Eyes in the nest

– Breeding phenology of Golden Eagles
characterized using remote cameras

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Abstract

In situ monitoring of raptor breeding ecology with field personnel is costly, difficult and demanding. Installing camera traps in raptor nests can provide researchers with diverse information and long-term monitoring. Furthermore, it allows for relatively cheap data collection. However, comparisons between camera traps and other methods are important to allow comparisons of results between different studies.

This thesis aims to investigate the potential of camera traps to monitor Golden Eagle breeding phenology and explore what events are suitable for quantifying with cameras. Data from 54 cameras, each monitoring one unique Golden Eagle breeding, was used. Nine of these cameras monitored the nest for almost a full year. With this dataset I was able to estimate all chosen phenological events, only using photographs from the camera traps.

My results show comparable estimates with established facts for Sweden and previous studies from other countries. This demonstrates the potential of this technology to be used for ecological studies of breeding raptors.

Keywords: Golden Eagle, breeding, Aquila chrysaetos, camera trap, phenology, Sweden

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1. Introduction

The Golden Eagle

The Golden Eagle (Aquila chrysaetos) is a large raptor with a range covering most of the northern hemisphere stretching from Japan to North America (Watson, 2010). In Sweden the species occur primarily in the northern parts, with scattered populations occurring throughout the country to the most southern region (Hjernquist, 2011). There also exists a relatively large population on the island of Gotland, an area with a high concentration of Golden Eagles (Hjernquist, 2011).

The Golden Eagle is a protected species in Sweden and managed according to the government's politics regarding Sweden's main large predators. Historically it has been intensely persecuted, especially in the 1800s and early 1900s before its protection in 1924 (Naturvårdsverket, 2013). Albeit the population has recovered since, it is currently classified as NT (Near Threatened) in Sweden. Today it is still being persecuted in several countries in its range (Watson, 2010), including Sweden (Tjernberg, 2006), despite being protected by law. In addition to the direct persecution, several other threats such as degrading habitat, traffic collisions, lead poisoning and disturbance also exist (Ecke et al., 2017, Harrison et al., 2019).

The Swedish national management plan for the Golden Eagle, states that an adaptive management approach is needed with a continuous collection of information to fill knowledge gaps for the species (Naturvårdsverket, 2013). Much of the compiled knowledge about Golden Eagle breeding ecology in Sweden is based on data from nest visits (Moss et al., 2012, Hogstrom and Wiss, 1992, Tjernberg, 1983, Tjernberg, 1981). The majority about prey preference and breeding production. The addition of alternative methods could give new insights and aid in validating some of the established assumptions regarding the breeding ecology of the species in general, in Sweden and elsewhere.

Golden Eagle phenology

For majority of Sweden, adult eagles tend to stay in the vicinity of their breeding area throughout the year and juveniles undertake long distance movements. However, adult eagles have also been observed to migrate long distances from their nesting sites (Hipkiss et al., 2013, Moss et al., 2014, Singh et al., 2017).

Eagles in breeding areas inhabited throughout the year usually visit the nest occasionally year-round. Such visits are usually displayed with some fresh branches dropped into the nest and nest visit frequency increases before the breeding season in February (Tjernberg, 2006).

Due to its large range, the timing of incubation of Golden Eagles depends heavily on the where they are breeding. As an example, in Oman, at 21°N, the median laying date falls on December 2nd. In Alaska at 69 °N, the median laying date is more than five months later on the 7th of May (Watson, 2010). The incubation period, is known to be around 41-45 days (Watson, 2010) and the Golden Eagle is known to lay eggs successively with a 3-5 day interval (Watson, 2010).

In Sweden, Golden Eagles are known to incubate for 43-45 days (Tjernberg, 2006). The hatching usually occurs in early May (Tjernberg, 2006), meaning the laying occur around late March and beginning of April (Tjernberg, 1983). Fledging usually occurs 60-80 days (Tjernberg, 2006, Watson, 2010), 65-90 days (Artdatabanken, 2019) after hatching. In western Scotland, an area with more limited food supply, (Watson, 2010) comments that few fledge before an age of 70 days.

Phenology

Species shifting their timing of key events in their annual cycles with ongoing climate change (Cotton, 2003) has raised the interest in phenological studies (Therrien et al., 2017). The importance of studying phenology surpasses the knowledge accumulation for single species as the changes in yearly events could be connected to ecological responses to climate change (2018, Walther et al., 2002). The changes in global climate trends have caused shifts in phenology visible for numerous species of a broad spectrum (Dunn and Moller, 2014), such as migration of raptors (Therrien et al., 2017), hibernation and migration of altitudinal mammals and birds (Inouye et al., 2000) and flowering of plants (Fitter and Fitter, 2002). Furthermore, the changed timing of yearly climate cycles may also trigger contradicting responses in different animals (Therrien et al., 2017). It may also affect different trophic levels to a varying degree (Both et al., 2009), and prey-predator interactions, potentially affecting population dynamics for the predator (Durant et al., 2007). Furthermore, there is evidence that migratory bird species that fail to adjust phenology to changing conditions are experiencing population declines (Both et al., 2006, Moller et al., 2008).

(Dunn and Moller, 2014) suggest that the correlations between egg laying and population trends found in other studies are results of poorly understood mechanisms. The relation between phenology and environment is complex and assumptions may have to be adjusted for different species (Dunn and Moller, 2014). The complexity also demands that long term, large scale studies are carried out on

multiple species to investigate the interaction between phenology and climate change (Therrien et al., 2017).

Using cameras in wildlife research

Cameras have been used in multiple studies on nesting raptors and birds (Black et al., 2017, Harrison et al., 2019, Hinke et al., 2018, Maphalala and Monadjem, 2017, Vali, 2018). Technical innovation has allowed cameras to operate for longer timespans without the need of field maintenance while at the same time providing low interference surveillance (Hinke et al., 2018).

Furthermore, in breeding studies, multiple cameras may be set up to capture numerous nests simultaneously (Maphalala and Monadjem, 2017). Cameras have been used in several studies looking at phenology (Hinke et al., 2018, Vali, 2018) and diets (Harrison et al., 2019, Maphalala and Monadjem, 2017). These attributes make autonomous cameras excellent for monitoring numerous distant nests continuously for long periods of time.

Not having personnel repeatedly visiting nests or observing nests for data collection has numerous advantages. Training personnel to be able to correctly monitor desired properties and have fieldworkers repeatedly visit nests for making observations, can be costly (Harrison et al., 2019, Hinke et al., 2018). The few visits required when monitoring with cameras is cheaper in terms of fieldwork associated costs. It also allows researchers to monitor nests located in remote areas where conventional in-situ monitoring by field personnel would be deemed too time inefficient (Hinke et al., 2018). Another advantage is potentially lowered disturbance as a result of fewer visits to the nest (Hinke et al., 2018).

Comparing camera accuracy compared to conventional methods is necessary when comparing results between studies using different data collection methods (Harrison et al., 2019). Combining different methods can also prove to be very useful. (Hinke et al., 2018) utilized the conventionally measured phenological time-intervals and combined this with timing data from cameras to map the phenology of penguins in Antarctica. The time-intervals between phenological events are more fixed than the timing of the whole sequence. With this assumption, timing of phenological events that remained unobservable for the camera could be estimated by (Hinke et al., 2018) based on timing of observable events and known intervals from conventional studies using field personnel.

Cameras in phenological research

The need for long term, multi-species data studies (Therrien et al., 2017) to better understand the complex mechanisms behind phenological responses to climate is clearly sought after (Dunn and Moller, 2014, Therrien et al., 2017). Cameras can be utilized even in extreme environments for prolonged periods of time (Black et al., 2017, Hinke et al., 2018) and impracticable places (Harrison et al., 2019).

Furthermore, the time cost saved by the use of cameras (Hinke et al., 2018), could be spent surveilling more specimens, a larger area or for a longer period.

The purpose of this thesis

This thesis aims to investigate the potential of camera traps to capture different types of Golden Eagle breeding events and explore what visually distinct phenological events during Golden Eagle breeding that are suitable for quantifying with cameras. Furthermore, study this subject by descriptively exploring how this method compares to more traditional methods and how the pros and cons could affect the balance and conjunction between methods.

2.   Method and material

In the ongoing Swedish monitoring program that has been running for several years, camera traps have been set up at known active Golden Eagle nests. Cameras are installed by volunteer ornithologists from the Golden Eagle group of Sweden, involved with The Swedish Golden Eagle project. No camera has been continuously active for more than one season. Therefore, the same physical camera may have been reused the next season on the same or another nest.

2.1. Cameras

This thesis uses data from time-lapse cameras with an interval between photographs set to one hour. The cameras were active every hour during the monitoring period. All cameras were installed in 2017, 2018 or 2019.

In this thesis one camera refers to one camera-monitoring-period. For example, if the same physical camera has been used to monitor three different nesting seasons, it will be referred to as three different cameras, for simplicity.

First, all cameras were analyzed for the presence of breeding eagles at the nests. Only cameras containing photographs capturing breeding or attempted breeding were used. Unfortunately, several cameras had to be excluded due to camera failure, absence of breeding eagles, SIM-card failure and pre-breeding destruction of nests.

Out of a total of 79 cameras, 58 contained suitable data for the scope of the thesis. Of these 58, two cameras were excluded due to them having the same monitoring time and nest as other cameras but with different angles. Two more were excluded for having wrong date information making their material unsuitable for analysis. Consequently, the final dataset was composed of 54 cameras, each covering one unique Golden Eagle breeding attempt.

A total of 175 544 photographs were analyzed visually. All events recorded from photographs are listed and described in section 2.3.

The monitoring period varies greatly and ranges from 31 to 362 days. 48 cameras, which is the vast majority, were set up after hatching in summer, between mid June and early July. Most of them were taken down again in autumn. A total of nine cameras were put up in autumn and early winter to allow the whole breeding season to be captured. One of these cameras monitored the breeding season of 2018

and the eight remaining cameras monitored the breeding season of 2019. The differences and patterns in monitoring periods can be seen in Figure 1. The full-season-monitoring cameras have been highlighted in black.
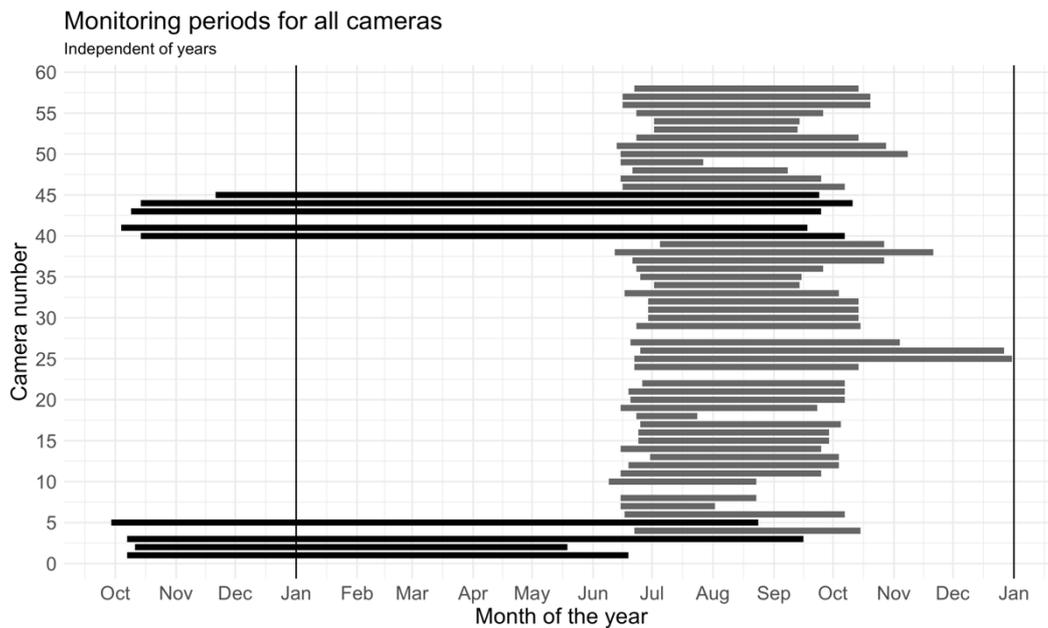
Figure 1. Simplified figure of monitoring period for each camera regardless of which year they monitored. Note that the cameras attempting to monitor the full breeding season have been painted black. In total, all 54 cameras are shown with the four removed cameras representing the gaps. Subsequently, every bar in the figure represent one monitored unique Golden Eagle breeding attempt.

2.1.1. Camera locations

The cameras were installed at nests in the following Swedish counties: Västerbotten, Gävleborg, Dalarna, Jämtland, Västernorrland and Norrbotten (see Melin 2020, Master thesis).

2.2. Recording of events

Two pre studies were carried out before the main data collection. First, all cameras were briefly scanned to determine data usability, nest occupancy, monitoring length and breeding success. Consequently, the cameras were sorted based on usability, number of chicks born and monitoring length. This allowed for cameras lacking usable data to be excluded and an assessment for the forthcoming workload based on the monitoring length of all units. Second, three randomly picked cameras, with at least one from the full-season cameras, were analyzed thoroughly to determine

suitability of different events for documentation and subsequently used to compile a set of events to record, see section 2.3.

The photographs were streamed into a computer and viewed one by one. The photographs were streamed at a variable speed depending on visibility and visual complexity. A maximum speed of approximately four photographs per second could be utilized during low intensity and high visibility periods. The high rate was necessary to complete the recording of events within given time constraints.

Events were noted in an excel sheet immediately upon discovery. For every event the following was noted: Camera number, type of event, picture number in camera memory card, date and time, temperature and any notes if needed, see Figure 2.

CameraNr	Event	PictureNr	DateAndTime	Temperature
41	Nest building	6133	2019-06-28 07:18	10
41	Nest building	6176	2019-06-30 04:13	5
41	Fledging chick	6480	2019-07-13 09:23	23
41	Fledging chick	6484	2019-07-13 14:06	27

Figure 2. Example of structure of data recording.

2.3. Event types

A total of six events were recorded from the photographs. These included: Nest building, Incubation start, Incubation end, Death, Fledging chick and Returning chick, see Table 1.

Table 1. All recorded events.

Recorded events
Nest building
Incubation start
Incubation end
Death
Fledging chick
Returning chick

2.3.1. Nest building

Nest building was determined as an event where new nest material is placed on the nest, excluding all food items. Several limitations of the data material had to be considered when determining how to classify this event. Firstly, having a camera that activates on a timely schedule contrary to activation by movement, means that capturing an actual nest building event, i.e. when an eagle is seen adding a branch to the nest, is uncommon. Even more so if the picture frequency is set to one picture per hour. Secondly, during the incubation and nestling period, movement of chicks and adults cause the branches of the nest to move around substantially making tracking branches considerably more difficult. Taking this into account and the fact that all photo analysis had to be done manually, a system had to be implemented to balance time consumption as well as minimizing error. Therefore, a nest building event was recorded if:

- A new branch could be seen in the picture.
- It was not thought to be an old repositioned branch determined by earlier consecutive pictures.

Naturally, every camera provided vastly different ability to identify the occurrence of the event, causing accuracy to vary.

Figure 4. Picture before a nest building event.

Figure 3. Picture that captures a nest building event showing added green branches located just right of the chick.

2.3.2. Incubation start

The incubation period was regarded as initiated when an adult bird was lying down in the same spot in the nest, see Figure 5, the vast majority of consecutive pictures. The incubation start event was recorded the first picture of the consecutive pictures with the lying adult. Egg laying was never observed.

Figure 5. Golden Eagle hen incubating in early April.

2.3.3. Incubation end

Only one camera managed to capture an egg hatching. Additionally, this egg was also the final one of the two in the clutch, thus providing the exact time when the incubation ended. For all other cameras the event of incubation end had to be estimated based on an age estimation of the last-born chick when it was first seen. The visual guides used were (Hardey et al., 2009) and (Watson, 2010). Furthermore, the date of incubation start in combination with known incubation periods (Tjernberg, 2006, Watson, 2010) and the visual development of the chick of known age shown in Figure 6, were used to calibrate the estimated age for each of the other chicks.

Figure 6. The only picture that captured a hatching egg.

2.3.4. Death

The death event was recorded for two scenarios. If a chick could be seen dead in the nest or if a chick disappeared and never reappeared. The assumption was made that a chick that left before having the ability to fly, would not survive. For the nests where a chick went missing, all disappearances occurred early in the nestling period, reinforcing this assumption.

2.3.5. Fledging chick

The event of fledging was defined as when a fully developed chick left the nest and neighboring branches. The ability for each camera to capture this varied considerably. For cameras that didn't capture the whole nest, fledging could not be determined as soon as the chick was gone. Instead, depending on the severity of lost vision due to angles and obstacles, fledging was determined when a chick could not be seen for a number of consecutive pictures (Also see Dahlen 2019, Master thesis).

When a nest had two chicks, individual identification of chicks was necessary to allow individual fledging times to be recorded. Plumage differences was used for markers. If the chicks could not be individually identified due to indifferences in plumage or inadequate picture quality, fledging confirmation had to be simplified. Following the same procedure as for single clutches mentioned above, the first fledging was determined when only one chick could be seen in the nest. The last fledging was determined when no chicks could be seen in the nest.

2.3.6. Returning chick

After the chick was confirmed to have fledged, every subsequent picture of it was recorded as a returning chick event. Individual identification of chicks becomes increasingly more difficult as they age. Returning chick event observations for two chick clutches were kept simplified for this reason, and chicks post fledging were not individually identified. Regardless of the number of returning chicks present in a picture, one returning chick event was recorded.

2.4. Data handling

All recorded events have been organized in two categories. The first category are single-occurrence-events which are events only occurring once per individual or nest, per breeding season. This type of event includes; fledging, hatching, death and incubation endpoints.

The second category are repeatedly-occurring-events which occur in varying frequency over extended periods of time. This type of event includes; nest building and returning chicks.

2.4.1. R packages

R version 3.6.2. was used for all data analysis (R Core Team, 2019). The following packages were used for data handling and visualization:

- dplyr (Wickham et al., 2020)
- egg (Auguie, 2019)
- ggplot2 (Wickham, 2016)
- lubridate (Grolemund and Wickham, 2011)
- RColorBrewer (Neuwirth, 2014)
- readxl (Wickham and Bryan, 2019)
- scales (Wickham and Seidel, 2019)
- tidyr (Wickham and Henry, 2020)

2.4.2. Use of mean values for frequencies

The second type of data are events that repeat through time which makes both timing and frequency interesting properties.

However, this type of data had to be transformed into usable formats before it could be plotted or analyzed. The main reason for this is a constantly changing number of active cameras, see Figure 1. This makes the total number of frequencies recorded for a set time period confusing, since it is heavily dependent on the number of active cameras. Furthermore, if a frequency mean is to be calculated for a month of the year, as illustrated in Figure 10, some cameras have only partly covered that month. Therefore, a monthly mean based on the total frequency for each camera that month, can have substantial errors. Consequently, days were chosen as an adequately sized unit for mean frequency calculations and months and weeks were regarded too large. When calculating monthly and weekly means seen in Figure 10 and Figure 11, all monitored days by all cameras active that week or month where pooled together and a daily mean was calculated.

2.4.3. Calculations of phenological periods

Two different phenological periods were estimated based on the estimated timings of certain events. Incubation period and nestling age at fledging. The incubation endpoints are observations or estimations when the first egg is laid and the last chick has hatched, as described in 2.3.2 and 2.3.3 respectively. However, because of the

successive egg laying with a three to five day interval (Watson, 2010), these endpoints can only be used for single egg clutches to directly estimate the incubation period. The mean of the proposed time interval between the eggs (Watson, 2010), which is four days, was therefore subtracted from estimated incubation periods for two egg clutches.

The same principle was applied on chick ages when fledging. Age at fledging was estimated as the time between incubation end and fledging. However, since incubation end was the estimated or observed hatching for the last chick, the older chick was to my knowledge already three to five days old. Consequently, contrary to the incubation period, four days was instead added to the fledging age of the oldest chick.

3. Results

The number of recorded events varied greatly between the different types of events. In total, 1754 events were recorded by the 54 cameras. Nine incubation starts were recorded. However, two of these attempts were abandoned prematurely and seven ended with a hatching. The two prematurely abandoned attempts only contributed to the incubation start date, resulting in seven "incubation ended" observations. 64 fledging events were recorded and returning chicks were seen 770 times at or by their nests post-fledging. In total 896 nest building events were recorded, and chick death events were captured six times.
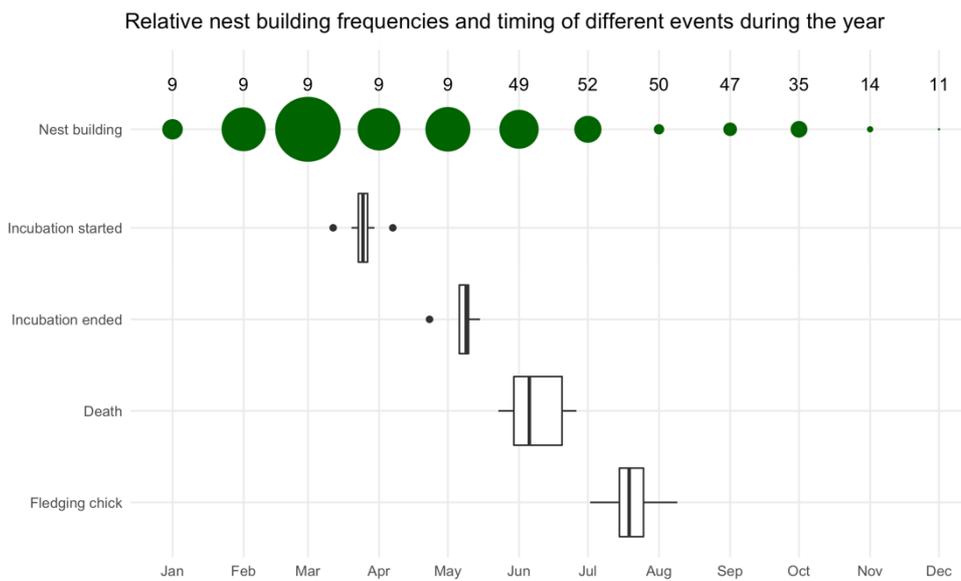
Figure 7. Combined plot illustrating the timing of single-occurrence-events during the year and the relative nest building frequencies. The size of each green point refers to the daily average of nestbuilding events that month. The numbers above each point is the number of cameras that were active each month. Returning chick frequencies cannot be displayed on this timescale as they are relative to fledging dates and not quantified along the Gregorian calendar.

3.1. Single-occurrence-events

The dates of important breeding events for all cameras
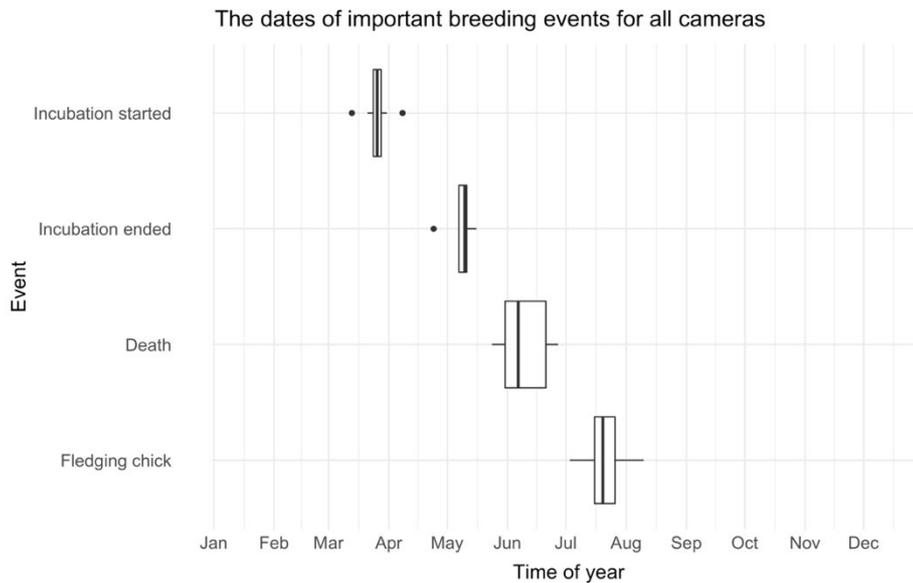
Figure 8. Box plot of the single-occurrence-events, showing their timing and spread during a calendar year.

3.1.1. Incubation

The earliest recorded incubation start was 12th of March and the latest occurred on 7th of April. The sample of a total of nine observations gave a mean for incubation start at 25th of March. The earliest incubation end was estimated to have occurred 23rd of April and the latest on 15th of May. The mean being 7th of May.

Table 2. Incubation dates and periods. Times indicated with an (*) have been corrected using inter-egg-laying-interval of 4 days from (Watson, 2010). The last row shows the means and standard deviations in days for the columns.

Incubation start	Incubation end	Incubation time
March 23rd	Failed	-
April 7th	Failed	-
March 24th	May 6th	43 Days
March 30th	May 15th	46 Days
March 20th	May 6th	43 Days*
March 12th	April 23rd	38 Days*
March 27th	May 10th	40 Days*
March 25th	May 10th	42 Days*
March 26th	May 9th	40 Days*
March 25th ± 7,05	May 7th ± 6,88	41,68 ± 2,45

3.1.2. Fledging dates

Due to the fact that most cameras were set up post-hatching, the number of fledging events recorded, far outnumbers the other single-occurrence-events. 64 fledgings were recorded by 50 of the cameras. The earliest chick fledged 2nd of July and the latest one fledged at 9th of August. The mean being 20th of July and standard deviation 9.31 days.

3.1.3. Age at fledging for full season cameras
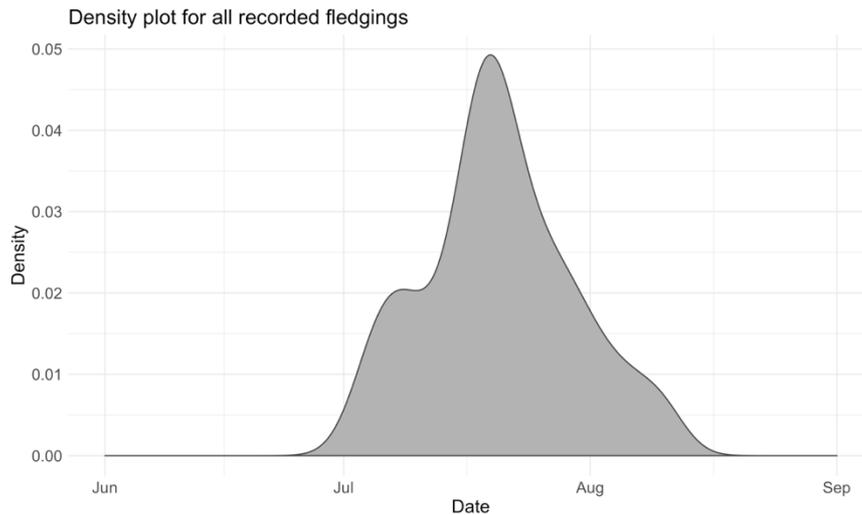
Figure 9. Density plot of all recorded fledgings.

The estimated age when fledging, was only performed on chicks from nests monitored since before egg laying (full-season cameras). Six cameras fulfilled this requirement and captured at least one fledging event. The estimated mean age of fledging chicks was 77,7 days with a standard deviation of 4,1 days, see Table 3.

Table 3. Age in days of fledging chicks. Every row is a full season camera (n=6) that captured at least one fledging event. Times indicated with an (*) have been corrected using inter-egg-laying-interval of 4 days from (Watson, 2010).

Age (days) first fledgling	Age (days) second fledgling
77,3	-
75,2*	73,3
84,4*	80,6
74,2*	Died
82,0*	Died
74,7*	Died
Mean age when fledging for all aged chicks (n = 8): 77,7 ± 4,1	

3.1.4. Chick deaths

Six chick deaths were observed, the earliest being 23rd of May and latest at 26th of June. Mean lies on 8th of June, with a standard deviation of 14,0 days. The chicks were not aged at the point of death and therefore no age at the point of death can be given.

3.2. Repeatedly-occurring-events

3.2.1. Nest building frequencies

Nest building was observed in 48 out of the 54 cameras. The first nest building event based on the Gregorian year was 2nd of January. The latest nest building event was captured the 3rd of November. December was the only month with no recorded nest building events. However, the number of cameras monitoring a nest each month varied greatly, see Figure 1. The month with the highest frequency of daily nest building events per nest, by a substantial margin, was March. See Figure 10.
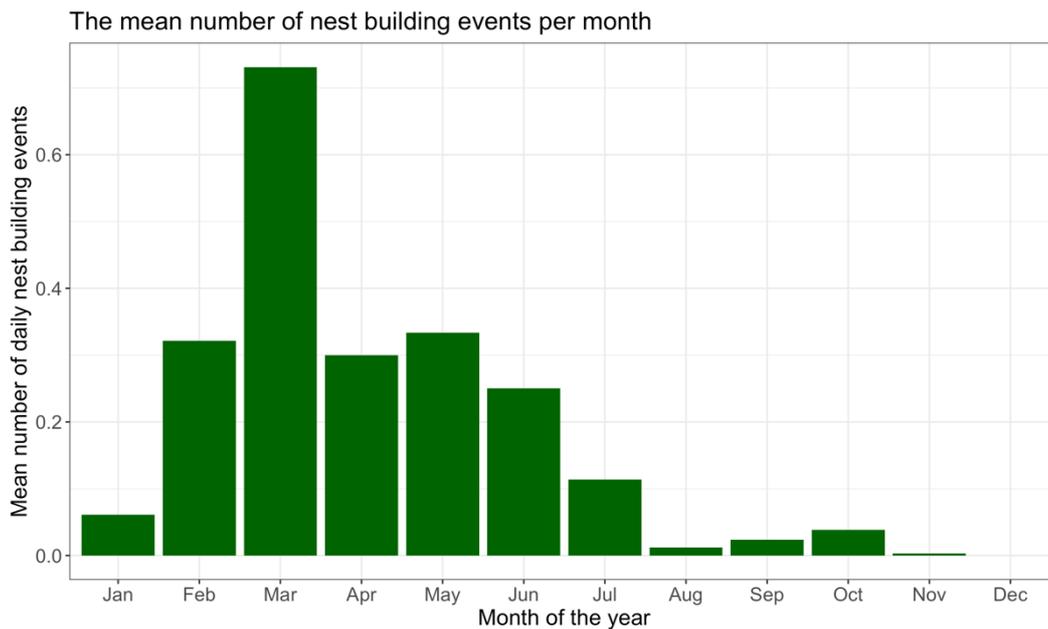
Figure 10. Daily average number of nest building events for all active cameras for each month.

3.2.2. Returning chick frequencies

Returning chick events were recorded by 32 out of the 50 cameras that recorded fledging. Once again, the monitoring times past fledging varies greatly between cameras, affecting the results. The last returning chick was seen 83 days after fledging.
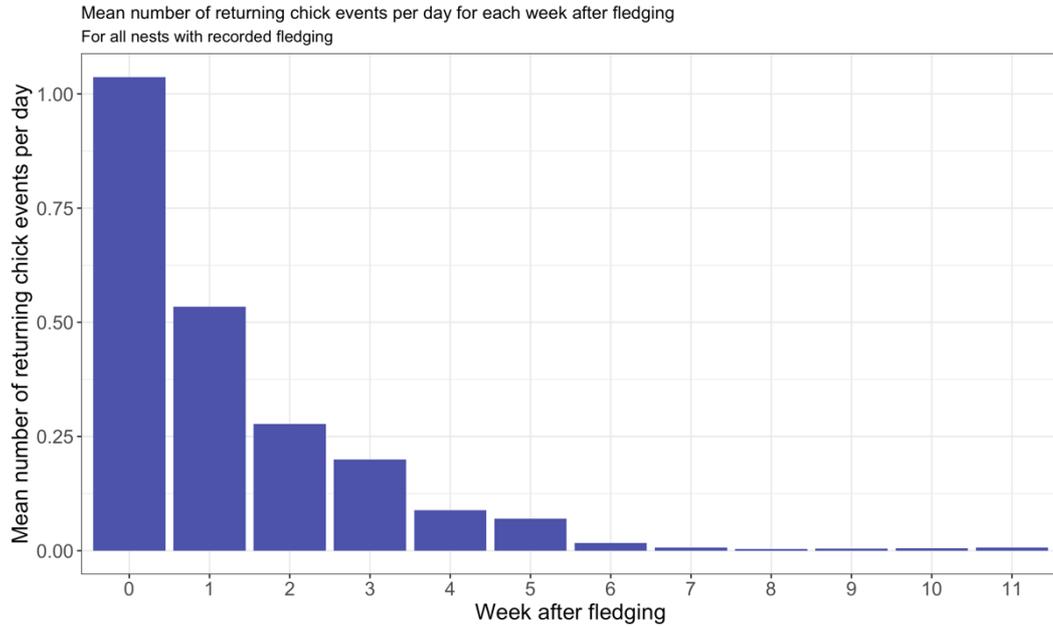
Figure 11. Daily average of returning chick events for all active cameras for each week post fledging.

4. Discussion

4.1. Main findings

My estimated timing of phenological events from the photographs corresponds with the established knowledge about the Swedish population presented in (Tjernberg, 2006). The results show that timing of all chosen phenological events could be estimated from all cameras that surveilled the period within which the event occurred. The provided photographs from the nest cameras, in combination with guides of visual aging of chicks (Hardey et al., 2009, Watson, 2010), provided the basis for confirming or estimating all phenological events.

However, no additional method of field monitoring was performed, therefore denying the possibility of a direct comparison of event estimation accuracy between time-lapse camera traps and other methods for these specific nests. However, one could compare the estimates obtained and the variation observed in my data with other studies.

4.2. My results in relation to established facts and studies

Most phenological and life history data for the breeding period of Golden Eagles are estimations based on chick plumage during nest visits when ringing (Steenhof et al., 1997, Young et al., 1995, Harrison et al., 2019) and hybrids using both observations and estimations (Ellis, 1979), the Scottish national survey described in (Watson, 2010). Back-calculating egg laying based on chick plumage creates a bias towards breeding pairs successful in their incubation (Watson, 2010). This study avoided this bias by including pairs that failed either during incubation (two nests seen in Table 1) or early during the nestling period (one nest).

Continuously monitoring the full breeding season of Golden Eagles have further advantages compared to estimates based solely on accepted phenological time-intervals. It allows for adjustments and variation to be added to the phenological

time-intervals when more exact timing of events can be visually confirmed (Hinke et al., 2018).

The documented facts for the breeding phenology of Golden Eagles in Sweden have been mainly acquired by M. Tjernberg in (Tjernberg, 2006, Tjernberg, 1983, Tjernberg, 1981) during extensive work with the species. My literature search did not yield any studies focused on phenology in Sweden. In fact, global Golden Eagle phenological data and facts are usually documented in studies focused on other breeding parameters such as reproductive success (Tjernberg, 1983), diets (Tjernberg, 1981, Harrison et al., 2019) and behavior (Ellis, 1979).

Table 4. Overview of comparison for phenological dates and time periods between this study and previous knowledge. Values after ± are the standard deviations.

Event	My results	Previous studies or knowledge
Incubation start	25th of March ± 7,05 days	Late-March to early April (Tjernberg, 1983)
Incubation end	7th of May ± 6,88 days	First half of May (Tjernberg, 2006)
Incubation period	41,7 days ± 2,45 days	43 - 45 days (Tjernberg, 2006), 41 - 45 days (Watson, 2010)
Fledging	20th of July ± 9.31 days	Mid to late July (Artdatabanken, 2019, Tjernberg, 2006)
Fledging age	77,7 ± 4.1 days	60 - 80 days (Tjernberg, 2006, Watson, 2010), 65 - 90 days (Artdatabanken, 2019)

Incubation

My estimated mean egg laying date of 25th of March (± 7,05 days) corresponds with the time period for Sweden presented in (Tjernberg, 1983), that egg laying occurs from late-March to early April. The established Swedish knowledge for hatching date (Tjernberg, 2006) is first half of May. This also corresponds well with my estimated mean hatching date of 7th of May (± 6,88 days). However, the presented incubation period for Swedish eagles is slightly longer with a narrower range (43-

45 days) (Tjernberg, 2006) than my estimation of 41,7 days (± 2,45 days) which is more in line with the global estimation of (41-45 days) presented in (Watson, 2010).

Fledging

My estimated mean date of fledging (20th of July ± 9.31 days) fits well with established Swedish knowledge of mid to late July (Artdatabanken, 2019, Tjernberg, 2006). Furthermore, the estimated mean fledging age of (77,7 ± 4.1 days) also agrees with the published Swedish fledging age of 60-80 days (Tjernberg, 2006) and 65-90 days (Artdatabanken, 2019).

Nest building

Nest building events were recorded throughout the whole year with the exception of December. Year round nest building activities agrees with both Swedish publications (Tjernberg, 2006) and global (Watson, 2010). Interestingly, my estimated timing for egg laying is the same date as presented for Scotland in (Watson, 2010). However, Scottish nest building data display highest nest building frequencies between October and April and very little nest building in summer (Watson, 2010). My data indicate the highest frequencies between February and July with very low frequencies in autumn to mid-winter. However, substantial differences in the methodology for the Scottish nest building survey and mine exist, with the Scottish service using flight behavior of adults as data. This might be a factor behind the unsynchronized frequencies in nest building as an adult carrying nest building material might be delivering to alternate nests or not sighted in general that frequently (Watson, 2010).

Returning chicks

Chicks usually spend the time post-fledging in close proximity of the nest (Watson, 2010). (Ellis, 1979) reported that fledglings returned frequently to rest at the nest and observed these visits up to five weeks post fledging. My results are in agreement with other observations for Sweden, with fledged chicks being observed up to eleven weeks (83 days) post fledging, see Figure 11. (Sandgren et al., 2014) monitored Swedish GPS tagged juveniles and estimated a post-fledging period. This period was defined as the period a chick spent in its natal area post fledging and varied between 7 and 14 weeks (49-97 days). (Soutullo et al., 2006) estimated this period to between 8 and 17 weeks (60-120 days) for juveniles in Spain and (McIntyre and Collopy, 2006) did the same thing for a migratory population is Alaska and reported a five to nine week (39 to 63 days) period. 18 out of 50 cameras did not contain any observations of returning chicks for the whole post-fledging period. This could be a result of a visit mistiming with the time-lapse photographs or that the chick was outside the limited focal coverage of the camera.

4.3. Event estimations and observability

The degree of event detectability discussed in this session is purely measured in my invested effort to distinguish the patterns and signs indicating each event. As discussed in (Hinke et al., 2018), using time-intervals between phenological events for mapping seasonal phenology, requires a clearly visible and distinct event as an anchor. In this section I will elaborate on event visibility based on the 175 544 analyzed pictures in this thesis.

4.3.1. Variation in visibility between cameras.

The mounting of the cameras was performed independently from this study. Consequently, the planning and preparatory work for this thesis did not affect how these cameras where set up. Furthermore, the cameras were mounted on available tree stems, sturdy branches or other props, changing the options for mounting with each nest. As a result, both the angle and the distance to the nests, differs greatly, which are both important attributes for correct identification of events. Some cameras were mounted on the nesting tree vertically above the nest bowl, giving a view strictly from above, in close proximity. Other cameras were instead mounted on a neighboring tree with a varying horizontal side view from a longer distance.

This has substantial effect on the correct identification of more obscure events, such as egg hatching. While viewability of egg hatching also depends heavily on adult eagle positioning, the viewability is greatly improved with a close view looking down into the nest bowl. Fledging estimation on the other hand as defined in, 2.3.5 is more easily detected with a broad view of the whole nest and neighboring branches. Certainly, this variation affects the estimates and the observability. However, standardizing this method is relatively difficult, as one has to rely upon the availability of appropriate trees to mount the cameras on.

4.3.2. Event visibility and estimation

Nest building.
Nest building is usually a permanent manipulation of the nest that can be seen in several consecutive pictures. This allows for the event to be recorded even if the actual installation of the branch or material was not captured. Only one of the 896 photographs indicating nest building, displayed an actual delivery of material by an adult eagle. Nest building events are most elusive during the nestling period. Movement by adults and chicks stir the branches on the nest making new additions blend in with the constantly moving formations of branches. Nest building visibility tends to improve in the later stages of the breeding season. Figure 10 indicates a lowered level of nest building activity in July and August. Furthermore, the green branches from the more intensive nest building weeks prior are starting to turn

brown. This combination leads to a mostly brown nest, making new branch additions easily detectable, see Figure 12.

Figure 12. A nest building event. Notice the lone green branch addition to the right of the chick.

Incubation start – Egg laying.

The initiation of incubation was a clearly visible event. Normally the breeding couple could only be seen sporadically in pictures prior to incubation. Once the female started incubating, she became very stationary and present in all but a few pictures. This distinct shift was easily observed. However, while the incubation posture of the incubating adult is easily detectable, egg laying is not. This is mainly due to the covering posture of the adult. Furthermore, a widely accepted time period for incubation of an empty nest prior to egg laying mentioned in (Ellis, 1979), could not be found in the literature. Therefore, this easily distinguishable incubation posture was used as the event indicator for egg laying.

Figure 13. Successive pictures showing incubation start.

Incubation end - Chick ageing

Incubating adults remain in the incubation posture post hatching (Ellis, 1979) shielding the event from the camera. This often makes the event difficult to observe directly even with sufficient camera angles. If the event is hidden, the observer must rely on calculations based on chick plumage for incubation end estimations. However, ability to estimate chick age based on plumage development may differ between individuals due to varying visibility and chick positioning.

Incubation end - Hatching

As demonstrated in Figure 6, hatching can also be highly visible if photographs occur during a pause in incubation. Observations made by (Ellis, 1979) indicate that hatching occurs in a few hours, making the time estimation very precise compared to plumage estimations that gives an estimated age in day intervals (Watson, 2010).

Chick death

As long as the camera angle allows a clear view of the whole nest bowl, chick death events are clear and distinct. In the cases when the event occurred during a period of intense adult shielding, the movement of the shielding adult allows for the more stationary chick carcass to be identified.

Fledging.

Since the chosen definition of fledging is when the chick leaves the nest voluntarily for the first time (Steenhof et al., 2017), it is beneficial if the whole nest is monitored. When a nestling is missing in photographs only partly covering the nest, fledging can only be assumed when consecutive pictures support the assumption. As a result, a returning fledged chick might falsely be identified as having been out

of the frame and remains classified as a nestling and not a fledgling, as defined in (Steenhof et al., 2017). One camera in this study with adequate viewing angles and distance to the nest, recorded over 200 returning chick events. This suggests that attempting to determine the fledging events of that same nest with a less ideal camera angle would be very troublesome. This would presumably have resulted in an overestimation of fledging age and also fledging date.

Since the fledged chick may return repeatedly for a prolonged time (Ellis, 1979, Watson, 2010), time-lapse photography may fail to capture the exact time of fledging. A returning fledgling may be falsely identified as a nestling due to lack of continuous data (Watson, 2010), because its first flight happened within the interval between photographs. By using motion activated cameras instead, (Harrison et al., 2019) reported the ability to have been able to assess exact date and age for fledging chicks. However, if the goal is primarily about the approximate general knowledge of the event, then my estimates are rather robust due to a reasonably good sample size (n = 64).

Returning chick sighting

The presence of a returning chick is usually easily detectable provided that the visibility is adequate. The chicks plumage differs substantially from adults aiding in identification (Tjernberg and Landgren, 2010). However, separation between individual chicks is very hard due to the few pictures and lack of identifiable patterns. Furthermore, as discussed with fledging, time-lapse photography may simply fail to capture visits due to unfortunate timing and poor viewing angles.

4.4. Camera traps as monitoring tools

Remote cameras have been widely used to obtain valuable data about breeding ecology in raptors (Harrison et al., 2019, Kristan et al., 1996, Lopez-Lopez and Urios, 2010, Maphalala and Monadjem, 2017, Martinez et al., 2006, Reif and Tornberg, 2006, Vali, 2018), phenology of remote bird species (Black et al., 2017, Hinke et al., 2018) and linkage between climate, plant phenology and animal phenology (Hofmeester et al., 2020). Naturally, the method of using camera traps for monitoring also comes with disadvantages. These drawbacks are important to consider when deciding whether camera traps are suitable for collecting the desired information. However, if the study is designed appropriately, there are numerous possible benefits from incorporating camera traps in one's research.

4.4.1. Drawbacks of using camera traps

(Hinke et al., 2018) described one of the major disadvantages to be the time investment required to analyze the substantial number of pictures recorded.

However, they also state that time spent analyzing cameras may still be substantially lower than corresponding effort to get the same data from direct field observations.

The mounted camera is a permanent manipulation of the nest surroundings throughout the breeding season. The potential disturbance of the breeding couple must be considered to prevent harmful effects on chick attendance or investigator effects (Harrison et al., 2019). Mechanical failure and power supply demands of cameras is also important to consider (Lopez-Lopez and Urios, 2010, Maphalala and Monadjem, 2017). For cameras that are not maintained during the breeding season, mechanical failures are impossible to fix during ongoing monitoring (Lopez-Lopez and Urios, 2010) with resulting data loss (Maphalala and Monadjem, 2017). Furthermore, the available power supply may restrict monitoring periods (Lopez-Lopez and Urios, 2010) and result in increased disturbance from battery changes (Maphalala and Monadjem, 2017).

Lastly, the limited visual range of cameras may prevent detection of objects or events occurring in the vicinity but outside the cameras field of view (Black et al., 2017). Time-lapse cameras add one additional dimension to this drawback by adding the risk of mistiming between event and photograph. This means that even if an event occurs within the field of view, the camera might be in a dormant state, thus failing to capture the event.

If a study aims to investigate sudden events that start and end within a short time interval, time-lapse cameras such as the ones used in this study may therefore be unsuitable. The main reason is that there is only a slim chance that said event coincides with the hourly photograph. A suitable example is nest building. In this study, if the event instead had been defined as the direct observation of an adult eagle arriving with nest material to the nest, which I estimate would be an event occurring within a short window of time, only one of the 896 nest building observations would have been registered as a nest building event, see 4.3.2. However, as discussed for fledging event visibility, using motion-activated nest cameras could potentially minimise this weakness (Harrison et al., 2019).

4.4.2. Possibilities of using camera traps in raptor research

My ability to view or estimate all chosen phenological events exclusively from camera trap photographs demonstrate the usability of camera traps in raptor research. Compared to direct observations of events, cameras allow for a more objective approach and pictures can be repeatedly analyzed by researchers to address many different aspects (Reif and Tornberg, 2006).

Camera traps can also provide environmental information (Hofmeester et al., 2020) e.g. snow arrival, snow melting, temperature and weather, all of which were attainable from the cameras in this study. This information can provide further insight to potential causes of observed events. For example, (Dahlén, 2019 Master

thesis) used camera measured temperatures and visible weather to explain an incident of Golden Eagle chick mortality. Additionally, (Melin, 2020) investigated how the food delivery rate to the Golden Eagle chicks varied during the breeding season and tested the hypothesis that if parents incite fledging of offspring by reducing food delivery.

Nest visits by other species can also be studied and interspecific interactions can be observed. In this study several other species visited Golden Eagle nests post breeding, including Eurasian Jay (*Garrulus glandarius*), Siberian Jay (*Perisoreus infaustus*) and European Pine Marten (*Martes martes*). Interspecific interaction was also observed in one instance involving repeated visits by an Eurasian Jay, see Figure 14.

Furthermore, (Hofmeester et al., 2020) showed how motion-activated and time-lapse photography can be captured concurrently using the same device. This allows objects and events whose identification benefits from either technique to be monitored by the same unit.

To conclude, camera traps provide researchers with cost efficient (Hinke et al., 2018), accurate (Harrison et al., 2019) and diverse (Hofmeester et al., 2020) data that can be further supplemented with other methods such as GPS tracking to fully cover the breeding season of raptors (Vali, 2018) and other aspects of their biology and their ecosystem.

Figure 14. Interspecific interaction between Eurasian Jay and Golden Eagle nestlings.

4.5. Conclusion

Time-lapse camera traps in Swedish Golden Eagle nests allowed for key events in breeding phenology to be estimated for the whole breeding season. Some nests could be monitored continuously for almost one full year. Full season monitoring can provide more detailed phenological estimations because variation and accuracy can be adjusted with directly observed events in conjunction with traditional estimations based on known phenological intervals. This method is relatively cheap, less intrusive and has immense potential to be used for monitoring interannual phenological trends as well as demographic parameters and their variation for the Swedish Golden Eagle population. A species which is formally protected and managed based on a national level management plan. Moreover, such data can be effectively used for investigations on how different factors such as climate and land-use change, affect Golden Eagle phenology.

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