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Habitat selection by adult Golden Eagles *Aquila chrysaetos* during the breeding season and implications for wind farm establishment

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ABSTRACT

Capsule: Global Positioning System (GPS)-tagged adult Golden Eagles *Aquila chrysaetos* breeding in forests in northern Sweden selected clear-cuts, coniferous forests with lichens and steep slopes during the breeding season but avoided wetlands and mixed forest.

Aims: To investigate the habitat selection patterns of tree-nesting Golden Eagles, and identify how potential conflicts with wind farm development could be minimized.

Methods: The study is based on GPS tracking data from 22 adult eagles. We estimated home range sizes using a biased random bridge approach and habitat selection patterns using resource selection functions following a use-availability design.

Results: Core home range size among adults was variable during the breeding season (5–30 km^2). Individual movement extents were variable, but sexes did not significantly differ in their scale of movement. At the landscape scale, individuals selected for clear-cuts and coniferous forest with ground lichens, whereas wetland, water bodies and mixed forest were avoided. Steeper and south facing slopes were selected for, whereas, north facing slopes were avoided.

Conclusions: Potential conflicts between eagles and wind energy establishment can be reduced if wind farms are placed away from steep slopes, minimizing areas that are clear-cut during construction, and locating turbines within dense, young and other less favoured forest habitats.

The drive to replace fossil fuels with renewable energy sources has led to a global increase in the establishment of wind power plants (GWEC 2015). This is also the case at the national level in Sweden, where there were 2961 wind turbines with an installed capacity of around 5100 MW at the end of 2014 (Energimyndigheten 2015). There is increasing concern over the potential negative effects on birds and other wildlife of poorly placed wind farms (Langston & Pullan 2004, Drewitt & Langston 2006, Bright *et al.* 2008, Pearce-Higgins *et al.* 2009, Schuster *et al.* 2015). Such wind farms likely have a greater negative impact on wildlife compared to wind farms that have involved extensive planning and comprehensive habitat analyses (Langston & Pullan 2004). Raptors are frequently killed at poorly planned wind farms; some notorious cases include Altamont Pass, California (Thelander & Smallwood 2007), Smøla, Norway (Bevanger *et al.* 2010) and Tarifa, Spain (Barrios & Rodríguez 2004). While much of the debate on the effects on birds of

wind power plants focuses on collision mortality, disturbance, avoidance and subsequent habitat loss are also important (Langston & Pullan 2004). Some individuals, however, are able to compensate for this type of habitat loss by adjusting their ranging behaviour (Madders & Whitfield 2006).

In Sweden, one species that has received much attention because of wind power–wildlife conflicts is the Golden Eagle *Aquila chrysaetos*. This large raptor is red-listed in Sweden as near-threatened (ArtDatabanken 2015) and is listed in Annex 1 (species needing special habitat conservation measures) of the EU Birds Directive (European Union 2009). The majority of Sweden's Golden Eagles are found in the country's northern boreal forest (Tjernberg 2010), a sparsely populated area that is also becoming increasingly exploited for wind energy projects. Wind farm establishment is considered a potential threat to Golden Eagles in Sweden that is likely to increase in the future (Tjernberg 2010). The heavily managed

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forested landscape is dominated by a mixture of clear-cuts and patches of mainly even-aged, even-height forest containing Scots Pine *Pinus sylvestris* and Norway Spruce *Picea abies* with incidence of deciduous trees and stands of non-native Lodgepole Pine *Pinus contorta* (Essen *et al.* 1997). Golden Eagles favour upland environments throughout the northern hemisphere and usually remain in one home range for many years (Watson 2010). Individual eagles can occasionally live as long as 30 years in the wild, potentially enabling them to breed for many years after establishing a home range (Harmata 2012). In northern Sweden the breeding season starts during late March to early April when eggs are laid (Tjernberg 1983a). In this area their principal prey species (Mountain Hare *Lepus timidus* and grouse species, such as Capercaillie *Tetrao urogallus*) show strong short-term population fluctuations (Tjernberg 1981, 1983b, Nyström *et al.* 2006) that influences much of the Golden Eagle's ecology (Moss *et al.* 2012).

Golden Eagles utilize their home ranges in unequal proportions (Marzluff *et al.* 1997) preferring certain types of habitat due to increased prey detectability, enhanced nesting and foraging opportunities or more efficient movement across the landscape resulting from thermals and updrafts (Bohrer *et al.* 2012, Katzner *et al.* 2012). Thermal winds occur when the sun warms steep slopes that force air masses to rise, and updraft occurs when topography drives air masses to higher elevations, and in connection with this many studies have found significant use by Golden Eagles of different topographical features. For example, McIntyre *et al.* (2006) found that core areas of territories were categorized as rugged terrain, while Bohrer *et al.* (2012) and Katzner *et al.* (2012) reported migratory movements along mountain ridges. Golden Eagles are generally considered to prefer landscapes characterized by open habitats that increase prey detectability (Watson 2010). However, old growth forest is also important since it contains suitable nesting trees (mean age of nest trees in Sweden >335 years old, Tjernberg 1983a). Since Golden Eagles utilize their home range unequally, detailed studies of habitat selection are crucial throughout the wind farm planning and development process. We predict that clear-cuts are an important habitat for eagles in managed forested areas in northern Sweden, since they open up forest habitat for hunting and increase prey detectability. In this study, we aim to determine how land cover type and topographic variables affect the habitat selection by Golden Eagles in northern Sweden and provide management suggestions on how to decrease potentially negative effects of wind power development on Golden Eagles.

Materials and methods

Study area and GPS tracking

The study area lies in northern Sweden (63–65°N, 17–20°E), in lowland forests east of the Swedish mountains. We captured 22 adult Golden Eagles (10 females and 12 males) and fitted them with backpack mounted GPS transmitters. Three types of transmitters were used: manufactured by Microwave Telemetry Inc., USA (75 g; < 2% of eagles' body mass), Vectronic Aerospace GmbH, Germany (140 g; approximately 3% of eagles' body mass) in 2010–11 and Cellular Tracking Technologies, Inc., USA (70 g) in 2014. Birds were captured using remote controlled bownets (Jackman *et al.* 1994, Bloom *et al.* 2007, Bloom *et al.* 2015). Sexes were identified based on their body mass and were later confirmed genetically from blood samples, using the protocol described in Fridolfsson & Ellegren (1999). For this study, we obtained 6 locations a day for each bird, between 04:00 and 18:00 h. The error obtained from all three GPS transmitter types was never more than 18 m. The breeding season locations for this study were selected based on the season which was individually defined for each bird, starting from March onwards (when pairs were confirmed from field observations to be occupying their territories), and until an individual suddenly left its home range, which indicates nest abandonment after breeding failure (Moss *et al.* 2014). These movements are captured when net squared displacement (NSD) suddenly rises with time especially during autumn months (Turchin 1998, Weston *et al.* 2013). The breeding season, on average, stretched between March and the end of August. The total number of locations used in this study was 26 457. The database is hosted within the Wireless Remote Animal Monitoring project (Dettki *et al.* 2013).

Extent of movements and home ranges

We calculated the extent of movements of all individuals from their NSD, which is the square of the distance to the first location for each location of a movement path of an animal (Turchin 1998). We estimated the individual home ranges based on the utilization distributions (UDs) calculated using the biased random bridge approach (also known as the 'movement-based kernel estimation'; Benhamou & Cornelis 2010, Benhamou 2011). This movement-based kernel approach assumes the framework of the biased random walk model, the main strength of which is that it does not assume a purely diffusive movement, whereas the Brownian bridge

method supposes only diffusion. It instead includes an advection component in the trajectory (i.e. a 'drift' between successive relocations). This model is therefore more realistic when animal movements are studied. This approach was implemented in the adehabitatHR package in R (Calenge 2006; R Development Core Team 2012).

We first estimated the diffusion coefficient (*D*) for each individual based on its movement trajectory during the breeding season. The diffusion coefficient took the unit of m^2/s. This diffusion parameter was then further used to estimate the UD using the function 'BrB'. The grid size and extent parameters for each individual were individually defined based on the geographical extent of their movement, that is, the minimum and maximum longitude and latitude for an individual (Calenge 2011). From the UDs, we extracted the 50% and 95% Volume Contours (VC) as a representative of the core and extended areas of use (Watson *et al.* 2014, Braham *et al.* 2015). The differences between the sexes were tested using a binomial generalized linear model (Zuur *et al.* 2007).

Landscape and topographic variables

To characterize the habitat selection of Golden Eagles in Sweden, we obtained the habitat and topographic maps as rasters (25 × 25 m resolution; Lantmäteriet 2015a). The main land cover classes were clear-cuts, closed canopy forests, closed canopy forests with lichens, young forest, open wetlands, wooded wetlands, settlements and urban areas, water, and pastures and arable land. The topographic variables were elevation (m), slope (°) and aspect (direction) extracted from a digital elevation model of 25 m spatial resolution (Lantmäteriet 2015b). Aspect, being a circular variable (0–360°), was transformed into the linear variables eastness and northness using cosine (aspect) and sine (aspect), respectively. Both of these variables vary between −1 and 1, where positive values indicate inclination towards east and negative values towards west. Similarly, positive values for northness indicate inclination towards north.

Habitat selection analyses

To identify the cover types and topographic features selected by eagles we used the 'Design III' approach of habitat selection proposed by Thomas & Taylor (2006), Johnson *et al.* (2006) and Gillies *et al.* (2006). In this approach individual animals are tracked and the use and availability for each individual is estimated separately. We extracted the use and availability values for our variables (elevation, slope, aspect and habitat

type) from the raster maps. Use is based on the GPS locations recorded for each individual and the availability corresponds to the pixels falling inside the limits of the minimum convex polygon enclosing all its relocations. These used and availability values were then incorporated into a linear mixed effects model with binomial response variable (use/available) modelled against elevation, slope, aspect and habitat type as explanatory variables and individual ID as the random effect (Johnson *et al.* 2006). A large *t*-value (absolute value) is associated with a larger effect. Variable selection was performed using Akiake's Information Criterion approach (Burnham & Anderson 2002) and the best model was selected using a model average. We also estimated the relative contribution of variables in determining resource selection by adult eagles (Burnham & Anderson 2002, Singh *et al.* 2012).

Results

Movements and home ranges, differences between sexes

Extent of movement during the breeding season varied between 10 and 1296 km^2 across individuals. Sexes did not differ in their extent of movement (males: mean ± sd = 275 ± 367 km^2 and females: 276 ± 289 km^2, t_{22} = 0.83, P = 0.40, Fig. 1). The core home range size (50% VC) of individuals varied between 5 and 30 km^2, whereas the extended home range (95% VC) varied between 30 and 70 km^2. Again, there was no significant difference between breeding season home range size of sexes (t_{22} = 0.63, P = 0.70).

Habitat selection

Adult Golden Eagles during the breeding season selected for clear-cuts and coniferous forests with ground lichens, but avoided wetlands, settlements and water bodies (mean ± std. error: clear-cuts 2.34 ± 0.12, t = 23.22, Table 1). Among the topographic features, eagles selected for steeper as well as south facing slopes (slope: 6.14 ± 1.11, t_{17} = 92.11, northness: −0.24 ± 0.16, t_{17} = 14.88, Table 1, Fig. 2). Overall, habitat features were relatively more important than topographic features based on AIC model selection criteria (Table 2). Habitat type had the highest contribution (100%), followed by slope (91%) and northness (76%) in explaining the resource selection by adult eagles (Table 2). About 10% of the variation in the resource selection behaviour was attributed to individual identity, which was included as a random effect.
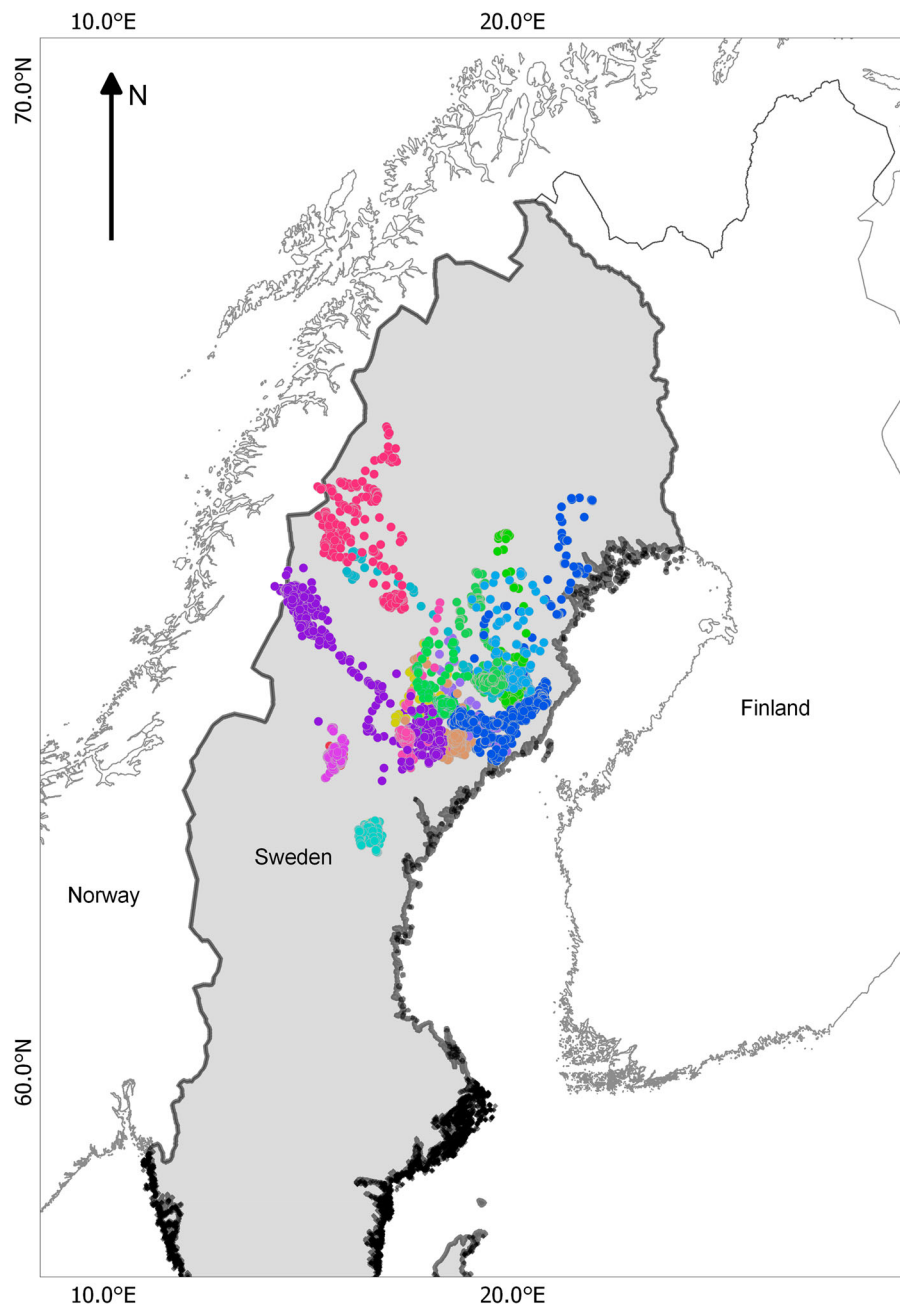
Figure 1. Map of the study area with GPS locations of marked adult Golden Eagles during the breeding season. Individuals are represented in different colours.

Discussion

We have shown that Golden Eagles selected for clear-cuts, coniferous forest and coniferous forest with ground lichens. Although forestry poses a threat to nesting trees and surrounding forest stands (Tjernberg 1983a), the selection for clear-cuts also suggests a positive effect of forestry on Golden Eagles, by opening up the boreal landscape thereby creating suitable hunting habitats and increasing prey detectability for the eagles (Moss et al. 2014, Sandgren et al. 2014). This selection for clear-cuts is in line with studies from open landscapes in the

Scottish uplands that found negative effects from plantation forestry, as there was a correlation between number of non-breeding pairs and the amount of closed canopy forest (Whitfield et al. 2001, 2007). Conversely, but in line with our results, Pedrini & Sergio (2001) found that Golden Eagle nest density decreased with the extent of woodland within the eagles' potential hunting range. This was thought to be caused by land abandonment and subsequent loss of alpine pastures and woodland encroachment, thus further demonstrating the importance of open landscapes for Golden Eagles.

Table 1. Parameter estimates from a linear mixed effects model showing the influence of environmental variables on the probability of use of locations by individual Golden Eagles during the breeding season in northern Sweden.

Variable	Estimate	Std. error	t-Value
Intercept	3.12	0.01	308.94
Elevation	−0.41	0.01	−2.60
Slope	6.14	1.11	92.11
Eastness	0.18	0.13	0.45
Northness	−0.24	0.16	14.88
Clear cuts	2.34	0.12	23.22
Closed canopy forests with lichens	1.01	0.19	11.95
Open wetlands	−0.16	0.03	6.28
Other open areas	−0.19	0.05	7.07
Pastures and arable land	0.07	0.04	5.71
Roads and railroads	−0.61	0.12	−0.24
Settlements	−0.53	0.13	−4.21
Thickets	−0.04	0.05	−7.72
Water	−0.75	0.07	−96.47
Wooded wetlands	−0.47	0.03	−52.00
Young forest	0.21	0.11	7.62
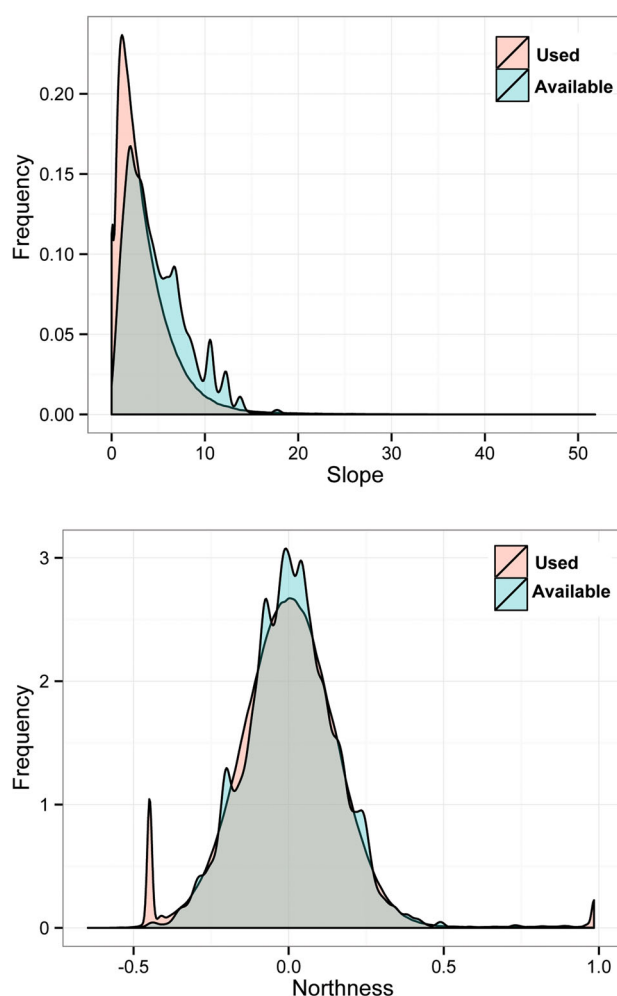
Figure 2. Distribution of slope (degree) and northness (aspect) variables observed in used and available sites of Golden Eagles in the breeding season from northern Sweden. Use is the binomial variable which defines the used and available sites in linear mixed effects models. The shaded region is where the distributions of the variables overlap.

Eagles also selected coniferous forest with ground lichens, reflecting the tree-nesting habits of the Swedish Golden Eagle population (Tjernberg 1983a). In some parts of northern Sweden's coniferous forest where ground lichens are particularly rich this habitat is used as winter grazing pasture for Reindeer *Rangifer tarandus* herds (Heggberget *et al.* 2002). Thus, this habitat may also attract Golden Eagles by potentially supplying Reindeer carcasses from nearby road kills or left-overs from mammalian predators. This habitat is also an important habitat for Capercaillie. Since coniferous forest with ground lichens, in contrast to common coniferous forest, is less dense and contains fewer dwarf shrubs, this forest type potentially provides more suitable hunting areas.

Adult eagles avoided open and wooded wetlands, and to a lesser extent, mixed forest. Young and mixed forests, representing successional stages following re-growth of forest were not selected perhaps due to lower prey detectability for eagles in these denser forests. However, these habitats are also likely to be less favoured due to trees being of inferior structural strength for nesting when compared to those in coniferous forest of older age. The avoidance of open and wooded wetlands we found more surprising. However, we cannot rule out that wetlands may be used more in winter. On the other hand, wetlands can also be rich in dense dwarf shrubs (e.g. *Rhododendron tomentosum* and *Betula nana*), which provide cover for prey, and render these habitats as less suitable hunting grounds.

Selection of steeper and south facing slopes is in line with observations from other areas in the geographical range of Golden Eagles. For example, in Alaska McIntyre *et al.* (2006) constructed a terrain ruggedness index displaying rugged terrain as one of the most common features within territory cores. In our study, stronger selection was observed as slope incline increased. Steeper slopes are usually places where orographic updrafts develop, acting as a low altitude energy resource (Kerlinger 1989, Katzner *et al.* 2012, Bohrer *et al.* 2012). Overall, a higher importance of habitat variables than topography is also indicative of the general lack of dramatic topography in the part of Sweden where our study was conducted, but rather on dependence of Golden Eagles on nesting trees and hunting habitats created by forestry.

Implications for wind farm establishment

Fielding *et al.* (2006) concluded that wind farms did not necessarily present a problem to Golden Eagles if they were well-planned and sited to minimize disturbance.

Table 2. Three best models ranked by importance, containing the variables explaining the use of locations by Golden Eagles during the breeding season in northern Sweden. '+' sign in the 'Habitat type' variable indicates that habitat type was included in the model. For other variables (Elevation, Northness and Slope), the numbers denote the parameter estimates. The models are ranked based on AICc score and weight.

Model number	Intercept	Habitat type	Eastness	Elevation	Northness	Slope	df	LogLikelihood	AICc	Delta	Weight
26	3.12	+			−0.24	6.14	16	1 212 577	−2 425 122	0	0.9
18	3.12	+				6.14	15	1 212 571	−2 425 112	10.13	0.06
30	3.12	+		−0.41	−0.23	6.12	17	1 212 572	−2 425 110	11.13	0.003

In boreal Sweden we suggest making wind farms unattractive to Golden Eagles by locating them in areas of poor prey detectability for eagles, on high altitude plateaus or slopes with northern aspects. The eagles' selection for steep slopes has been highlighted in earlier studies in the USA, and we reaffirm recommendations that wind turbines should be placed back from cliff and rim edges (see Johnson *et al.* 2007). In addition, we would like to stress the potential for using the young, mixed and other 'unpopular' forest habitat classes to discourage eagles from using an area. Forest management could be used as a tool for encouraging eagles to stay away from otherwise poorly sited wind farms. For example, in a small study in Scotland, clear-cutting forest outside a wind farm created suitable hunting grounds and encouraged a shift in activity away from the wind farm by Golden Eagles, reducing collision risk (Walker *et al.* 2005). In Sweden, it is likewise desirable that management of forest within and outside that farm is carried out in a manner so that eagle activity is encouraged away from the wind farm. Within wind farms, clear-cutting should be minimized, so that the time to clear-cutting exceeds the expected life time of the wind farm, to discourage eagles from hunting within it. We acknowledge that this may be difficult, given that a new wind farm with its service roads requires a substantial amount of forest clearance. However, we encourage wind energy and forestry companies to collaborate more closely in future both before, during and after wind farm construction to minimize disturbance and collision risk to Golden Eagles.

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