



Habitat use by post-fledging white-tailed eagles shows avoidance of human infrastructure and agricultural areas

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Abstract

Habitat use studies provide invaluable information for the conservation of species that suffer from habitat loss or degradation. We used satellite telemetry to study the habitat use of white-tailed eagles (*Haliaeetus albicilla*) in relation to six habitat classes (artificial surfaces, agricultural areas, forests, semi-natural areas, wetlands and waterbodies) and five forest age classes (0–9, 10–19, 20–59, 60–99 and ≥ 100 years old) during the post-fledging period in Finland. The post-fledging period, defined here as the period between fledging and dispersal from the natal area, is a critical life-history stage. Our primary objective was to provide information that could be integrated into landscape planning, including wind-energy development (which poses a threat to white-tailed eagles). We found that the habitat classes that were selected by the young white-tailed eagles were forests, semi-natural areas (*i.e.*, transitional woodland and bare rock) and wetlands. When using forests, the eagles selected stands of 0–9 years old, presumably due to the use of retention trees surrounded by a clear-cut as perching sites. Conversely, the habitat classes that were avoided were artificial surfaces, agricultural areas and (the immediate vicinity of) waterbodies. We conclude that the conversion of natural habitats into built and agricultural areas is detrimental to young white-tailed eagles because it reduces habitat availability. They, however, appear to be capable of using forests recently impacted by forestry if perch trees are present. Careful landscape planning is needed to protect priority habitats and avoid conflicts with an expanding white-tailed eagle population (e.g., by building wind farms in areas already environmentally disturbed).

Keywords Raptor · Spatial ecology · Selection ratios · Land use · Conservation

Introduction

Land-use change poses a major threat to biodiversity and population viability worldwide (Sala et al. 2000). In particular, habitat loss or degradation driven by agricultural intensification, deforestation and infrastructure development is associated with a growing number of threatened species within higher taxa (Mace et al. 2005; Baillie et al. 2010; Pereira et al. 2010; Pimm et al. 2014). The conservation of a target species can thus benefit from an understanding of its space use, habitat requirements and the relative importance of local resources (Manly et al. 2002).

Raptors are easily subject to disturbance and often depend on large hunting areas (Hardey et al. 2013). Raptors are vulnerable to the loss or degradation of natural habitats (Bildstein et al. 1998; Herremans and Herremans-Tonnoeyr 2000; Kirby et al. 2008) and can be significantly stressed and thus negatively affected by human infrastructure (e.g., roads and paths; Krone et al. 2019). Some species, such as the peregrine falcon (*Falco peregrinus*), the tawny owl (*Strix aluco*) and the American kestrel (*Falco sparverius*), have shown to be adaptable to urbanisation (Chace and Walsh 2006). However, many raptor species across the world have an unfavourable conservation status or a declining trend (McClure et al. 2018), thus requiring protection of breeding and foraging habitats (Suárez et al. 2000; Balbontín 2005; Tanferna et al. 2013; Rivers et al. 2014). The white-tailed eagle is a large, diurnal raptor with a history of population declines. In the 1960s and 1970s, its numbers declined dramatically as a result of widespread environmental pollution (Cramp and Simmons 1980), notably around the Baltic Sea (HELCOM 2018). Following the ban of harmful bio-accumulating substances (HELCOM 2018),

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the species has recovered significantly in the last decades and has been downlisted from vulnerable (VU) to least concern (LC) in the Finnish Red List (Hyvärinen et al. 2019). However, the white-tailed eagle still faces a range of threats and limiting factors over its vast geographical distribution and is listed in Annex I of the EU's Birds Directive (Directive 2009/147/EC 2009). At present, notable pressures include lead poisoning (Isomursu et al. 2018) and habitat loss or degradation in the form of forestry, land exploitation, river regulation and wetland drainage (Helander and Stjernberg 2002; Probst and Gaborik 2011).

Some studies of white-tailed eagles have focused on nest-site selection. These include nest-site selection in reintroduced (Evans et al. 2010), naturally returning (Treinys et al. 2016) and recovering populations (Radović and Mikuska 2009; Sándor et al. 2015). Other studies have focused on individual movements with high-precision telemetry data to study home ranges and habitat use (Scholz 2010; Krone et al. 2013; May et al. 2013; Balotari-Chiebao et al. 2016a; Bragin et al. 2018). However, the post-fledging period, defined as the period between fledging and dispersal from the natal area (Morrison and Wood 2009), has generally received less attention. The post-fledging period is a critical life-history stage, for it is when young birds enhance muscular development, begin to explore the surroundings, interact with conspecifics and acquire crucial foraging skills for later survival (Delgado et al. 2009). During this period, white-tailed eagles lack flight experience and manoeuvrability and are also more naïve towards the environment (Bevanger et al. 2010). In the case of wind farms, this may increase collision risk (May et al. 2011; May et al. 2013; Krone and Treu 2018). Also, it appears that collision fatalities do not show an age bias (when the age composition of a population is taken into account), meaning that juveniles may be equally in danger as, e.g. adults (Heuck et al. 2020), which often collide in greater numbers. Wind-farm fatalities are a concern for white-tailed eagles (Krone and Schamweber 2003; Dahl et al. 2012; Kitano and Shiraki 2013) and other large soaring raptors (Barrios and Rodríguez 2004; Smallwood and Thelander 2008).

In white-tailed eagles, post-fledging parental dependency decreases gradually over *ca.* 35–40 days (Cramp and Simmons 1980) or longer (Hardey et al. 2013). Dispersal from the natal area occurs in their first year of life, usually between September and January (Hardey et al. 2013; Balotari-Chiebao et al. 2016a). Here, we use high-precision telemetry data to study the movements of Finnish white-tailed eagles during the post-fledging period. We examine their habitat use in relation to six habitat classes and five forest age classes, discussing their ecological relevance for landscape planning. We provide general recommendations for wind-energy planners, given the interests in building wind farms particularly along the coast (Finnish Wind Power Association 2020) and the growing concern about negative impacts of wind turbine collisions on the

white-tailed eagle population (Balotari-Chiebao et al. 2016b; Tikkanen et al. 2018).

Materials and methods

Satellite telemetry

In 2009–2011 and 2013, a total of 14 white-tailed eagles nestlings from 13 nests were equipped with a 70 g Argos/GPS Solar Powered PTT (Platform Transmitter Terminal; Microwave Telemetry, Inc.). The satellite tags were placed as a backpack with a Teflon harness. They were programmed to transmit fixes at 1-hour intervals during daytime, with a decreasing number of fixes as the length of day became shorter. The total weight carried by an eaglet at the time of fitting (~ 100 g, including an additional battery for data collection during the winter) complied with recommendations on loading (Kenward 2001). Permission for ringing and satellite tagging was issued by the Centre for Economic Development, Transport and the Environment (ELY) of Finland.

Study period

Our study focused on the post-fledging period, that is, the period between fledging and dispersal from the natal area. Here, fledging was assumed to have occurred when an eagle's distance to the nest was at least twice as long as the average location error (~ 10 m; Balotari-Chiebao et al. (2016a)) for ≥ 5 consecutive relocations. Dispersal was assumed to have occurred when an eagle stayed ≥ 5 km away from the nest for ≥ 10 consecutive days. Data collected during the study period ($\bar{x} = 85$ days ± 31 SD, range = 37–164 days, $n = 14$) amounted to 11,171 observations ($\bar{x} = 798 \pm 308$ SD, $n = 14$). In-flight positions were *c.* 4% of total observations.

Study areas

We established our study areas based on the home ranges of the satellite-tracked eagles. Firstly, home ranges were estimated using a normal bivariate Kernel Density Estimator (KDE) with 95% probability contours (Worton 1989), with default settings in the *kernelUD* function from the R package *adehabitatHR* (Calenge 2006). Secondly, we identified for each eagle the outermost location relative to the nest that fell inside its home range (95% kernel-based home range size: $\bar{x} = 7.83$ km² ± 6.66 SD, $n = 14$; outermost location: $\bar{x} = 3.6$ km ± 1.1 SD, $n = 14$). We then used this location to draw a circle centred on the nest. These resulting circular areas were our study areas. Further details on the space use and ranging behaviour of the study eagles can be found in Balotari-Chiebao et al. (2016a).

Our study areas were located in the Åland Islands and the coastal regions of Southwest Finland, Satakunta and Ostrobothnia (Fig. 1). Altogether they covered 620 km² of mostly waterbodies (the Baltic Sea and lakes) and coniferous and mixed forests, with tracts of transitional woodland and agricultural areas (Table 1). They were all fragmented by roads, particularly gravel roads. Only a small proportion of the forests were ≥ 100 years old ($\sim 7\%$), reflecting the widespread impact of commercial forestry on old-growth trees (Kontula and Raunio 2018). The terrain was generally flat, with no elevation higher than 60 m above sea level.

Spatial datasets

We used CORINE Land Cover 2012 (20-m resolution; Finnish Environment Institute 2014) to obtain information on Finland's national land cover. The CORINE dataset consisted of 48 habitat classes arranged in four hierarchical levels. For the analysis, we grouped the habitats present in our study areas into six large classes: (I) artificial surfaces, (II) agricultural areas, (III) forests, (IV) semi-natural areas, (V)

wetlands and (VI) waterbodies (Table 1). The Baltic Sea and lakes were treated as a single class (i.e. waterbodies), as the latter were present at a highly variable amount in the study areas ($\bar{x} = 4.8\% \pm 15.4$ SD; range = 0–58.1%). In addition, we used the topographic database from the National Land Survey (NLS) of Finland to extract roads (paved and unpaved). The road layer was rasterised, with the same resolution as the CORINE dataset, to produce a binary image indicating which pixels were occupied by a road. The road pixels were then classified as artificial surfaces and incorporated into the CORINE dataset (Table 1). To obtain information on forest age, we relied on the Multi-Source National Forest Inventory (MS-NFI) produced by the Natural Resources Institute Finland (Luke). Forest age inventories were available at two resolutions (16 m and 20 m) for three different years (2009, 2011 and 2013). To ensure matching origin and resolution between these raster layers, we adjusted the pixel size of the 16-m inventory to a 20-m resolution by resampling with the bilinear method (Wegmann et al. 2016). We used all three inventories in an effort to match the available forest age information with the study period (see Section 2.1). Following

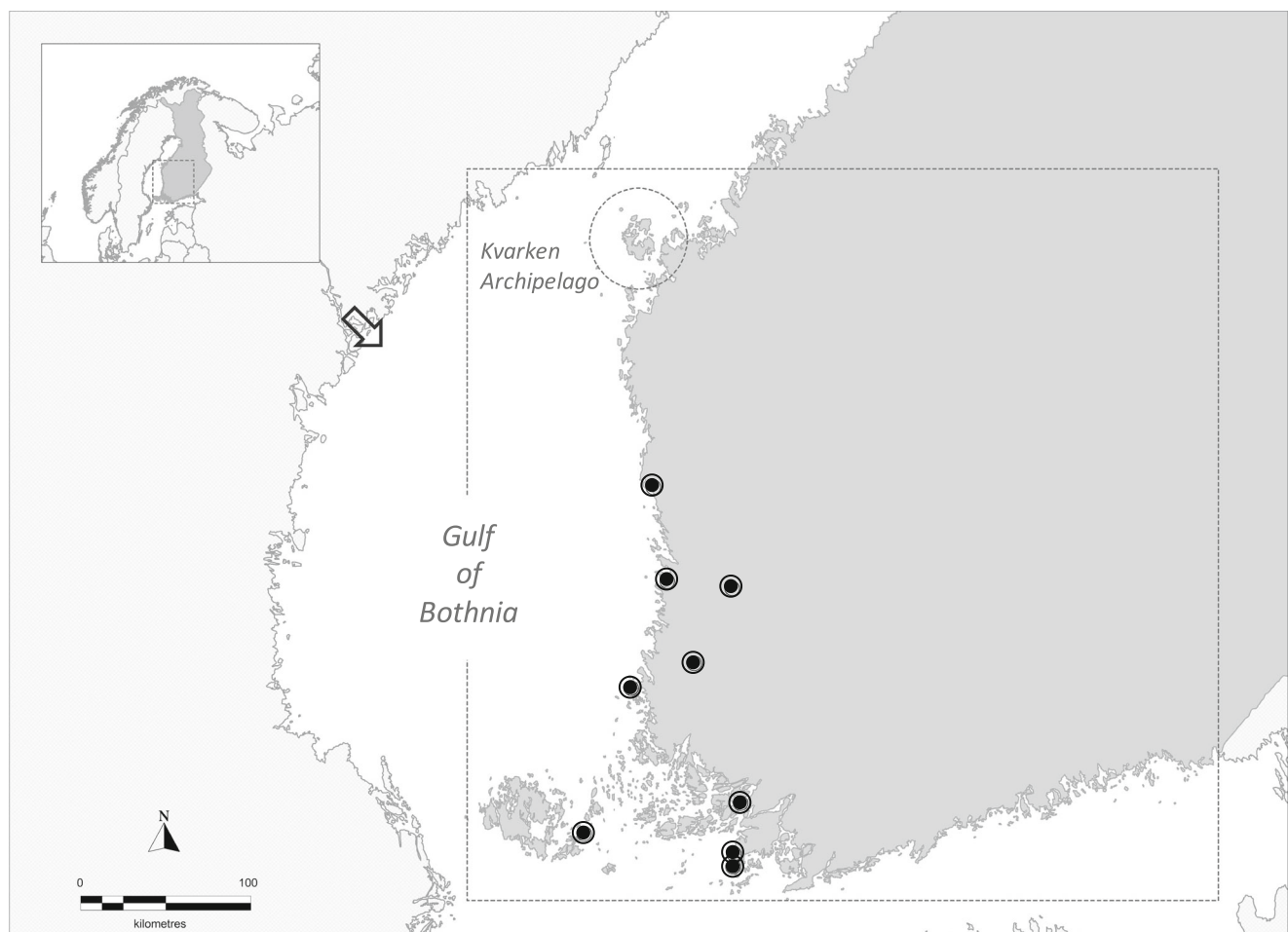


Fig. 1 Approximate nest site locations of the study white-tailed eagles. The dashed circle is used to indicate an area containing five nests that are closely separated from each other, and therefore difficult to visualise at the used scale

Table 1 Detailed composition of all habitats that were present in our study areas, presented here in two hierarchical levels. The relative proportion of each habitat class is given within parentheses

Habitats grouped for analysis (%)	Corine level-3 classification (%)
Artificial surfaces (4.39)	Discontinuous urban fabric (0.36)
	Industrial or commercial units (0.17)
	Road and rail networks and associated land (0.02)
	Mineral extraction sites (0.09)
	Sport and leisure facilities (0.6)
	Paved and unpaved roads* (3.15)
Agricultural areas (3.92)	Non-irrigated arable land (2.96)
	Fruit trees and berry plantations (0.03)
	Pastures (0.07)
	Land principally occupied by agriculture (0.44)
Forests (38.72)	Agro-forestry areas (0.42)
	Broad-leaved forest (1.5)
	Coniferous forest (25.15)
Semi-natural areas (7.05)	Mixed forest (12.07)
	Transitional woodland/shrub (6.6)
	Bare rock (0.45)
Wetlands (2.33)	Inland marshes (0.23)
	Peatbogs (1.22)
	Salt marshes (0.88)
Waterbodies (43.59)	Lakes (2.68)
	Baltic Sea (40.91)

*Extracted from the NLS topographic database and incorporated into the Corine dataset (see the “Study areas” section for details).

Sandgren et al. (2014), we then divided forest age into five classes: (I) 0–9, (II) 10–19, (III) 20–59, (IV) 60–99 and (V) ≥ 100 years old. We used R (version 4.0.2; R Core Team 2020) for data analysis and as a geographic information system (GIS) for handling and processing all spatial datasets.

Habitat use

We analysed habitat use via the estimation of selection ratios. This approach is appropriate when resource units (e.g. the pixels in a raster) can be classified into one of several categories (e.g. habitat classes; Manly et al. 2002). Habitat use is considered to be selective when a resource category is used disproportionately to its availability. Here, use and availability were quantified separately for each eagle (Design III as classified by Thomas and Taylor (1990)), as our satellite-tracked eagles were uniquely identified. For use, we calculated the number of resource units per habitat and forest age classes within a 30-m buffer added to each position. We deemed this buffer size sufficiently large to account for habitat misclassification due to locational error (~ 10 m). For availability, we

calculated the number of resource units based on the relative proportion of habitat and forest age classes in the study areas. We then used the following estimator to obtain the selection ratios (Manly et al. 2002):

$$\hat{w}_i = u_{i+} / \sum_{j=1}^n \pi_{ij} u_{+j}$$

where u_{i+} is the total number of used resource units in category i , π_{ij} the proportion of resources available to eagle j in category i and u_{+j} the total number of used resource units by eagle j . A selection ratio > 1 indicates selection, while < 1 indicates avoidance (Manly et al. 2002).

Addressing spatial and temporal autocorrelation

Spatial and temporal autocorrelation are a common difficulty in spatial data analysis, because they violate the assumption of independence of observations. Spatial and temporal autocorrelation decrease as the time interval between animal relocations is increased (Thomas and Taylor 2006). Based on this rationale, we increased the location-time interval by randomly sampling one observation per day per eagle. We applied the Durbin-Watson test (implemented with the *dwtest* function from the R package *lmtest*; Zeileis and Hothorn 2002) to ensure that this location-time interval was appropriate to treat autocorrelation. To avoid unequal sample sizes, the number of observations per eagle was further reduced to 38, which is the minimum number of successfully tracking days among all eagles ($\bar{x} = 78 \pm 25$ SD, range = 38–139, $n = 14$). Given such a reduction of the original dataset, we performed the random sampling (1 observation per day, totalling 38 observations per eagle) 1000 times for a thorough exploration of the available data. Confidence intervals for the selection ratios corresponded to the 2.5% lower and upper quantiles.

Results

The post-fledging period ranged from 20 June (the earliest fledging) to 23 December (latest onset of dispersal). Nestlings fledged at 71–86 days old ($\bar{x} = 79 \pm 4$ SD) and juveniles dispersed at 115–244 days old ($\bar{x} = 164 \pm 31$ SD). The post-fledging white-tailed eagles showed selection for forests, semi-natural areas and wetlands. Semi-natural areas, which in our study areas were mostly composed of transitional woodland/shrub (Table 1), were the habitat class with the highest selection ratio (Fig. 2a). Conversely, the eagles avoided artificial surfaces, agricultural areas and waterbodies. The avoidance of waterbodies, a major foraging habitat for the species, was expected given the small proportion of in-flight positions (*c.* 4%) and the subsampling of the data (1 observation/day/eagle). When using forests, they selected (though with a marginal significance) young patches between 0 and

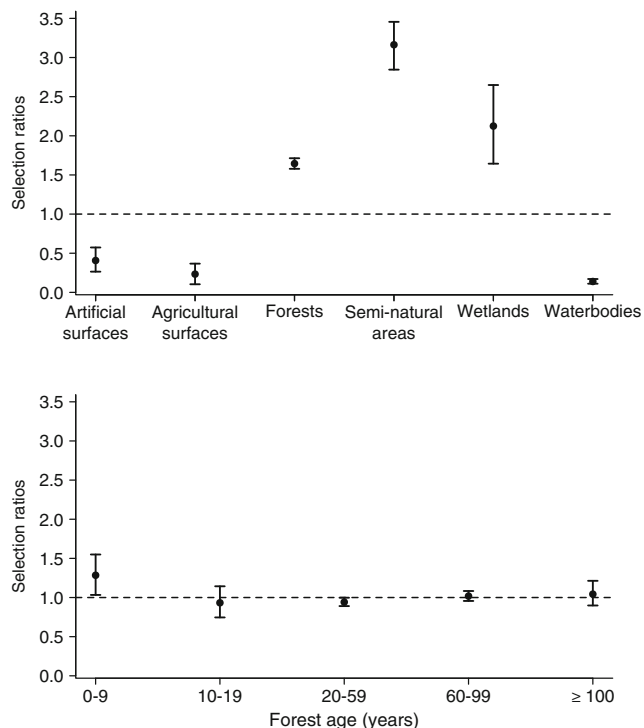


Fig. 2 Selection ratios for different habitat and forest age classes for white-tailed eagles during the post-fledging period. Values above the dashed line indicate selection, whereas values below the dashed line indicate avoidance. The points are median estimates from the analysis of 1000 randomised datasets. Confidence intervals correspond to the 2.5% lower and upper quantiles (see the “Habitat use” section for details)

9 years old. All the other forest age classes were used in proportion to their availability (Fig. 2b).

Discussion

We studied the habitat use of white-tailed eagles during the post-fledging period in the west and southwest of Finland, primarily in coastal areas. Our study highlights the selection of forests (0–9 years old), semi-natural areas and wetlands. It also highlights the avoidance of artificial surfaces, agricultural areas and waterbodies. This pattern gives clear indication that the loss or alteration of natural habitats (resulting from the development of various types of artificial surfaces and agricultural areas) reduces habitat availability to post-fledging white-tailed eagles.

Sandgren et al. (2014) showed that post-fledging golden eagles in Swedish Lapland favoured forests of the same age class that was selected here by white-tailed eagles and related such selection to prey availability. In our case, given the differences in the feeding ecology of the two species, the selection of young forests may be explained by the use of retention trees as perching sites. Green tree retention (GTR) is a forestry practice applied to boreal forest management, with a retention of normally 5–10 trees/ha in Fennoscandia (Vanha-Majamaa

and Jalonen 2001). Retention trees are surrounded by clear-cut areas and provide the eagles with a largely unobstructed view and sufficient space for flying. The selective use of young forests thus suggests that post-fledging white-tailed eagles are capable of using an environment recently impacted by forestry (as long as there are perch trees).

Artificial surfaces and agricultural areas were clearly avoided by the eagles. These results are in line with previous satellite-tracking studies of adult (Scholz 2010) and sub-adult white-tailed eagles (May et al. 2013). It is worth adding that construction and land clearing for agricultural purposes are major threats to various habitat types in Finland, leading to negative consequences for associated taxa (Kontula and Raunio 2018). Waterbodies (the other avoided habitat class) were abundant in the study areas, but they were used less than expected from their availability. As revealed by the 30-m buffer (used here to assess the habitats that were in the immediate vicinity of the observed positions), the eagles tended not to be in close proximity with waterbodies (or e.g. sitting on skerries). The relatively small proportion of in-flight positions (c. 4%) may have contributed to overestimate of the avoidance of waterbodies.

Wind energy poses a new threat to white-tailed eagles, which are known to be vulnerable to collision mortality (Dahl et al. 2012). In Finland at least 20 white-tailed eagles, including juveniles, have been found dead and reported by the general public since 2005 (T. Stjernberg, pers. comm., 17 March 2020). A lack of long-term, systematic carcass searches prevents an understanding of the impact of this type of fatality on the population. Finland’s installed wind-energy capacity is currently modest (754 turbines produced 7% [5.9 TWh] of its electricity consumption in 2019; Finnish Wind Power Association 2020), but it will continue to increase in the near future (Huttunen 2017). The threats posed by future wind farms, which will help to reach the goal of 7–9 TWh of wind-derived electricity by 2030 (Huttunen 2017), will largely depend on site selection (Meller 2017). Siting wind farms away from important habitats and in areas already environmentally disturbed would presumably reduce the likelihood of conflicts with white-tailed eagles. We note, however, that simply siting wind farms where raptors are less abundant does not necessarily minimise fatalities (De Lucas et al. 2008), as collision mortality depends on a range of factors, including species, topography and wind-farm specifications.

Management implications

The conversion of natural habitats into built and agricultural areas reduces the availability of suitable habitats to white-tailed eagles during the post-fledging period. Conversely, the protection of forests, semi-natural areas and wetlands would benefit them during this critical life-history stage. As regards

wind energy, to reduce the likelihood of conflicts, wind farms should be sited away from important habitats and in areas that are already environmentally disturbed (e.g., agricultural areas). This precautionary measure, combined with other mitigation strategies (e.g., wind-farm configuration), would presumably reduce the risk of collision among young white-tailed eagles and possibly among adult white-tailed eagles. This is particularly important for coastal areas, as most of the existing, planned and proposed Finnish wind farms are located on the coast, and the presence of breeding white-tailed eagles is significant.

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