
**Habitat use and ranging behaviour of GPS tracked
juvenile golden eagles (*Aquila chrysaetos*)**

Carolin Sandgren





Examensarbete i ämnet biologi

2012:6

Habitat use and ranging behaviour of GPS tracked juvenile golden eagles (*Aquila chrysaetos*)

*Biotopval och hemområdesrörelser hos GPS-försedda
årsungar av kungsörn*

Carolin Sandgren

Keywords: GPS transmitter, fledging, post-fledging, migration, home range, boreal Sweden, forestry, wind farm

**Handledare: Birger Hörnfeldt, Tim Hipkiss,
Frauke Ecke och Holger Dettki**
Examinator: Jean-Michel Roberge

30 hp, A2E
Kurskod EX0633

SLU, Sveriges lantbruksuniversitet
Fakulteten för skogsvetenskap
Institutionen för vilt, fisk och miljö

Swedish University of Agricultural Sciences
Faculty of Forestry
Dept. of Wildlife, Fish, and Environmental Studies

Umeå 2012

Abstract

Throughout its wide distribution in the northern hemisphere, the golden eagle occurs in a diverse range of environments, e.g., mountainous, forest and open areas. The literature on juvenile golden eagles is limited, and this study provides further knowledge on habitat use and ranging behaviour during the post-fledging period in boreal Sweden. A total of 14 golden eagle juveniles were tagged with GPS transmitters during 2010 and 2011, and nine could be followed during the entire post-fledging period from fledging until migration.

The juveniles fledged at the end of July and beginning of August and initiated migration during October and beginning of November. The length of the post-fledging period, until migration started, ranged from 49 to 97 days. During this period, the juveniles' distance from their natal nest and their GPS height increased with time as their flying abilities developed. The juveniles showed a preference for clearcuts and edges between clearcuts and forest, probably because these habitats had prominent properties as hunting grounds due to prey availability, openness and occurrence of look-out posts. The juveniles also preferred lichen-pine forest, which was most likely used for roosting. Furthermore, the juveniles showed a preference for south-facing slopes, where they could take advantage of thermal updrafts for flying. The results show that a landscape mosaic of open areas and older pine forest could be favourable for the juvenile eagles and that south-facing slopes should be excluded from forestry and wind farm establishment. Dense, younger forest within wind farms could possibly discourage the juvenile eagles from the wind farm.

Sammanfattning

Kungsörnen har en vid utbredning på norra halvklotet och kan återfinnas i bergstrakter och i skogliga miljöer såväl som i öppna områden. Mängden publicerade artiklar om unga kungsörnar är dock begränsad. Denna studie, utförd i norra Sverige inom den boreala zonen, behandlar biotoputnyttjande och hemområdesstorlek hos årsungar av kungsörn under perioden från att de är flygfärdiga till att de påbörjar höstflyttningen söderut. Totalt 14 årsungar märktes med GPS-sändare och nio av dem kunde följas under hela studieperioden.

Ungarna blev flygfärdiga under slutet av juli och början av augusti och de påbörjade höstflyttningen under oktober och början av november. Perioden mellan dessa händelser varade 49-97 dagar och då ökade årsungarnas avstånd från boet samt GPS-höjden successivt. De unga kungsörnarna visade en preferens för kalhyggen och kantzoner mellan kalhyggen och skog, troligtvis eftersom dessa biotoper har goda egenskaper som jaktmarker med avseende på bytestillgång, öppenhet och tillgång till sittplatser med utsikt. Årsungarna föredrog även lavtallskog, troligen främst för viloplatsen nattetid. Utöver detta visade ungarna en preferens för sydsluttningar, där de kan utnyttja uppvindar vid flykt. Resultaten visar att en landskapsmosaik av öppna områden och äldre tallskog skulle kunna vara gynnsam för unga kungsörnar samt att sydsluttningar bör undantas från skogs- och vindbruk. Tät, yngre skog i vindkraftsparker skulle kunna uppmuntra örnarna att söka sig till ett annat område.

Photo, front cover: Jeff Kidd.

Introduction

The golden eagle (*Aquila chrysaetos*) is a large raptor adapted to a broad range of habitats throughout its wide distribution in the northern hemisphere. The eagle shows preferences for undisturbed areas in mountainous or forest regions with cliffs or trees for nesting, and medium-sized mammals and birds as its main prey (Watson 1997). The eagle prefers open habitats as hunting grounds (Cramp 1980, Watson 1997), old forest with wide tree spacing as hunting and nesting habitat (McGrady *et al.* 2004), and shows an avoidance of dense forests (Cramp 1980, Watson 1997).

In Sweden, there are approximately 500 golden eagle pairs (Tjernberg 2010). The majority of the golden eagles in Sweden are located in the boreal and the mountainous region in the north, but there is also a dense population on the Baltic island of Gotland and some scattered territories elsewhere in the south (Tjernberg 2010). Most adult eagles are thought to be resident, whereas juvenile eagles from the north migrate to central or southern Sweden before the winter (Tjernberg 1983, Falkdalen *et al.* 2009). In Sweden, the eagle's main prey consists of grouse species such as capercaillie (*Tetrao urogallus*), black grouse (*T. tetrix*), willow grouse (*Lagopus lagopus*) and ptarmigan (*L. mutus*), as well as mountain hare (*Lepus timidus*). Carrion is of great importance during some parts of the year (Tjernberg 1981). Breeding performance is affected by abundance of small game in the same year (Tjernberg 1983, Moss *et al.* 2012). Golden eagles in Sweden are mainly tree-nesting, preferring old, large pines; in a study conducted in the early 1980s, the mean age of nesting trees was about 350 years, more than 90% of the trees were older than 200 years, and the mean trunk diameter was 53 cm at breast height (Tjernberg 1983).

The breeding season of the golden eagle starts in March or the beginning of April, when egg-laying occurs. The chicks hatch after 43-45 days of incubation, usually during the first weeks in May. The duration of the nestling period is around 65-90 days, after which fledging occurs in the middle or end of July (Tjernberg 2010). The fledging is the beginning of the challenging post-fledging period, when the juvenile eagles have to develop and refine their flying skills, as well as learn to hunt and kill prey to be able survive without their parents' support (Watson 1997). Previously, little has been known about the post-fledging period (Watson 1997), but during the last decade, our knowledge has increased primarily due to use of radio and satellite telemetry (see, e.g., McIntyre & Collopy 2006 and Soutullo *et al.* 2008).

The golden eagle is classified as Near Threatened on the Swedish Red List (Gärdenfors 2010) and listed in Annex 1 (species needing special habitat conservation measures) of the EU Birds Directive (The European Parliament and Council 2009) and the EU Habitats Directive (The European Parliament and Council 1992). The main threats to the golden eagle are collisions with primarily trains, power lines and transformers, human disturbance in previously remote areas due to an extended network of roads, illegal persecution, lack of suitable nesting trees and a decline in prey as a cause of extensive forestry (Tjernberg 2010, Hjernquist 2011). Another potential threat is the establishment of wind farms, due to risks of direct collisions with the turbines, disturbance during construction and maintenance, barrier effects and habitat loss (Drewitt & Langston 2006). In the county of Västerbotten, there are currently 159 operational wind turbines at 13 sites, and permission has been granted for another 320 turbines at 15 sites (May 2012; County Administrative Board of Västerbotten 2012). In the county of Västernorrland, there are currently 21 wind turbines

(December 2011; Swedish Energy Agency 2012). In total in Sweden, the amount of electricity produced by onshore wind power was almost 6 TWh in 2011 and there is a national plan to increase this to 20 TWh per year by 2020 (Swedish Energy Agency 2012).

This master's thesis is a part of a wider research project concerning potential wind-farm effects on golden eagles, and focuses on juvenile eagles during their post-fledging period. The aim is to examine habitat use and ranging behaviour of the juveniles during their first months after fledging, in particular, when fledging and southward migration occur, the size of the fledged eagles' home range and whether they show a preference for certain habitats and topographical features. This information will provide important insights into how land use changes such as forestry and wind farm establishment might affect eagles during the first stage of independency and thereby the reproductive success of golden eagles in boreal Sweden.

Materials and methods

Study area

The study area is located in the counties of Västerbotten and Västernorrland in northern Sweden (63-65°N, 17-20°E, Figure 1), in the middle and northern boreal zone (Sjörs 1999), which is characterised by coniferous forests, mires and lakes (Engelmark & Hytteborn 1999). Elevation in the studied eagle territories is about 150-600 metres above sea level (m.a.s.l.). The forests are dominated by the tree species Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) with some elements of broad-leaved trees such as birch (*Betula pubescens* and *B. pendula*), aspen (*Populus tremula*) and goat willow (*Salix caprea*) (Engelmark & Hytteborn 1999). During the 19th century, forest practices in the area included potash burning, tar production and selective cutting of, e.g., large old-growth pines (Östlund *et al.* 1997). During the 20th century forestry with clearcutting and planting has successively transformed the forest land into production forests with mainly even-aged stands (Östlund *et al.* 1997) and today intensive commercial forestry affects most of the productive forest land (Engelmark & Hytteborn 1999).

GPS tracking

During 2010 and 2011, a total of 14 golden eagle nestlings from nine nests were tagged with either of two different types of solar powered GPS transmitters (see Table A1, in Appendix). Nestlings were tagged while still in the nest (except for one eagle, ID 2011 10, which was tagged after fledging), around two weeks prior to fledging, with the cooperation of licensed ringers from the Swedish Golden Eagle Society. Teflon backpack harnesses with weakened points were used so the transmitter drops off after about two years. Because of the difficulty to distinguish between nestling females and males, the sex of the nestlings could not be determined at tagging, and juveniles are not differentiated by sex in this study.

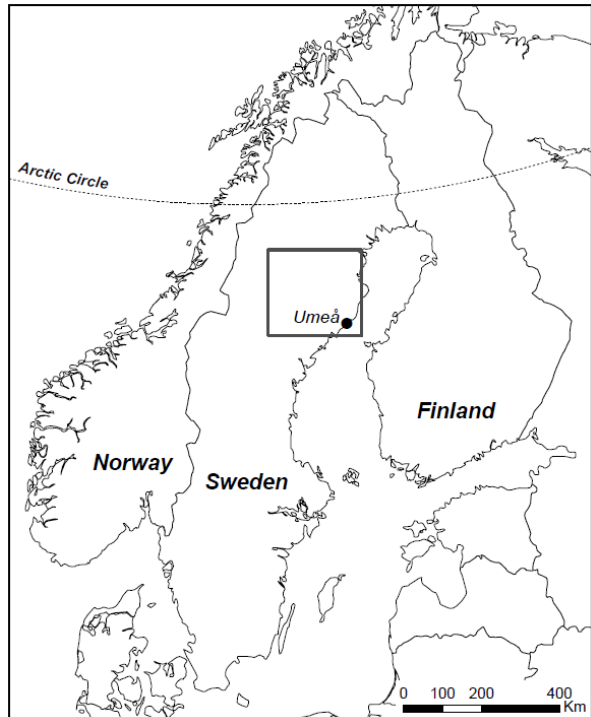


Figure 1. Map of Fennoscandia; the square shows the study area.

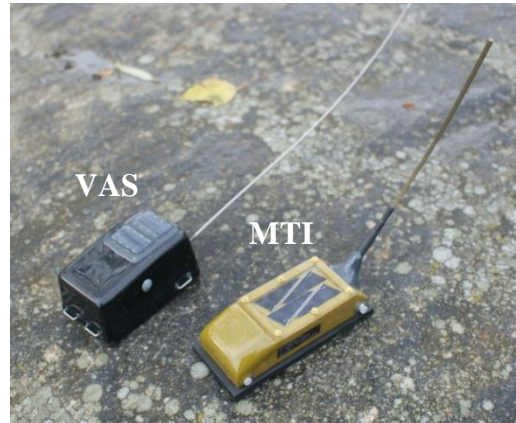


Figure 2. The two transmitter types used in the study. Photo: Tim Hipkiss.

The transmitter units from Microwave Telemetry Inc. (MTI; Figure 2) were 70 g Argos/GPS Solar Powered PTT-100 (Platform Transmitting Terminals) with an accuracy of ± 18 m according to the manufacturer (Microwave Telemetry Inc. 2012). The MTI units recorded eagle positions up to once per hour according to a programmed schedule (Table A2). The transmitter units from Vectronic Aerospace GmbH (VAS; Figure 2) were 135 g GPS PLUS Bird provided with activity sensors and with an accuracy of ± 2 m according to the manufacturer (Robert Schulte, Vectronic Aerospace GmbH, *pers. comm.*). The activity was measured as accumulated differences of acceleration four times per second and stored every five minutes. Each time the activity was stored, the tilt angle was measured, and a tilt within 30° from the horizontal plane (e.g., when the eagle was flying) set off the GPS to record a position next time it was switched on. The GPS was switched on every ten minutes, during a maximum of three minutes to be able to record a GPS position and increase the accuracy of the position (Robert Schulte, *pers. comm.*). Recorded positions from both MTI and VAS transmitters were automatically transferred into the Wireless Remote Animal Monitoring (WRAM 2011) database system at the Swedish University of Agricultural Sciences (SLU) and position data used in this thesis were latitude, longitude and altitude (m.a.s.l., height system RH 70) in the Swedish national coordinate system RT 90 2.5 gon V.

Ranging behaviour during the post-fledging period

The post-fledging period was defined as the period between fledging and autumn migration (Gerrard *et al.* 1974, McIntyre & Collopy 2006) and the definition used for initiation of autumn migration was “oriented migratory movements” (Gerrard *et al.* 1974, Hunt *et al.* 1992). To define fledging, data were divided into three-day periods starting at 1 July each year (2010 and 2011) and fledging was considered to have occurred on the intermediate day

of the first three-day period when 10% of the GPS positions were recorded more than 100 m from nest. Fledging has usually been considered as the juvenile's first departure from the nest (McClelland *et al.* 1996, Watson 1997, O'Toole *et al.* 1999), a definition probably useful for direct field observations, but not applicable for the GPS position data in this study due to the potential inaccuracy of some positions. Several GPS positions were located outside the nest shortly after the nestlings were tagged, even though the nestlings were not developed enough to fledge.

According to the definitions used, fledging and migration date were normally estimated for each eagle. Median fledging and migration dates were calculated per year and for both years pooled, for nine eagles with GPS positions during the entire post-fledging period, and in addition, one eagle (eagle ID 2011 11, see Table A1) not from the same brood as any other eagle included. Brood siblings can affect each others' fledging and migration dates (O'Toole *et al.* 1999, Soutullo *et al.* 2006a). Mean (\pm SE) length of post-fledging period was calculated per year and for both years pooled.

To be able to detect any possible time-dependent behavioural changes of the juveniles (for nine eagles with GPS positions during the entire period) the post-fledging period was divided into three four-week periods starting on the day of fledging: 1-28, 29-56 and 57-97 days after fledging. The last period was prolonged due to three individuals' longer post-fledging period. The number of GPS positions per individual and four-week period for each transmitter type is presented in Table A3 and number of GPS positions per local standard time for each transmitter type is presented in Figure A1. For each of the four-week periods, mean (\pm SE) distance from the nest was calculated. The home range of each juvenile was defined and calculated as the 100% Minimum Convex Polygon (hereafter denoted as MCP; Mohr 1947, Southwood 1966) for the entire post-fledging period as well as for each of the four-week periods. MCP calculations were performed in the statistical program R (hereafter denoted as R) (R Development Core Team 2012) with the packages *adehabitatHR* (Calenge 2006) and *maptools* (Lewin-Koh *et al.* 2012). To statistically test possible differences in distance from nest and home range size depending on time after fledging, Kruskal-Wallis rank sum tests (in the result denoted as KW) were performed.

Landscape parameters and GIS procedures

Potentially important landscape properties for the eagles were prepared as digital maps in raster format with the Swedish national coordinate system RT 90 2.5 gon V. ArcGIS Desktop with ArcInfo license (Environmental Systems Research Institute Inc. 2010) was used for preparing maps and processing geographical data. Swedish Land and Vegetation Cover (SMD, pixelwise, resolution 25×25 m, Lantmäteriet 2004) was only available for the year 2004 and therefore updated by Union (in ArcGIS) with a layer of forest height (m) from *kNN-Sweden 2010* (resolution 25×25 m, SLU 2011a). *kNN-Sweden 2010* is produced by combining satellite images from SPOT 4 and SPOT 5 with field data from the National Forest Inventory using the method *k* nearest neighbours, and covers only areas classified as forest land in the road map supplied by Lantmäteriet (SLU 2011b; for a description of *kNN-Sweden 2000* see Reese *et al.* 2003). The new raster layer was combined with a layer of power lines digitalised from orthophotos (resolution 0.5×0.5 m, Lantmäteriet 2009). This procedure resulted in a raster layer (resolution 25×25 m) with 12 categories of land use (Table A4). Another forest parameter used from *kNN-Sweden 2010* was forest age (years) divided into five classes. Majority filters based on the majority of eight neighbouring

spatially connected cells were used for the raster layers with SMD and forest height before and after union, as well as for the raster layer with forest age. An elevation grid float raster layer (resolution 50×50 m, height system RH 70, Lantmäteriet 1999) was used for deriving information on elevation (m.a.s.l.) to the GPS positions, and in addition, for derivation of aspect (cardinal direction) and slope (degrees), both with resolution 50×50 m. Aspect was categorised into five classes and slope into four classes. Roads were not included in the analyses, since the currently available road layer at SLU (Lantmäteriet 2012a) was estimated to be not accurate enough in comparison with orthophotos (Lantmäteriet 2009).

Several raptors, including the golden eagle, show positive relationships with edges between two different types of certain habitats, e.g., between forest and extensive agriculture (Sánchez-Zapata & Calvo 1999, Carrete *et al.* 2000, Balbontín 2005). In his review of edge effects, Paton (1994) concluded that edge effects such as increased predation rates on nesting birds were most apparent within 50 m from an edge. To examine the importance of edges for the golden eagle juveniles, two layers with edge habitats were prepared. Four classes from the prepared land use raster were considered as open habitats (arable land/pastures, open mires, clearcuts and power lines) and four classes as closed habitats (coniferous forest, coniferous forest on lichen-dominated ground/open bedrock, mixed/broadleaved forest and other forest). Using ArcGIS, a 50 m buffer was created outside the open habitats and used for clipping the closed habitats, as was a 50 m buffer created outside the closed habitats and used for clipping the open habitats. The purpose of these procedures was to obtain one layer with a buffer strip of closed habitats (i.e., “closed edges”) facing open habitats, and one layer with a buffer strip of open habitats (“open edges”) facing closed ones. Both buffer strip layers were converted into rasters, resolution 25×25 m.

For information on the areas around the juveniles’ nests, a circular buffer with a radius of 100 m was created around the nests and used for clipping all raster layers. In that way, the proportional area of each category in the raster layers could be calculated for the nest areas.

Habitat use analyses

Two of the nine eagles with GPS positions during the entire post-fledging period were siblings from different years, thus, they had overlapping home ranges. To minimise sampling bias in the habitat analyses due to the overlapping areas, one of the siblings was randomly selected using R and excluded from the habitat analyses. For the eight remaining eagles, values from all raster layers were extracted to the GPS positions and denominated as observed number of habitat use positions.

To obtain expected number of habitat use positions, the proportional area of each category in the landscape parameter raster layers was calculated within the home ranges (as the 100% MCPs) of the entire post-fledging period for the eight individuals. The area proportions were recalculated to the corresponding number of positions as the observed numbers of GPS positions, resulting in expected number of habitat use positions. Categories representing a percentage area of < 2% of each raster layer were excluded from the analyses due to the limited number of positions in those areas. As a consequence, water, arable land/pastures, power line and built-up areas were excluded from the land use analyses, but see Table A4 for numbers of observed and expected habitat use positions in each of these categories. Furthermore, flat areas (representing 22 observed and 34 expected

habitat use positions) were excluded from the aspect analyses, as well as arable land/pastures and power lines (representing 2 observed and 26 expected positions, and 24 observed and 13 expected positions, respectively) from the open-edge-analysis. To examine any behavioural differences depending on time of day, land use data for two time periods were selected: 1000 to 1400 hours (day) and 2300 to 0300 hours (night).

For the entire post-fledging period, as well as for each of the four-week periods and both time-of-day periods, observed and expected habitat use of the landscape parameters were compared applying Pearson's χ^2 -tests. Additionally, use of any specific features by the juveniles was studied by comparing the GPS positions with identified structures on orthophotos (Lantmäteriet 2009).

GPS height positions

To obtain the height above ground (m) of the GPS positions, the extracted elevation values (m.a.s.l.) were subtracted from the GPS altitude (m.a.s.l.). For each position, VAS units provided information on the number of satellites, as well as information on the geometric configuration of the satellites, i.e., the dilution of precision (hereafter denoted as DOP; Langley 1999). A higher number of satellites and a lower DOP value result in more accurate GPS positions, e.g., a position based on ≥ 3 satellites and with $DOP < 5$ has an accuracy of ± 2 m according to the manufacturer (Robert Schulte, *pers. comm.*). Since GPS height data in general are less accurate than horizontal data; the error of height data is usually 1.5 times greater than the horizontal error (Lantmäteriet 2012b), only GPS positions based on ≥ 3 satellites were used in height calculations and height analyses. These GPS positions were also compared with positions based on ≥ 3 satellites and with $DOP < 5$ (Table A5). MTI transmitters did not provide any information on number of, or geometric configuration of satellites; hence, all MTI positions with height data were used in comparison to the height data received from the VAS transmitters (Table A5). To get an overview of the GPS height positions, the height distribution of the GPS positions per local standard time for each transmitter type was presented graphically (Figure A2-A3). The MTI transmitters produced a majority of implausible underground positions (see Table A5 and Figure A2), and therefore, only the seemingly more accurate height data received from VAS transmitters (see Table A5 and Figure A3) were used in further calculations.

Daily activity pattern of juveniles was interpreted in Figure A3. Mean (\pm SE) height above ground was calculated and compared between daytime (1000 to 1400) and nighttime (2300 to 0300 hours), and also compared between all three four-week periods. To examine any possible differences depending on time of day or time after fledging, Kruskal-Wallis rank sum tests were performed. To obtain the frequency distribution in height, the number of GPS height positions within different height intervals was calculated.

Treatment of uncertainty

There was a risk of temporal autocorrelation in the data, since the GPS positions were recorded as a time series with a relatively short period (≥ 10 minutes) between the recorded positions. This is not in accordance with the independence assumption in parametric statistical analyses (Swihart & Slade 1985, Thomas & Taylor 2006), although it should be of minor importance when using the non-parametric methods MCP (Swihart & Slade 1985, Andersen & Rongstad 1989), Kruskal-Wallis rank sum test and Pearson's χ^2 -test (Hawkins

2005). Moreover, for highly mobile species like the golden eagle, it is possible that relatively short recording intervals do not substantially underestimate home range sizes (Andersen & Rongstad 1989), as proposed for other species (Swihart & Slade 1985).

In addition to the temporal autocorrelation problem, the number of GPS positions differed among individuals, and thus, there was a risk of bias towards habitat use of the over-represented individuals (Thomas & Taylor 2006). To adjust for this problem, a specific number of GPS positions per juvenile and time period (1-28, 29-56, 57-97 days after fledging) was randomly selected using R. The specific number was based on the individual and period with the minimum number of positions: 25 positions for data in habitat analyses and 24 positions for height data. The selections rendered data sets with equal number of positions for all individuals, but substantial reductions in number of positions compared to the complete data sets (600 compared to 5862 positions (n=8) for data in habitat analyses and 432 compared to 4707 positions (n=6) for height data).

Habitat use according to the land use raster was compared between the reduced and complete data set for habitat analyses and Pearson's χ^2 -tests were performed on each data set (n=8). The reduced height data set was compared to the complete set for height data and Kruskal-Wallis rank sum tests were performed on each data set (n=6). Based on the similarity in results from the reduced and complete data sets, each complete data set was used in the analyses.

All statistical tests in this study were performed using R and a significance level of $\alpha=0.05$.

Results

Ranging behaviour during the post-fledging period

The juveniles fledged between 14 July and 14 August (Table A1). Median fledging date was 1 August (n=4) and 29 July (n=6) in 2010 and 2011, respectively, with an overall median of 29 July. The juveniles initiated migration between 2 October and 6 November (Table A1). Median migration date was 21 October (n=4) and 11 October (n=5) in 2010 and 2011, respectively, with an overall median of 12 October. Length of the post-fledging period ranged from 49 to 97 days (Table A1), the overall mean length was 77 ± 5 (SE) days: 83 ± 8 days (n=4) and 72 ± 6 days (n=5) in 2010 and 2011, respectively.

Mean distance from the nest significantly increased during the three four-week periods, from 0.4 ± 0.2 km via 1.9 ± 0.5 km to 3.2 ± 0.8 km (KW $\chi^2 = 2901.2$, df = 2, $p < 0.001$, n = 9, Figure 3a). Similarly, mean home range significantly increased with time, from 1.8 ± 0.5 km² via 21 ± 6 km² to 34 ± 11 km² (KW $\chi^2 = 11.4$, df = 2, $p < 0.01$, n = 9, Figure 3b). During the entire post-fledging period, the average home range was 41 ± 10 km² (n=9), ranging from 3 to 96 km² (Table A1).

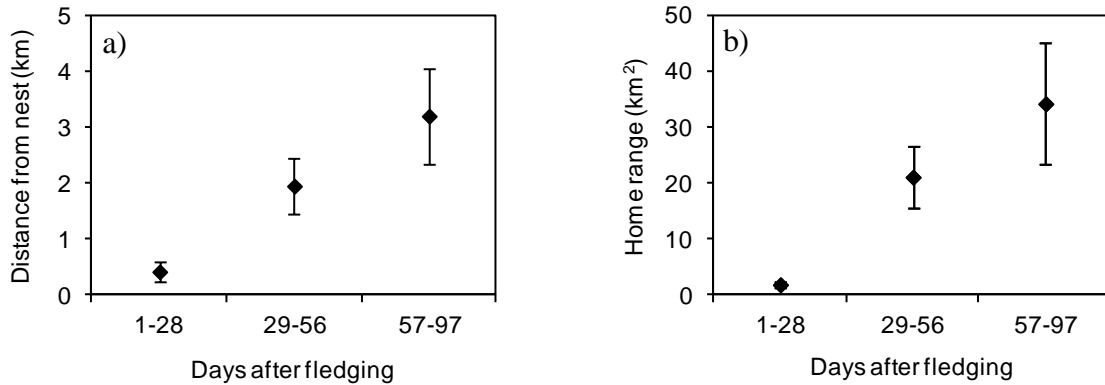


Figure 3. a) Mean \pm SE distance from the nest, and b) mean \pm SE home range (as MCP 100%) for the juveniles (day 1-28 and 29-56: $n=9$, day 57-97: $n=8$) during three four-week periods in the post-fledging period.

Habitat use

During the entire post-fledging period, clearcuts and coniferous forest on lichen ground/open bedrock (the latter hereafter denoted as lichen-pine forest) were used significantly more than expected ($\chi^2 = 1219.8$, $df = 7$, $p < 0.001$, $n = 8$; Figure 4). All other analysed habitats were used less than expected. Figure 5 shows a part of the land use raster map with observed habitat use positions and visualises the use of certain habitats, primarily clearcuts. The reduced data set, that accounted for unequal number of GPS positions per individual, rendered the same patterns of habitat use as the complete data set ($\chi^2 = 111.3$, $df = 7$, $p < 0.001$, $n = 8$). In addition to the obtained result of important habitats, observational studies of the aerial photos revealed some insight in important features for the juveniles. For most juveniles, GPS positions on clearcuts often coincided with trees and sometimes with boulders.

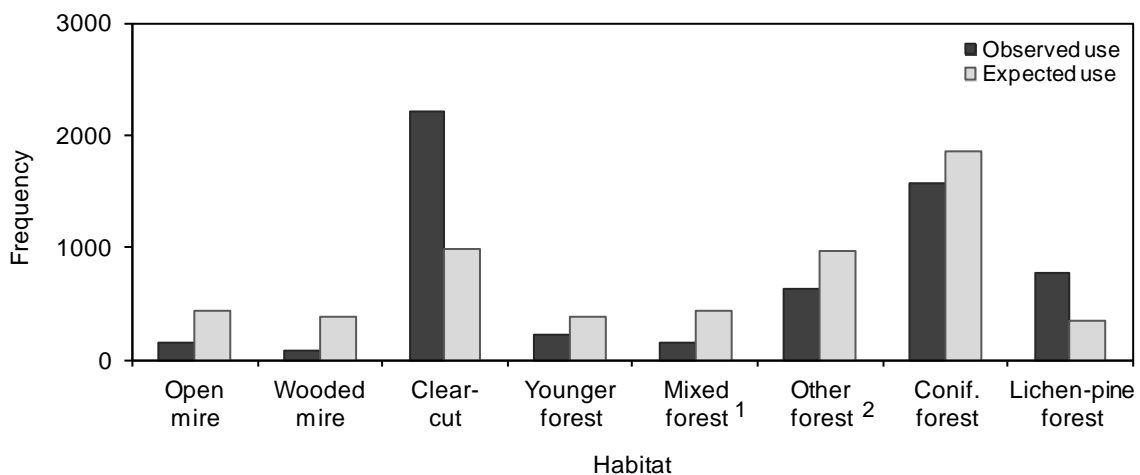


Figure 4. Observed and expected habitat use by the juveniles ($n=8$) during the post-fledging period. Only habitats with a percentage area of $> 2\%$ are included. Conif. = coniferous. ¹Mixed or broad-leaved forest. ²Areas with clearcuts or younger forest in year 2004, the production year for the Swedish Land and Vegetation Cover (Lantmäteriet 2004), but with a height of ≥ 6 m in year 2010 (kNN-Sweden; SLU 2011a).

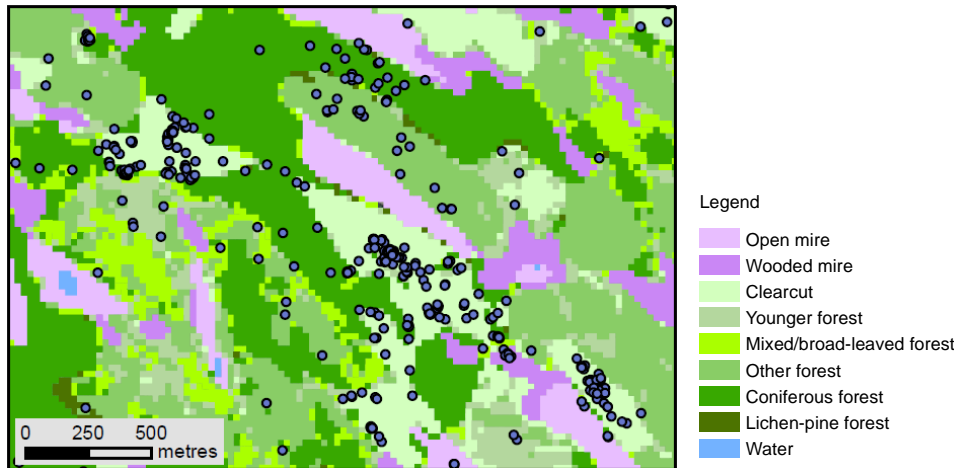


Figure 5. Land use map showing observed habitat use positions at clearcuts, coniferous forest and other habitats (see legend) for one of the juveniles (eagle ID 2010 03, Table A1) during the post-fledging period.

For all three four-week periods, there was also a significant difference between observed and expected habitat use (day 1-28: $\chi^2 = 687.1$, $df = 7$, $p < 0.001$, day 29-56: $\chi^2 = 430.5$, $df = 7$, $p < 0.001$, day 57-97: $\chi^2 = 258.8$, $df = 7$, $p < 0.001$, $n = 8$). Clearcuts were used more than expected during all three periods, and in addition, lichen-pine forest was used more than expected during day 1-28 and 29-56 after fledging (Figure 6). Coniferous forest was used as expected during day 1-28 after fledging, and thereafter less than expected (Figure 6). All other habitats analysed were used less than expected during all four-week periods. The areas within the 100 m circular radii around the nests consisted of 55% coniferous forest, 20% lichen-pine forest, 11% other forest and a total of 14% for the rest of the habitats (in order of magnitude: clearcut, younger forest, mixed/broad-leaved forest, wooded mire, open mire).

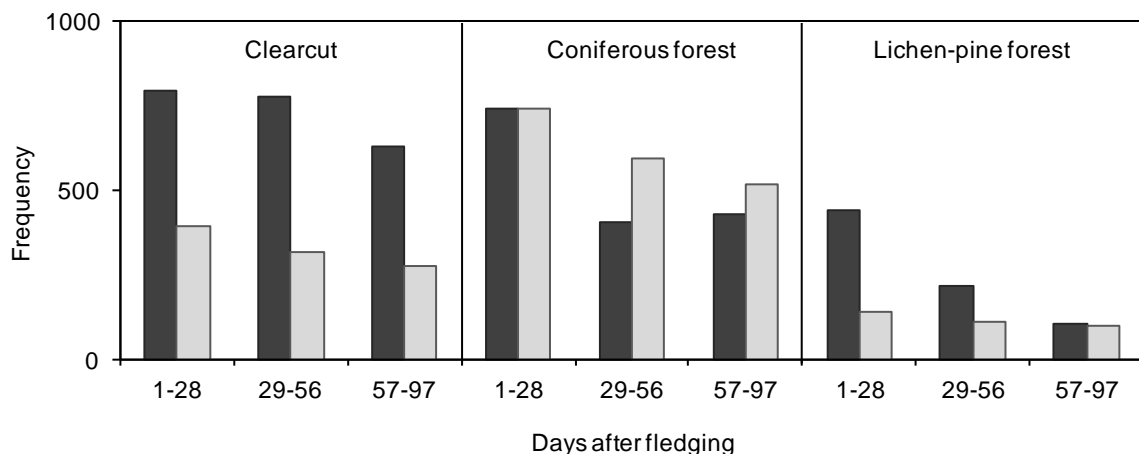


Figure 6. Observed (black bars) and expected (grey bars) habitat use of three major habitats by the juveniles ($n=8$) during three four-week periods after fledging. Total number of positions in the successive three periods was 2345, 1888 and 1629, respectively.

During daytime, clearcuts and lichen-pine forest were used significantly more than expected ($\chi^2 = 403.1$, $df = 7$, $p < 0.001$, $n = 8$; Figure 7a). During nighttime, lichen-pine forest, clearcuts and coniferous forest were used significantly more than expected ($\chi^2 = 34.8$, $df = 7$, $p < 0.001$, $n = 8$; Figure 7b).

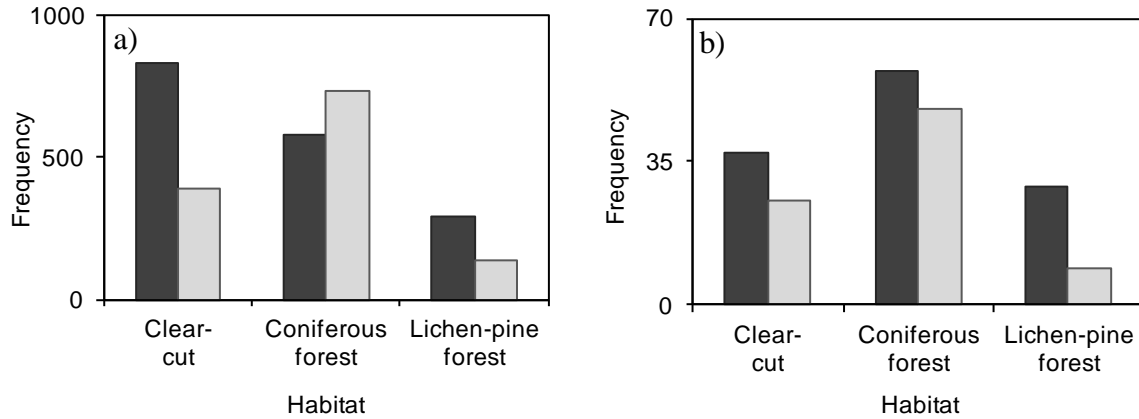


Figure 7. Observed (black bars) and expected (grey bars) habitat use of three major habitats by the juveniles during a) daytime (1000 to 1400 hours, $n=8$) and b) nighttime (2300 to 0300 hours, $n=7$) during the post-fledging period. Total number of positions in the two time periods was 2295 and 150, respectively.

The open edges of forest-bordered clearcuts were used more than expected (see Figure 8 for an example), in contrast, edges of forest-bordered open mires were used less than expected ($\chi^2 = 342.9$, $df = 1$, $p < 0.001$, $n = 8$). There was also a significant difference between observed and expected use of closed edges of forests contiguous to open habitats, primarily because of the over-expected use of coniferous forest edges and under-expected use of edges of mixed/broadleaved forest and other forest ($\chi^2 = 43.2$, $df = 3$, $p < 0.001$, $n = 8$).

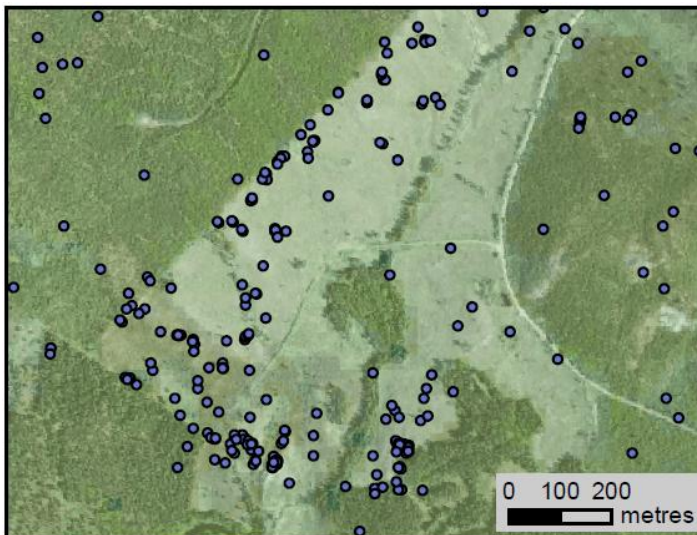


Figure 8. Aerial photo showing observed habitat use positions at edges between a clearcut and a forest for one of the juveniles (eagle ID 2010 05, Table A1) during the post-fledging period. Light green areas = clearcut, dark green areas = forest.

The difference between observed and expected use of forest of different ages was significant ($\chi^2 = 609.1$, $df = 4$, $p < 0.001$, $n = 8$), mostly due to the over-expected use of young forest (0-9 years), but also because of an under-expected use of forest aged 20-59 years (Figure 9).

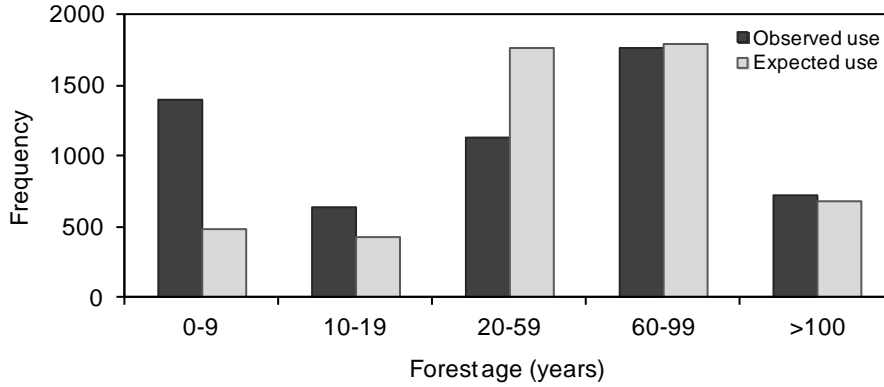


Figure 9. Observed and expected use of forest of different ages by the juveniles ($n=8$) during the post-fledging period.

For each of the three four-week periods, the difference between observed and expected use of forest age was also significant (1-28 days after fledging: $\chi^2 = 240.3$, $df = 4$, $p < 0.001$, 29-56 days: $\chi^2 = 281.1$, $df = 4$, $p < 0.001$, 57-97 days: $\chi^2 = 169.6$, $df = 4$, $p < 0.001$, $n = 8$). During all three periods, there was an over-expected use of the ages 0-9 and an under-expected use of the ages 20-59. Forest > 60 years was used more than expected during the first four-week period (Figure 10a) and less than expected during day 29-56 (Figure 10b) and 57-97 (not shown, because of a very similar pattern as day 29-56). The areas within 100 m from the nests consisted of 48% forest 60-100 years, 30% forest > 100 years, 19% forest 20-60 years and 3% forest < 20 years.

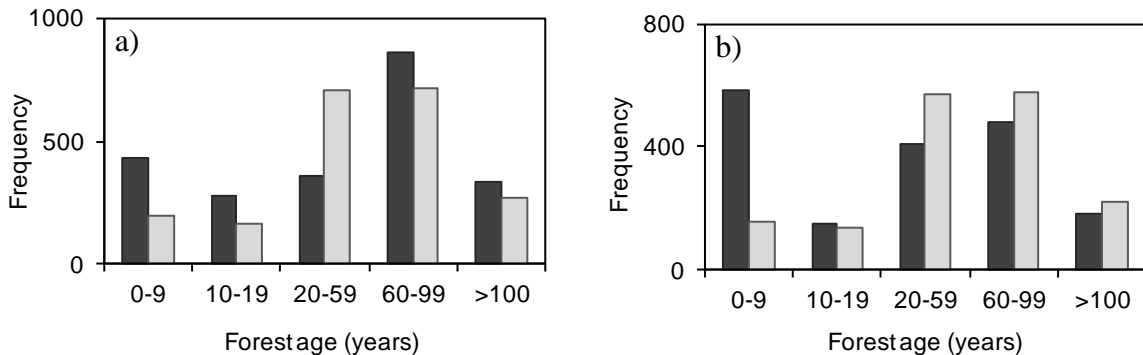


Figure 10. Observed (black bars) and expected (grey bars) use of forest of different ages by the juveniles ($n=8$) during a) 1-28 days and b) 29-56 days after fledging. Number of positions in the two periods was 2345 and 1888, respectively.

Topographical features and GPS height positions

The difference between observed and expected use of different slopes was significant ($\chi^2 = 1789.4$, $df = 3$, $p < 0.001$, $n = 8$). During the entire post-fledging period, the juvenile eagles used all slope classes of over 5° more than expected and there was an indication that the over-expected use increased with increasing incline of the slope (Figure 11a). The pattern was the same for all three four-week periods (day 1-28: $\chi^2 = 1242.9$, $df = 3$, $p < 0.001$, day 29-56: $\chi^2 = 270.5$, $df = 3$, $p < 0.001$, and day 57-97: $\chi^2 = 446.7$, $df = 3$, $p < 0.001$, $n = 8$). The slope used to the greatest extent during the entire post-fledging period was a slope of $5-10^\circ$, and the over-expected use of this slope class was greater during day 1-28 after fledging compared to later during the post-fledging period (the ratio between observed and expected number of GPS positions for the slope class $5-10^\circ$ was 2.0, 1.5 and 1.4 for each four-week period, respectively). Most of the area around the nests had a slope of $5-10^\circ$ (39%), and the other slope classes covered approximately equal areas.

The juveniles preferred southern aspects, which were used more than expected ($\chi^2 = 241.8$, $df = 3$, $p < 0.001$, $n = 8$, Figure 11b), primarily during the first weeks after fledging (days 1-28: $\chi^2 = 387.6$, $df = 3$, $p < 0.001$). Use of different aspects during day 29-56 after fledging did not differ significantly ($\chi^2 = 7.8$, $df = 3$, $p > 0.05$), whereas the eagles showed a preference for southern and western aspects during day 57-97 ($\chi^2 = 38.5$, $df = 3$, $p < 0.001$). Most of the area around the nests had a southern aspect (52%), a minor part had a northern aspect (4%) and approximately equal areas faced east or west (representing 22% each).

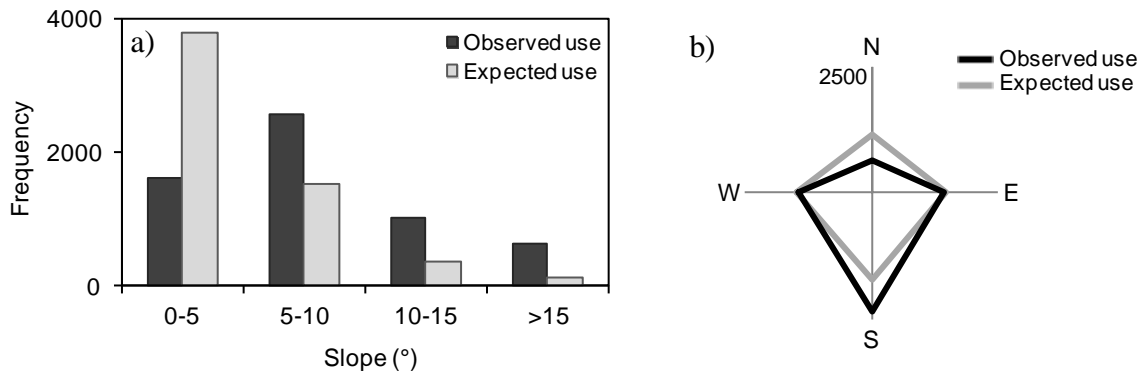


Figure 11. Observed and expected use by the juveniles ($n=8$) of a) slope and b) aspect (axes = frequency).

According to the GPS height positions from the VAS units (only positions based on \geq three satellites, see Materials and methods), there seemed to be a peak of daily activity from 1000 to 1400 hours and an increased activity between approximately 0500 to 1600 hours compared to nighttime (Figure A3). The positions of the juveniles were on average at a higher height during daytime than nighttime (KW $\chi^2 = 13.5$, $df = 1$, $p < 0.001$, $n = 6$, Figure 12a) and at a higher height during the second and third four-week period compared to the first (KW $\chi^2 = 66.6$, $df = 2$, $p < 0.001$, $n = 6$, Figure 12b). The reduced data set, accounting for unequal number of positions per individual, showed the same pattern as the complete data set, and the increase in GPS height with time after fledging was significant (KW $\chi^2 = 6.5$, $df = 2$, $p < 0.05$, $n = 6$). The number of GPS height positions was greatest 0-25 m above ground, and decreased with an increase in height (Figure A4).

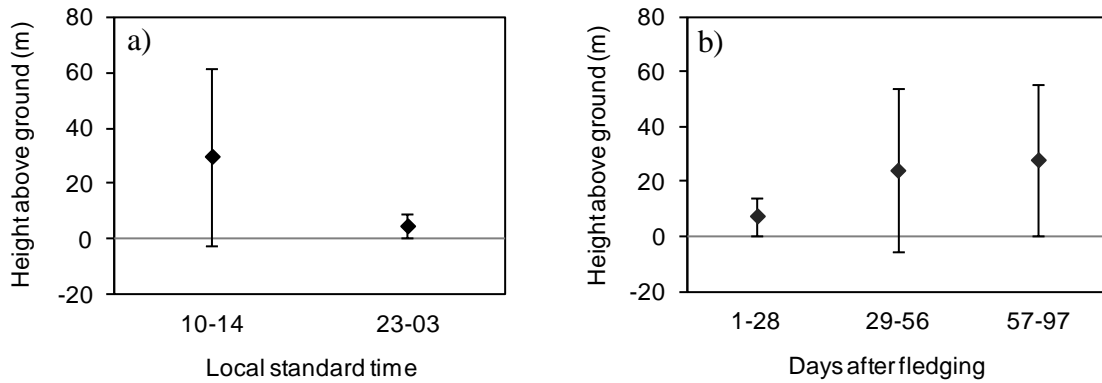


Figure 12. Mean \pm SE height above ground of the juveniles during a) daytime (1000 to 1400 hours, $n=6$, no. of positions: 1866) and nighttime (2300 to 0300 hours, $n=5$, no. of positions: 90) and b) number of days after fledging (1-28, 29-56 and 57-97 days, $n=6$, no. of positions: 1752, 1538 and 1417 for each period, respectively). Only data from VAS transmitters with positions based on ≥ 3 satellites are included.

Discussion

Ranging behaviour during the post-fledging period

A total of 14 juvenile golden eagles were tagged with GPS transmitters during 2010 and 2011 and nine could be followed during the entire post-fledging period. All nine fledged between 14 July and 14 August, which is in line with golden eagle field observations in Sweden, stating fledging to occur at the middle to the end of July (Tjernberg 2010). Juveniles initiated migration from their home ranges between 2 October and 6 November, which is also in agreement with previous observations; GPS tagged juveniles in the Swedish mountains (the county of Jämtland) started to migrate from the end of October to the beginning of November (Falkdalen *et al.* 2009), the same as visually observed juveniles in Norway (Fremming 1980).

In the present study, the length of post-fledging period, from fledging to the start of migration, ranged between 49-97 days. For migratory juvenile golden eagles in Alaska (63°N, USA), the post-fledging period lasted between 39-63 days (McIntyre & Collopy 2006), and for non-migratory juvenile golden eagles in Spain (37-41°N), the post-fledging period lasted 60-120 days (Soutullo *et al.* 2006a). For juveniles from non-migratory populations, the post-fledging period ends with the initiation of juvenile dispersal, characterised by exploratory and wandering movements (Gonzalez *et al.* 1989, Watson 1997). One proposed reason for both migration and at least the first phase of juvenile dispersal is food shortage (Tjernberg 1983, Gonzalez *et al.* 1989, Watson 1997).

Onset of migration or dispersal, and thereby the length of the post-fledging period, is probably influenced by both environmental and endogenous factors (Mínguez *et al.* 2001). For juvenile Bonelli's eagles (*Aquila fasciatus*) from non-migratory populations in Spain, dispersal was directly related to decreased abundance of main prey (Mínguez *et al.* 2001). Migration of juvenile golden eagles has been observed to coincide with decreasing daylight and prey diversity in Alaska (McIntyre & Collopy 2006), whereas these factors did not explain migration of bald eagles (*Haliaeetus leucocephalus*) from Montana, which was

suggested to be triggered by genetic factors (McClelland *et al.* 1996). It seems very likely that the aforementioned factors also influence the juvenile golden eagles in boreal Sweden.

In the present study, the juvenile eagles' distance from the nest increased as their flying skills developed, a similar pattern as observed in previous studies (Bahat 1992, Real *et al.* 1998, O'Toole *et al.* 1999, Mínguez *et al.* 2001). The progressive movements away from the nest have been suggested to be caused by increased mobility and hunting effort as eagles begin with soaring flight (Ferrer 1992, Real *et al.* 1998). As observed in the current study, the home range increased with the successive increase in distance from the nest. The same pattern was found by Falkdalen *et al.* (2009) in their study with GPS tagged golden eagle juveniles in Jämtland, Sweden, where the home range increased from 10 km² in August to 20 km² in September (with 5% of the outermost positions removed).

Open habitat

This study confirms the importance of open habitats for the juvenile golden eagles, as previously has been stated for juvenile and adult golden eagles (Cramp 1980, Watson 1997, McGrady *et al.* 1997, Walker *et al.* 2005, Soutullo *et al.* 2008), as well as for immature and adult Bonelli's eagle (Balbontín 2005). In Scotland, the open habitat is primarily constituted by montane habitat, heather moorland and grassland (McGrady *et al.* 1997), in Spain by pastures and other cultivated areas (Balbontín 2005, Soutullo *et al.* 2008) and in boreal Sweden, according to this study, by clearcuts. As supported by the greater over-expected use during daytime than nighttime, open habitats are mostly used as hunting grounds; the openness facilitates prey detection and capture (Tjernberg 1983, Watson 1997, Balbontín 2005, Soutullo *et al.* 2008).

Eagles' preferences of hunting grounds are also closely connected to prey availability (Marzluff *et al.* 1997, Balbontín 2005, Caro 2011). Marzluff *et al.* (1997) found large variations in spatial use of golden eagles and discussed the eagle's ability to adjust and take advantage of different patterns in prey availability. In boreal Sweden, during the post-fledging period in late summer and autumn, the golden eagle's main prey are forest grouse and mountain hare (Tjernberg 1983), which during this period feed on plant parts from, e.g., deciduous trees and bilberry (*Vaccinium myrtillus*) in clearcuts, younger forest and transitional zones such as forest edges (Cramp 1980, Swenson & Angelstam 1993, Dahl 2005). In other words, the juveniles' use of clearcuts and forest edges in this study may be explained by the habitat preference of the golden eagle's main prey as well as the hunting-favoured properties of these habitats.

Tjernberg (1986) studied hunting behaviour of golden eagles in southern Sweden and detected three types of hunting techniques; hunting from a sitting position on look-outs, hunting from a soaring or hanging position, and hunting by contour flight (the last two also discussed by Watson, 1997). For the inexperienced juveniles (Watson 1997), hunting from a sitting position on a look-out is reasonably the simplest and most common technique, stressing the importance of look-out features on and around the clearcuts. Suitable look-out features could be crags, trees (Cramp 1980, Tjernberg 1986, Watson 1997) and large boulders (Tjernberg 1986), which is in consistency with the present study, where use of such features on clearcuts could be seen on the aerial photos. Some of the eagle positions at the forest edges along clearcuts might also represent the use of look-out trees, hence, edges between, e.g., clearcuts and forests can be advantageous for the eagles both because of

good habitat for the prey and because of availability of look-outs. Other studies on raptors have also found that edges can be favourable for raptors' foraging (Sánchez-Zapata & Calvo 1999, Carrete *et al.* 2000, Balbontín 2005), and as an example, McGrady *et al.* (2004) claim the importance of wide ecotones to favour black grouse, and thereby also golden eagles.

Concerning other open habitats in this study, arable land/pastures and power lines covered too small an area to be included in the analyses, but there was an indication of the former being used less than expected and the latter more than expected. The properties of the long, open habitat running the length of the power line could be very similar to the properties of a clearcut, and those areas are, as discussed earlier, suitable for the eagle's prey. Both open and wooded mires were used less than expected, even though these are potential habitats for grouse and hares (Cramp 1980, Dahl 2005). During late summer and autumn, when this study took place, clearcuts, younger forest and forest edges are very productive and provide nutrient-rich plants and berries for the prey. Perhaps grouse and hares prefer these very productive areas rather than mires during this period (as found for mountain hare; Dahl 2005), and as a consequence, the golden eagle juveniles select these areas because of the prey availability.

Closed habitat

In addition to the juveniles' preference for open habitats, the juveniles showed a preference for lichen-pine forest, a forest type characterised by nutrient-poor soils and an open tree layer (Engelmark & Hytteborn 1999). In general, for a bird as large as the golden eagle, most of the coniferous forest in boreal Sweden should be too dense for flying or hunting, but the lichen-pine forest might be sufficiently open. This habitat could for example be used for perching (Walker 1987, Watson 1997). During nighttime, both lichen-pine forest and coniferous forest were used more than expected, which suggests that they offer important, sheltered places for roosting (Watson 1997, Soutullo *et al.* 2006a). Soutullo *et al.* (2006a) followed juvenile golden eagles during their first year of life and found the same patterns as in this study. The open habitat, which in their study area comprised of mainly cultivated areas, was important for hunting, and the closed habitat, represented by coniferous forest, was important for roosting (Soutullo *et al.* 2006a).

The juveniles' preference for lichen-pine forest was greatest during the first four weeks after fledging and thereafter decreased. The coniferous forest was used as expected in proportion to availability day 1-28 after fledging, and thereafter less than expected. The area around the nests consisted of 75% coniferous forest and lichen-pine forest, and my conclusion is that the juveniles returned to the vicinity of the nest more frequently during the first month after fledging (supported by comparing the GPS positions in relation to the nest on aerial photos). The reasons for the return visits to the nest are probably roosting and food supply from the parents, as observed by Walker (1987) and Bahat (1992). The frequency of the return visits to the nest decreased with time as the juveniles get older and more independent, as proposed by Walker (1987) and Bahat (1992). The return visits to the nest area were also visible when comparing the use of forest of different age classes with the composition of the nest area. During the first month after fledging, older forest (> 60 years) (in addition to the clearcuts) was used more than expected, and this age class of forest constituted almost 80% of the area around the nests. Later during the post-fledging

period, the use of forest > 60 years was less than expected, whereas the over-expected use of clearcuts had increased, reflecting the juveniles' development towards independence.

During the entire post-fledging period, the juveniles used forest aged 20-59 years less than expected. Similarly, younger forest, mixed/broad-leaved forest as well as the category other forest (consisting of areas that were clearcuts or younger forest in 2004, but ≥ 6 m in 2010) were used less than expected. The common property of these habitats, according to my interpretation, is that they are quite dense. Despite some of the prey's preferences for these habitats (Cramp 1980, Swenson & Angelstam 1993, Dahl 2005), the habitats do not seem to be favourable enough, i.e. open enough, for hunting. Cramp (1980) and Watson (1997) have observed avoidance of dense forest among golden eagles.

In summary, important habitats for the golden eagle juveniles are older pine/conifer forest for roosting (and which also serves as a nesting areas for their parents), as well as clearcuts, with suitable look-out structures, and forest edges as hunting grounds.

Topographical features and GPS height positions

Topography influences eagles' selection of certain habitats (Cramp 1980, Watson 1997), as well as their selection of dispersal areas and breeding areas (Ontiveros 1999, Balbontín 2005, Caro 2011). The eagles prefer rugged terrain and south-facing slopes, where they can take advantage of warmed ascending air – thermal updrafts – when soaring (Watson 1997, Balbontín 2005, Caro 2011). In the present study, the juvenile golden eagles preferred slopes of southern orientation primarily during day 1-28, but also during day 57-97 after fledging. As previously stated, the juveniles regularly returned to the vicinity of the nest during the first weeks after fledging, which partly reflects their south-slope preference during this period; more than half of the area around the nests was located in southern aspects. Similarly, of the Swedish tree and cliff nests studied by Tjernberg (1983), more than half were south-west exposed, and of the Spanish cliff nests studied by Ontiveros (1999), the majority was also in southern aspects. Both authors related their results to the advantage of greater insolation and higher temperature during the eagles' breeding season (Tjernberg 1983, Ontiveros 1999), and Ontiveros (1999) also highlighted the advantage of thermal updrafts.

The inclination of the slope was also of relevance for the juveniles' habitat selection; slopes of over 5° were used more than expected during the entire post-fledging period, and the steepest slopes were used even more than expected. One reason could be that the eagles get a good view of the surrounding landscape from the top of steep slopes (Tjernberg 1983). Balbontín (2005) suggested hunting success and flight facilitation as reasons for preference of steep slopes by juveniles of Bonelli's eagle. During day 1-28 after fledging, slopes of $5-10^\circ$ were used most, reflecting the nest areas where this slope class was in majority. Of the 170 tree nests studied by Tjernberg (1983), almost half were located in slopes of over 18° , whereas the rest were approximately evenly distributed on slopes of $0-18^\circ$. In other words, the preference for $5-10^\circ$ for the nest locations observed in the present study could possibly be an artefact of the limited number of nests studied. Bonelli's eagles in Spain chose the steepest slopes for their nests, due to the same advantages given by the southern orientation (Ontiveros 1999). Tjernberg (1983) discussed the impact of forestry on the eagle nest locations. Forests in steep terrain have often been spared from cutting due to their

inaccessibility, and consequently, the availability of suitable old, large trees for nesting is greater in steeper than in flatter areas (Tjernberg 1983).

The most active time of the day of the juveniles in the current study was at midday, between 1000 and 1400 hours, although there was an increased activity from around 0500 to 1600 hours compared to nighttime. Previous work in Spain identified the peak of daily activity for juveniles the first months after dispersal to 1100 to 1800 hours for golden eagle juveniles (Soutullo *et al.* 2006b), and 1300 to 1800 for Bonelli's eagle juveniles (Cadahía *et al.* 2007). There was a distinct decline in activity after 1800 hours and almost no activity at all after 2100 hours (Soutullo *et al.* 2006b, Cadahía *et al.* 2007). The daily peak of activity has been proposed to relate to occurrence of thermal updrafts (Soutullo *et al.* 2006b, Cadahía *et al.* 2007, McIntyre *et al.* 2008), which will vary among geographic locations, but also to a combination of prey activity and hunting success (Soutullo *et al.* 2006b).

The juveniles' mean height above ground should be interpreted with caution, since not only the MTI units that were excluded from the mean height calculations, but also the Vectronic units gave many erroneous underground positions. Moreover, since there is an error in the belowground positions, it is likely that there is also an error in the aboveground positions. Nevertheless, the difference between mean height during daytime and nighttime, as well as the difference between the three four-week periods, seem to be plausible. My interpretation is that the higher mean value of height during daytime reflects the juveniles' greater activity and higher GPS height, and the lower mean during nighttime reflects the juveniles' roosting in, e.g., trees. The increase in mean height above ground from the first four weeks after fledging to later during the post-fledging period most likely reflects the juveniles' development of flying ability. For conclusions of any exact GPS height, it is important to once again stress the uncertainty in the data due to the potential inaccuracy of the GPS height positions. A majority of the GPS positions in this study were located 0-25 m above ground, which indicates that most positions were recorded when the juveniles were sitting, e.g., in trees. Only a minor part of the positions was recorded at 50-150 m height, which is the approximate sweep height for the wind turbine rotor blades at one of the wind farms in the study area (Vattenfall Vindkraft AB 2011). One explanation for the minor part of the GPS positions at this height could, as I speculate, be that the juveniles' flights were relatively short, so just a few positions were recorded before the juveniles returned to a lower height, for example to sit in a tree. I would also like to stress that this study only includes juvenile eagles during the first months after they have fledged, and it is possible that the GPS height would be different for juvenile eagles later in their development as well as for adult eagles. Furthermore, the number of juveniles in this study is very limited, and it is possible that GPS height, as well as habitat use, differs among the individuals.

Implications for forestry and wind farm establishment

One impact on the juvenile golden eagles from intensive, modern forestry is, according to the results in this study, that the juveniles' hunting possibilities might be favoured by clearcutting. Another impact is that the removal of older forest (Östlund *et al.* 1997) could limit the adult eagles' possibility to build nests and breed. In addition, forestry can have indirect effects on the juvenile eagles by affecting their preferred prey; for example, Swenson & Angelstam (1993) concluded that black grouse was probably favoured by modern forestry, whereas capercaillie was negatively affected. My suggestion, based on the results in this study, is that a landscape mosaic of areas of older forest and open areas, such

as clearcut patches, could be favourable for the golden eagle juveniles. The open areas should be sufficiently open for hunting (i.e., with a forest height of < 2 m) and have stable retention trees for look-out posts. Smaller open patches would increase the length of edge zone, in relation to the size of the open patch, and could favour grouse and hares. Areas of older forest, with old and large pines (Tjernberg 1983), are important for the adult eagles' nesting as observed by the composition of the nest areas, and pine forest in south-facing slopes seems to be particularly valuable.

According to the current study, one potential impact from wind farms on juvenile golden eagles is habitat loss; older forests, lichen-pine forests in particular, should not be exploited for wind farm establishment since these seem to be important as nesting habitat for the adult eagles. Another potential impact of wind farms on juvenile golden eagles is direct collisions with turbines, since this study indicate that the juveniles are able to fly at the same height as the sweep height for rotor blades. The juveniles in this study preferred slopes, probably to take advantage of thermal updrafts (Watson 1997, Balbontín 2005, Caro 2011), and therefore, to reduce collision risks, I would recommend not placing wind turbines along ridges or near slopes, especially not south-facing slopes. Within the wind farm site, I suggest minimising the clear-felled area which could attract the juvenile eagles according to this study. After establishment I recommend maintaining younger, dense forest, which the juveniles seem to avoid, within the wind farm and keeping areas outside the wind farm open and suitable for prey, to try to keep the eagles away from the wind farm. Forest stages such as clearcuts are transitional; hence, management is required to maintain open, prey-favoured areas in the long run. Finally, since this is a very short-term study limited to a period during late summer and autumn in the juveniles' first year, it is probable that other habitats are important later in their life and during other parts of the year.

This study has highlighted preferred habitats and topographical features of juvenile golden eagles. Future studies should focus on before-and-after studies of wind farm effects, e.g., whether eagles alter their ranging behaviour after wind farm establishments.

Acknowledgements

I wish to thank my supervisors Birger Hörnfeldt, Tim Hipkiss, Frauke Ecke and Holger Dettki for interesting discussions, exchange of ideas and proof-reading. I wish to thank Jean-Michel Roberge for valuable comments on the final report. Thanks to Per-Olof Nilsson for guidance in the inland of Västerbotten, to Mats Högström for GIS support and to others at the Department of Wildlife, Fish and Environmental Studies for additional help. I am grateful for the constant encouragement I have received at home, many thanks to family and friends for always expressing your support.

This master's thesis was carried out as part of a larger project on GPS tracking of golden eagles within the Vindval research programme, financed by the Swedish Energy Agency, Vattenfall R&D AB and Statkraft Sverige AB. The project was also carried out with the help and cooperation of the Swedish Golden Eagle Society, and in particular, Thomas Birkö, Johan Ekenstedt, Jonas Gustafsson, Ove Källström, Bjarne Modig, Per-Olof Nilsson and Andro Stenman (in alphabetical order) are thanked for tagging the eagle nestlings.

References

- Andersen, D.E. & Rongstad, O.J. 1989. Home-range estimates of red-tailed hawks based on random and systematic relocations. *Journal of Wildlife Management*, **53**, 802-807.
- Bahat, O. 1992. Post-fledging movements of golden eagles (*Aquila chrysaetos homeyeri*) in the Negev Desert, Israel, as determined by radiotelemetry. - In Priede, I.G. & Swift, S.M. (eds.) 1992. *Wildlife telemetry*. Ellis Horwood, Chichester, UK. pp. 612-621.
- Balbontín, J. 2005. Identifying suitable habitat for dispersal in Bonelli's eagle: An important issue in halting its decline in Europe. *Biological Conservation*, **126**, 74-83.
- Cadahía, L., Urios, V. & Negro, J.J. 2007. Bonelli's eagle *Hieraaetus fasciatus* juvenile dispersal: hourly and daily movements tracked by GPS. *Bird Study*, **54**, 271-274.
- Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. *Ecological Modelling*, **197**, 516-519.
- Caro, J., Ontiveros, D., Pizarro, M. & Pleguezuelos, J.M. 2011. Habitat features of settlement areas used by floaters of Bonelli's and golden eagles. *Bird Conservation International*, **21**, 59-71.
- Carrete, M., Sánchez-Zapata, J.A. & Calvo, J.F. 2000. Breeding densities and habitat attributes of golden eagles in southeastern Spain. *Journal of Raptor Research*, **34**, 48-52.
- County Administrative Board of Västerbotten. 2012. Läget i länet. www.lansstyrelsen.se/vasterbotten/Sv/samhallsplanering-och-kulturmiljo/planfragor/vindkraft/lagetilanet/Pages/default.aspx [accessed 28 May 2012]. (In Swedish)
- Cramp, S. (chief ed.) 1980. *The Birds of the Western Palearctic*. Volume II. Oxford University Press, Oxford, UK.
- Dahl, F. 2005. Distinct seasonal habitat selection by annually sedentary mountain hares (*Lepus timidus*) in the boreal forest of Sweden. *European Journal of Wildlife Research*, **51**, 163-169.
- Drewitt, A.L. & Langston, R.H.W. 2006. Assessing the impacts of wind farms on birds. *Ibis*, **148**, 29-42.
- Engelmark, O. & Hytteborn, H. 1999. Coniferous forests. - In Rydin, H., Snoeijs, P. & Diekmann, M. (eds.) 1999. *Swedish Plant Geography*. Svenska Växtgeografiska Sällskapet, Uppsala, Sweden. pp. 55-74.
- Environmental Systems Research Institute Inc. 2010. ArcGIS Desktop ver. 10 Service Pack 4 ArcInfo. Redlands, California, USA.
- Falkdalen, U., Falkdalen Lindahl, L. & Nygård, T. 2009. Fågelundersökningar vid Storruns vindkraftanläggning, Jämtland. Resultat från förundersökningar 2003-2008. Vindval. The Swedish Environmental Protection Agency, Stockholm, Sweden. (In Swedish)
- Ferrer, M. 1992. Regulation of the period of postfledging dependence in the Spanish imperial eagle *Aquila adalberti*. *Ibis*, **134**, 128-133.
- Fremming, O.R. 1980. Kongeørn i Norge. Viltrapport, **12**, 1-63. (In Norwegian, with English summary)
- Gärdenfors, U. (ed.) 2010. *The 2010 Red list of Swedish Species*. The Swedish Species Information Centre, SLU, Uppsala, Sweden.
- Gerrard, P., Gerrard, J.M., Whitfield, D.W.A. & Maher, W.J. 1974. Post-fledging movements of juvenile bald eagles. *Blue Jay*, **32**, 218-226.
- Gonzalez, L.M., Heredia, B., Gonzalez, J.L. & Alonso, J.C. 1989. Juvenile dispersal of Spanish Imperial eagles. *Journal of Field Ornithology*, **60**, 369-379
- Hawkins, D. 2005. *Biomeasurement*. Oxford University Press, Oxford, UK.

- Hjernquist, M. 2011. Åtgärdsprogram för kungsörn, 2011-2015 (*Aquila chrysaetos*). Rapport 6430. The Swedish Environmental Protection Agency, Stockholm, Sweden. (In Swedish, with English summary)
- Hunt, W.G., Jackman, R.E., Jenkins, J.M., Thelander, C.G. & Lehman, R.N. 1992. Northward post-fledging migration of California bald eagles. *Journal of Raptor Research*, **26**, 19-23.
- Langley, R.B. 1999. Dilution of precision. GPS World. www.nrem.iastate.edu/class/assets/nrem446_546/week3/Dilution_of_Precision.pdf [accessed 24 May 2012]
- Lantmäteriet. 1999. Elevation 50 m grid float, height system RH 70. Gävle, Sweden.
- Lantmäteriet. 2004. Swedish Land and Vegetation Cover pixelwise raster. Gävle, Sweden.
- Lantmäteriet. 2009. Orthophotos 0.5 m årsvis. Gävle, Sweden.
- Lantmäteriet. 2012a. Road map vector. Gävle, Sweden.
- Lantmäteriet. 2012b. GPS and other surveying techniques - Tips for hand-held GPS receivers. Gävle, Sweden. www.lantmateriet.se/templates/LMV_Page.aspx?id=4953 [accessed 24 May 2012]
- Lewin-Koh, N.J. & Bivand, R., contributions by Pebesma, E.J., Archer, E., Baddeley, A., Jörg Bibiko, H.J., Callahan, J., Dray, S., Forrest, D., Friendly, M., Giraudoux, P., Golicher, D., Gómez Rubio, V., Hausmann, P., Hufthammer, K.O., Jagger, T., Luque, S.P., MacQueen, D., Niccolai, A., Short, T., Snow, G., Stabler, B. & Turner, R. 2012. *maptools: Tools for reading and handling spatial objects*. R package version 0.8-14. <http://CRAN.R-project.org/package=maptools>
- Marzluff, J.M., Knick, S.T., Vekasy, M.S., Schueck, L.S. & Zarriello, T.J. 1997. Spatial use and habitat selection of golden eagles in southwestern Idaho. *The Auk*, **114**, 673-687.
- McClelland, B.R., McClelland, P.T., Yates, R.E., Caton, E.L. & McFadzen, M.E. 1996. Fledging and migration of juvenile bald eagles from Glacier National Park, Montana. *Journal of Raptor Research*, **30**, 79-89.
- McGrady, M.J., McLeod, D.R.A., Petty, S.J., Grant, J.R. & Bainbridge, I.P. 1997. Golden eagles and forestry. Research Information Note 292. Forestry Commission, Farnham Surrey, UK.
- McGrady, M.J., Petty, S.J. & McLeod, D.R.A. 2004. Potential impacts of new native woodland expansion on golden eagles in Scotland. Scottish Natural Heritage Commissioned Report No. 018 (ROAME No. F99LD01).
- McIntyre, C.L. & Collopy, M.W. 2006. Postfledging dependence period of migratory golden eagles (*Aquila chrysaetos*) in Denali National Park and Preserve, Alaska. *Auk*, **123**, 877-884.
- McIntyre, C.L., Douglas, D.C. & Collopy, M.W. 2008. Movements of golden eagles (*Aquila chrysaetos*) from interior Alaska during their first year of independence. *Auk*, **125**, 214-224.
- Microwave Telemetry Inc. 2012. Microwave Telemetry Inc. website. Columbia, Maryland, USA. www.microwavetelemetry.com/bird/solarArgosGPS_70g.cfm [accessed 14 May 2012].
- Mínguez, E., Angulo, E. & Siebering, V. 2001. Factors influencing length of the post-fledging period and timing of dispersal in Bonelli's eagle (*Hieraetus fasciatus*) in southwestern Spain. *Journal of Raptor Research*, **35**, 228-234.
- Mohr, C.O. 1947. Table of equivalent populations of North American small mammals. *American Midland Naturalist*, **37**, 223-249.
- Moss, E.H.R., Hipkiss, T., Oskarsson, I., Häger, A., Eriksson, T., Nilsson, L.E., Halling, S., Nilsson, P.O. & Hörnfeldt, B. 2012. Long-term study of reproductive performance in

- golden eagles in relation to food supply in boreal Sweden. *Journal of Raptor Research*, in press.
- Ontiveros, D. 1999. Selection of nest cliffs by Bonelli's eagle (*Hieraetus fasciatus*) in southeastern Spain. *Journal of Raptor Research*, **33**, 110-116.
- Östlund, L., Zackrisson, O. & Axelsson, A.L. 1997. The history and transformation of a Scandinavian boreal forest landscape since the 19th century. *The Canadian Journal of Forest Research*, **27**, 1198-1206.
- O'Toole, L.T., Kennedy, P.L., Knight, R.L. & McEwen, L.C. 1999. Postfledging behavior of golden eagles. *Wilson Bulletin*, **111**, 472-477.
- Paton, P.W.C. 1994. The effect of edge on avian nest success: how strong is the evidence? *Conservation Biology*, **8**, 17-26.
- R Development Core Team. 2012. R: A language and environment for statistical computing, version 2.14.2. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL www.R-project.org/.
- Real, J., Mañosa, S. & Codina, J. 1998. Post-nestling dependence period in the Bonelli's eagle *Hieraetus fasciatus*. *Ornis Fennica*, **75**, 1-9.
- Reese, H., Nilsson, M., Granqvist Pahlén, T., Hagner, O., Joyce, S., Tingelöf, U., Egberth, M. & Olsson, H. 2003. Countrywide estimations of forest variables using satellite data and field data from the National Forest Inventory. *Ambio*, **32**, 542-548.
- Sánchez-Zapata, J.A. & Calvo, J.F. 1999. Raptor distribution in relation to landscape composition in semi-arid Mediterranean habitats. *Journal of Applied Ecology*, **36**, 254-262.
- Schulte, Robert. *pers. comm.* 2012. Managing Director, Vectronic Aerospace GmbH, Germany.
- Sjörs, H. 1999. The background: geology, climate and zonation. - In Rydin, H., Snoeijs, P. & Diekmann, M. (eds.) 1999. *Swedish Plant Geography*. Svenska Växtgeografiska Sällskapet, Uppsala, Sweden. pp. 5-14.
- SLU. 2011a. *kNN-Sweden 2010*. Dept. of Forest Resource Management. Umeå, Sweden.
- SLU. 2011b. *kNN-Sverige - Aktuella kartdata över skogsmarken, årgång 2005 och 2010*. Dept. of Forest Resource Management. Umeå, Sweden. (In Swedish)
- Southwood, T.R.E. 1966. *Ecological methods*. Methuen, London, UK.
- Soutullo, A., Urios, V., Ferrer, M. & Peñarrubia, S.G. 2006a. Post-fledging behaviour in golden eagles *Aquila chrysaetos*: onset of juvenile dispersal and progressive distancing from the nest. *Ibis*, **148**, 307-312.
- Soutullo, A., Urios, V. & Ferrer, M. 2006b. How far away in an hour? Daily movements of juvenile golden eagles (*Aquila chrysaetos*) tracked with satellite telemetry. *Journal of Ornithology*, **147**, 69-72.
- Soutullo, A., Urios, V., Ferrer, M. & López-López, P. 2008. Habitat use by juvenile golden eagles *Aquila chrysaetos* in Spain. *Bird Study*, **55**, 236-240.
- Swenson, J.E. & Angelstam, P. 1993. Habitat separation by sympatric forest grouse in Fennoscandia in relation to boreal forest succession. *Canadian Journal of Zoology*, **71**, 1303-1310.
- Swedish Energy Agency. 2012. *Vindkraftsstatistik 2011*. ES 2012:02. <http://energimyndigheten.se/PageFiles/110/Vindkraftsstatistik-2011.pdf> [accessed 28 May 2012]. (In Swedish)
- Swihart, R.K. & Slade, N.A. 1985. Testing for independence of observations in animal movements. *Ecology*, **66**, 1176-1184.
- The European Parliament and Council. 1992. Directive 1992/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

- The European Parliament and Council. 2009. Directive 2009/147/EC of 30 November 2009 on the conservation of wild birds.
- Thomas, D.L. & Taylor, E.J. 2006. Study designs and tests for comparing resource use and availability II. *Journal of Wildlife Management*, **70**, 324-336.
- Tjernberg, M. 1981. Diet of the golden eagle (*Aquila chrysaetos*) during the breeding-season in Sweden. *Holarctic Ecology*, **4**, 12-19.
- Tjernberg, M. 1983. Breeding ecology of the golden eagle, *Aquila chrysaetos* (L.), in Sweden. PhD Thesis, Swedish University of Agricultural Sciences. Uppsala, Sweden.
- Tjernberg, M. 1986. Hunting behaviour, prey selection and strike success of wintering golden eagles in south Sweden. *Vår Fågelvärld*, **45**, 327-339. (In Swedish, with English summary)
- Tjernberg, M. (rev.) 2010. *Aquila chrysaetos*. Kungsörn. ArtDatabanken, SLU, Sweden. www.artfakta.se/Artfaktablad/Aquila_Chrysaetos_100011.pdf [accessed 14 May 2012]. (In Swedish)
- Walker, D.G. 1987. Observations on the post-fledging period of the golden eagle *Aquila chrysaetos* in England. *Ibis*, **129**, 92-96.
- Walker, D., McGrady, M., McCluskie, A., Madders, M. & McLeod D.R.A. 2005. Resident golden eagle ranging behaviour before and after construction of a windfarm in Argyll. *Scottish Birds*, **25**, 24-40.
- Watson, J. 1997. *The Golden Eagle*. 1st ed. T. and A.D. Poyser, London, UK.
- Vattenfall Vindkraft AB. 2011. Stor-Rotliden vindkraftpark. www.vattenfall.se/sv/file/Broschyr_Stor-Rotliden_18346667.pdf [accessed 28 May 2012]. (In Swedish)
- WRAM. 2011. Wireless Remote Animal Monitoring (WRAM). <http://www.slu.se/WRAM/> [last accessed 31 January 2012].

Appendix

Table A1. Mass, wing length, transmitter type, dates of tagging, fledging and migration, length of post-fledging period (no. of days), and size of home range (as MCP 100%, see explanation in the text) for each golden eagle juvenile (Eagle ID) tracked in the present study.

Eagle ID	Mass (g)	Wing L (mm)	Transmitter type	Date of tagging	Juvenile has fledged	Start of migration	Post-fledging period (no. of days)	Home range (km ²)
2010 02 ¹	3600	425	VAS	2010-07-07	2010-08-01	2010-11-06	97	30
2010 03 ¹	3200	430	VAS	2010-07-07	2010-07-23	2010-10-27	96	96
2010 04 ¹	3600	390	VAS	2010-07-14	2010-08-07	2010-10-10	64	33
2010 05 ¹	3500	450	VAS	2010-07-14	2010-08-01	2010-10-15	75	27
2011 03 ¹	-	435	VAS	2011-07-06	2011-07-29	2011-10-12	75	11
2011 05 ¹	4400	462	VAS	2011-07-11	2011-07-29	2011-10-13	76	56
2011 01 ¹	3300	410	MTI	2011-06-28	2011-07-14	2011-10-11	89	82
2011 06 ¹	4000	480	MTI	2011-07-11	2011-07-29	2011-10-08	71	3
2011 04 ²	3780	431	MTI	2011-07-11	2011-08-14	2011-10-02	49	34
2011 11 ³	3300	435	MTI	2011-07-06	2011-07-20	-	-	-
2011 02 ⁴	3400	430	MTI	2011-06-28	2011-07-14	-	-	-
2011 12 ⁵	3080	404	MTI	2011-07-06	-	-	-	-
2010 01 ⁶	2900	390	VAS	2010-07-07	-	-	-	-
2011 10 ⁷	3650	604	VAS	2011-09-29	-	2011-10-11	-	-

¹ Included in all calculations as well as in habitat analyses.

² Sibling to 2010 04 (not brood sibling). Included in all calculations, but not in habitat analyses.

³ Juvenile lost transmitter 2011-08-14, prior to migration. Brood sibling with 2011 12. Only included in calculations on fledging date.

⁴ SLU lost contact with transmitter 2011-09-08, prior to migration. Brood sibling with 2011 01.

⁵ SLU lost contact with transmitter 2011-07-15, prior to fledging. Brood sibling with 2011 11.

⁶ Juvenile died prior to fledging.

⁷ Juvenile was marked after fledging. Brood sibling with 2011 03.

Table A2. Recording intervals for VAS and MTI transmitters and recording start and stop hours (local standard time) for MTI units on juveniles from June to November. The longer intervals prolong the life of the solar powered batteries during darker periods of the year.

Months	VAS	MTI		
	Interval	Start	Stop	Interval
June-Aug	10 min	0300	1900	1 hr
Sep-Oct	30 min	0800	1600	1 hr
Nov	2 hr	0900	1500	2 hr

Table A3. Numbers and sums of GPS positions per juvenile (Eagle ID) and per four-week period (no. of days after fledging) during the post-fledging period.

Eagle ID	Transmitter type	No. of days after fledging			Sum per individual
		1-28	29-56	57-97	
2010 02	VAS	476	221	175	872
2010 03	VAS	458	487	732	1677
2010 04	VAS	246	247	91	584
2010 05	VAS	336	480	357	1173
2011 03	VAS	154	55	25	234
2011 05	VAS	108	63	51	222
2011 01	MTI	303	244	172	719
2011 06	MTI	264	91	26	381
2011 04	MTI	108	113	0	221
Sum per period		2453	2001	1629	6083

Table A4. Percentage of home ranges and explanations for the land use categories. Observed and expected number of GPS positions for each category during the juveniles' entire post-fledging period. Only habitats above dashed line (> 2% of the home range area) are included in habitat analyses.

Land use category	Explanation	% of home range area	Observed no. of positions	Expected no. of positions
Coniferous forest	height \geq 6 m	31.0	1581	1819
Clearcut	height 0-2 m	16.5	2211	968
Other forest ¹	height \geq 6 m	16.1	625	944
Mixed/broad-leaved forest	height \geq 6 m	7.5	151	437
Open mires	< 30% canopy cover	7.2	157	424
Younger forest	height 3-5 m	6.5	231	383
Wooded mire	> 30% canopy cover	6.4	85	373
Coniferous forest on lichen ground or open bedrock	height \geq 6 m	5.9	771	347
Lakes, water courses and marshes		1.8	20	108
Arable land and pastures		0.6	2	37
Power lines		0.3	26	16
Built-up areas		0.1	2	6
Sum		100.0	5862	5862

¹ Areas with clearcuts or younger forest in year 2004, the production year for the Swedish Land and Vegetation Cover (Lantmäteriet 2004), but with a height of \geq 6 m in year 2010 (according to *k*NN-Sweden 2010; SLU 2011a).

Table A5. Comparison of GPS height between the two transmitter unit types used: VAS (only positions based on \geq 3 satellites, n=6) and MTI (n=3). For each transmitter type: minimum and maximum values, overall mean \pm SE, mean \pm SE separately for positions located belowground and aboveground, number and percentage of positions located aboveground, and total number of positions.

Transmitter type	Min	Max	Mean \pm SE	Mean \pm SE,	Mean \pm SE,	No. of positions aboveground	% of positions aboveground	Total no. of positions
				belowground positions	aboveground positions			
VAS ¹	-139	815	19 \pm 23	-7 \pm 4	29 \pm 26	3414	73	4707
VAS ²	-139	815	19 \pm 24	-7 \pm 4	29 \pm 27	2998	73	4093
MTI	-520	834	104 \pm 95	-142 \pm 92	36 \pm 48	280	22	1296

¹ Only positions based on \geq 3 satellites.

² Only positions based on \geq 3 satellites and DOP < 5. See the text for explanation on DOP.

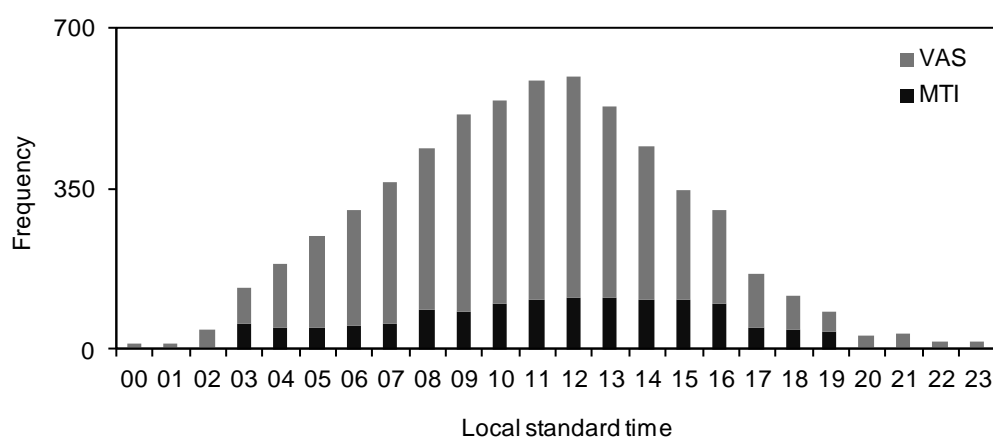


Figure A1. Number of GPS locations per local standard time during the juveniles post-fledging period, for VAS transmitters (only positions based on \geq 3 satellites, n=6) and MTI transmitters (n=3).

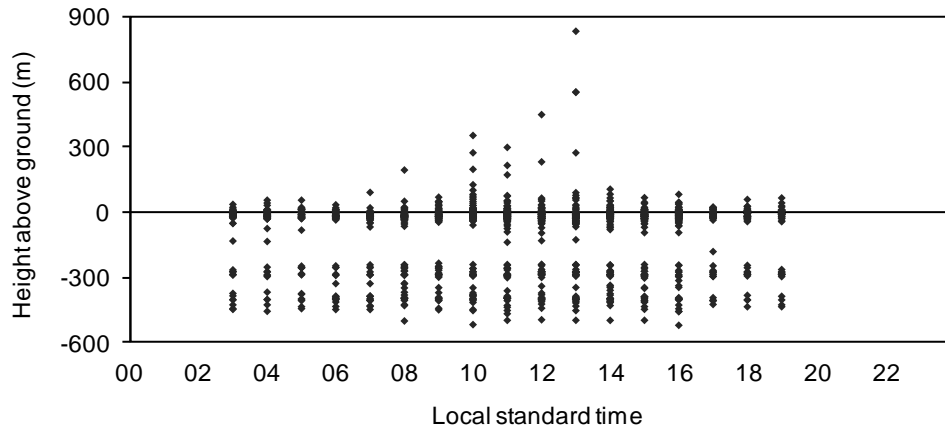


Figure A2. Distribution of GPS height positions of the juveniles (n=3) according to MTI units during the post-fledging period.

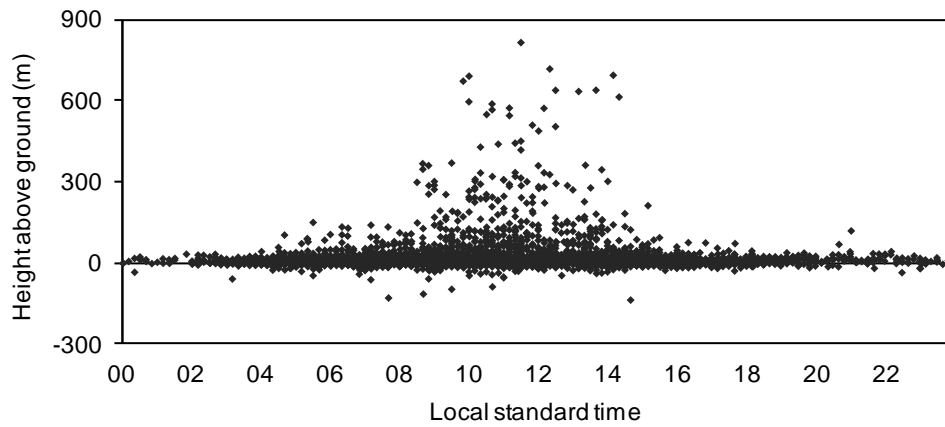


Figure A3. Distribution of GPS height positions of the juveniles (n=6) according to VAS units (only positions based on ≥ 3 satellites) during the post-fledging period.

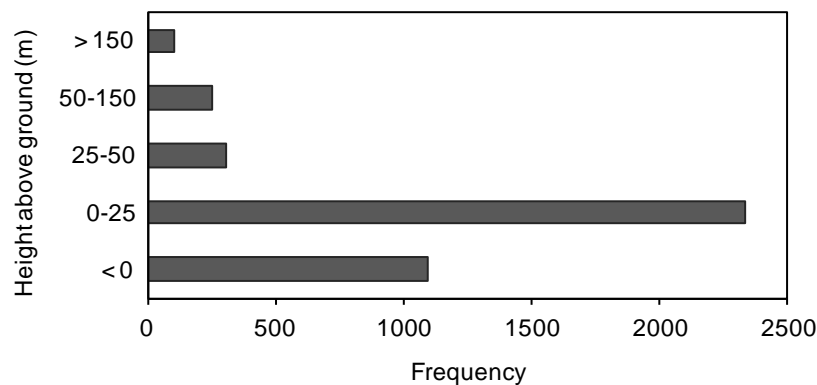


Figure A4. Number of GPS height positions of the juveniles (n=6) in different height intervals during the post-fledging period. Only positions received from VAS transmitters based on ≥ 3 satellites and $DOP < 5$. See the text for explanation on DOP.

SENASTE UTGIVNA NUMMER

- 2011:1 Pre-spawning habitat selection of subarctic brown trout (*Salmo trutta* L.) in the River Vindelälven, Sweden.
Författare: Erik Spade
- 2011:2 Vilka faktorer samvarierar med användandet av viltkött, vildfångad fisk, bär och svamp i svenska hushåll? – Stad vs. Landsbygd.
Författare: Jerker Hellstadius
- 2011:3 Konsekvenser av födoval och minskande sorkstammar för populationer av sorkätande ugglor och rovfåglar.
Författare: Katie Andrie
- 2011:4 Tjäderns (*Tetrao urogallus* L.) vinterdiet i norra Sverige: Är gran (*Picea abies*) viktig i vissa habitat?
Författare: Staffan Öberg
- 2011:5 Grey-sided vole and bank vole abundance in old-growth forest patches of different size and connectivity.
Författare: Niklas Paulsson
- 2011:6 *De novo* sequencing and SNP discovery in the Scandinavian brown bear (*Ursus arctos*).
Författare: Anita J Norman
- 2011:7 A genetic approach to identify raccoon dog within a large native meso-carnivore community.
Författare: Dan Wang
- 2011:8 Is old forest like old forest? Patterns in abundance and species number of resident birds in old boreal forest stands in relation to stand structure and landscape context.
Författare: Ortrud Leibinger
- 2011:9 Klövviltets nyttjande av foderraps på viltåker och betespåverkan på angränsande skog.
Författare: Maria Lidberg
- 2012:1 Attityder till återintroduktion av visent i Sverige
Författare: Axel Bergsten
- 2012:2 Viltanpassad röjning längs skogsbilvägar som en foderskapande åtgärd för älgen.
Författare: Ida Forslund
- 2012:3 Spawning site selection of brown trout in habitat restored streams.
Författare: Jonas Svensson
- 2012:4 The shift in forest and tree limits in Troms County – with a main focus on temperature and herbivores.
Författare: Kristoffer Normark
- 2012:5 Clover (*Trifolium* spp) gamefields: Forage production, utilization by ungulates and browsing on adjacent forest.
Författare: Karl Komstedt