Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Wildlife, Fish, and Environmental Studies

Population ecology of golden eagles (Aquila chrysaetos) using remote cameras

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Master´s thesis • 60 credits

Management of Fish and Wildlife Populations
Examensarbete/Master's thesis, 2019:14
Umeå 2019

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Credits:	60 credits
Level:	Second cycle, A2E
Course title:	Master Thesis in Biology, A2E – Management of Fish and Wildlife Populations – Master's Programme
Course code:	EX0935
Programme/education:	Management of Fish and Wildlife Populations
Course coordinating department:	Department of Wildlife, Fish, and Environmental Studies

Place of publication:	Umeå
Year of publication:	2019
Cover picture:	From camera traps
Title of series:	Examensarbete/Master's thesis
Part number:	2019:14
Online publication:	https://stud.epsilon.slu.se

Keywords:	Golden eagle, camera traps, demographic parameters, fledging parameters, survival

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Abstract

The golden eagle populations have been studied across their range but basic demographic information is missing for a large part of their range. As an apex predator and scavenger, eagles are essential to the ecosystems they inhabit. In this study I analyzed pictures from installed camera traps around eagle nests in six counties in Sweden. In 2017 and 2018 a total of 182,249 pictures were taken by 53 cameras. The project aims to establish demographic parameters for the Swedish golden eagle population. In my visual analyses I extracted 20 variables that were important to my aims. In order to do so I created two groups for the young: Chick1 (the older) and Chick2 (the younger). I used this classification to estimate productivity, chick survival, fledging age and timing. The monitoring of chicks started at a minimum median age of 33 days and a maximum of 73, within the Chick1 with a mean(±sd) value 52(±12) days and Chick2 52(±6) days. The average day of the year to fledging was day 200 (in Julian day) which is equivalent to the 18th July for Chick1 and day 199 which is equivalent to the 19th July for Chick2. The chicks fledged with a minimum age of 71 days and a maximum of 96 days within the mean(±sd) fledging age value of 84(±6) days for Chick1 and 85(±5) days for Chick2. The survival rate among the monitored chicks was 0.952 (± 0329 and 95% CI 0.890 – 1) with only two known losses.

Key words: Golden eagle, camera traps, demographic parameters, fledging parameters, survival

List of Acronyms

CT – camera trap

PFDP - Post Fledging Dependence Period

Terminology

Terminology adapted from Steenhof *et al.* (2017)

Nesting site – specific location of the nest

Nesting territory – closed territory containing nests, with no more than one pair breeding at a time, usually in successive years

Occupied nest – a recently decorated or repaired nest with a mated pair in the area, or incubating, or eggs as well as youngsters

Territorial pairs – pairs which defend their territory

Egg-laying pair – pair which laid at least one egg in the given year

Territorial pair that does not breed (Non-laying pairs) – pair that does not lay at least one egg in a given year although they built or repaired a nest

Successful pairs – pairs where a minimum of one youngster reaches 80% of the average actual fledging age

Unsuccessful pairs – pairs whose offspring does not reach 80% of the average actual fledging age

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Fig. 2 - Pictures used as a guide for age determination. Chick A= 44 days, stands steady, underparts still predominantly down covered and, in the back, and wings, the dark contour feathers are prevalent over the white down (visible in the sequence of the pictures); B= 53 days dark feathers start to emerge in the head.

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1.0 Introduction

The golden eagle is a long-living raptor with sexual dimorphism, delayed maturity and low reproductive rates (Newton 1979, Brown and Amadon 1968 as cited in Steenhof 1983, Watson 2010). The species is highly adapted to a wide range of habitats and climatic zones. They use cliffs and tall trees as nesting places (Watson 2010). The common clutch has two eggs although one egg is frequent and three eggs comparatively rare (Newton 2010).

In Sweden, golden eagles occur dominantly in the northern boreal forest. In the south the densities are low, except for the island of Gotland, which has a unique high-density population (Tjernberg 1981, Tjernberg 1983, Watson 2010, Moss 2016). Protected by law throughout Europe, the golden eagle is red listed in Sweden (ArtDatabanken 2015) and has a national level management plan (Nilsson *et al.* 2018).

The Swedish Golden Eagle group (Kungsörngruppen) annually conducts an inventory to report the breeding performance of golden eagle pairs by numbers of successes and failures in reproduction and territory occupancy for known and any newly discovered territories. This monitoring group is comprised of citizens, some scientists and experts with additional help from County Administrative Board staff of the respective counties (Moss 2011, Daouti 2017, Nilsson *et al.* 2018). In each monitored territory, known nests are observed from the beginning of the breeding season on February. Nests with confirmed breeding activity and presence of eggs are visited to confirm chick presence, to ring the offspring's and to report the number of chicks born (Nilsson *et al.* 2018). The used methodology is documented in the "NFS 2014:23 - Naturvådsverkets författningssamling" (2014) with activities focused on breeding parameters as requested by the EU population status metric (Nilsson *et al.* 2018).

Studies using camera traps have rapidly grown over the last decades, making this to become a method of choice in ecological research (O´Connell *et al.* 2007). From 1996 onwards, camera traps have already been used to estimate numbers, densities, population growth rates, survival, recruitment and, movements as well as activity of diverse species (Karanth 1995 and Karanth and Nichols 1998 and O´Brien *et al.* 2003 and Silver *et al.* 2004 as cited in Kucera and Barret 2007). The use of camera traps in population monitoring, is most often concentrated on terrestrial mammals' species with some exceptions as studies on owls (Jachowski *et al.* 2015, Kouba *et al.* 2015, Väli 2018).

Selected studies have revealed information about habitat selection (Steenhof and Newton 2007, McIntyre and Schmidt 2012), reproduction (Steehof *et al.* 1997, Morneau *et al.* 2015, Shafaeipour 2015, Daouti 2017, Steenhof 2017), population fluctuation according to prey availability (Tjernberg 1981, Moss 2011), existing threats (Whitfield *et al.* 2004, Watson 2010), survivorship (McIntyre *et al.* 2006, Harmata *et al.* 2018, Crandal *et al.* 2019), migration and dispersal (Weston *et al.* 2018). Population fluctuations of raptors are often influenced by the breeding process (Steenhof *et al.* 1997), offspring development, and parental care (Collopy 1984, Karell *et al.* 2008). Other factors influencing the population growth of the golden eagle include fledging and post-fledging movements (Johnson *et al.* 2004, Soutullo *et al.* 2006), as well as food supply (Tjernberg 1981, Tjernberg 1983, Collopy 1984, Moss 2011, Moss 2012, McIntyre *et al.* 2006). Despite this understanding, information on age-specific survivorship, date and fledging age of chicks, reproductive rates, natural and anthropogenic factors affecting demographic parameters, are still understudied.

Estimation of age is a challenge for many bird species. Some methodologies are based on nestlings' measures like primary growth, weight curves, and the 4^{th} primary feather length (Peterson 1977). Plumage photography (Driscoll 2010, Steenhof 2017) has also been used although it can be criticized as being subjective. However, the sequence of photography can create the possibility of distinguishing not only the plumage differences but also the behavior.

Fledging, the process of leaving the nest, is a transition to a different life stage from nestling to post-nestling, where it is important for raptors to acquire the necessary physical and behavioral experiences in order to survive and mature sexually (Newton 1979, Bustamante and Hiraldo 1989, Bustamante 1993).

Most studies reporting the length of nestling periods and fledging dynamics come from passerine birds. Only few studies have evaluated these for raptors (Karell *et al.* 2008, Kouba *et al.* 2015). Moss *et al.* (2014) studied the post-fledging period movements in a Swedish golden eagle population, registering the movements of the young after they left the nest but did not estimate the fledging dates. Some studies as Cramp and Simmons 1980, Collopy 1984, O´Toole *et al.* 1999, Watson 2010, Shafaeipour 2015, Walker 1987 as cited in Soutullo 2016 and Steenhof *at al.* 2017, indicate the fledging age for golden eagles with a variation from 55 to 80 days. Moreover, the identification of the primary cause of death and survival probability are essential aspects in the species ecology and the survival rates of golden eagles are known to vary among different age classes (Harmata 2002).
In this pilot study, I assessed the potential of camera trap as a methodology for the monitoring of the Swedish golden eagle population especially in context of estimating demographic parameters, as camera trapping has not often been used for this purpose for raptors. The second objective was to quantify fledging parameters of age as well as the date of fledging, and chick survival.

2.0 Materials and methods

2.1 Study area and data acquisition

The study area lies in the counties of Norrbotten, Västerbotten, Västernorrland, Jämtland, and Dalarna in north and central Sweden. Fifty-three camera traps (Snapshot Mobil Black 5.1 Döerr) were installed close to the nests in the study areas during the years 2017-18. These cameras represent 41 nests / territories. Often a single territory can contain more than one nest (Newton 1979, Watson 2010; Brown and Amadon as cited in Kochert and Steenhof 2012). The cameras were set to take a picture every hour. The sites were selected based on prior knowledge during the annual golden eagle monitoring. In both years, the cameras were randomly installed within the known set of territories and in some nests where breeding was known.

I counted the death events from the first camera monitoring days until the juveniles abandoned the nest and also identified the causes of death. This data gave the opportunity to calculate the survival probability for the juveniles during the monitoring period.

2.2 Process of age the nestlings

The aging of the nestlings was based on an age guide created by pictures and information from four to five weeks old individuals monitored by one of the golden eagle project co-workers. The individuals were allocated to age classes pre-established according to plumage, development and physical changes by day of life (Newton 2010). Descriptions of nestling characteristics by Peterson (1997) and Watson (2010) were taken into consideration for accurate estimation of age. The age identification is based on differences regarding body development, morphology, color of the feathers and behavior (Figures 1, 2, 3, 4 and 5). Dark feathers emerge and grow within 25-60 days of age (Newton 2010). The difficulty to estimate the precise age of a nestling increases from about 50 days of life as the daily changes in the plumage are difficult to notice, or the timing for these changes can be affected by the youngster's condition (Mathieu 1985 in Watson 2010). The sequence of images provides the visualization of the subtle changes of the individual and thereby increases the credibility in the methodology of aging by visual analyses.

Fig. 1 - Pictures used as a guide for age determination. Both chicks have talons already black, feet and cere already yellow bright, and covers already emerging from the sheaths (these changes were clear by the sequence of pictures). For both young's the age was informed by the person who ringed them. A= 32 days; B= 34-35 days.

Fig. 2 - Pictures used as a guide for age determination. Chick A= 44 days, stands steady, underparts still predominantly down covered and, in the back, and wings, the dark contour feathers are prevalent over the white down (visible in the sequence of the pictures); B= 53 days dark feathers start to emerge in the head.

Fig. 3 - Pictures used as a guide for age determination. From 60 to 70 days of life, the chick still shows some down in the body (possible to see in the sequence of pictures). The white band on the tale becomes to be more visible, and the head each day browner. A= 64 days; B= 68 days.

Fig. 4 - Pictures used as a guide for age determination. From 70 days of life, the daily changes in youngsters are almost inconspicuous. Following a picture sequence, the feathers' growth and the change in the colors and behavior can be perceived. I based the 70 to 75 days aging determination on the perception that the young have no more the 60-70 days old characteristics (still some down been visible and the form of the white band in the base of the tail is not fully visible). A= 70 days; B= 80 days.

Fig. 5 - Pictures used as a guide for age determination. After 75 days, to determine the age visually is only possible following chick life history. A= 84 days, B= 90 days.

2.3Data Analysis

In total, 182.249 images were extracted from two years of monitoring by 53 cameras. The number of pictures varied for each nest according to the installation date of the cameras and recovery of the memory cards (Figures 6 and 7).

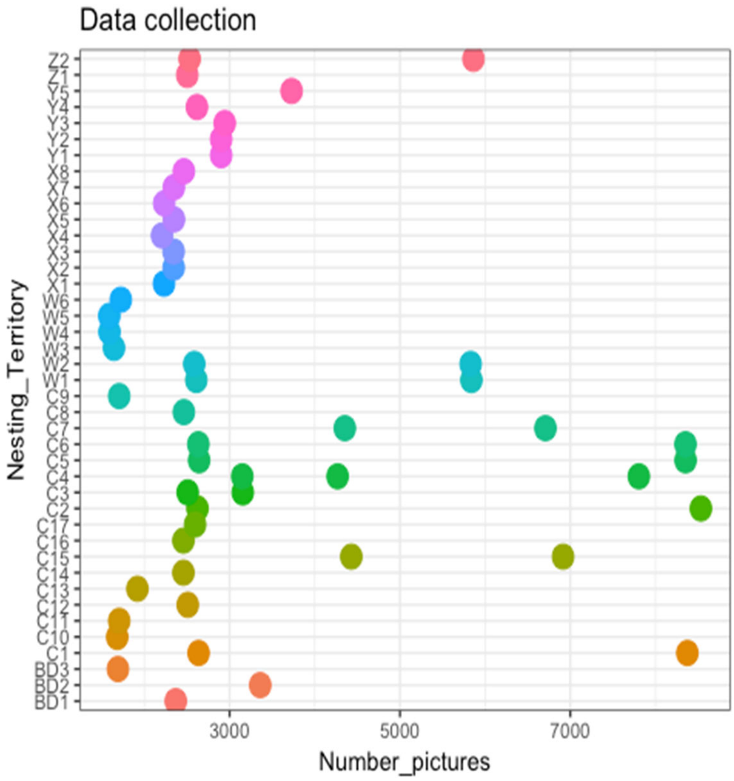

Fig. 6 - Number of pictures analyzed in each nesting territory. The nesting territories are here represented by codes for each county (AC=C, BD=BD, W=W, Y=Y and Z=Z).

County	date (interval) of camera installations - 2017	date (interval) of camera installations -2018
AC	06-06 to 25-06	17-06 to 02-07
BD	-	15-06 to 25-06
W	16-06 to 17-06	09-06 to 15-06
X	-	15-06 to 30-06
Y	-	12-06 to 05-07
Z	19-06 to 20-06	No offspring monitored

Fig. 7 - Camera installation date in each county with interval between the first picture and the last one.

The nesting sites were distributed in six counties with a sample size as follows; Norrbotten (BD, n=3), Västerbotten (AC, n=25), Jämtland (Z, n=3), Västernorrland (Y, n=5), Dalarna (W, n=8) and Gävleborg (X, n=8). The number of samples refers to nesting territories monitored by cameras for two years, while others where only monitored for one year (Figure 8).

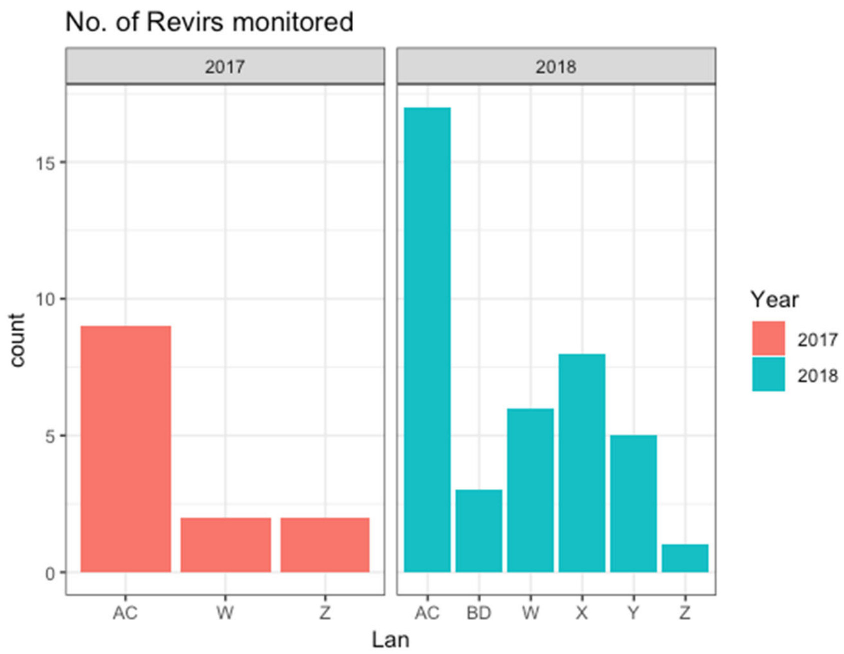

Fig. 8 - Number of territories monitored in each county per year (Lan = County).

From the pictures', through visual analyses 20 variables were extracted. As indicated in the analysis, nestlings were named as Chick1 and Chick2 based on which one hatched first.

The data analysis was performed using RStudio 3.5.2. The variables carrying the information of the pictures were handled for extraction of useful values such as nestlings number, fledging parameters, and survival by county. The packages zoo, dplyr and ggplot2 were used to create the graphs of the analyses.

Of the 53 territories, 42 were used to obtain the survival number, fledging age and fledging time since ten samples had no chicks and one nest was monitored by two cameras with the images being handled as one sample.

I allocated individuals into age groups and later used the median age for the statistical analyses. The fledging date was considered as the day the youngster was not observed in the nest for successive pictures (Watson 2010, Steenhof and Newton 2007) (Figures 9 and10). I calculated the fledging age as the time span between the hatching day and the day when the chick was absent from the nest.

Fig. 9 - Sequence of pictures from the Chick2 fledging day (one hour between pictures). A= older chick back to the nest after having fledged, B=older chick left the nest again, C= younger chick fledged, D= younger chick back to nest.

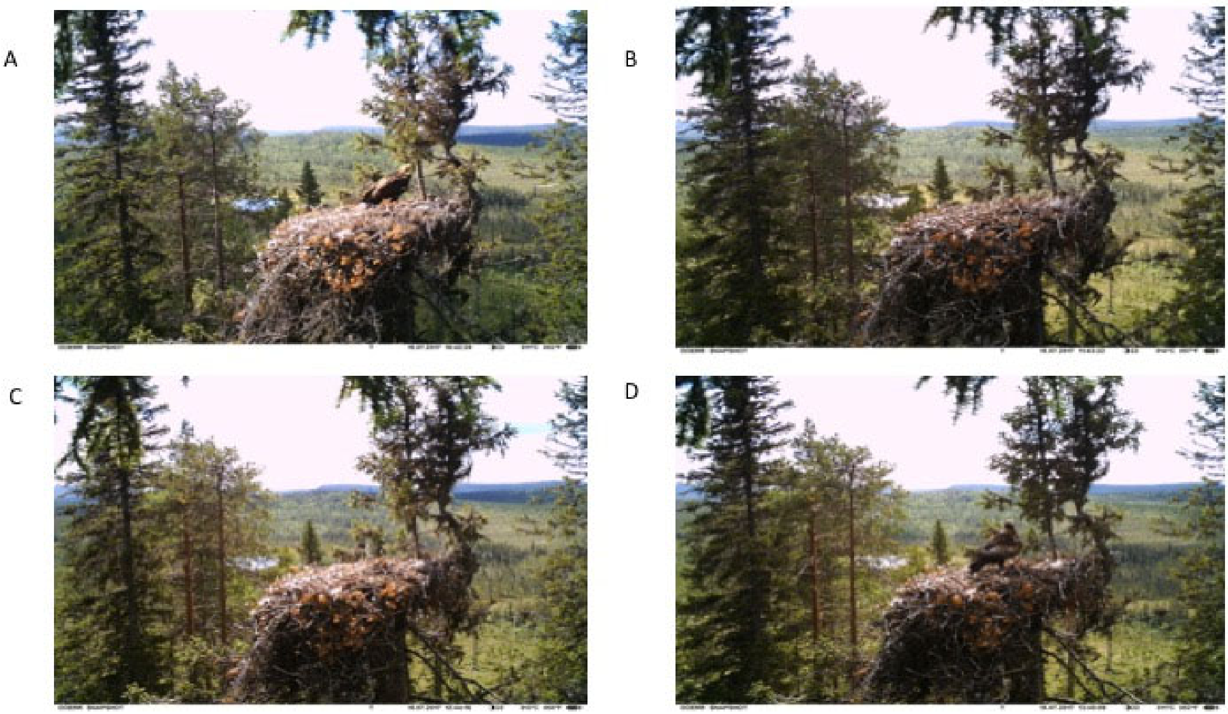

Fig. 10 - Sequence of pictures from the Chick1 fledging day (one hour between pictures). A= chick in the nest, B=chick fledged, C= chick still out, D= chick back to nest.

I used Spearman's rank correlation for analyses between fledging parameters. For further understanding I used the generalized linear model (GLM) to analyze correlations in each county for both group of young. The survival analyses were done using 'survival' package and the Kaplan-Meier estimator with non-parametric statistics

3.0 Results

3.1 Monitoring

3.1.1 Pictures

In 2018 the number of counties in which monitoring by cameras was conducted increased to six in comparison to the prior year, where only three participated. The number of cameras also considerably increased (2017 n=18, 2018 n=53) (Figure 11).

The number of nesting territories monitored in 2017 was 13 and 40 in 2018.

County	Territories 2017	Territories 2018	Total territories	No. of Pictures
AC Västerbotten	8	17	17	106,926
BD Norrbotten	0	3	3	7,417
W Dalarna	2	6	6	23,407
X Gävleborg	0	8	8	18,512
Y Västernorrland	0	5	5	15,090
Z Jämtlands	2	1	2	10,897

Fig. 11 - Number of nesting territories monitored, and the total pictures analyzed by county.

3.1.2 Nestlings

The total number of nestlings in 2017 was 15 and 37 in 2018. In the nesting territories from both years was found nests with one chick, two chicks and some with no chicks (Figures 12 and 13).

	2017						2018					
No. nests No. Chicks	AC	BD	W	X	Y	Z	AC	BD	W	X	Y	Z
0	0	0	0	0	0	0	7	0	2	0	0	1
1	6	0	1	0	0	2	7	2	4	7	3	0
2	2	0	1	0	0	0	3	1	0	1	2	0

Fig 12 - Number of nests with 0, 1 or 2 chicks in each county per year.

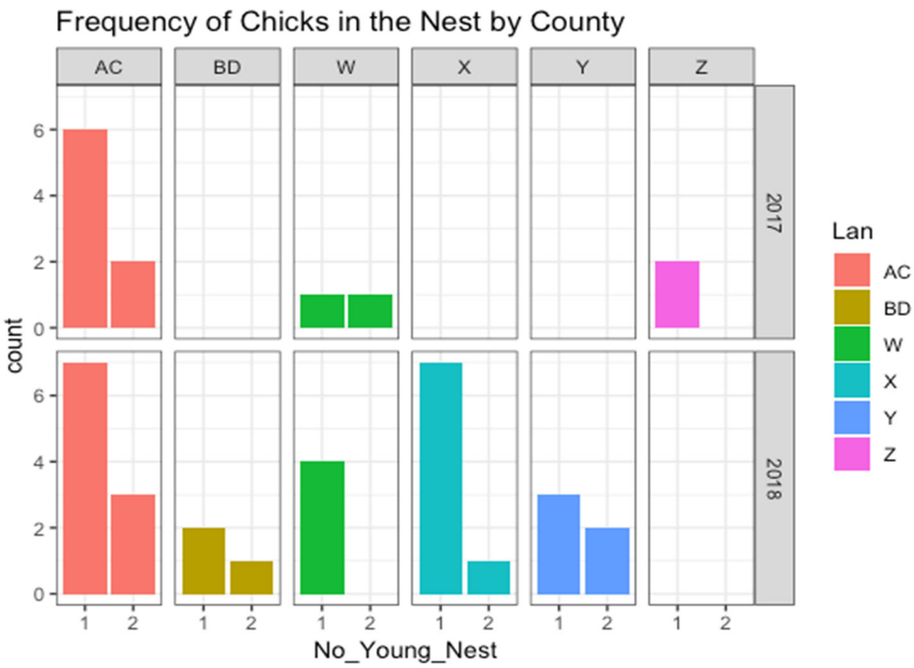

Fig. 13 - Frequency of chicks in each county per year (Lan = County).

3.2 Age distribution

The chicks' estimated age during the first recorded day of each camera image resulted in 9 age groups. (30-35, 35-40, 40-45, 45-50, 50-55, 55-60, 60-65, 65-70, 70-75). The lowest age group represented by the images was 30-35 (median age = 33) days and the highest 70-75 days (median age =73) (Figures 14, 15 and 16).

	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75
Chick1	2	3	5	4	10	11	5	1	1
Chick2			1	3	3	2	1		

Fig. 14 - Frequency in each age class for both Chick groups.

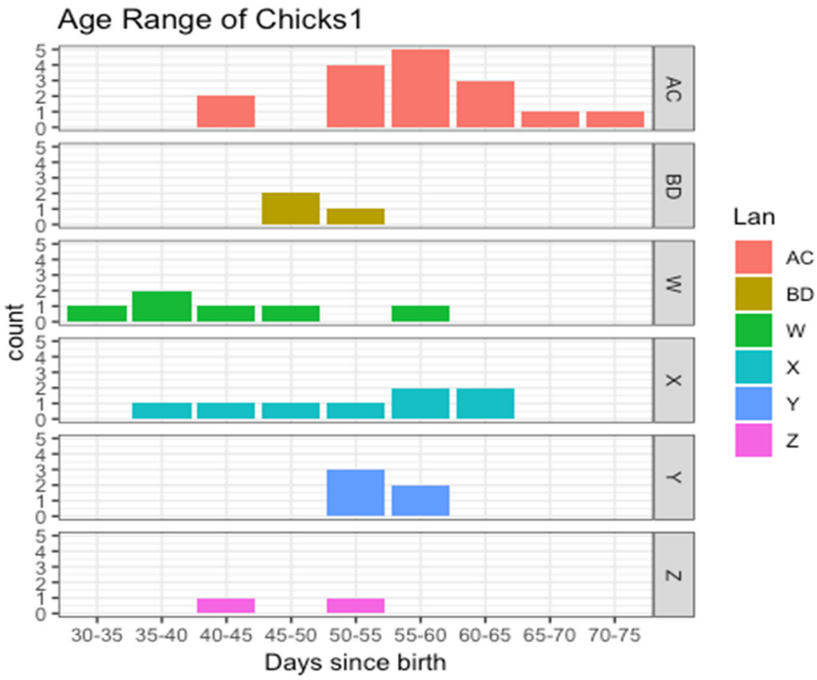

Fig. 15 - Frequency of individuals (Chick1) in each age group by county (Lan = County).

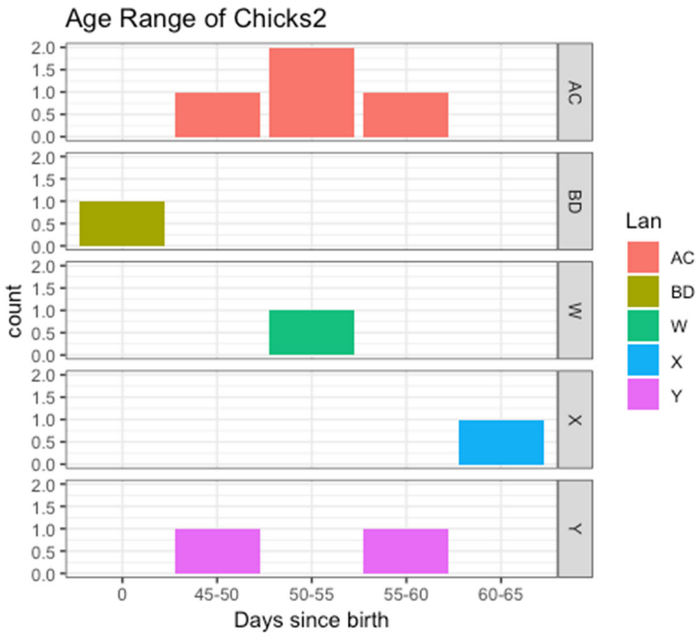

Fig. 16 - Frequency of individuals (Chick2) in each age group by county (Lan = County).

The highest proportion of nestlings was in the groups from 50-55 to 60-65 days (Figures 17, 18 and 19).

	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75
Chick1	0.07	0.05	0.10	0.10	0.24	0.27	0.12	0.02	0.02
Chick2			0.1	0.3	0.3	0.2	0.1		

Fig. 17 - Proportion of chicks represented in each age class.

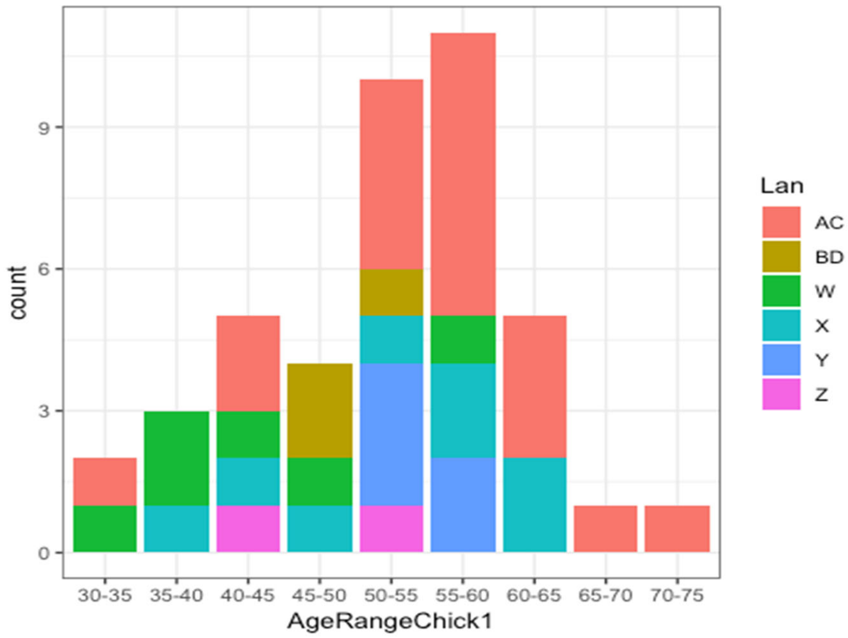

Fig. 18 - Proportion of Chick1 represented in each age class (Lan = County).

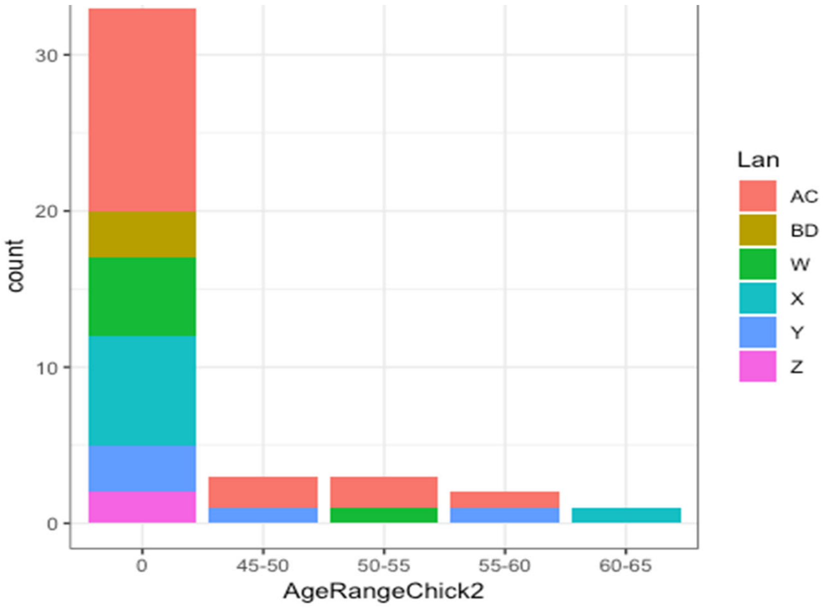

Fig. 19 - Proportion of Chick2 represented in each age class (Lan= County).

Both Chick1 and Chick2 had the median age of 53 days. The differences in median age by county were estimated (Figures 20 and 21).

County	Median age Chick1	Median age Chick2
AC	58.0	53.0
BD	48.0	43.0
W	40.5	53.0
X	55.5	63.0
Y	53.0	53.0
Z	48.0	NA

Fig. 20 - Median values for age in each county for both Chick groups separately.

The age for chick1 has a mean(±sd) value of 52(±12) days and chick2 52(±6) days.

County	Mean (±sd) age Chick1	Mean (±sd) age Chick2
AC	53(±16)	52(±4)
BD	50(±3)	43
W	43(±9)	53
X	53(±9)	64
Y	55(±3)	53(±7)
Z	48(±7)	NA

Fig. 21 - Mean(±sd) values for age in each county for both Chick groups separately.

3.3 Fledging parameters

3.3.1 Fledging date

The fledging date analyses to the total studied population (n=51) (in Julian-day) reveal a mean (±sd) date 200 (±12) for Chick1 and 199 (±15) for Chick2. Chick 2 on average fledged on day 18th of July and Chick1 19th of July.

The mean fledging date varied between the counties and between the chick groups by county (Figure 22). Overall, the fledging dates were rather close between the chicks.

County	Median fledging date Chick1	Mean (±sd) fledging date Chick1	Median fledging age Chick2	Mean (±sd) fledging date Chick2
AC	199.0	202 (±8)	205.0	199 (±23)
BD	208.0	205(±5)	207.0	207
W	209.0	205(±10)	194.0	194
X	196.0	201(±14)	198.0	198
Y	183.0	186(±17)	196.5	196 (±13)
Z	197.5	197(±12)	NA	NA

Fig. 22 - Mean(±sd) values for fledging date in each county for both Chick groups separately.

The median fledging date by county reveals a large variation in the fledging dates, however the number of samples by counties has a large difference as well. (Figures 23 and 24).

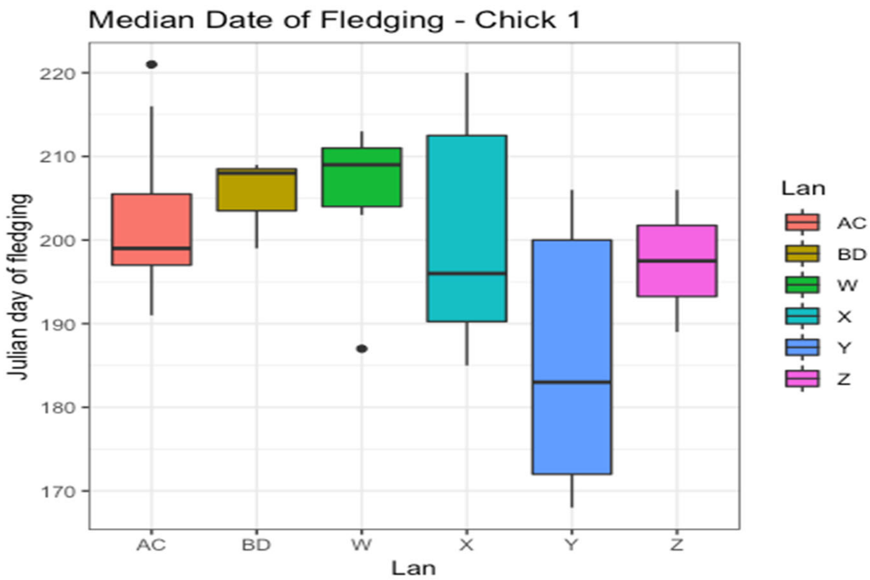

Fig. 23 - Median date of fledging for Chick1 in Julian-days (Lan = County).

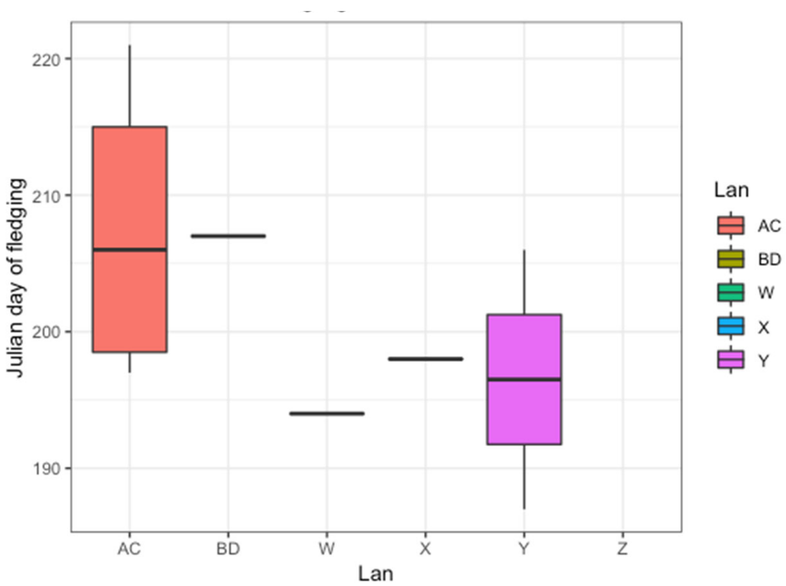

Fig. 24 - Median date of fledging for Chick2 in Julian-days (Lan = County).

3.3.2 Fledging age

The accuracy of fledging parameters identification as date and consequently age, relies on methodology to identify the exact moment of the first nest leaving movement. I identified these parameters for 41 nesting territories inside the six counties monitored by cameras.

The monitored nestlings fledged with a minimum age of 71 days after hatch and maximum of 96 days. The mean (±sd) fledging age of the Chick1 was 84 (±6) days and Chick2 85(±5).

The mean fledging age shows variation between the counties and between the chick groups by county. Even if there are counties that share the same mean value, they still have different variance (Figures 25, 26 and 27).

County	Median fledging age Chick1	Mean (±sd) fledging age Chick1	Median fledging age Chick2	Mean (±sd) fledging age Chick2
AC	86.0	85 (±4)	84.5	84(±2)
BD	81.0	85(±10)	84.0	84
W	83.5	84(±4)	80.0	80
X	86.0	85(±5)	95.0	95
Y	83.0	82(±9)	82.5	82(±6)
Z	75.0	72(±4)	NA	NA

Fig. 25 - Median and mean(±sd) values for fledging age in each county for both Chick groups separately.

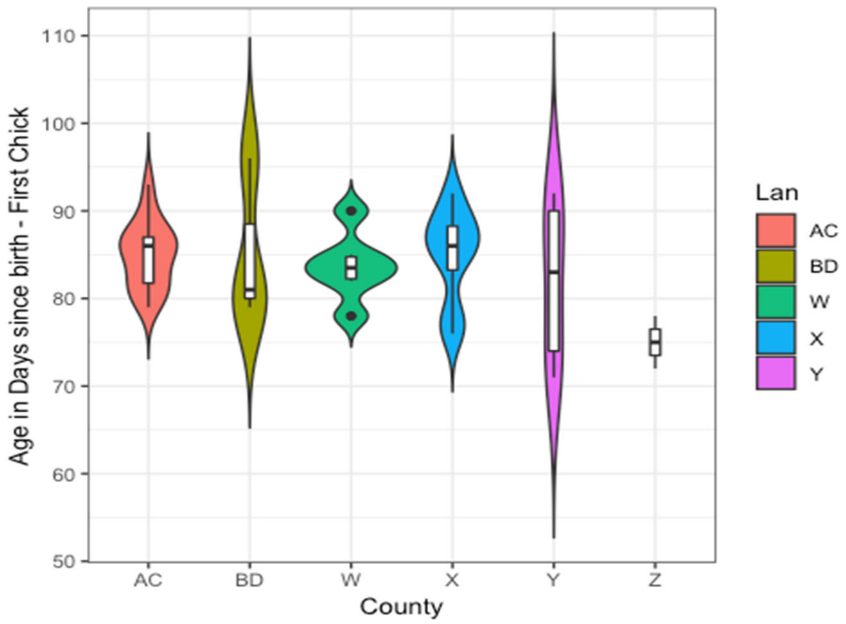

Fig. 26 - Mean fledging age for Chick1 by county. The age (in days of life) was estimated based on the first image (Lan = County).

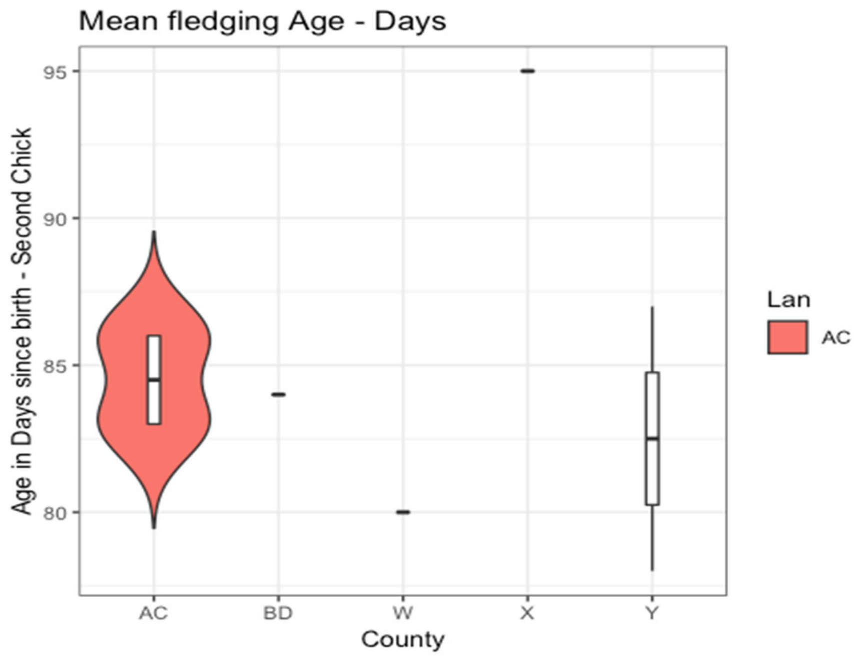

Fig. 27 - Mean fledging age for Chick2 by county. The age (in days of life) was estimated based on the first image (Lan = County).

The comparisons based on median fledging age show some variation between the counties (Figures 28, 29 and 30).

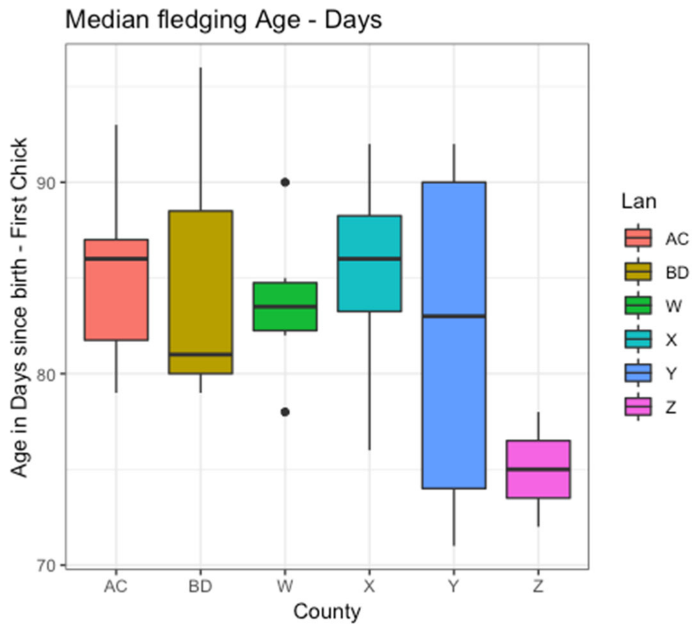

Fig. 28 - Median fledging age for Chick1 by county. The age (in days of life) was estimated based on the first image (Lan = County).

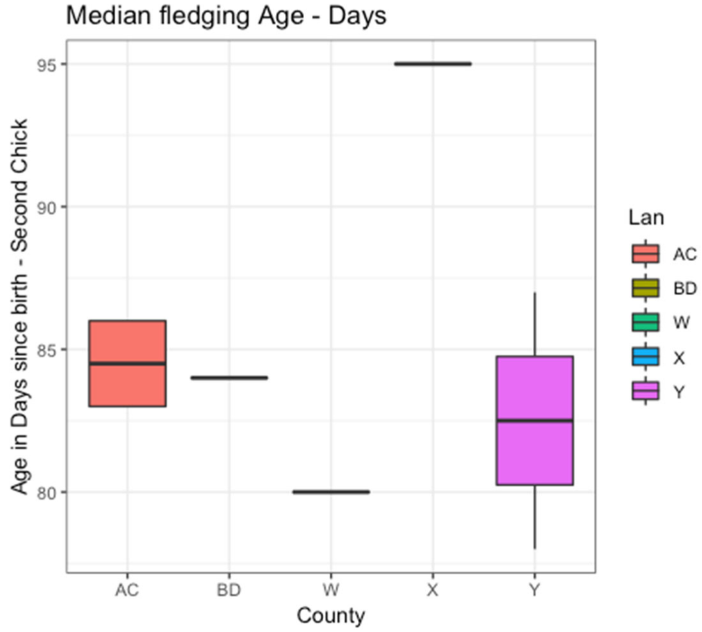

Fig. 29 - Median fledging age for Chick2 by county. The age (in days of life) was estimated based on the first image (Lan = County).

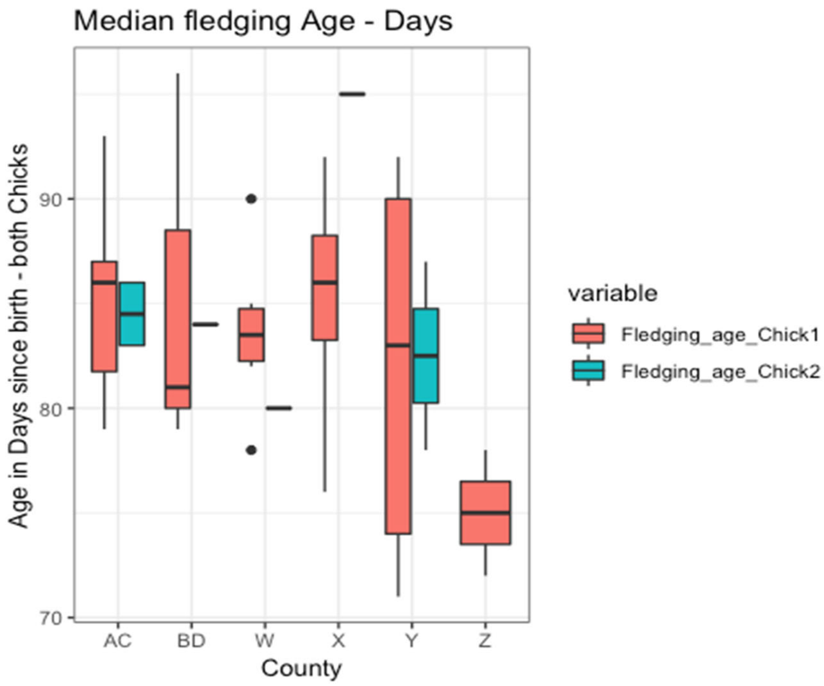

Fig. 30 - Comparison of median fledging age for both Chicks groups. The median values are based on the age of individuals in each county.

3.3.3 Fledging parameters correlation

The correlation between the fledging age and fledging date was tested with Spearman´s rank indicating a small correlation for Chick1 (rs [40] = .451, p = .003) and no evidence for Chick2 (rs [9] = .454, p = .220) (Figures 31 and 32).

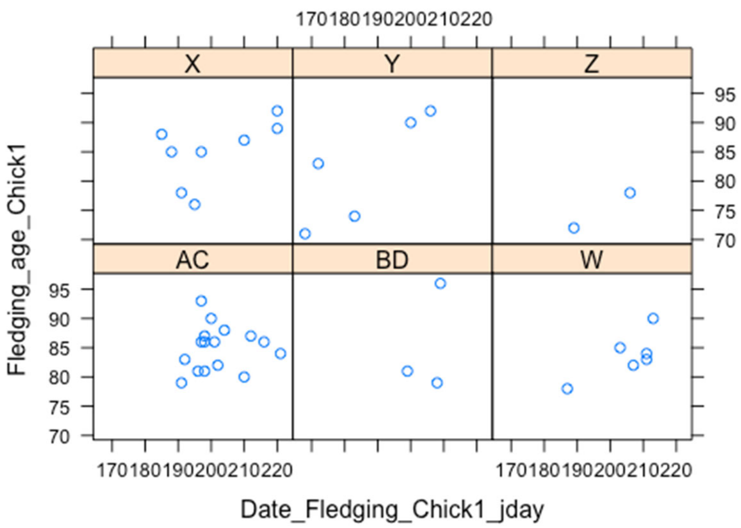

Fig. 31 - Plot of the fledging age and date of fledging correlation by county for Chick1.

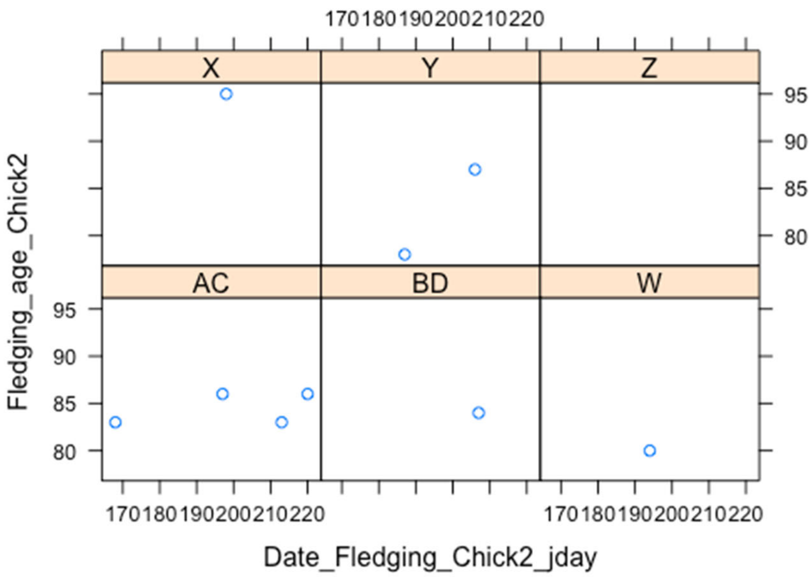

Fig. 32 - Plot of the fledging age and date of fledging correlation by county for Chick2.

For better indication of the fledging parameters correlation, the Generalized linear model was used for both groups Chick1 and Chick2 by the counties. The results for Chick1 indicated a correlation between the parameters for the county Y (Västernorrland), and for Chick2, no correlation was indicated (Figures 33 and 34).

	Estimate	Std.Error	t-value	Pr(>|t|)
Intercept	186.7684	55.7432	3.351	0.00232 **
Fledging Age Chick1	0.1801	0.6557	0.275	0.78562
CountyBD	-5.9807	84.0920	-0.071	0.94381
CountyW	-137.9494	107.5397	-1.283	0.21009
CountyX	-109.8405	79.7400	-1.377	0.17927
CountyY	-122.7969	70.1259	-1.751	0.09088.
CountyZ	-201.7684	179.7171	-1.123	0.27110
Fledging_age_Chick1:CountyBD	0.1076	0.9849	0.109	0.91380
Fledging_age_Chick1:CountyW	1.6906	1.2790	1.322	0.19693
Fledging_age_Chick1:CountyX	1.2767	0.9372	1.362	0.18397
Fledging_age_Chick1:CountyY	1.3057	0.8345	1.565	0.12891
Fledging_age_Chick1:CountyZ	2.6533	2.3688	1.120	0.27219

Fig. 33 - Generalized linear model for Chick1 relating the counties based in the CountyAC's values (Fledging Age Chick1 = CountyAC).
Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

	Estimate	Std.Error	t-value	Pr(>|t|)
Intercept	-307.500	711.843	-0.432	0.708
Fledging Age Chick2	6.000	8.423	0.712	0.550
CountyBD	10.500	28.563	0.368	0.748
CountyW	21.500	47.273	0.455	0.694
CountyX	-64.500	92.843	-0.695	0.559
CountyY	329.833	783.801	0.421	0.715
Fledging_age_Chick2:CountyBD	NA	NA	NA	NA
Fledging_age_Chick2:CountyW	NA	NA	NA	NA
Fledging_age_Chick2:CountyX	NA	NA	NA	NA
Fledging_age_Chick2:CountyY	-3.889	9.312	-0.418	0.717

Fig. 34 - Generalized linear model for Chick2 relating the counties based on the CountyAC's values (Fledging Age Chick2 = CountyAC).

3.4 Survival

The mean (±sd) survival in 2017(n=13) was 1.18(±0.40) and 1.24(±0.43) in 2018 (n=36), with only two deaths.

The difference between mean nestling and mean nestling survival was calculated for all counties bringing the same results except in AC (Västerbotten) (Figure 35).

County	Mean number of nestlings	Mean number of nestlings survived
AC	1.28 (±0.46)	1.25 (±0.45)
BD	1.33 (±0.58)	1.33 (±0.58)
W	1.17 (±0.41)	1.17 (±0.41)
X	1.12 (±0.35)	1.12 (±0.35)
Y	1.40 (±0.55)	1.40 (±0.55)
Z	1.00 (±0.00)	1.00 (±0.00)

Fig. 35 - Mean number of nestlings (±sd) and mean number of nestling survival (±sd) values by county.

The mortality (number of deaths, n=3) included dead individuals and a lost camera. The probability of survival after the day one was 0.967 (± 0.0235 and 95% CI 0.931 - 1) and 0.952 (± 0.329 and 95% CI 0.890-1) after day 10 (Figure 36).

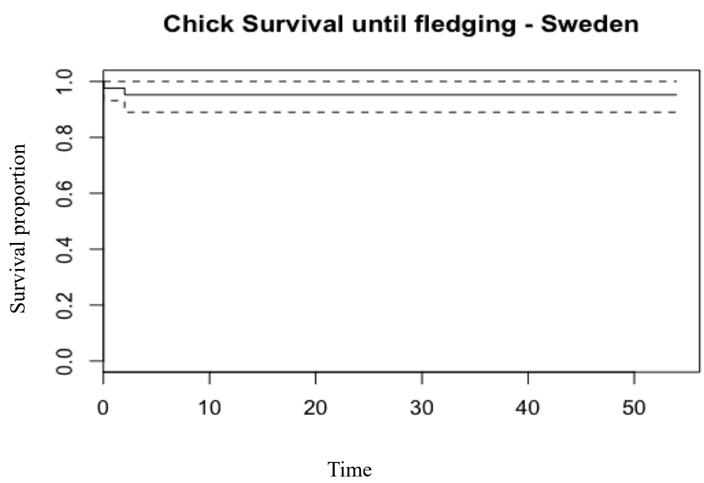

Fig. 36 - Survival curve from the first monitoring day of the chicks until the fledging day. Based on Kaplan-Meier survival estimate.

4.0 Discussion

4.1 Monitoring

The understanding of the methodology and the observed potential of generating a better quality of observations and information resulted in an increased interest in the use of images with a significant increase in the number of camera traps between 2017 to 2018. The images obtained from the cameras contained information about individual development, behavior, survival until the fledglings left the nest, among others.

During these two years of monitoring, most of the cameras were activated/installed during the ringing procedures. No register of pairing and egg posture was done. At the end of the 2018 season, the cameras were left active throughout the winter. Breeding season records will create the possibility to use the pictures in the productivity calculation for coming next seasons.

4.2 Age distribution

Both, the first and the second chicks had a median age of 53 days when the monitoring started. The age corresponds to the time the cameras were installed, around 6th June to 25th June in 2017 and 9th June to 5th July in 2018, most of the installations taking place in the middle of June. A common procedure of the monitoring group is to not disturb the chick before the fifth week of life (around 15th of June) to avoid the risk of some individuals falling down from the nest as a result of finding themselves in a stressful situation.

4.3 Fledging parameters

4.3.1 Fledging time

The delimitation of the fledging time in altricial birds suggests some hypothesis where the fledging is directly connected with the nestling development, morphology, and flight skills (Kouba *et al.* 2015). Little is known about the raptors' fledging dynamic. A study by Kouba *et al.* (2015) revealed that the fledging sequence between siblings follows the hatching order in Tengmalm's Owls with the first to hatch being the first to fledge. In my results, in some counties (AC, BD and Y), the younger chick fledged before the older one (mean Julian day Chick2< mean Julian day Chick1) (AC 199<202, BD 194<205 and Y 198<201 (Figures 19 and 20). The total number of nests with a second chick (n=10) were low compared to those with only one chick (n=32). The results possibly reproduced the high difference of samples for each group considering that in some counties I had only one chick2 (X, W and BD) as well as from the 10 individuals 9 survived of which 2 fledged before their older siblings.

4.3.2 Age of fledging

Diverse studies suggest a different range of the fledging age from 55 to 70 days (Steenhof *et al.* 2017), 63-70 days (Shafaeipour 2015) 65 to 75 days (Collopy 1984), 60 to 80 days (Cramp and Simmons 1980, Walker 1987 as cited in Soutullo 2006), 70 to 80 (O´Toole *et al.* 1999, Watson 2010). In Sweden, the monitored population's fledging age was ranging from 71-96 days. To determine the fledging age, a continuous observation protocol is required since the youngsters may frequently go back to the nest after fledging; this can subsequently bias the estimations as in some species of raptors, the young can keep using the nest as a feeding platform (Newton 1979). The pictures allowed a good view of the fledging moment providing a better accuracy for determining the age of each individual. The range of the fledging age can be explained with different theories. The low availability of food which creates a pressure for the offspring to reduce the nestling time (Johnson 2004); fledging begins when the specific development state is reached by the most developed nestling (Johnson 2004); competition between siblings regarding feeding necessity causing the less competitive and smaller juvenile to be the first to fledge (Lemel 1989). The quicker development of males can also be one explanation (Newton 1979). The extension of the period spent in the nest is also directly connected with the level of parental care and investment in reproduction success. Collopy (1984) observed a decrease of the food delivery during the last weeks of nestlings, suggesting parental strategy to encourage the fledging. This behavioral characteristic was identified in some of the nests I analyzed. In most images, I observed evidence of chicks training hunting methods by playing with the prey, through behaviors like jumping, catching, and immobilizing. Considering that youngsters in the fledging moment must already have some of the skills necessary in Post Fledging Dependence Period (PFDP), the extension of the pre-fledging period assure them higher chances of survival and success. Watson (2010) has observed prey availability as one of the possible reasons for a more extended nestling period.

4.3.3 Fledging parameters correlation

The fledging parameters were tested, indicating a correlation for the Y county (Västernorrland) only for the Chick1 group. The result can be a reproduction of the discrepancy in the number of samples between the counties. Other factors with a higher probability of influence in the fledging date as well as the fledging age as food availability, weather condition, and temperature can be analyzed using the same pictures, although with less influence of the counties' difference in sample number.

4.4 Survival

I observed two death events, both of them happening in 2017. The most common causes of death regarding chicks are disease or parasitism (Newton 1979), starvation, and a few cases of predation (Watson 2010). However, since the recovery of dead chicks is low, there is a lack of information on the death causes (Watson 2010).

One of the death events I observed was caused by a six weeks old chick was attacked by the older sibling (Figure 37).

Fig. 37 - Sequence of pictures from death event by cainism.

Some authors characterize siblicide as generally occurring in the first two weeks of life justified as a defense from starvation in situations of lack of food (Newton 1979, Watson 2010) being considered as a low influence factor in brood size reduction (Simmon 1988). Sibling aggression does not necessarily result in death (Williams 1981as cited in Simmons 1988, and Gargett 1982 as cited in Simmons 1988, Morandini and Ferrer 2015) but maybe a strategy of hierarchy (Simmons 1988). The dominance asserted by the oldest chick could be visually identified in the images, although I didn´t quantify it (Figure 38). Specific behaviors stating hierarchy were observed as being the first to eat when the prey was delivered, being the most active nestling, laying in the center pushing the other to the nest corners, as well as regularly laying closer or even on top of the pray. The interpretation of the images associating behavior with food delivery can test the affirmation whether golden eagles are siblicide in the absence of food shortage or not.

Fig. 38 - Pictures showing dominant behavior of the oldest chick.

Another cause of death of a 4 to 5 weeks old chick was due to exposure to rain and low temperatures (around 5°C) during the absence of the mother (Figures 36a and 36b). The temperatures in the two days before were around 14°C during the days and around 7°C during the evenings. The early morning of the death event (around 4 a.m.), the temperature dropped to 5°C when it starts to rain following all day and part of the night with the same weather condition. The last life signal of the chick was between 6 p.m. and 7 p.m. before the adult arrival.

Fig. 39a. - Sequence of pictures (one hour between the pictures) of death event by rain and low temperature.


Fig. 39b - Sequence of pictures (one hour between the pictures) of death event by rain and low temperature.

Environmental factors are known to influence the breeding success by influencing the egg laying date, incubation phase (Newton 1979, Village 1986 as cited in Steenhof *et al.* 1997), and early nestling survival (Newton, 1979, Steenhof *et al.* 1997). It has been proved that heat stress as low temperature can cause loss of young golden eagles from the third to sixth week of life (Mosher and White 1976 as cited in Steenhof *et al.* 1997).

Golden eagles' survival rates can vary in different ages and stages of life. Different factors may affect these rates such as behavior of subadults and breeders, the migration, and territory establishment (Harmata 2002, McIntyre *et al.* 2006, Crandal *et al.* 2019). The survival of juveniles is associated with environmental factors and parental care (Steenhof *et al.* 1997). In this study, the survival rate was stable around 95%, after the second death. No nests had pictures from the chick's first days of life as the monitoring started late due to logistical reasons. Perhaps, earlier monitoring could throw some light on the mortality during first days of life.

5.0 Conclusion

The use of camera traps for demographic monitoring of golden eagles holds a great potential for Sweden. This method can be used to complement the ongoing inventory to identify mortality and survival rates, which are currently missing.

The pictures showed valuable information among factors which influence the fledging parameters. These correlations are not explored well enough for most large raptors especially the golden eagle. The understanding of factors which trigger the fledging as well as the reasons which can delay or accelerate this has high importance for species ecology.

I identified several possibilities of new studies which will increase the knowledge of golden eagles and prove the efficacy of the methodology of determining bird species:

- Growth and feeding patterns, and visitation rates of parents
- Frequency of food delivery in the pre-fledging period
- Frequency of food delivery after the fledging period while youngsters and adults still use the nest
- Comparison of development of the young in different nests
- The influence of weather conditions on the fledging
- Phenology of juveniles

New images covering all the seasons should be added to the data collection for the Swedish population.

6.0 Acknowledgements

I want to express my gratitude to my supervisors Navinder Singh and Birger Hörnfeldt, for the opportunity to work with the Swedish Golden Eagle project, in particular with the camera traps and images analyses; and Frauke Ecke for the valuable contribution to this working construction.

I also want to thank the Swedish Golden Eagle Society volunteers who carry out the golden eagles' monitoring, making it possible for the implementation and continuity of the remote camera methodology.

To Christer Wilhelmsson, Börge Dahlén, Magnus Magnusson, and Johan Ekenstedt, a special thank you for the vital information and discussions which contributed to enriching my knowledge.

To John P. Ball, Fernanda Miranda, Francisco Vasconcelos, Mabo Lwabania and Linn Lockert, essential people during the duration of this course, and the elaboration of this thesis, I want to say a huge thank you.

To Jonas Dahlén and Alisse Dahlén, who dedicated all their patience and time to help me in all aspects to make all this possible, Thank you.

The fieldwork was approved by The Swedish Environmental Protection Agency and The Animal Experiment Ethics Committee.

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