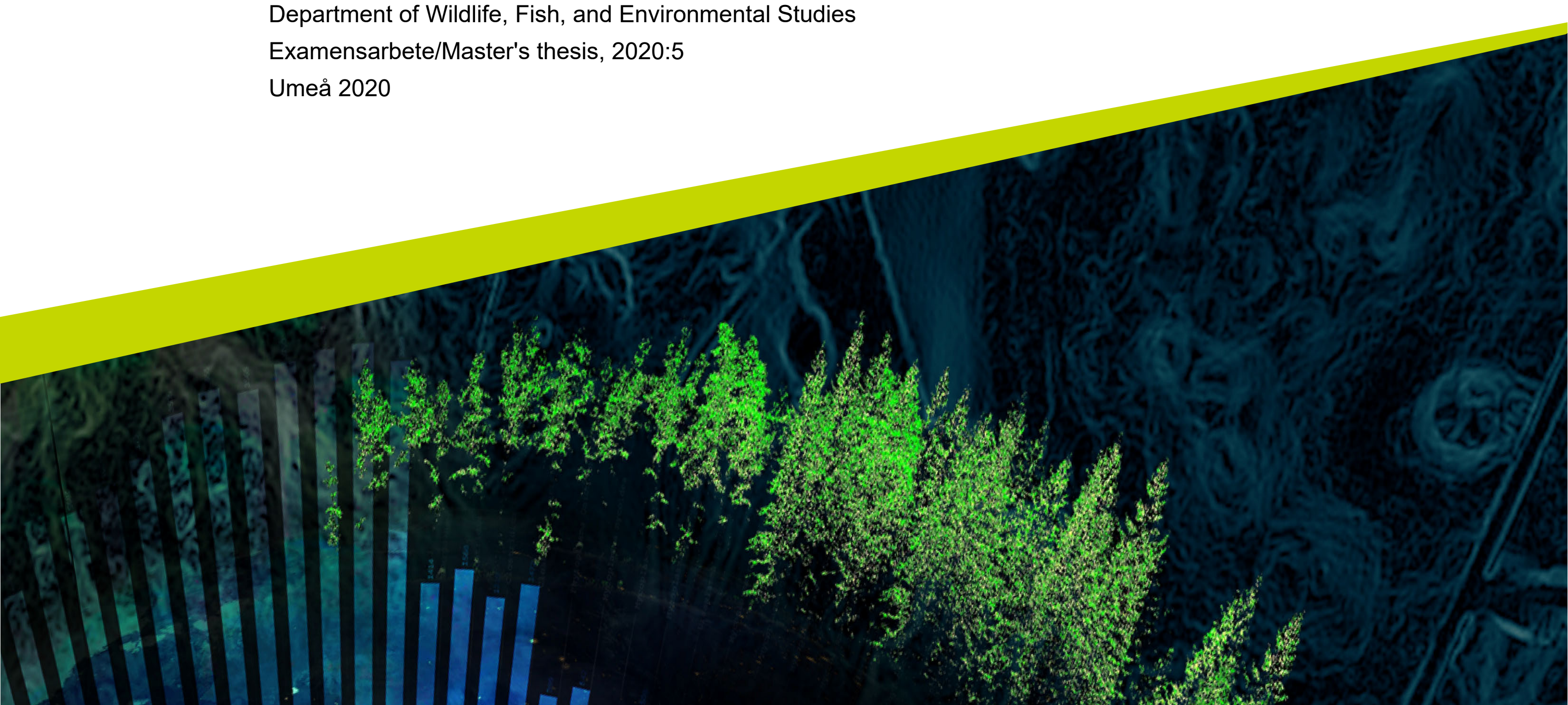
Master thesis – 30 credits
Swedish University of Agricultural Sciences, SLU
Department of Wildlife, Fish, and Environmental Studies
Examensarbete/Master's thesis, 2020:5
Umeå 2020



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Credits:	30 credits
Level:	Second cycle, A2E
Course title:	Master thesis in biology
Course code:	EX0971
Course coordinating dept:	Department of Wildlife, Fish, and Environmental Studies
Place of publication:	Umeå
Year of publication:	2020
Title of series:	Examensarbete/Master's thesis
Part number:	2020:5

Keywords: Aquilla chrysaetos, breeding, camera trap, Golden eagle, nestling, prey, Sweden

Swedish University of Agricultural Sciences
Faculty of forest sciences
Department of Wildlife, Fish, and Environmental Studies

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Abstract

Food availability and suitable habitat are necessary for reproductive success of raptors. Monitoring these variables may therefore provide important insights on fitness and population dynamics of species such as the golden eagle (*Aquila chrysaetos*), which are often very difficult to monitor. Even more difficult is to monitor their diets and its variation as well as factors affecting this variation, as it involves disturbing the nest and birds constantly. Tree mounted camera traps (CTs) with a view of the nest were tested with an aim to determine the spatio-temporal variation in diet composition of golden eagles. Ten CTs distributed in the northern parts of Sweden was part of the study. The most common species caught on the CTs were birds and hares, whilst the common crane and vipers were rare. A trend of increased time between deliveries as the breeding season progressed was noted and a decrease in time the prey items stayed in the nest. In general, the CT method involved minimum intrusion and disturbance and questions concerning prey composition and deliveries during the breeding and non-breeding period could be achieved in addition to the timing of fledging of chicks and their survivorship.

Keywords: Aquilla chrysaetos, breeding, camera trap, fledge, Golden eagle, nestling, prey, Sweden

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Abbreviations

CT	Camera trap
GE	Golden eagle
Md	Median value
Mn	Mean value

1. Introduction

1.1. Importance of food habits

Food habitats affect species survival, reproduction and population dynamics. Timing, abundance, and the variety of prey has been shown to influence several aspects of a species life history (Bedrosian *et al.,* 2017). When a rapid decrease in prey species occur, the predator's reproductive success may decrease in response (Ripple *et al.,* 2014). Even though predators can adapt to the changes in prey populations (Chiaradia *et al.,* 2010; Xavier *et al.,* 2013), it takes them time and puts them in an unfavourable situation where they are susceptible to further influences, such as lead poisoning (Ecke *et al.,* 2017).

Concerning raptor species, different raptors has shown to have varying abilities to switch to alternate prey species and widen their diets and intake in response to a decline in the main prey availability (Stenhof & Kochert, 1988).

The more prominent approaches of studying birds of prey diets has been collecting of regurgitated prey items, analysis of the digestive contents, examining the nest remains, direct observations, the delaying of fledge time by restriction of nestlings, and the use of camera and video technology. Where the most practiced way of identifying raptor prey species has been through collecting regurgitated prey and remains in and around the nest (Tornberg & Reif, 2007). Each of these methods come with their own strengths and limitations (*Table 1, RRF, 2007; Tornberg & Reif, 2007*).

Table 1: Summary of analysis on methods of studying raptor diets (RRF, 2007; Tornberg & Reif, 2007).

Regurgitated prey items	
+ Representative for ingested food + Easy to collect large samples + Low disturbance + Possible to estimate variations between seasons and years	- Best used for species which swallows prey whole - Hard to quantify food items which is ingested at multiple occasions - Should be collected as fresh as possible
Digestive contents	
+ Good use on road killed subjects	- Post-mortem analysis - Highly invasive if done on alive raptors - Small sample of data at each collection
Nest remains	
+ Good for measuring biomass	- High disturbance - Needs to be done regularly
Direct observation	
+ Best for measuring biomass + Includes food items which is not shown after digestion + Includes behaviour	- Time consuming - Slight disturbance
Restriction of nestlings	
+ Increases data collection per individual	- High disturbance - High risks on nestling survival - Behaviour manipulation
Digital equipment	
+ Remote control possible + Automatic sampling + Low disturbance + Frame by frame monitoring	- Equipment cost - Potential bias towards larger prey - Underestimation of small prey

1.2. Golden eagles and diets

Golden eagles (GEs) (*Aquila chrysaetos*) are distributed across the entire northern hemisphere as well as the mountains of central and south Asia. A GE population can be grouped into the following categories (*Figure 1,* Steenhof *et al.,* 2017):

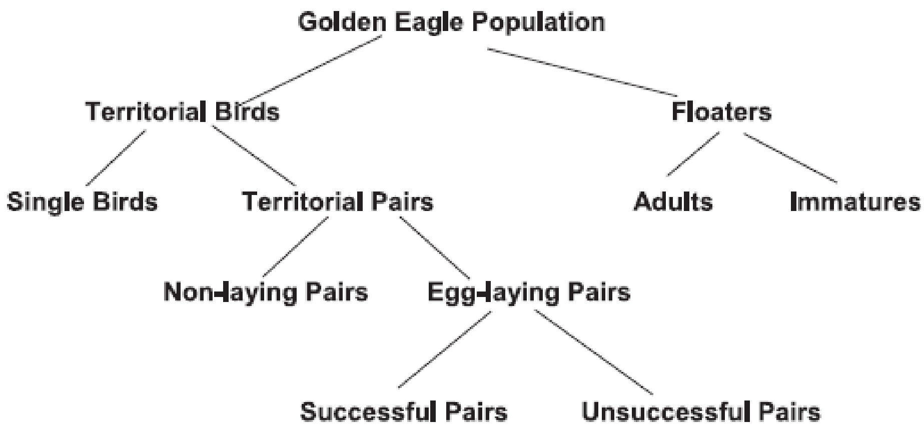

Figure 1: GE population categories (Steenhof et al., 2017)

Amongst which we have (Hunt *et al.,* 1998):

1) Juveniles: Under the age of one year
2) Subadults: Between the ages of one and three years
3) Floaters: Eagles which has not yet established a breeding territory
4) Breeders: Eagles that has established a breeding territory

Nests sites are chosen with a wide variety of placements, this regularly on cliffs and in trees (Menkens & Anderson, 1987). Positioned so that a good overview of the landscape is achieved (Bates & Moretti, 1994), close to areas where hunting is performed (Camenzind, 1969).

The GE hunts in open areas (Kochert *et al.,* 2002), by utilizing three main ways of hunting: Perched observation, low flight, and soaring (Edwards, 1969; Dunstan *et al.,* 1978; Palmer, 1988). Which strategy that is used depend on current weather, the landscape, and which prey that is hunted (Watson, 1997). For hunt on larger prey, two adult individuals sometimes cooperate in the procedure (Deblinger & Alldredge, 1996). Interspecies interactions around the nest occurs commonly with other birds (Collopy & Edwards, 1989), but the need of defending the nest uncommon since the nestlings are rarely under pressure of predation (Kochert *et al.,* 2002).

The GE diet across the globe consists of varied proportions of different sized mammals such as leporids and marmotini. Other birds and reptile species are also caught as well as the utilization of carrion (National geographic, 2020, American eagle foundation, 2020). The Ge hunts by ambush tactics, making sure a chase is avoided. The prey weight limit for the GE is around four to five kg (RSPB,2020). Though the GE occasionally prey on fish, which is only seen on rare occasions (National eagle center, 2018).

Whilst the GEs are adaptable through their capacity as a generalist predator, they also support their intake need by combining this with opportunistic catches. By comparing their regional distributions and movement it is possible to infer the different abundances and changes of the prey populations (Bedrosian *et al.,* 2017; Haworth *et al.*, 2006). The time of the year during which prey supply is most important for the breeders are between mid March until early May (Moss *et al.,* 2012). This because of the extra energy consumed due to production and incubation of eggs. The number of nestlings produced, and the number of territories occupied has shown to be in positive correlation with the main prey population size (Watson *et al.,* 1992; Moss *et al.,* 2012).

One further factor which affect not only choice of where to spawn (Morneau et al., 1994), but also the breeding success is temperature (Steenhof *et al.,* 1997; Mcintyre & Schmidt, 2012; Daouti *et al.,* 2017). The number of days with extremely high temperatures influences brood size and brood success negatively, while extreme cold during winter is negatively related to number of breeders that laid eggs as well as increased time for how long it takes for the eggs to hatch (Karen *et al.,* 1997). Which in turn also affects the prey populations, indirectly affecting the GEs.

The main cause of registered mortality around the world for GEs are human related. This including poisoning, death by vehicles and structures, and illegal hunting (Franson *et al.,* 1995).

1.3. Golden eagles and diets in Sweden

Within Sweden, the distribution of the GEs is biased towards the north, with sparse occurrence in the south. However, a substantial independent population resides on the island of Gotland, which is distinguished by their geographical isolation from the rest of the Scandinavian populations (Näsman, 2018). The eagles in the northern parts embark on migrations outside of the breeding season which can stretch from 1 to over 1600 km (Nilsson, 2014). This coincides well with when the reindeers start their migration.

The reindeer herders in Sweden suffer the predation from the GEs mostly during calving seasons. No rigid documentation on how many calves are taken by the GE exists (Hjernquist, 2011). In a study conducted in Finland (Nieminen *et al.,* 2013) it was approximated that amongst the calves killed, the GEs were responsible for 0-3,5%. The GEs are red listed in Sweden and is protected under EU bird directive (ec.europa, 2019). The population was estimated to be 166 successful breeding pairs as of 2018 (Naturvårdsverket, 2019).

GEs scavenge on remains after human conducted hunts, which contains residues from using lead ammunition (Garofke *et al.,* 2018). Lead poisoning can cause serious health issues in living organisms, affecting the animals fitness (MSD, 2020) In the provinces of the Canadian prairie, the increase of lead residues found in GEs coincided with the hunting period (Wayland & Bollinger, 1999), while in Sweden it was correlated to the moose hunting season (Ecke *et al.,* 2017). Behavioural symptoms registered was a decrease in the height of which the GEs flew, and a decrease in movement rate. Even though the lead exposure had not reached lethal concentrations, it had serious implications affecting the GEs mortality. Additionally, contributing to the mortality rate of the GE is traffic accidents. 2019 there were 33 registered traffic accidents in which GEs died (Viltolycka, 2020). Currently, measures are under development and implemented for decreasing the traffic related accidents with wildlife (trafikverket, 2020).

Previous studies have shown that the main prey species for the GEs in Sweden are Willow Ptarmigan (*Lagopus lagopus*), Capercaillie (*Tetra urogallus*), Black grouse (*Lyrurus tetrix*), Reindeer fawns (*Rangifer tarandus*) and mountain hare (*Lepus timidus*) (Tjernberg 1981), which depends on their local availability (Nyström *et al.,* 2006; Sulkava *et al.,* 1998). Which falls within the optimal prey size for the GE in contrast to energy consumption (Schweiger *et al.,* 2015). Earlier studies have shown that the diet composition of the population on Gotland consisted of about 30% birds and 70% mammals, compared to northern Sweden where birds covered 66% and mammals 34% of the diet (Högström & Wiss, 1992). GEs are capable of finding and exploiting a variety of prey species (Nyström *et* al, 2006) though studies suggest that the more diverse range of species that is hunted by the GE, the more of a negative impact it has on breeding success (Watson 1998).

1.4. Use of camera traps

CTs are a promising method for collecting remote observations. They can be placed around nests and programmed to take regular images of events occurring in the GEs life cycle. Relatively little is known about many aspects of GEs life history such as timing of hatching, events occurring during growth, and development of chicks, as well as survival rate of chicks. What species comprise the GE diets is also crucial in a continuously changing landscape where human modifications, climate change and species distributions are changing rapidly (Ripple *et al.,* 2014). In this study I tested the use of CTs to study:

- What species comprise the diets of the GEs?
- How do the prey deliveries vary over time?
- How does the time the prey item stay in the nest vary over time?

- I test a well-known hypothesis - Does the adult eagle induce fledging of chicks by reducing the time between batch deliveries?
- Using the method of collecting data through CTs: What are the pros and cons of the method, and what kind of data is viable to collect?

2. Methods

2.1. Equipment

In this study images from ten CTs in four Swedish counties were examined. Five CTs were placed in Västerbotten, two in Dalarna, two in Västernorrland, and one in Norrbotten (*Figure 2*). Among these ten CTs, six of them had accessible GPS coordinates. An eleventh CT was excluded from the study due to few days of image recordings. These ten CTs where amongst ca 40 available cameras, of which ca 30 had nesting occurrences distributed across the above four counties.

The image data collected through the CTs covered the month of June to August. The CTs were configured to take one photo each hour, with a flash range of 6 m, and a 12 Megapixel resolution, which was stored on a 32GB SD card. The CT model used were DÖRR´s Snapshot Mobil Black 5.1 (SMS) version 04.2017.

The CTs were put in place at different times for different locations during 2018. This was usually done in combination with ringing of the nestlings or before the arrival of harsh winter weather. Also depending on when voluntary workers aided with their workforce.

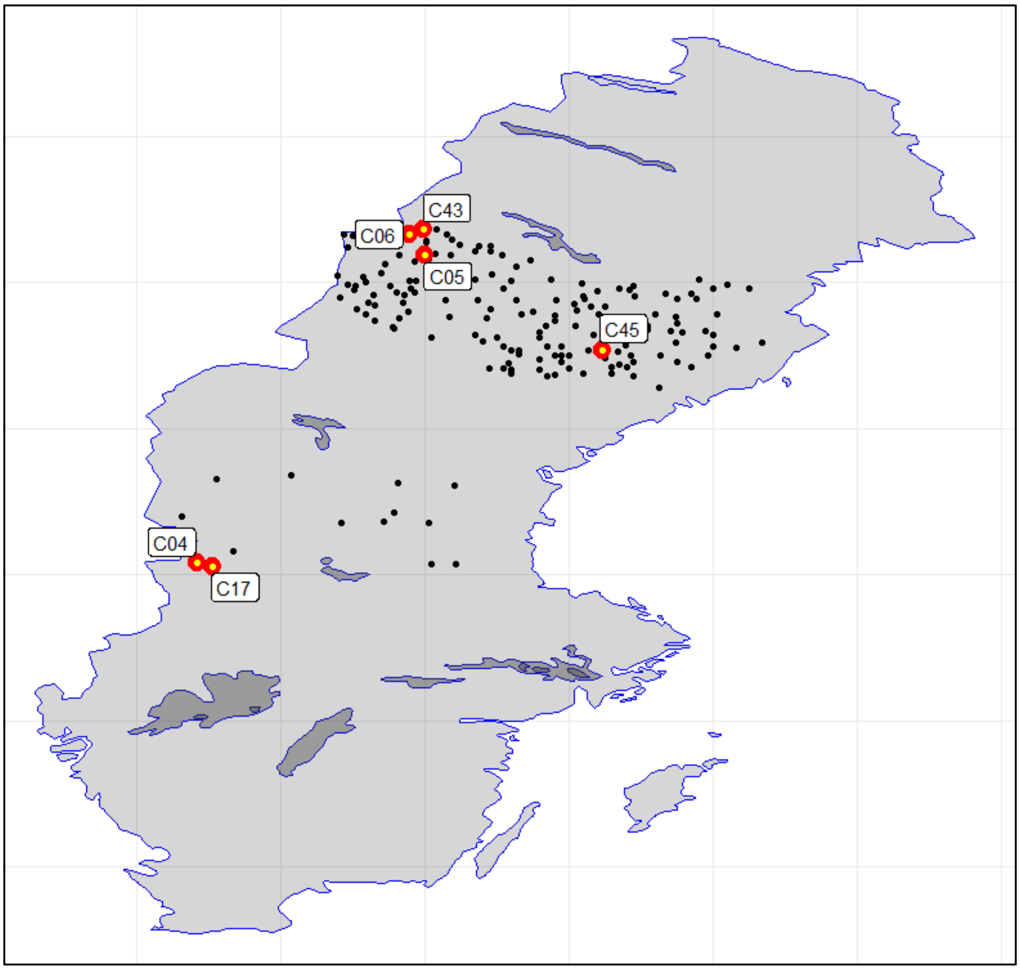

Figure 2: CT sites in Sweden. Red areas with yellow dots mark six sites used in study.

CTs included were chosen by image quality where the angle of the CT on the nest and the distance of the CT to the nest was the main factors determining if the images could be used or not. Criteria's for choosing cameras was that the concave inside of the nest should be mostly visible, a CT distance so that batch arrivals and species could be identified, and that almost none of the nest was out of frame.

2.2. Recording information from images

The images were reviewed in Microsoft´s image editing program Photos. Prey items were visually classified based on their characteristics. The data collected from the images was noted in a Microsoft excel sheet as a CNS encoded document. This CNS document was later exported to a R project for statistical computing in R studio. The variables that were recorded from the images (*Appendix 1 & 2*) and collected in an excel document was:

- Camera nr
- County ID
- Prey batch nr
- Species delivered per prey batch
- Image nr per delivery of prey species
- Image nr per removal of prey species
- Date and time per delivery of prey species
- Date and time per removal of prey species
- Temperature °C per delivery of prey species
- Temperature °C per removal of prey species

The first image noted down as batch nr one, was when the first visible delivery could be acknowledged. Already present content from prey items before the first image was ignored and not noted down in the data collection.

Sometimes hints could be interpreted from nestling behaviour, such as increased attention or time spent at a particular spot, often covering the visibility of the prey items in the image. For collection of data, visual acknowledgement of the prey item was a requirement. Locating the prey items was often done by keeping an eye out for red meat parts, since these have distinct contrast to the rest of the present debris and remains in the nest. The red colour rarely occurs otherwise there is meat from a prey or reddish leaves. If two prey items arrive on the same image, they are noted down as separate prey batches.

Determining when a prey item has been removed was done as so that the carcass or bone pile where no longer visible for a series of five images where it should have been seen, from the image of suspected removal. Not counting night images if the prey item was not visible. Locating the last image on which you are as certain as possible that the prey remains are not hidden, moved or blocked by nestling or other debris. If a prey item was still present at the end of the available image series, or after the nestling had left the nest, it was removed from the data set. This was determined true if the nestling´s were not seen for a series of 50 images, approximately two days.

2.3. The special case of hares

To determine when the hares (*Lepus europaeus* & *timidus*) are recorded as removed, the paws are taken out of the equation. A hare is determined to have been removed when the main carcass is no longer present as described previously, and no visible meaty parts are left on the parts connected to the separated paws. This means that the hare can be determined to have been removed even though the paws are still present. This distinction was not made for birds. The reason for this is that to be able to distinguish when no relevant meat tissue is connected to the bones, much higher resolution would be needed with multiple camera angles to exclude hindrances in the image in front of the carcass. For this reason, a bird is determined to have been removed when no visible signs of the carcass or bone pile is present. Bone Piles are not excluded since repeatability for determining when a bone is absent enough from feathers or tissue would create difficulties.

2.4. Identification of species

Identification of species was done by image comparisons of species from various web pages and books. Looking at key features such as:

- Paw size, shape and colour
- Carcass anatomy, size, bone structure and muscle disposition
- Coat texture and colour with seasonal changes for different species
- Presence of feathers and/or talons
- Anatomy of talons

If a characteristic prey, such as a red fox (*Vulpes Vulpes*) or marten (*Martes martes*) , is brought to the nest and later is determined as dispatched of, but the same prey species is seen within a near time frame. The characteristics of the carcass should be compared between the two prey items on the images to ensure that it is not the same individual. This adjustment was not done for bird species because of the high frequency of batches consisting of birds, and the difficulty of distinguishing between individuals.

Uncommon prey was defined down to species or genus, such as red fox or marten, whilst most birds were noted down to family with exception to common crane (*Grus grus*), raptors, and grouse. These were grouped into collected pots (*Table 2*)

Table 2: Specification of data labels and how these date labels were grouped

Group	Data label	Specification
No ID's	No ID	Unidentified prey species
Birds	Bird	Unidentified bird species
	Common crane	Common crane
	Raptor	Unidentified raptor
	Grouse	Unidentified grouse species
Mammals	Mammal	Unidentified mammal
	Red fox	Red fox
	Marten	Unidentified marten species
Hares	Hare	Unidentified hare species
Vipers	Viper	Common European viper

3. Results

3.1. Species deliveries

Covering all the sampled cameras (*Appendix 1*) the batch deliveries consisting of birds was the most dominant (*Figure 3*) with a combined percentage of 51%. Amongst the grouped birds the grouse with 18% and the unidentified birds with 31% of that group was most prominent. The category of “No ID’s” was distinguishable with a total presence of 36%, and the hares & mammals covering a total of 12% . One observation of a common European viper (*Vipera berus*) was recorded. Some difference can be seen when comparing between nests with one or two nestlings (*Figure 4*).

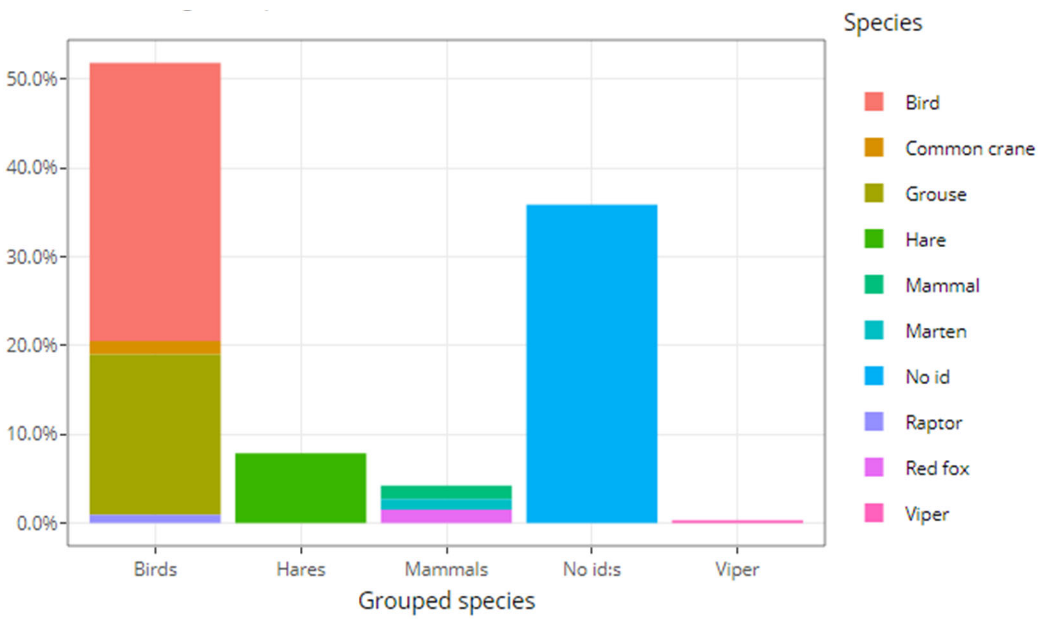

Figure 3: Categorical percentage by grouped species, sub divided by ungrouped species by colour.

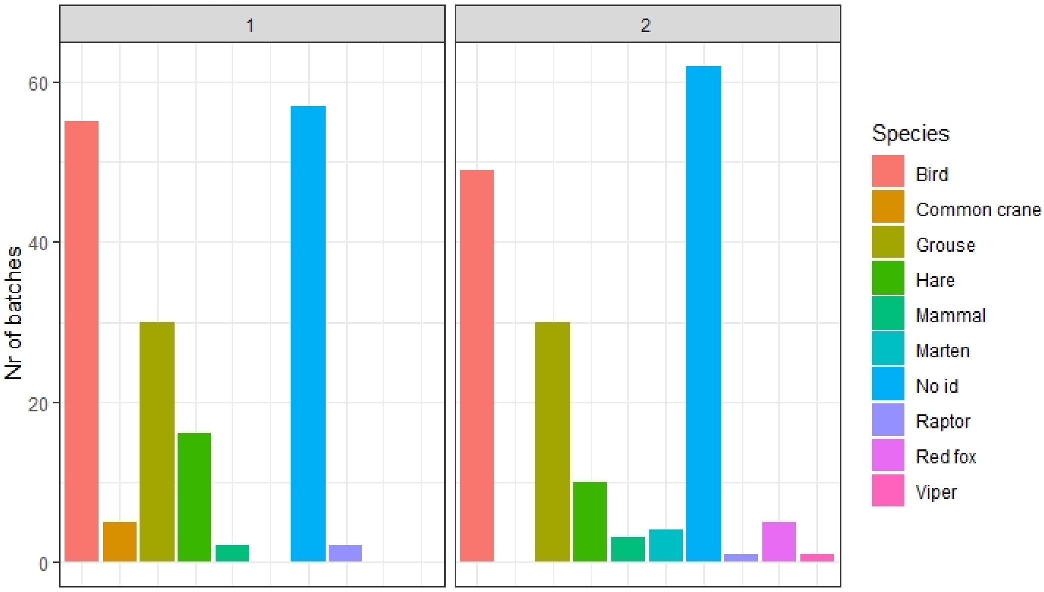

Figure 4: Nr of batches per species per nest with one or two nestlings, sub divided by species by colour.

"Birds" were the most common diet item, which was found in 10/10 nest, "No ID's" representing a group of unidentifiable items were observed in 9/10 nests, and "Grouse" were observed in 8/10 nests (*Figure 5*). Some uncommon species were "Vipers" which were recorded in 1/10 nests, "The Common crane" & "Marten" which were seen in 2/10 nests, and "Red fox" & "Raptors" which was present in 3/10 nests. This distribution (*Appendix* 2) is highlighted in more depth whilst looking at the relative presence of species per camera, ungrouped (*Figure 6*) and

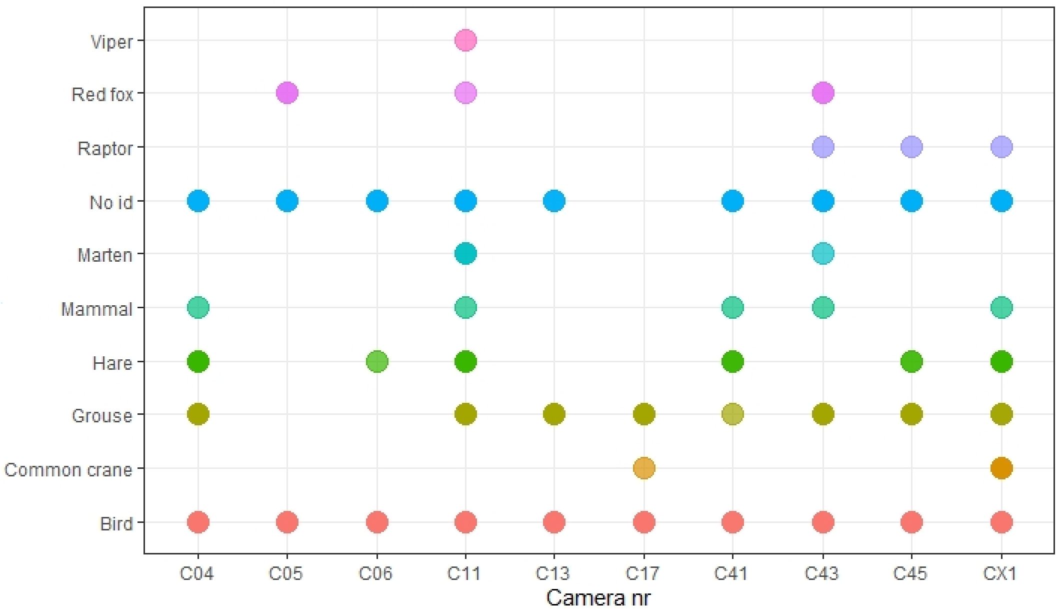

Figure 5: Presence of species per camera.

grouped (*Figure 7*). Showing the quantity of the different species delivered to the different nests.

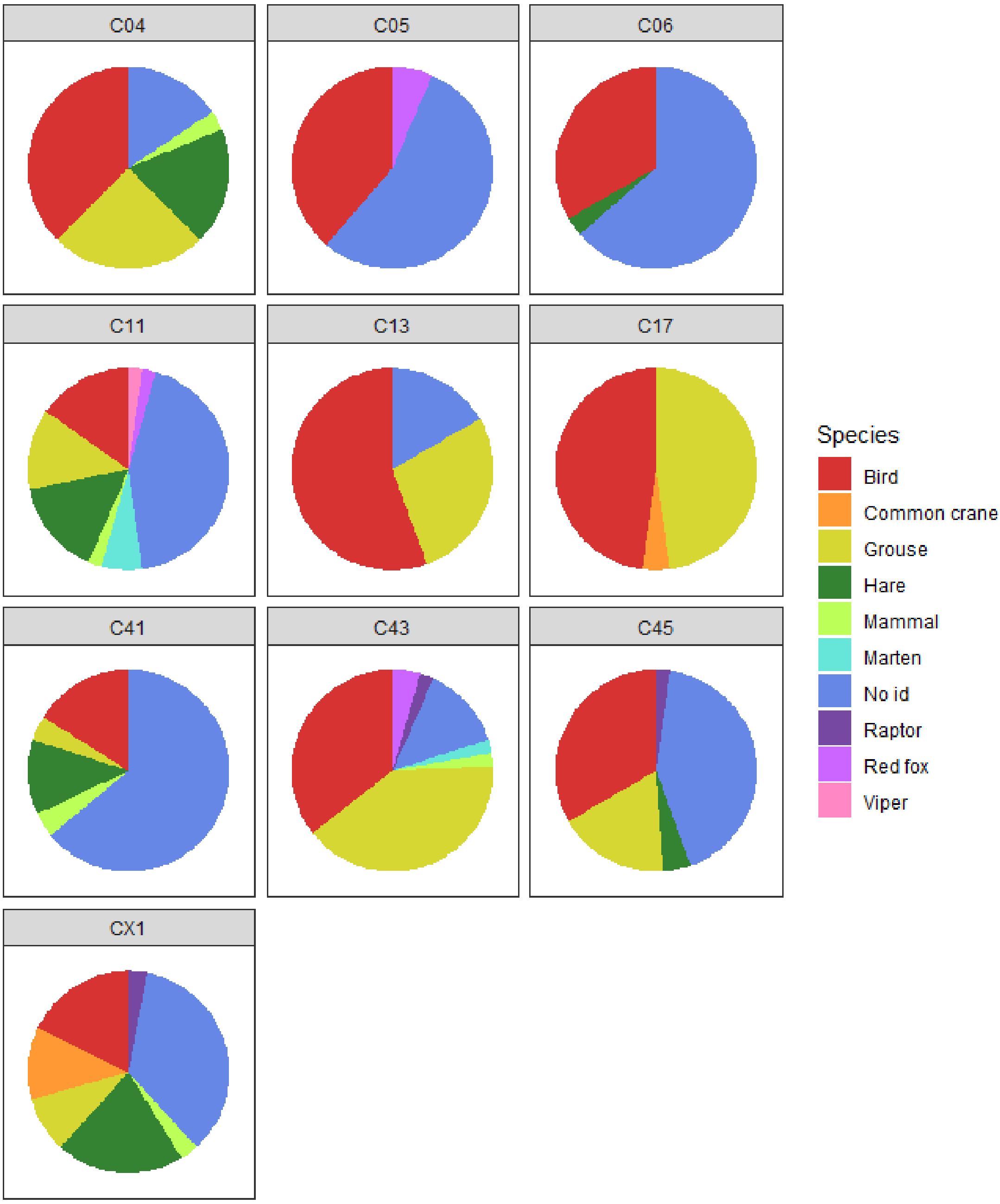

Figure 6: Percentage of delivered prey per camera.

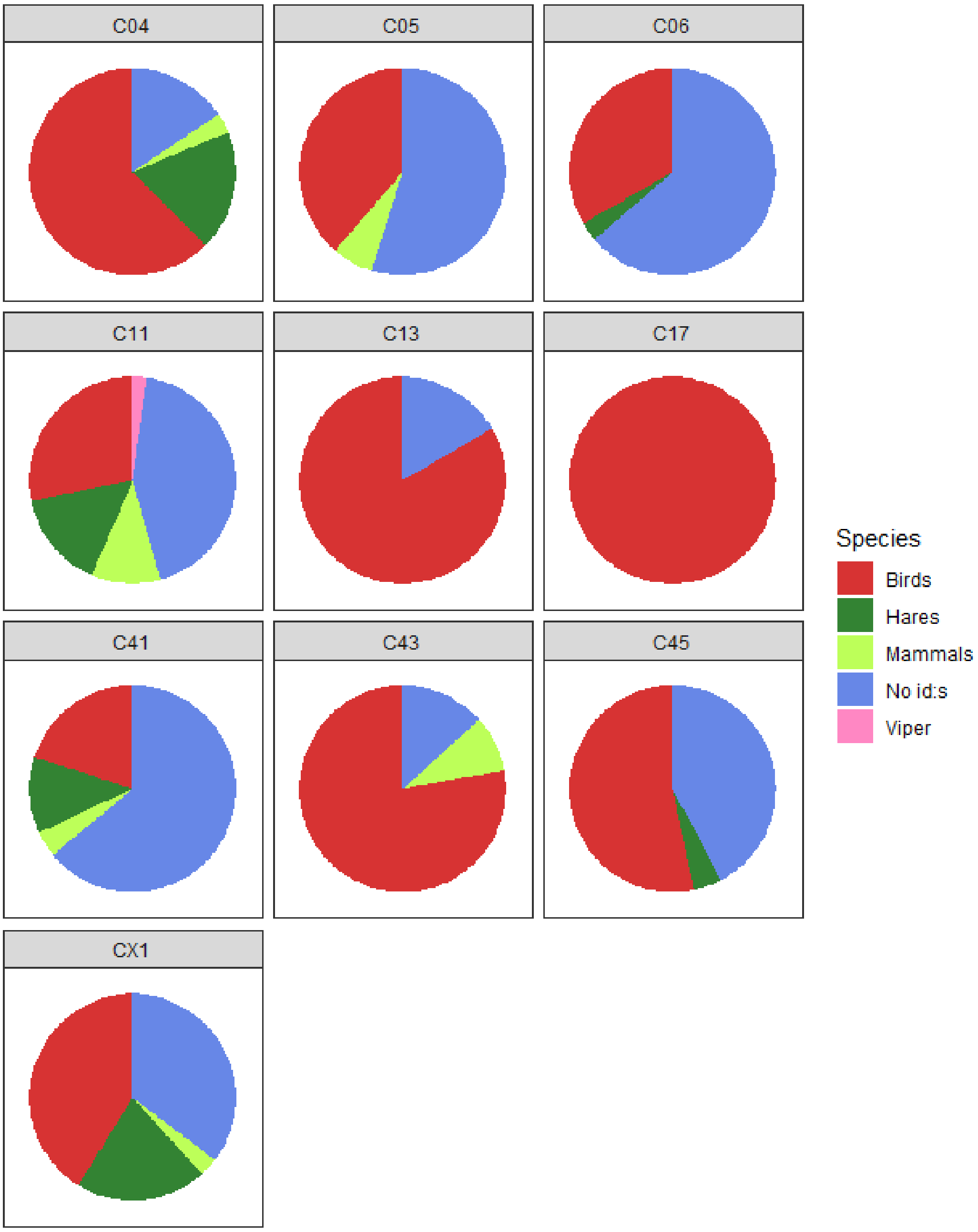

Figure 7: Percentage of delivered prey per camera by prey category.

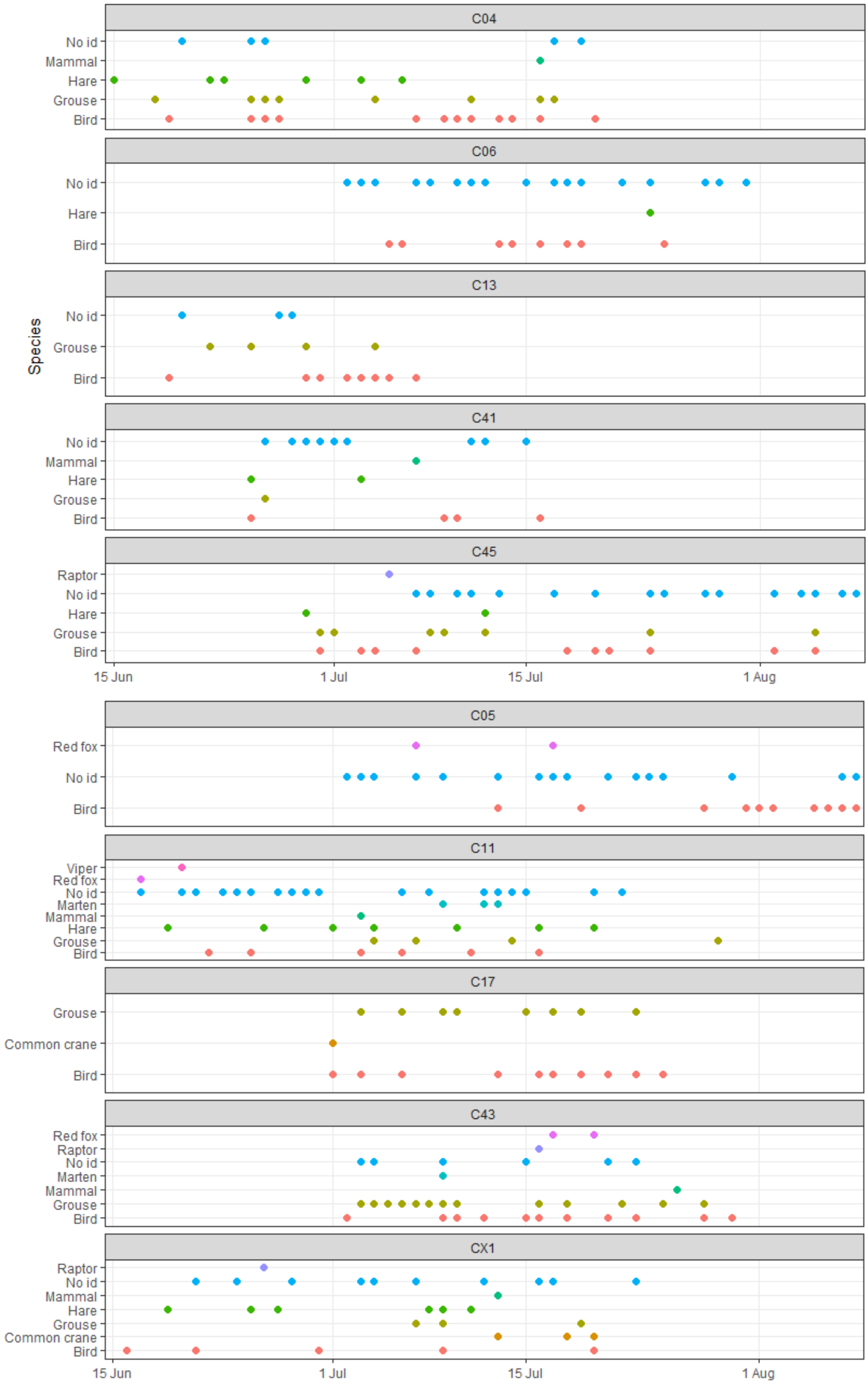

Figure 8: Species frequency over time per camera

The frequency of which the species were delivered over time (*Figure 8*) shows which days the different species were delivered to the different nests. In comparison to the total number of deliveries of species per week over all the nests (*Figure 9*).

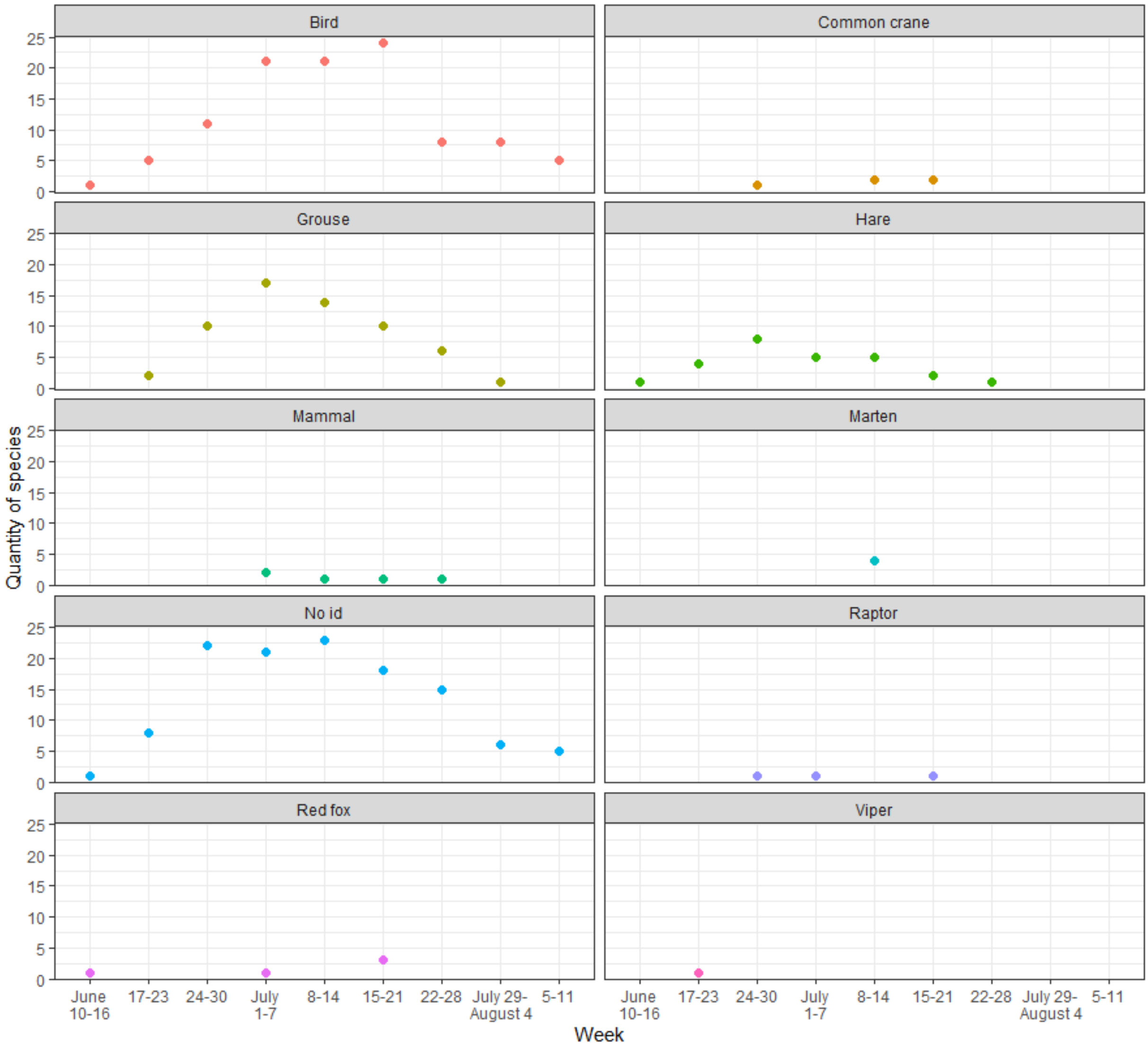

Figure 9: Total number of deliveries for each prey per week.

The time intervals of the images cover different lengths of the studied period. This because the CTs were put in place at different times and dates. Looking at the number of deliveries per day (*Figure 10*), the green line indicates the day of the first image available and usable, the red line the departure day of the first nestling, and the blue line the departure day of the second nestling when present. This showing the comparison towards first and last day of prey batch delivery. For camera 11 the first and second fledge occurred at the same day, hence only one line.

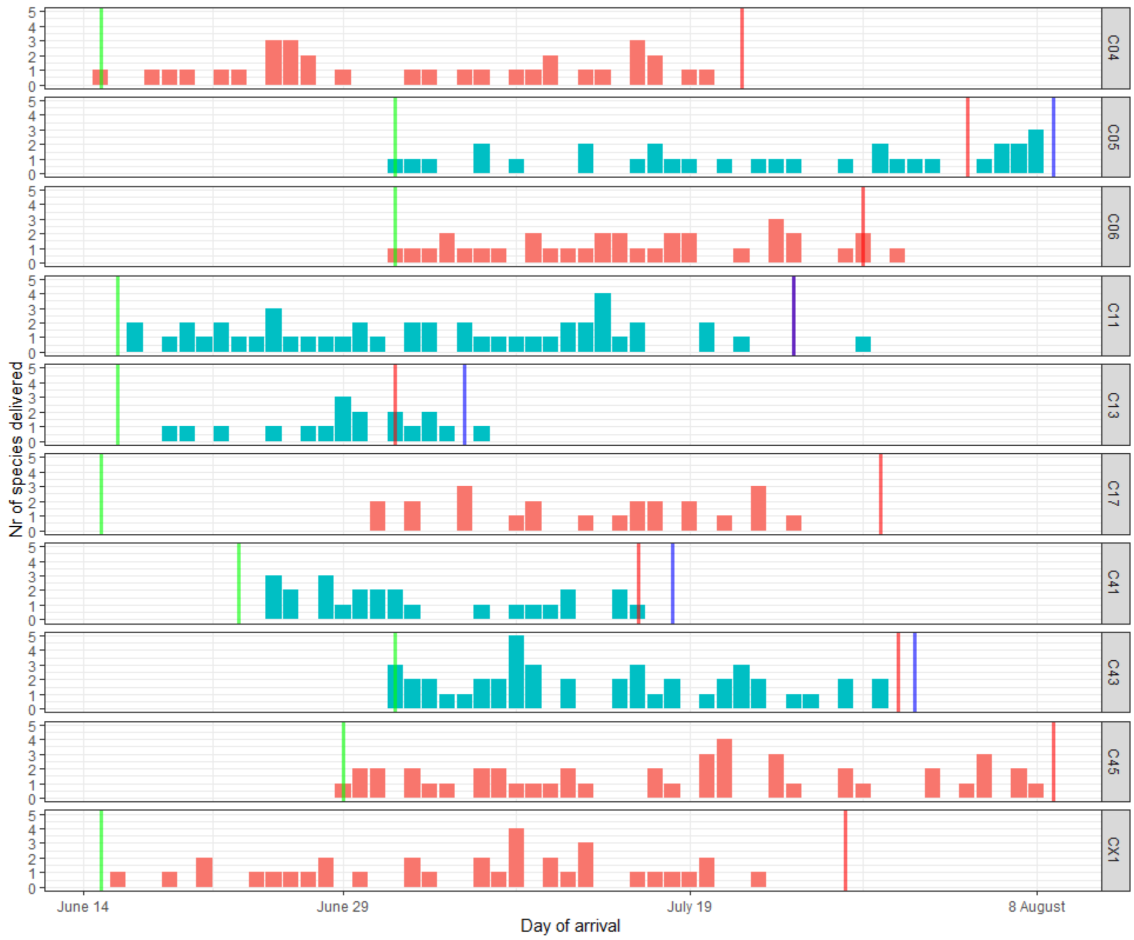

Figure 10: Number of deliveries per day per camera, colour-divided by number of nestlings. Red fill for one nestling and blue fill for two. Green line indicates start of image set, the red line as first nestling departure, and the blue line as second nestling departure if present.

Comparing the number of arrivals and removals of prey items (*Figure 11*), it is possible to determine if, and when multiple items exist at the same time in the nest. When the number of arrivals, indicated by the green line, are greater than the number of removals, indicted by the red line, there exists multiple prey items in the nest. Hence when the red line is situated above the green line, more items are being removed than delivered.

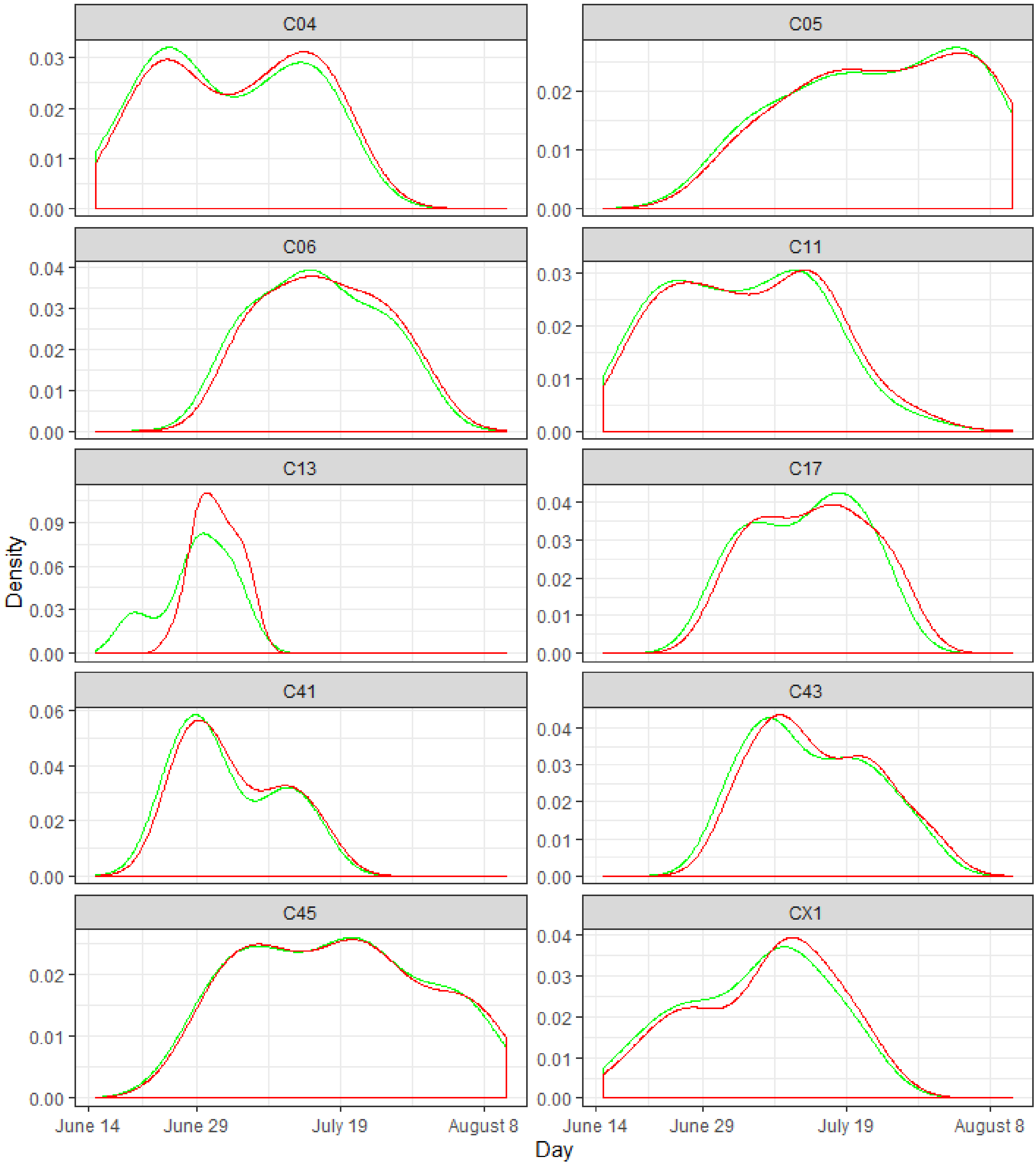

Figure 11: Density plot of number of batch deliveries in green, and number of removals in red per day per camera,

3.2. Batch nest time

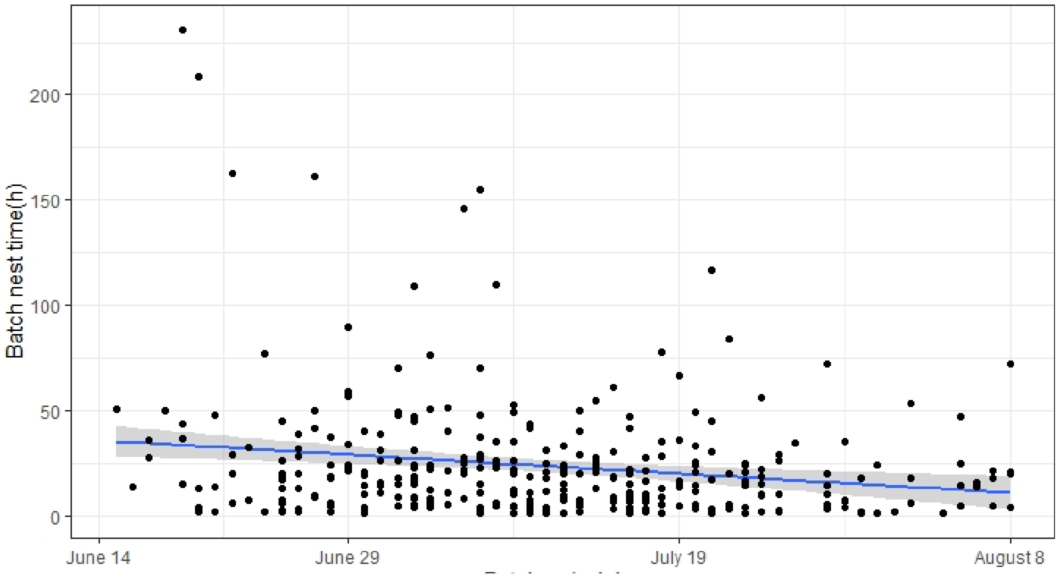

Figure 12: How long time the prey batch stays in the nest depending on the day of arrival.

As the days progress there is a minor declining trend for how long the prey items stay in the nest, with a correlation value of -0.17 (*Figure 12*), For some of the nests there are differences in how long the species remains (*Appendix 1 & 2*). Descriptively there is some variation in how long the different species stay in the nest (*Figure 13*).

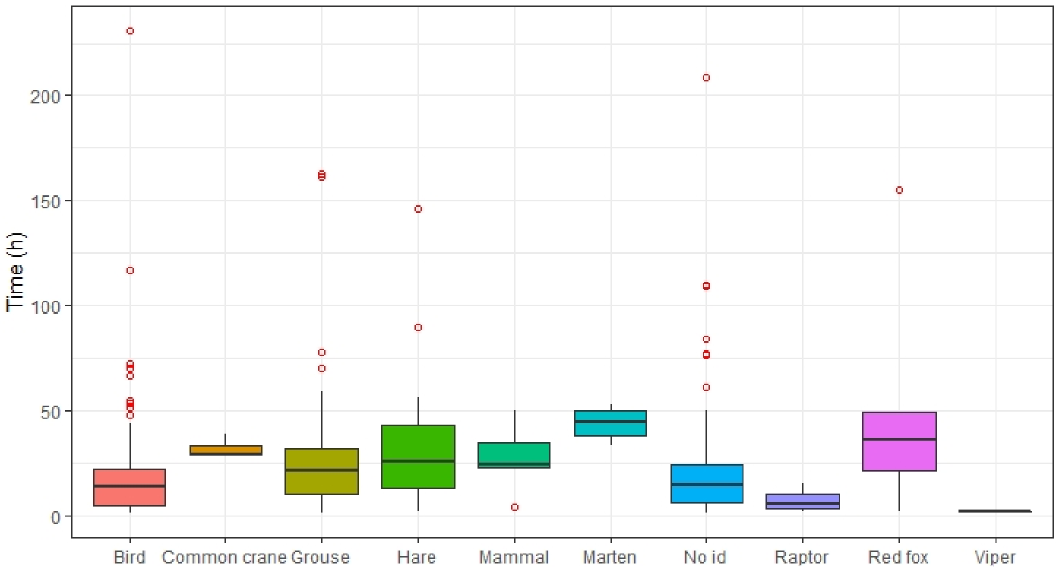

Figure 13: Nr of hours species remained in the nests

3.3. Time between deliveries

The development of the time difference between deliveries (*Figure 14*) show us a wide variety for the individual nests (*appendix 2*). A regression analysis with the Pearson´s product-moment correlation test (*Table 3*) shows mixed results between the separate nests.

Table 3: Pearson´s product moment correlation test for day of arrival with time between batches per camera

Camera	Correlation	P-Value	95% C.I.
C04	-0,08	0,68	-0,43 <> 0,29
C05	-0,21	0,30	-0,54 <> 0,18
C06	0,16	0,38	-0,20 <> 0,48
C11	0,16	0,31	-0,15 <> 0,44
C13	-0,3	0,25	-0,68 <> 0,22
C17	-0,17	0,48	-0,58 <> 0,31
C41	0,37	0,07	-0,04 <> 0,67
C43	0,36	0,03	0,05 <> 0,61
C45	0,15	0,36	-0,17 <> 0,43
Cx1	-0,21	0,26	-0,53 <> 0,16

Camera 43 was the only data set that showed a statistically significant result, that the time is increasing between the batches delivered. Camera 41 had near significance and showed a similar trend, whilst camera 4 was furthest away from showing significant results (*Table 4*).

Table 4: Statistics for camera 43, 41 & 4 with overall mean value for each variable

	C43	C41	C04	Overall Mn
N species	7	5	5	4,9
N batches	46	25	34	33,5
Batch time in nest	Mn = 21,1	Mn = 19,6	Mn = 28,5	Mn =23,7
(h)	Md = 17,9	Md = 20,0	Md = 15,0	Md = 17,8
N days monitored	29	22	36	32
Batches / Day	1,6	1,14	0,94	1,06

It is not evident that the day of arrival can explain the time difference for the previous batch delivery (*Appendix 3, fm1*).

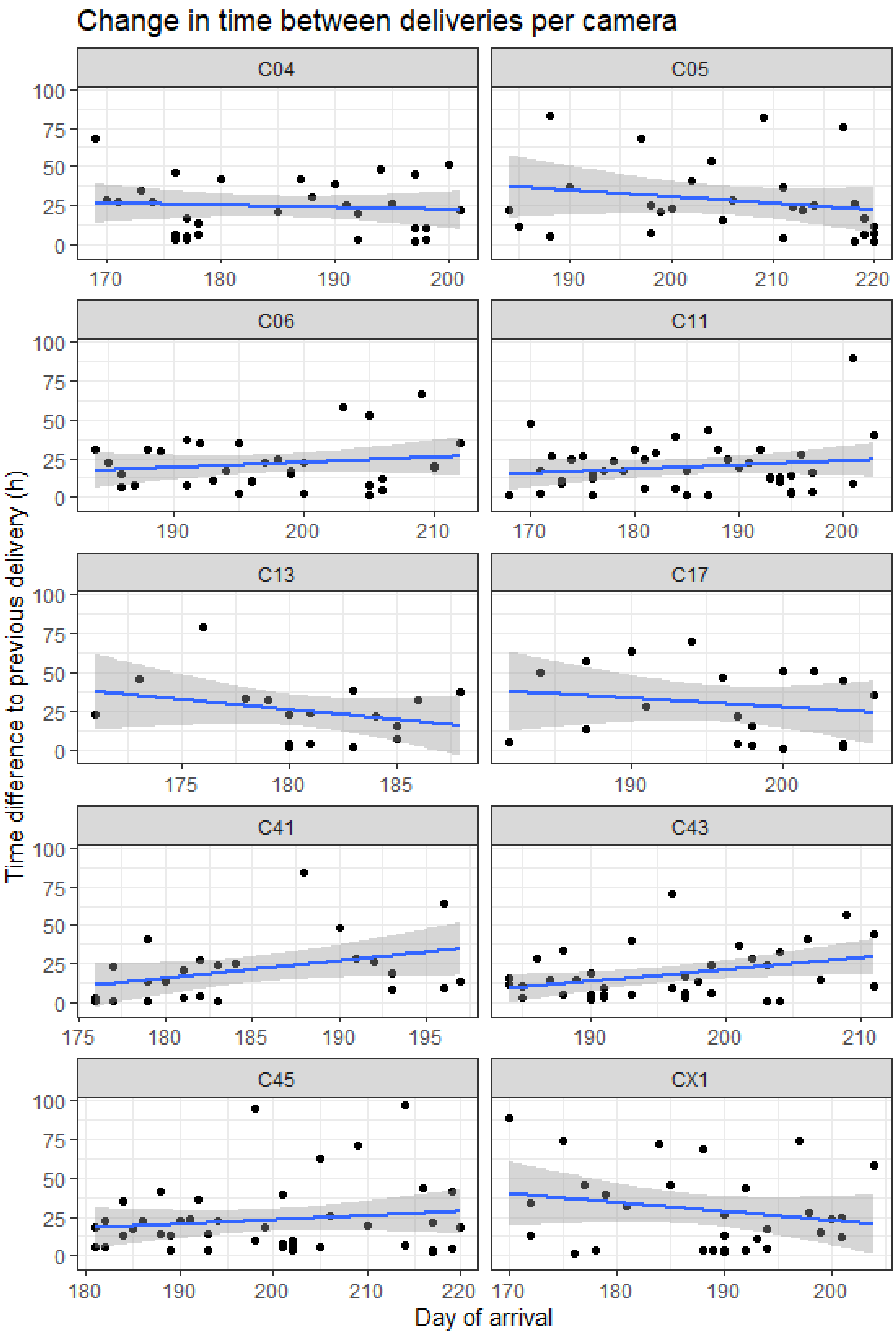

Figure 14: The time between the n and n-1 delivery depending on day of delivery.

4. Discussion

4.1. What species comprise the diets of the GEs

Species that are easier to identify are those which arrive as whole prey items to the nest. Species with niched characteristic such as size and coating make it possible to separate within groups. Such as the length and colour of the common crane legs, the coating of martens and red foxes, and the talons of raptors.

We should see a variation in which prey is brought to the nest in accordance to the variation in prey species availability. A higher part of the diet should for example consist of grouse after the chicks become subadults, increasing the availability of grouse for the GE to hunt. This should also be true while prey species are changing coat colour, decreasing their camouflage.

The data shows us that grouse have a high nest presence between 1 – 7 of July, whilst "Birds" show a top between the 1 - 21 of July. The hare is only present in the nests between 15 June – 15 July and have its highest presence between 24 - 30 of June. As should be expected, the no ID:s has a high presence over a large timespan. This is not surprising since those batches probably are carrion and can consist of all species available. Which also explains why we do not see any reindeer or larger mammals on the images, since these probably are amongst the no ID:s. The remaining species has sparse occurrences and low tops. We can see a lower amount of deliveries towards the fledge date. But no real connection to certain species over certain times for the GEs life cycle, other than that no ID:s, birds, and grouse are prevalent over the whole time for each camera. Since the GEs aren't specialist predators, maybe we should not see a huge impact on which prey items are taken depending on the GEs nesting cycle?

What is known of the GEs predation is that they are opportunistic predators and scavengers. Which can be seen in these results as well. The prey items brought to the nest can reflects the available prey in the habitat. Compared to earlier results (Högström & Wiss, 1992) which recorded birds to cover approximately 66% and mammals 34% of the GE diet in northern Sweden. This study results show that birds comprise 51% of the diet, 13% of mammals , and others including no IDs 36%. No ID:s occurs over the entire timeframe, which indicates that they could consist of either other species, comparing to earlier results though, the no IDs in this study could be most mammalian prey items which we know that the GE hunt, but has not shown on the images.

4.2. How does the batch deliveries vary over time

The results show that which prey species the batch deliveries consists of, vary a lot between nests (*Figure 8*). Some of the nests show a high variation in prey species selection, whilst others show specificity. Unidentifiable species and birds cover a large percentage of the diet. Studies has shown that the fluctuations of the main prey species coincide with how well the GEs successfully breed and that the populations are dependant on one another (Mcintyre, 2002; Nyström *et al.,* 2006; Mcintyre & Schmidt, 2012). Which conclusions are strengthened by similar results with other raptors taken into account (Baines *et al.,* 2004). By observing the catch rate of the presumed main prey species, this should reflect the prospect for successful areas. If the results are more dependant on prey availability, or hunting skills by the GE could be tested by cross-referencing nest areas and GE age.

There does not appear to be a strong correlation between the day of batch arrival and the time between the previous delivery (Appendix 3*, fm1*). Though when examining the separate regression curves for the individual cameras, one showed statistically significant increase in the time between the consecutive deliveries.

Out of the total ten cameras, five showed a decreasing trend whereas the five others showed an increasing (*Table 3*). Comparing the statistics between camera 43, 41, and 4 (*Table 4*), indicates that the number of batches per day might be important for determining the significance of the change in time between them, instead of the number of days monitored. A higher rate of delivery should give us more data per day. Ecology wise, an increased delivery rate at certain periods may not require parents to deliver more items overall. They may just balance the number of deliveries needed by hunting more at one time than another. Delivering a lot of food at once. Studies on delivery rate during the nesting periods for the GE in America showed an average of 0,9 – 1,8 deliveries per day, with peaks recorded in Idaho with three deliveries per day (Hardley *et al.,* 2006). Which covers the results from this study which ranges from 0,92 – 1,6 deliveries per day with an average of 1,06. This has previously been seen with significant different results when comparing between pairs of GEs (Collopy, 1984).

The results presented on the density of arrival and removal of prey batches (*Figure 11*) shows us that the removals always end up higher than the arrivals. This indicates that the nest is rather empty around fledging date. The larger difference there are between the lines, the longer time it is between the batch deliveries. This gives us indications if the number of delivered batches change over time depending on how much prey that is already in the nest. Interesting is that the densities seems to have different peaks. These peaks occur twice or thrice across the different cameras. Could it be that the adult is forcing the nestlings to learn how to maximize the prey carcass, adjusting them to not have as much contact with the adult, or is it that the adult delivers a lot of prey to be able to take care of themselves for a while, and therefore do not deliver as much to the nest periodically? To inspect this, data would be needed for adult activity outside of the nest. A similar pattern concerning the bald eagle (*Haliaeetus leucocephalus*) with one peak was acknowledged in Florida bay around nestling age of week seven to eight (Hanson, 2012). Two pairs of kestrels showed evidence that these peaks are dependent on nestling age, and not environmental conditions (Newton, 1979). Yet even though the same pattern was seen during the same nestling age for GEs in Idaho, comparing between one and two nestlings there was no difference in delivery rate (Collopy, 1984). A difference could be seen that the nest with two nestlings had a higher prey item mass delivered, but in older ages the individual nestlings ate less food per time unit than single nestling nests. The same study also acknowledges that the delivery rates decreases as the fledge time grows closer. Feeding rates amongst the different raptors worldwide varies a lot depending on preferred prey. From raptors specializing on insects, such as red-footed falcons with up to 57 deliveries a day, and such as the American harpy eagle specializing in large mammals, with a little more than one prey per week (Newton, 1979).

4.3. How does the time the prey batch stay in the nest vary over time

The result of the time the grouped prey species stays in the nest (*Appendix 3, fm2gr*) shows us no statistical significance. Meaning that when species are grouped as specified, there is no statistical difference in how long these groups stays in the nest. This result might be because the grouping is not relevant for the GEs. A common crane and a grouse might seem reasonable to group together because they are both birds. Though for the GE a grouse might be valued for the practice it gives the nestlings in dismembering a carcass, whilst a common crane might be valued for its meat content. Therefore, differing in the premises how long they are valuable in the nest.

The results for the ungrouped species (*Appendix 3, fm2*) showed a statistical significance for the species of grouse, hare, marten, and red fox. These differing results might be due to the method´s weakness in accurately defining meat remains. Remains from mammals are easier to distinguish as removed, than for bird species. Feathers might stay longer in the nest even though it does not serve a nutritional value, it may serve the purpose for playing behaviour, practice in dismantling a carcass, or visual stimulation. No ID's are more difficult in analysis since it can be

whichever species, which would explain the spread in how long time the prey item stays in the nest (*Figure 13*). And as mentioned earlier, no ID:s may consist of mostly mammals. No ID:s should instead be interpreted as bringing easy consumable prey pieces.
It is possible to explain how long the prey item stays in the nest, depending on which day it arrives (*Appendix 3, fm5*). The later the date, the smaller amount of time the prey items remains. This significance is still true with calculations between nr of nestlings, instead of between cameras (*Appendix 3, fm6*). A probable explanation might be while the nestlings are getting older, they have a higher nutritional requirement and have developed their skill of picking a carcass. Which means that they devour the prey item faster.

Whilst correcting for body mass, another study has produced results that amongst nine studied raptor species the time it takes for the nestling to handle bird prey items, without help from the adult, was significant longer for birds than for mammals for seven out of eight raptors (Sonerud *et al.,* 2014). They also saw that the older the nestlings got, the more reluctant they were in eating the prey items with help from the adult.

4.4. Does the adult induce fledge by reducing the time between batches

The tests show us that there are great variations between nests when comparing the time between the N:th delivery and the N:th-1 against the progression of delivered day (*Figure 14*). Looking at all the camera data collectively no significance can be concluded that the adult increases or decreases the food deliveries (*Appendix 3, fm1*). Inspecting the regression analysis camera 43 showed a statistical significance that the time between deliveries are increasing. Additionally, camera 41 had near statistical significance showing a trend towards the same conclusion. Though since the results are greatly divergent between cameras, no rigid conclusion should be made. To test this hypothesis in more detail, data should be collected from the day the egg hatches, to the day of fledging to eliminate uncertainties

Similar results for the post-fledge period has been obtained for other raptor species (Eldegard *et al.,* 2003). The adults of the Eurasian Sparrowhawk (*Accipiter nisus*) showed a trend to decrease the food items delivered towards the stages of late post-fledging, which has also shown true for the Eurasian Kestrel (*Falco tinnunculus*) in France (Boileau & Bretagnolle, 2014), and the Black kite (*Milvus migrans*) in Japan (Koga & Shiraishi, 1994). The Black kite was also shown spending less time around the nest (Koga & Shiraishi, 1994). Though the Eurasian Sparrowhawk seemed to increase the period of which they delivered prey items if the availability of prey was good (Eldegard *et al., 2003*). Amongst the Eurasian Kestrel, increasing the time spent on delivering prey items and caring for the young ones post-fledge has shown to give the fledglings better chances of survival in the long run (López-Idiáquez *et al.,* 2018).

These results are not true among all birds of prey or between sexes. One study in Scotland concerning the Osprey (*Pandion haliaetus*) saw that whilst the female stopped caring for the fledglings, the male continued to support them with prey items (Bustamente, 1995). Showing no indications of inducing self sustainability post fledge. Furthermore, another study conducted in Finland and the Czech Republic on the Boreal owl (*Aegolius funereus*), found no significance for nestling period other than the length of the wings on the nestlings (Kouba *et al.,* 2015).

How many prey items that are delivered per day could possibly be explained by the quality of the territory with the number of nestlings. Since the more nestlings which the adults successfully rear, should reflect the adult's ability to feed those numbers (Eldegard, 2003). The time the nestlings stay in the nest can therefore depend on the food availability in the area (Kouba *et al.,* 2015).

Post-fledge juveniles has a learning curve for catching prey, which might explain the decrease in prey deliveries by the adult (Bustamente, 1995), this amongst other factors such as the availability of food, and how experienced and competent the adults are at catching prey and rearing juveniles (Boileau, 2014). Cooper´s hawk (*Accipiter cooperii*) has shown to vary how early the female abandon their juveniles during spans of impaired weather and food periods (Eldegard, 2003), and those who did had decreased physique. The condition of the parents plays an important role in how much they can invest in their offspring. The better physique the adults have, the more energy and longer time they can spend on rearing (López-Idiáquez *et al.,* 2018). Comparing this to the Snail Kite (*Rostrhamus sociabilis*) which increasingly abandons juveniles during periods of favourable conditions when there is a good chance of establishing a new successful nest (Eldegard, 2003).

Some raptors migrate, such as the Black Kite, which plays a role when adults stop investing in offspring (Koga & Shiraishi, 1994). In this case though the main prey consists of carrion from fish, which doesn't involve a high learning curve for catching. Resulting in that the juveniles can fend for themselves at younger ages.

The energy needs of the nestlings can be balanced by more frequent deliveries or bigger prey items. This might depend on food availability in the hunting area and the adult's ability to hunt, which may vary between years. In contrast to meeting the demand of the young ones, decreasing food deliveries may be to induce fledge and/or support the development of self sustainability. During certain periods and when the juveniles are coming of age to independency, adults might have a higher need for sustaining themselves after intense rearing. Or perhaps some individuals or raptor species are more or less eager to induce fledge and independency than others?

4.5. Pros and cons of the CT methodology

Choosing which variables to collect will control the possibilities of the study. For this study the main aspects are: Species data, and delivery & removal time/date of prey items. Collection and tweaks of all data variables per camera took, after some training, approximately one day per camera. Maintenance, configuration, fieldwork, and communications need to be taken into consideration when calculating the total time-investment needed for this method.

Temperature was detailed on the images and collected through sensors in the camera. This gave a local temperature at almost the exact spot of the nest. Though this temperature reading would differ if put in a sunny or shaded spot, the relative differences at deliveries or removals should be comparable. The collection was therefore done without difficulty. The error and deviation of the temperature reader is unknown but should prove no impediment on the study. Complementary information for more in depth analysis of the meteorological impacts would be wind, precipitation, and humidity.

The collection of the time and date variables proved useful in testing and analysing the questions. The time and date for the delivery and removal of prey batches exposed some in-between software communication issues. Knowledge of how different software programs calculate these kinds of data and communicate with each other are needed when considering the format of which time and date variables should be collected. The time collected was dependant on the frequency setting for which images were taken. In this case once each hour. The date collected was dependant on that the correct dates were put in during the configuration step before set-up. Camera CX1 had this wrong, which shows the importance of keeping separate manually information sheets for these kinds of information. For camera CX1 the date could be corrected for, though not the time. Making the time variable non-comparable between cameras, only the relative time differences from that camera was of use.

The species was grouped by relevance of the study. Whilst the level of details can be organized after the species identification, the identification should be done to an as low taxonomic rank as possible. Collection of species data through camera images might not give the most meticulous species data, such as a DNA analysis might do. CTs are a relatively cheap method, and the expensive part will be to organize and finding manpower. This study had the extraordinary help of voluntary workers, making the project achievable. Collection of the species data was the variable with the hardest reproducible methodology and the level of detail and accuracy of species identification is variable depending on the surveyor. Using camera images results in a rather high amount of no ID:s which consist of prey items to distressed to identify, or carrion meat of prey species to heavy to carry.

Differentiating between different prey items when all of them is one big meat pile provided challenges. When a prey item arrives at the nest is straightforward if the prey is visible. Determining when it leaves the nest requires a definition of what "leaves" means, and that it is applicable across all different species or defined between them. How to determine when different item of the same species is a new item or just the first moved around in the nest requires training in image observation skills. The method for determining when a hare has been removed was chosen in coherence to the goal of the study. The importance of the food items for the study was how long it stayed in the nest as a viable food source, and which species they consisted of. For this goal the paws were determined to be outside of the scope of interest. Hare paws stayed for a long time after the main carcass was disposed of which skewed the data set and were therefore removed. They might play an important role for nestling behaviour, such as playing and training. Though this behaviour is not examined in this study. Collecting the data on how long the species of the batches stays in the nest, was the most time-consuming variable to collect.

For optimal research on prey batch time in nest, one might determine that the prey is no longer of importance for the study after the nestlings have finished eating of it. This can be accomplished by defining when a prey batch has lost its nutritional, learning, and/or play function. Depending on what question is being examined. For this study it was determined that the prey had lost its research value after removal or loss of visibility, because of the difficulty of determining a good moment of when it was to be noted as finished feeding on, or when the meat was gone enough etc. This for reproducible reasons of the study.

For some occasions two nestlings might show to have a certain delivery rate, though the truth might be that they consume the prey faster. Which might happen between photo opportunities. So, the number of prey batches delivered might be a low estimate for two nestlings.

The utilization of CTs images gave manageable amounts of data compared to video recordings which collect a massive amount of data, more useful for studying special events and occurrences that can be triggered by the cameras motion sensor (Booms & Fuller, 2003). Approximately one third of the usable cameras was of value for collection of this methods variables. The main hindrances which excluded two thirds of the cameras was not qualifying for the necessities of visual interpretation of prey item data. Necessities for an ideal camera setup optimal for this study would be:

- Placement of the camera right above the nest with no nest edges outside of the frame of the images, or obstacles blocking the view of the nest.
- A secondary camera placed with a longer distance and less of an angle to more accurately establish what happens outside of the nest and possible effects of this.
- Placement of camera before the hatching of eggs. This to eliminate some uncertainties, monitoring of siblicide, and comparison of prey batch deliveries pre hatching.

4.6. Species identification and tech use

The angle of the camera on the nest, size of the nest, how much of the nest that is in frame, weather, and obstacles such as nestlings are some variables that determines the observational ease of the images. These variables are more and less important for identifying different species. Following are images of all the present species covered and used in the study (*Table 5*):

Table 5: Examples of images used for identification of species in the study.

 Viper	 Red fox
 Marten	 Grouse
 Raptor	 Bird

 Common crane	 No id
 Hare	 Mammal

Following are a batch of examples from images which fulfils the criteria of visibility and quality (*Table 6*):

Table 6: Examples of images that fulfilled criteria of visibility.

	

The configuration was set to one photo each hour. And even though the one-hour gap, other valuable information is caught. The chances of catching rare situations with this interval is low. Meaning that the information collected should cover more regular occurrences, that do not only happen exactly at the photo opportunity. Such as other species ending up on the images (*Table 7*):

Table 7: Examples of other species found during data collection.

Eurasian jay

Eurasian jay

	
Passerine	Black grouse

Phrasing the method for optimal reproduction of the study determines what is collectable. How to determine prey presence for example. If feathers, or large parts of a carcass is visible this provides no problems. Presence of prey is not only possible to locate through visibility variables, but also through behavioural observations. Behavioural observations are more difficult to replicate with other studies and might tend towards subjective results. Therefore, none of the behavioural implications towards that a prey item was present was used to determine prey deliveries. These behaviours could for example be nestlings showing exaggerated interest or time spent at the periphery of the nest, or just outside of the camera frame (*Table 8*):

Table 8: Images showing behaviour that indicates that a prey is present but not visible

	

Following are some examples of cameras that did not fulfil the requirements of visibility and quality, and were therefore excluded from the study (*Table 9*):

Table 9: Examples of images that were inappropriate for use in the study.

Unforeseen incidents always happen and is difficult to consider beforehand. These occurrences highlight the importance of good groundwork, preparations and execution. Such as a storm tearing down the nest (*Table 10*):

Table 10:: Image sequence of a nest being blown out of a tree by a storm

4.7. General discussion

In some cases, as mentioned previously, some adults bring other predators to the nest. This behaviour might be based on geographic position, individual preference, or an opportunistic catch. Predators have a higher risk of carrying substantial amounts of heavy metals. Symptoms from devouring other prey species with increased concentration of lead residues in them are lowered animal welfare and decreased fitness (Ecke *et al.,* 2017. Which gives rise to concern if the golden eagles are consuming other top predators (Pain *et al.,* 2019; Mateo, 2009). In this case it means that by identifying prey species with possibly high concentrations of lead residues, we might conclude if it is a behavioural individuality, or a geographic phenomenon. For this to be examined, a greater number of nests with recorded deliveries of predatory birds with different geographical positions should be used.

It has been discussed that the smaller number of different species delivered, the better it is for the eagle in terms of energetic benefits (Watson 1998). Spending less energy on collecting prey, it might result in better rearing of the nestlings and the possibility of having more than one at a time. If this is true, having two successful nestlings where both fledge should indicate an energetic efficiency from the adult. Meaning that one might see a smaller number of different species delivered to nests with two nestlings with adults of the same experience. From this study we can see a trend that the number of deliveries has a positive correlation to how many different species that are collected. But we can neither determine the comparability of the adults in terms of experience. To be able to do this comparison a long-term data set on successful rearing of offspring is needed on multiple adults.

Is it meaningful to study the time that the prey stays in the nest with this kind of method? The removal of the prey batch might be active, random, or accidental. Such as an adult actively removing, nestlings actively kicking or throwing away prey remains, or a result of kleptoparasitism. Random in the fact that there is no systematism in the removal, sometimes its an active choice, and sometimes an accident. Such as an accidental removal when the nestling is rummaging around and, in the process, kicking the prey out over the edge of the nest. This might be an increasing variable as well. Since as the nestlings gets older, they start to get more restless. This since it seems as they pick and scatter about the prey remains in the nest more at an older age. Which could be seen during data collection.

I chose to exclude prey items which was already present in the nest on the first available image. This decision was made because a lot of uncertainties evolves around this prey item. When was it placed in the nest, how long has it been in there, who placed it there, was it some important event that occurred before the start of the image sequence connected to the prey item? These are some questions that can be answered for the forthcoming prey items. Though for diet composition this would still give valuable data.

4.8. Conclusion

The species brought to the nest consisted mostly of birds and no ID:s. Which seems not to differ if there are one or two nestlings. Even though the percentage of mammalian species was relatively low compared to bird species, mammals was present in seven out of ten nests. These results seem to be in cohesion with previous studies, with exception of the high numbers of no ID:s. The unidentified prey items are probably carrion from prey species to large to carry or was found in bits and pieces after other scavengers, predators, or vehicles. The individual nests show high variety in diet composition.

Trends towards an increased time between deliveries can be seen. Examining the data of deliveries per day, tops and lows could be seen alternating over time. Which previous studies has seen around chick age of week seven and eight. Giving rise to questions such as if the adult depletes its energy capacity and focuses on self sustainability by decreasing deliveries for a period?

Results from data on the time the prey stays in the nest, shows a trend towards a decreased time in which the prey carcass is left in the nest. A reasonable conclusion is that as the nestlings gets older, they have a higher need for intake quantity. This with a developed skill of consuming the prey item unassisted with more efficiency, leaving fewer leftovers at a quicker rate.

If the adult eagle induces fledge date cannot be satisfactorily answered with enough data to back it up. Though trends towards that this might be the case can be seen.

Analysing the methodology of the Cts, pros and cons were as follow:

Table 11: Pros and cons of the methodology

Pros	**Cons**
+ Low intrusion + Low financial cost + Medium time consumption + Low knowledge needed for equipment use + Reusable data	- Finding volunteer help - High species knowledge - Errors after field set-up are difficult to adjust for - Achieving quality of photos at field set-up - Handling confidential data

Hopefully this study provides foundation for further research and shows indications towards points of interest, making it possible to adapt the correct methodology for future hypothesis. Concluding that viable variables to collect depends on the hypothesis and resources available.

4.9. Limits of the study

This method has proven suitable to certain degrees of identifying which species are brought to nest and frequency of delivery. For more detailed species information on genus or species, other methods might prove more valuable (Tornberg & Reif, 2007), though if class is of interest CTs are suitable. Conclusions on prey deliverance and effects on nestlings can be drawn, though you can not be certain that these are the same species the breeder is sustained on since not all prey are brought to the nest (Tornberg & Reif, 2007). Which means there is no certainty that there is no discrimination between what prey is brought to the nest, and which prey is fed upon by the adult.

Some bias towards species identification might be of relevance. Since the skills of the observer will impact the details obtainable for the results. Categorization might for instance be of higher accuracy within mammals than birds etc. Collection of these kind of data takes a relatively large amount of time to perform. Which needs to be taken into consideration when determining if the method is suitable for the size of the data collection. This method might not be optimal for very larger data collections without adequate manpower, compared to other fairly reliable methods depending on hypothesis (Tornberg, & Reif, 2007).

Images taken during dark hours are much more difficult to determine changes in. Some prey batches are for example similar in colour and texture as the nest on the images during night-time. Often resulting in that scarce data could be collected for these images. The time between images can possibly hide information. Such as prey batches arriving and being removed within this void time frame. Therefore, the photo interval should be narrowed down to at least 30 min.

Though the variable of temperature is collected, this study does not take other environmental changes in account. Such as changes dependant on land use, which could impact the rate of deliveries and prey species available (Whitfield (1) *et el.,* 2007).

The hare paws were determined to play a minor role for the hypothesis examined. Though this was not transferred to other mammals. Though then the problem occurs to specify when a paw is just a paw, and not part of a leg anymore if it is semidetached. This was more easily perceived for the hares than for example the red foxes. Since the hare paws were detached from the main carcass early and easy distinguishable and was not removed in a similar fashion from the fox carcass.

4.10. Further research

Since the prey supply is important during production and incubation of eggs as well as whilst the nestlings are present (Moss *et al.,* 2012). Future studies using CTs should focus on the time before the eggs hatch. Since the period before egg laying determines the fitness of the female for egg production and care, as well as to better understand the connection between prey deliverance and nestling survival with earlier photos from incubation. This would also make it possible to take siblicide and survival rate into account. For better understanding of behaviour, as discussed previously, smaller intervals for the photo sequence is needed for such as prey preference, play behaviour, and intra-species behaviour.

For relevant discussions of prey deliverance, we must take prey availability into consideration. This data could be collected through bag statistics and roadkill data. Other complementing methods can be used to determine this, such as the involvement of further citizen science. Though the places for golden eagles might be to remote for this implementation with other than active scientific collection of trapping data for specific areas. And since a variety of attitudes towards larger raptors exist (Whitfield (2) *et al.,* 2007), the knowledge of nest location and voluntary work might not be suited for public knowledge and should be handled with care.

An aspect which was not part of the studied variables was nestling behaviour around the nest. Worth mentioning for further studies is that some of the fledged eagles was later caught on camera revisiting the nest, sometimes many days after departure. This kind of data can also be collected with GPS tracking devices. Collecting data through CTs with motion sensor, might make in-depth behaviour analysis with revisiting fledglings possible.

Since not one of the different methods currently used for identifying prey species is complete in itself (Redpath *et al.,* 2001; Huang *et al.,* 2006). For a full comprehension of which prey species is brought to the nest, a combination of different methods would be preferable (Margalida *et al.,* 2004).

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Acknowledgements

Special thanks to my supervisor Navinder Singh for his inestimable help and dedication to the subject, to my wife for her endless support, and a huge gratefulness to all the voluntary workers dedicating their time to make this kind of research possible.

Appendix 1

Cam	C04	C05	C06	C11	C13	C17	C41	C43	C45	CX1
N species	5	3	3	8	3	3	5	7	5	7
N batches	34	31	33	46	18	23	25	46	45	34
Batch time in nest(h)	**Max** 161,3 **Min** 1,0 **Mn** 28,5 **Md** 15,0	**Max** 155,1 **Min** 1,0 **Mn** 19,0 **Md** 7,9	**Max** 66,4 **Min** 2,1 **Mn** 22,0 **Md** 18,9	**Max** 110,2 **Min** 1 **Mn** 24,8 **Md** 21,5	**Max** 231,2 **Min** 4,1 **Mn** 58,2 **Md** 30,1	**Max** 117,0 **Min** 2,0 **Mn** 22,3 **Md** 19,0	**Max** 49 **Min** 1,6 **Mn** 19,6 **Md** 20,0	**Max** 77,5 **Min** 1,0 **Mean** 21,1 **Med.** 17,9	**Max** 47,0 **Min** 1,0 **Mn** 12,2 **Md** 7,5	**Max** 109,4 **Min** 2,1 **Mn** 28,2 **Md** 22,0
N days of images used	36	40	30	42	18	25	22	29	41	37
Batches / Day	0,95	0,78	1,1	1,1	1,0	0,92	1,14	1,6	1,1	0,92

Appendix 2

Variable	Max	Min	Mean	Median	N
N species	8	3	4,9	5	10
N Batches	46	18	33,5	33,5	332
N days of images used	42	18	32	33	320
Batch time in nest (h)	231,2	1,0	23,7	17,8	7873,2
Time between previous batch (h)	173	1	24,3	18,7	7421,7
Time in nest (h):					
“Bird”	231,2	1,0	20,0	13,9	104
“Common crane”	38,9	28,1	31,7	29,2	5
“Grouse”	162,9	1,0	28,1	21,5	60
“Hare”	146,0	2,0	33,4	25,4	26
“Mammal”	50,1	4,1	27,2	24,0	5
“Marten”	52,8	33,1	43,8	44,7	4
“No id”	208,9	1,0	20,8	14,9	119
“Raptor”	15,4	2,1	7,5	5,2	3
“Red fox”	155,1	2,1	52,7	361	5
“Viper”	2,0	2,0	2,0	2,0	1
Time in nest (h) for grouped categories:					
“Birds”	231,2	1	23,0	16,9	172
“Hares”	146,0	2,0	33,4	25,4	26
“Mammals”	155,1	2,0	41,1	35,4	14
“No ID’s”	208,9	1,0	20,8	14,9	119
“Viper”	2,0	2,0	2,0	2,0	1

Appendix 3

Test ID	Dependant variable	Fixed effect	Random effect	Estimate	Std error	T-value
fm1	Time differenceper previous batch (h)	Batch arrival day	Camera nr	0,002699	0.005429	0,497
fm2gr	Batch nest time (m)	Species grouped	Camera nr	7,87	70,61	0,111
fm2	Batch nest time (m)	Species	Camera nr	**Grouse** 507,64 **Hare** 832,07 **Marten** 1568,50 **Red fox** 2180,23 **Common crane** 626,95 **Mammal** 487,99 **No id** 178,07 **Raptor** -515,01 **Viper** -975,99	**Grouse** 270,56 **Hare** 373,17 **Marten** 845,62 **Red fox** 752,69 **Common crane** 774,03 **Mammal** 749,53 **No id** 229,50 **Raptor** 956,92 **Viper** 1646,31	**Grouse** 1,88 **Hare** 2,23 **Marten** 1,855 **Red fox** 2,897 **Common crane** 0,810 **Mammal** 0,651 **No id** 0,776 **Raptor** -0,538 **Viper** -0,593
fm5	Batch nest time (h)	Batch arrival day	Camera nr	-0,31	0,15	-2,14
fm6	Batch nest time (h)	Batch arrival day	Nr of nestlings	-0,45	0,13	-3.5

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