Turun yliopisto
University of Turku

SPATIAL BEHAVIOUR, HABITAT USE AND BREEDING PERFORMANCE OF A LONG-LIVED RAPTOR IN THE CONTEXT OF WIND ENERGY

Fábio Balotari Chiebáo

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
Sarja - ser. AII osa - tom. 339 | Biologica - Geographica - Geologica | Turku 2018

Turun yliopisto
University of Turku

SPATIAL BEHAVIOUR, HABITAT USE AND BREEDING PERFORMANCE OF A LONG-LIVED RAPTOR IN THE CONTEXT OF WIND ENERGY

Fábio Balotari Chiebáo

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
Sarja - ser. A II osa - tom. 339 | Biologica - Geographica - Geologica | Turku 2018

University of Turku

Faculty of Science and Engineering
Department of Biology
Section of Ecology

Supervised by

Senior Lecturer Toni Laaksonen
Department of Biology
Section of Ecology
University of Turku

Professor Jon E. Brommer
Department of Biology
Section of Ecology
University of Turku

Reviewed by

Professor Miguel Ferrer
Spanish National Research Council
Department of Ethology and
Biodiversity Conservation
Spain

Senior Researcher Torgeir Nygård
Norwegian Institute For Nature Research
Norway

Opponent

Professor Oliver Krüger
Department of Animal Behaviour
Universität Bielefeld
Germany

Cover illustration by Hadi Rahimi

The originality of this thesis has been checked in accordance with the University of Turku quality assurance system using the Turnitin OriginalityCheck service.

ISBN 978-951-29-7144-2 (PRINT)
ISBN 978-951-29-7145-9 (PDF)
ISSN 0082-6979 (PRINT)
ISSN 2343-3183 (ONLINE)
Painosalama Oy - Turku, Finland 2018

I visited a hermit in the country of Bilqan
And requested him to purge me of ignorance by instruction.
He replied: 'Be patient like earth, O lawyer,
Or else, bury under the earth all thy learning.'

The Rose Garden (1258 CE), Saadi Shirazi

TABLE OF CONTENTS

ABSTRACT

Natural ecosystems and associated biota suffer from a wide range of human activities, including habitat destruction, land-use changes and climate warming. Easily subject to disturbance and often requiring large hunting grounds, raptors are notoriously vulnerable to habitat loss or degradation. In the 1960s and 1970s, many white-tailed eagle populations experienced a drastic decline primarily due to environmental pollutants. Although the species has recovered and expanded rapidly with the implementation of protective measures, human interference still constitutes a relevant source of disturbance and mortality. In Finland, forestry and land exploitation for the development of *e.g.* industries, summer houses, roads and wind farms, are among the greatest concerns. In this thesis, I studied various aspects of the life history, ecology and behaviour of the white-tailed eagle with an emphasis on its future conservation, particularly with respect to wind energy. More specifically, I focused on white-tailed eagles breeding in proximity to wind farms, to test whether the distance between an eagle territory and the nearest installation had a potential impact on breeding success. With the use of high-precision telemetry data, I discussed the spatial behaviour of white-tailed eagles during the post-fledging period in light of a hypothetical scenario of turbine deployment around the nests. As a complement, I evaluated their habitat use by determining selection or avoidance of habitat classes such as artificial surfaces, agricultural areas, semi-natural areas, waterbodies, roads, and forest stand age. Furthermore, I studied the large-scale movements of white-tailed eagles during the dispersal period, assessing their space use in relation to the distribution of existing and proposed wind farms across Finland. I found that a breeding pair holding a territory closer to an installation has a lower probability to breed successfully when compared to a pair from a territory lying farther away. Such lower probability may in part reflect a harmful interaction between the eagles and wind turbines in the form of collision mortality, to which the adults appear to be particularly vulnerable during the breeding season. Regarding the post-fledging period, I found that the probability of a young eagle approaching a wind turbine decreases sharply as the turbine is installed at increasing distances from the nest. In terms of habitat use, the young eagles showed selection towards semi-natural areas (mostly transitional woodland/shrub), while consistently avoiding habitats associated with human disturbance, namely artificial surfaces, agricultural areas, and roads. When using forest patches, they selected young tree stands, and were also more likely to be closer to waterbodies than would be expected by chance. As for the dispersal period, I found that the eagles tended to use coastal areas with a very limited amount of artificial surfaces, where also the potential for wind-energy production is considerable. However, the areas targeted for wind-energy development did not coincide with the eagles' highest relocation frequency, suggesting that they do not represent an elevated threat to dispersing eagles. Nevertheless, caution should be taken against interpreting that co-occurrence poses no potential harm at any given site. The conversion of natural habitats into human infrastructure, including wind farms, leads to greater encroachment of unfavourable or potentially harmful areas for white-tailed eagles. As their populations continue to expand, land-use planning will play an increasing role in the protection of nesting sites and surrounding areas identified as important for their normal activities, such as coastal habitats.

TIIVISTELMÄ

Luonnolliset ekosysteemit ja niiden eliöstö kärsivät ihmisten aiheuttamista toimista, kuten elinympäristöjen tuhoutumisesta, maankäytön muutoksista ja ilmaston lämpenemisestä. Petolinnut ovat erityisen herkkiä elinympäristöjen tuhoutumiselle tai heikkenemiselle, koska vaativat usein suuria saalistusalueita ja ovat sensitiivisiä häiriölle. 1960- ja 1970-luvuilla monet merikotkapopulaatiot romahtivat ympäristösaasteiden vaikutuksesta. Vaikka laji on suojelutoimenpiteiden ansiosta toipunut ja levinnyt voimakkaasti, ihmistoiminta on edelleen varteenotettava häirinnän ja kuolleisuuden aiheuttaja. Suomessa mahdollisia häiriöiden aiheuttajia ovat esimerkiksi metsänhoito, maankäytön kehittäminen muun muassa teollisuuden tarpeisiin, sekä kesämökkien, teiden ja tuulipuistojen rakentaminen. Väitöskirjassani tutkin merikotkan elinkiertoa, ekologiaa ja käyttäytymistä eri näkökulmista lajin tulevaisuuden suojelun kannalta, erityisesti huomioiden tuulivoiman vaikutuksen. Ensin tutkin tuulipuistojen läheisyydessä pesivien merikotkien pesimämenestystä suhteessa etäisyyteen lähimpään tuulivoimalaan. Paikannustietoja käyttäen tarkastelin merikotkien tilankäyttöä pesäpoikasvaiheen jälkeisenä aikana, huomioiden tuulivoimaturbiinien teoreettisen sijoittamisen pesien ympärille. Lisäksi tarkastelin elinympäristön käyttöä arvioimalla, mikäli kotkat pesäpoikasvaiheen jälkeen valitsivat tai välttivät eri elinympäristöluokkia kuten keinotekoisia pintoja, maatalousmaita, luontaisen kaltaisia elinympäristöjä, vesistöjä, teitä tai eri-ikäisiä metsikköjä. Lopuksi tutkin merikotkien liikkeitä muuttoaikana laajassa mittakaavassa ja arvioin kotkien tilankäyttöä suhteessa toimivien ja suunnitteilla olevien tuulipuistojen sijaintiin Suomessa. Havaitsin, että sellaisen parin pesintä, jonka reviiri sijaitsee lähempänä rakennelmaa, epäonnistuu todennäköisemmin kuin parin, jonka reviiri sijaitsee kauempana. Tämä voi osittain johtua tuuliturbiinin aiheuttamasta törmäyskuoleman uhasta, jolle aikuiset näyttävät olevan erityisen alttiita pesimäkautena. Pesäpoikasvaiheen jälkeisenä aikana nuoren merikotkan todennäköisyys lähestyä tuuliturbiinia vähenee huomattavasti, kun turbiini asennetaan kauemmaksi pesästä. Elinympäristön käytössä nuoret kotkat näyttivät valitsevan luontaisen kaltaisia elinympäristöjä (lähinnä siirtymävaiheista metsää/pensaikkoa) ja järjestelmällisesti välttävän ihmisten muokkaamia elinympäristöjä, kuten keinotekoisia pintoja, maatalousmaita sekä teitä. Metsäalueita käyttäessä kotkat valitsivat nuoria metsikköjä (joilla on todennäköisesti siemenpuita ja lentotilaa), ja oleilivat lähempänä vesistöjä kuin mitä sattumalta odotettaisiin. Havaitsin myös, että kotkat muuttovaiheessa yleensä käyttivät rannikkoalueita, joilla oli hyvin rajallisesti keinotekoisia rakenteita, ja joilla myös tuulivoiman tuotannon mahdollisuudet ovat huomattavia. Tuulivoimaloiden suunnitellut sijainnit eivät kuitenkaan olleet paikkoja, joilla kotkat liikkuisivat enempää kuin muualla samalla alueella, eivätkä ne näin ollen merkitse korotettua uhkaa liikkuville merikotkille. Varovaisuuden nimissä on kuitenkin vältettävä väittämästä, että esiintyminen samoilla alueilla ei olisi uhkatekijä missään paikassa. Luonnollisten elinympäristöjen muuttaminen ihmisrakennelmiksi, myös tuulivoimapuistoiksi, johtaa enenevään määrään alueita, jotka ovat epäsuotuisia tai potentiaalisesti haitallisia merikotkille. Kun populaatiot jatkavat levittäytymistä, maankäytön suunnittelulla tulee olemaan kasvava merkitys pesimäpaikkojen ja ympäröivien, tärkeäksi todettujen alueiden, kuten rannikkoalueiden, suojelussa.

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications and manuscripts, referred to in the text by their Roman numerals.

Balotari-Chiebao, F., Brommer, J.E., Niinimäki, T., Laaksonen, T. (2016). Proximity to wind-power plants reduces the breeding success of the white-tailed eagle. *Animal Conservation* **19**, 265–272.

Balotari-Chiebao, F., Villers, A., Ijäs, A., Ovaskainen, O., Repka, S., Laaksonen, T. (2016). Post-fledging movements of white-tailed eagles: Conservation implications for wind-energy development. *AMBIO. A Journal of the Human Environment*, **45**, 831–840.

Balotari-Chiebao, F., Brommer, J.E., Tikkanen H., Laaksonen T. Habitat use by post-fledging white-tailed eagles shows avoidance of human infrastructure and agricultural areas. *Manuscript*.

Balotari-Chiebao, F., Brommer, J.E., Saurola P., Ijäs A., Laaksonen T. Assessing space use by pre-breeding white-tailed eagles in the context of wind-energy development in Finland. *Submitted*.

1. INTRODUCTION

Natural ecosystems and associated biota suffer from human interference in the form of habitat destruction, overexploitation, introduction of alien species, pollution, disease, and climate change (Mace et al. 2005). It is estimated that the species extinction rate is now 1000 times higher than background rates from the fossil record (De Vos et al. 2015), making humans responsible for a truly global biodiversity crisis. Although species extinction is the most dramatic consequence of an ecological disaster, the unfavourable conservation status of numerous species within higher taxa may already represent a significant loss of biodiversity in terms of genes, populations, and communities (Hanski 2016).

A major challenge for biodiversity conservation is to deal with the growing conflicts with land-use changes, whose intensification is predicted to have devastating effects on population viability worldwide (Sala et al. 2000). Political will, adequate legislation, consumer education, active citizenship, and coordinated action among various stakeholders are urgently needed to create the conditions for a more sustainable living. In Europe, the greatest threats to biodiversity stem from the modern intensification of agricultural and forestry practices, which effectively translate into loss or degradation of natural habitats (Young et al. 2005). A similar scenario is seen in Finland, where habitat changes via *e.g.* prolonged and intensive commercial forestry are associated with major ecological impacts (Seppälä et al. 1998); a third of Finland's threatened species lives in forests (Mikkola-Roos et al. 2010).

Easily subject to disturbance and often requiring large hunting grounds, raptors are notoriously vulnerable to habitat loss or degradation. Moreover, artificial structures such as wind turbines and power lines may impose further pressure as a source of mortality (Kirby et al. 2008). At present, many raptor species would require effective protection of nesting and foraging habitats to have their conservation status improved (BirdLife International 2015).

The white-tailed eagle (*Haliaeetus albicilla*) is currently classified as a vulnerable species in the Finnish Red List (Tiainen et al. 2016), and is listed in Annex I of the European Union's Birds Directive (Directive 2009/147/EC 2009). The species has a long history of large-scale population declines, the last of which took place in the 1960s and 1970s. The causes in that period for a drastic reduction of its numbers were all related to humans, namely persecution, poisoned bait, habitat loss, disturbance, and most importantly the widespread use of bio-accumulating contaminants (Stjernberg et al. 2005). Over the last decades, the conditions for successful breeding have generally improved, allowing the species to recover and expand across its range. Nevertheless, various are the threats and limiting factors that are of great relevance today, including the issue of land use. In Finland, forestry and land exploitation for the development of *e.g.* industries, summer houses, roads and wind farms, are among the greatest concerns (Helander and Stjernberg 2002). For instance, when breeding occurs in forested areas, the white-tailed eagle relies on large old-growth trees (Cramp and Simmons 1980). Thus, the felling of mature trees reduces the availability of its nesting habitat, while the road network required for forestry activities causes habitat fragmentation and may also constitute a source of disturbance. As regards wind farms, undesirable impacts may follow if development occurs in areas that are important for the eagles. According to the Finnish Wind Atlas, a 30-km wide coastal strip (including an extension to offshore zones), highlands, large lakes and fields are the most favourable areas for wind energy in the country (Tammelin et al. 2011). The coastal-offshore strip is the largest of such areas, and contains most of the existing wind farms and development proposals (Finnish Wind Power Association 2016). At the same time, coastal areas encompass a large extent of the range of the white-tailed eagle in Finland, supporting an estimated 80-90% of the breeding population (Herrmann et al. 2011). Research, active conservation and public awareness will play a major role in the future protection of this apex predator. In this thesis, I studied various aspects of its life history, ecology and behaviour, with an emphasis on conservation-related issues, particularly with respect to wind energy.

1.1 Wind energy: a fast-growing renewable energy source

Climate change, resulting primarily from the enormous emission of greenhouse gases by industrialised nations, constitutes an unprecedented human-induced threat to biodiversity. In view of the demands for energy services by an ever-growing human population, the use of renewable energy as an alternative to the combustion of fossil fuels has acquired a special meaning. Wind energy is one of the alternative energy-generation technologies, widely promoted and with a rapid increase over the last decades, particularly in Europe, Asia, and North America. In 2015, wind energy installations accounted for nearly half of the electricity growth in the world (Global Wind Energy Council 2015).

Wind energy is an integral part of Finland’s National Energy and Climate Strategy, with a goal to supply 8TWh of wind-derived electricity by 2030 (National Energy and Climate Strategy 2013). In 2016, an installed capacity of approximately 1500 MW accounted for 3.5% (3 TWh) of its electricity consumption (Finnish Energy Industries 2017). Modest at present, Finland’s installed capacity is expected to increase substantially in a more distant future, helping the country to achieve a carbon-neutral economy (National Energy and Climate Strategy 2013).

Despite its climate change-related benefits, the construction of wind farms can be detrimental to birds, as they have been associated in certain cases with collision mortality, displacement, habitat loss, and barriers to movements (Drewitt and Langston

2006). Comparisons with other man-made structures (*e.g.* buildings, communication towers, and power lines) suggest the collision impact of wind turbines to be minor (Erickson et al., 2005; Loss, 2016). However, there is great uncertainty as to their true impact, which raises concerns about development in areas inhabited by species of high conservation value. The rapid growth of this energy sector has prevented researchers from closely following its expansion, while an improved and standardised methodology supported by long-term impact assessments is needed (Stewart et al. 2007). Besides attempting to detect a negative impact from existing facilities, efforts should also be directed at providing recommendations for future developments, especially in terms of site selection. Avoiding priority habitats and the geographical range of sensitive species (e.g. by building in areas environmentally disturbed) seems to be paramount (Gove et al. 2013).

1.2 Growing conflicts with raptor conservation

The great variation that exists in birds in terms of ecology, behaviour and morphology means that not all species are affected by wind energy. Moreover, in the case of those species that have been identified as vulnerable, the chances of a harmful interaction are dependent on range of factors, such as site selection, time of year, and weather conditions. Large soaring raptors, together with *e.g.* swans, geese, ducks, waders and owls, appear to be at greatest risk of collision (Tosh et al. 2014). Because raptorial species have long generation times and low reproductive output (Newton 1998), turbine-related incidents may bring mortality to levels of concern. Notable examples include the golden eagle *Aquila chrysaetos* in the Altamont Pass Wind Resource Area in the USA (Hunt 2002; Smallwood and Thelander 2008), and the griffon vulture *Gyps fulvus* in southern Spain (Barrios and Rodríguez 2004; de Lucas et al. 2012).

As regards the white-tailed eagle, the most notable research on its interactions with wind energy, namely the studies by the Norwegian Institute for Nature Research (NINA) on the island of Smøla, indicates that poor site selection can have an impact on breeding success due to collision mortality and displacement (Dahl et al. 2012). As of October 2017, at least 83 white-tailed eagle casualties have been reported (T. Nygård, pers. comm.). The high mortality rates on Smøla likely reflect a lack of flight behaviour with a clear avoidance of the wind resource area (Dahl et al. 2013). Also, the adult eagles appear to be vulnerable to collision especially during spring, owing to increased flight activity and territorial fights (Bevanger et al. 2010). Interestingly, there is no indication that the eagles acquire a greater capacity to actively avoid collision, as the mortality rate has not decreased over time. Collisions involving white-tailed eagles have also been reported in other countries, including Germany (Krone and Scharnweber 2003), Poland (Zieliński et al. 2011), and Japan (Ueta et al. 2010), adding to the mortality attributed to other anthropogenic causes (e.g. lead poisoning; Krone *et al.*, 2003).

Aims of the thesis

In this thesis, my primary purpose was to study the white-tailed eagle in relation to wind-energy development in Finland, and, to some extent, address the broader issue of land use. In chapter **I**, I focused on the potential perils faced by white-tailed eagles breeding and fledging in proximity to wind-power plants. More specifically, I tested whether the distance between an eagle territory and the nearest installation had an association with the probability of successful breeding. In the same way, this distance effect was tested on post-fledging survival and displacement of breeding pairs via changes in nesting site over the years. In chapter **II**, I discussed the home range characteristics and ranging behaviour of post-fledging individuals in light of a hypothetical scenario of turbine deployment around the nests. Despite its importance, the post-fledging period has received relatively little attention. Here, I presented the probability of a fledgling visiting the vicinity of a turbine hypothetically placed at various distances from the nest. Because avian space use is unlikely to be uniform, the scope was to broadly identify the distances at which such probability is high or low, thereby providing some indication as to where turbine deployment should be more or less problematic. To complement this objective, I conducted a general habitat use analysis based on a subdivision of the landscape into a number of habitat classes. In chapter **III**, I made use of open source geospatial data to evaluate habitat use in detail during the post-fledging period. Based on the estimation of selection ratios, my purpose was to assess the white-tailed eagle's response to numerous habitat classes and features, namely artificial surfaces, agricultural areas, forests, semi-natural areas, wetlands, waterbodies, roads, power lines, and forest stand age. The selection and classification of habitat variables were done with a view to enrich a discussion on some of the threats faced by the species in Finland, and thus provide general recommendations for its local conservation. In chapter **IV**, I attempted to compile all the existing and proposed Finnish wind farms to test whether their spatial distribution would signal a potential conflict with dispersing white-tailed eagles. In addition, I assessed the large-scale movements of the study eagles by making use of a rarely available wind energy-related measure, namely the potential to produce electricity at specific areas across the country.

2. MATERIALS AND METHODS

2.1 Study areas and species

In all chapters, the study areas were restricted to the political boundaries of Finland, including the autonomous region of the Åland Islands. In chapter **I**, they consisted of all the existing wind-power plants that contained at least one white-tailed eagle territory within a distance of 9 km from a reference point, defined as follows. For installations with a single turbine, the reference point was simply the geographical position of that turbine. In case of multiple turbines, this corresponded to the average coordinates of all turbines. The 27 wind-power plants considered in the study had 1-6 turbines, and were distributed over a large area (*c.* 600 km north-south and *c.* 300 km east-west), always within a short distance from the sea. Eighteen of them were built on islands, notably in the Åland Islands. At all sites, topography is low, with turbines at points no higher than 61 m above sea level. In some places, the turbines were arranged in a linear string on land or atop breakwaters for maritime activity.

In chapters **II-III**, I investigated various aspects of white-tailed eagle space use during a period in which the young – the focus of the studies – are dependent on the parents, meaning that the study areas were restricted to the nest surroundings. The nests were located in the Åland Islands and the coastal regions of Southwest Finland, Satakunta, and Ostrobothnia. The Åland Islands and the corner of Southwest Finland belong to the temperate continental forest zone, an ecological zone which at this latitude is generally characterised by mixed forests dominated by Norway spruce (*Picea abies*; (FAO 2001). The remaining areas are part of the boreal coniferous forest zone (FAO 2001). All nests were built in forested patches close to a waterbody, either the sea or a large lake, and most of them were within two of the three most important breeding areas for this species in the country, namely the Archipelago Sea and the Quark (Stjernberg et al. 2005).

The post-fledging period in white-tailed eagles ends with the dispersal of the juveniles from the natal areas, and this often involves large-scale movements over many years. Although the study eagles travelled hundreds or thousands of kilometres during dispersal, visiting neighbouring countries as well as countries across the Baltic Sea, I focused exclusively on the movements that occurred within Finland (**IV**). This is because the data needed for a wind energy-related assessment were readily available or easily accessible for Finland, where also the bulk of the movement data was found.

In all chapters, the study species was the white-tailed eagle, a large, diurnal raptor that is closely associated with aquatic habitats (Cramp & Simmons 1980).

2.2 WWF Finland White-tailed Sea Eagle Working Group: fieldwork data

In 1972, the World Wildlife Fund (WWF) Finland formed a special group, the White-tailed Sea Eagle Working Group, with a view to rescue, study and protect this raptor species in Finland. Around this time, the Finnish white-tailed eagle breeding population had reached its lowest level, with the number of occupied territories ranging between 11 and 23 (Stjernberg et al. 2005). Since 1973, a network of highly committed volunteers has been conducting annual breeding surveys, thereby monitoring the population and its breeding parameters (e.g. occupancy, breeding success, and productivity) in a comprehensive manner (Saurola 2008). In addition, nestlings have been ringed nationwide by licensed volunteers, and an extensive record of post-fledging re-sightings is currently available. Re-sighting of coded rings has taken place mainly at a number of winter feeding stations, which had been primarily established by the same working group to provide the eagles with additional, uncontaminated food during periods of scarcity (Saurola et al. 2013). In chapter **I**, I made use of the data briefly described above to study the potential influence of wind-power plants on the white-tailed eagle, notably on its breeding success and post-fledging survival.

2.3 Satellite tracking

In 2009-2011 and 2013, a total of 14 white-tailed eagle nestlings were outfitted with a 70 g Argos/GPS Solar Powered PTT (Platform Transmitter Terminal; manufactured by Microwave Telemetry, Inc.). The total weight carried by a bird was approximately 100 g (i.e. the PTT plus the harness and additional battery for data collection during the winter). The total weight corresponded on average to less than 2.6 % (± 0.6 SD) of individual body mass at the time of fitting, being thus in accordance with recommendations on loading (Kenward 2001). Permission for ringing and satellite tagging was issued by a local environmental authority, the Centre for Economic Development, Transport and the Environment (ELY).

The devices were programmed to transmit fixes at 1-hour intervals mostly during daytime. Besides georeferenced points, they provided information on instantaneous speed, altitude, and course over ground. A calculation of the average Global Positioning System (GPS) location error (± 10 m; chapter **II**) indicated greater accuracy than that reported by the manufacturer (± 18 m). The telemetry data used in the present thesis were gathered over multiple years (2009-2015), and allowed me to study the space use of white-tailed eagles in the post-fledging period *(i.e.* from fledging to independence; chapters **II-III**) and the dispersal period (*i.e.* during independence; chapter **IV**). Four eagles died from unknown causes during the study years.

2.4 Existing wind turbines and proposed wind farms

In chapter **IV**, I assessed the potential conflict between the white-tailed eagle and wind-energy development in Finland by focusing on the dispersal movements of pre-breeding individuals in relation to the existing wind turbines and proposed wind farms. I compiled the coordinates of the existing turbines using a high-resolution map available at the website of the National Land Survey (NLS) of Finland. Information on the proposed wind farms, for the 2016-2020 period, was supplied by the Finnish Wind Power Association (FWPA). The supplied material contained specifications such as project phase, number of turbines, nominal capacity and estimated location for individual proposals. Project phase refers to the stage in the planning and development process at the time of compilation (April 2016) by the FWPA, ranging from proposal (*Phase 0*) to operation (*Phase 8*). The accuracy of locations, which are informed by the developers, typically increases as the project moves forward. Only proposals from *Phase 3* and above, *i.e.* with at least an Environmental Impact Assessment (EIA) under process, were considered for analysis (Fig. 1).

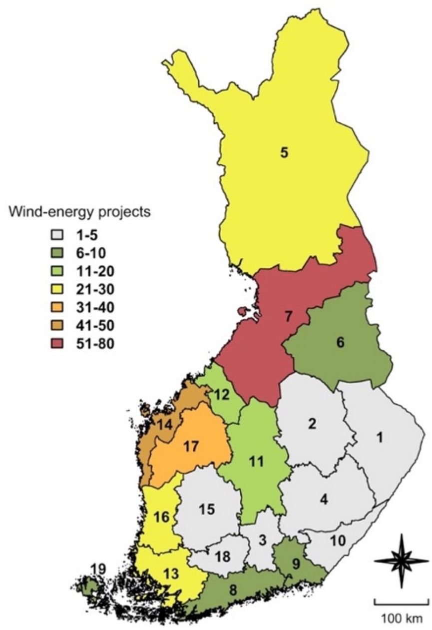

Figure 1 Number of wind-energy projects for all regions of Finland for the period of 2016-2020. 1: North Karelia; 2: Northern Savonia; 3: Päijänne Tavastia; 4: Southern Savonia; 5: Lapland; 6: Kainuu; 7: Northern Ostrobothnia; 8: Uusimaa; 9: Kymenlaakso; 10: South Karelia; 11: Central Finland; 12: Central Ostrobothnia; 13: Southwest Finland; 14: Ostrobothnia; 15: Pirkanmaa; 16: Satakunta; 17: Southern Ostrobothnia; 18: Tavastia Proper; 19: Åland Islands.

2.5 GIS and geospatial data

I used R as a Geographic Information System (GIS) to manipulate, process and analyse geospatial data from multiple open sources (**II**, **III**, **IV**). Also, I used R for most graphic displays. An inventory produced by the Finnish Environment Institute (SYKE), the CORINE Land Cover 2012, provided information on the national land cover (20-m resolution, **III-IV**). Roads and overhead power lines (including voltages 20-110kv in sparsely populated areas) were identified by using topographic maps from the National Land Survey (NLS) of Finland (**III**). Forest stand age was obtained from all the three raster maps (2009, 2011, and 2013) so far produced by the Natural Resources Institute Finland (Luke, **III**). Forest stand age is part of the Multi-Source National Forest Inventory (MS-NFI), which is composed of digital thematic maps with extensive information on forest variables (Mäkisara et al. 2016).

Table 1 Details of the open-source geospatial data used in the present thesis, including original names and data providers.

Name	Format	Resolution	Source	Variables
CORINE Land Cover 2012	GeoTIFF	20 m	SYKE	Habitat classes
Topographic Database	Vector	-	NLS	Roads and power lines
Stand Age	Raster	16m/20 m	Luke	Forest stand age
Vuositason tuuliatlasaineisto	Shapefile	2500 m	Finnish Wind Atlas	Power production potential
ASTER GDEM	GeoTIFF	30 m	METI and NASA	Ground elevation
ASTER GDEM 2	GeoTIFF	30 m	METI and NASA	Ground elevation

In 2011, a new Finnish Wind Atlas was produced in order to facilitate site selection for wind-energy development across the country. In addition to wind speed, this guidance tool informs the power output that can potentially be obtained at a given location from turbines with different specifications in terms of nominal capacity and hub height. To test whether the satellite-tracked eagles were using areas with more or less favourable conditions for wind energy, I selected the estimated power production of a 3-MW turbine with a hub height of 150 m (2500-m resolution, **IV**). To complement the space-use assessment presented in chapters **II** and **IV**, I calculated the flight height for each in-flight position by subtracting the ground elevation from the altitude determined by the satellite devices. Ground elevation was obtained from a 30-m resolution Digital Elevation Model (DEM), the Advanced Spaceborne Thermal Emission Radiometer (ASTER GDEM, **II**; ASTER GDEM 2, **IV**), a product of the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and

Space Administration (NASA). Details of the geospatial data briefly described above are summarised in Table 1.

2.6 Statistical analyses

I used a Generalised Additive Mixed Model (GAMM) to model the potential effect of proximity to wind-power plants on the breeding success of the white-tailed eagle (**I**). In other words, I was interested in knowing whether a breeding pair holding a territory closer to an installation has a lower probability to breed successfully when compared to a pair breeding farther away. To this end, only eagle territories with at least one occupied nest (*i.e.* decorated, partially built or ready for egg laying) were considered. Breeding success was coded as 1 (successful) or 0 (unsuccessful), and territory distance to the nearest installation (explanatory variable) was fitted as a smoother in the model. The generalised additive mixed modelling allowed me to account for the hierarchical structure of the data (*e.g.* territories with repeated breeding attempts) and the correlation between observations (*e.g.* breeding attempts presumably done by the same pair in different years; (Zuur et al. 2009). Similar models were employed to investigate the potential effect of proximity also on territory occupancy and turbine avoidance. In addition, I performed a capture-mark-recapture (CMR) analysis with a focus on post-fledging survival, i.e. the survival of young white-tailed eagles coming from, and moving around, nests at various distances from an installation. This analysis was implemented in Program MARK (White and Burnham 1999) with the development of age-structured models containing an individual covariate.

To estimate the home range of the satellite-tracked eagles during the post-fledging period, I computed Utilisation Distributions (UDs) with the kernel method (**II**). Briefly, the kernel density estimation (KDE) is a technique that is commonly used in home-range studies to provide an indication as to the probability of an individual being located within a given area (Worton 1989). In this study, I specified the 50% and 95% home ranges, representing as such the smallest areas within which the probability to relocate an individual corresponded to 50% and 95%, respectively. Based on a hypothetical scenario of turbine deployment, I computed the probability P(*d*) of a fledgling visiting the vicinity (150 m) of a single turbine that is installed at a specific distance to the nest (*d*). The surrounding area was partitioned into concentric circles (100-5000 m from the nest, with a 100-m increment), along each of which 100 points were uniformly distributed. Each point at each distance from the nest was considered a potential location for a single turbine deployment. The probability for the different distances was obtained from:

$$P(d) = \frac{\sum_{i=1}^{100} W_i}{100}$$

where $W_i = 1$ if a grid cell (100 x 100 m) contained a bird track, and $W_i = 0$ if a grid cell (100 x 100 m) did not contain a bird track. In addition, I classified the surrounding landscape into three habitat categories to evaluate the general selection or avoidance of coastal, inland, and aquatic areas. I used the Chi-square technique to test whether the eagles used each habitat category in proportion to its availability as estimated by a random sampling. If the null hypothesis is rejected, it is possible to determine selection or avoidance of individual habitats based on confidence intervals calculated with a Bonferroni *z* statistic (Neu et al. 1974).

The evaluation of habitat use by animals requires the investigator to choose a study design and an analysis. Commonly, comparisons with the aim to detect habitat selection or avoidance are based on use and availability of habitats identified as important to the study species (Thomas and Taylor 2006). To study habitat use during the post-fledging period (**III**), I measured both use and availability for each individual eagle separately, thus following Design III as classified by (Thomas and Taylor 1990). Various are the statistical procedures to evaluate habitat use. Here, I opted for the estimation of so-called selection ratios, which are a widely used approach that is based on resource units classified into one of several categories (Manly et al. 2002). Using freely-available and high-resolution geospatial data, I was able to investigate habitat classes and features with fine-scale resource units (16x16 m or 20x20 m). The following estimator was used to obtain the selection ratio at the population level for any given resource category:

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

where u_{i+} is the total number of used resource units in category i, π_{ij} is the proportion of resources available to eagle j in category i, and u_{+j} is the total number of used resource units by eagle j. The chi-square technique was employed to compare used resource units with expected resource units based on availability, and Bonferroni 95% confidence intervals were computed to account for the simultaneous significance tests. A selection ratio > 1 indicates selection, while < 1 indicates avoidance (Manly et al. 2002). In addition, I fitted a logistic regression to test whether the eagles spent more time closer to waterbodies than would be predicted by chance. Specifically, I made a comparison, in terms of the distances to the nearest waterbody, between the actual positions (1) and random positions (0) sampled uniformly within the available habitats. Actual and random positions were at a ratio 1:2.

To study the large-scale movements of pre-breeding white-tailed eagles in the context of wind energy, I created a grid of 5-km square cells that fully covered the political boundaries of Finland (**IV**). I used the so-called queen's case to identify areas of occurrence as contiguous areas formed by cells with at least one eagle position; the queen's case considers all eight neighbours of a focal cell for common boundary. This procedure allowed me to identify, and focus the analysis on, the areas that are presumably more important for Finnish white-tailed eagles (from the western and south-western regions) during dispersal. For each cell, I calculated the total number of eagle positions and derived a number of explanatory variables for modelling purposes, including wind-power production potential. This variable, which is readily available from the Finnish Wind Atlas, was selected to enrich a discussion on site selection of future developments. To also assess a potential conflict between pre-breeding white-tailed eagles and the existing wind turbines and already proposed wind farms, I first identified the cells that contained (coded as 1) or did not contain (coded as 0) a facility. A GAMM was used to model the relationship between number of eagle positions (response variable) and explanatory variables, including the binomial variable for the conflict assessment. For the model, I chose the negative binomial distribution to account for overdispersion (*i.e.* the variance was considerably larger than the mean). A correlation matrix was used to assess collinearity between all explanatory variables as a means to avoid the inclusion of highly correlated variables, to which GAMMs are sensitive (Zuur et al. 2009). In addition, I applied a *t*-test to compare the mean power production potential of cells with a facility with that of cells without a facility.

3. RESULTS AND DISCUSSION

3.1 White-tailed eagles in proximity to wind-power plants

In chapter **I**, I assessed territory occupancy, breeding success, and post-fledging survival by considering a wind-energy scenario that involved long-term data on white-tailed eagles breeding or attempting to breed in proximity of a wind-power plant. I found that a pair holding a territory closer to an installation has a lower probability to breed successfully when compared to a pair from a territory lying farther away (Fig. 2). For territories within 4 km, this probability remains below 60%, which is the recommended threshold for the conservation of white-tailed eagles breeding on the Baltic Sea coast (Helander et al. 2013). Furthermore, the probability for territories within this distance is lower than the breeding success rates of 60-80% observed in recovered populations, *e.g.* along the Danube River (Probst and Gaborik 2011). This result may reflect a harmful interaction between the eagles and wind energy in the form of collision, to which the adults appear to be particularly vulnerable during the breeding season (Bevanger et al. 2010). At the time of writing, according to reports made by the general public, at least 10 white-tailed eagles have died from a turbine-related incident in Finland (T. Sternberg, pers. comm.). However, a lack of systematic carcass searches at the turbines considered in the study impedes a more solid conclusion. Thus, I should add that the correlation between breeding success and distance to wind-power plants does not prove causality; also, the causes for this pattern are likely to be multiple. Besides the widespread presence of hazardous substances in the environment, intraspecific competition (resulting in fatal territorial fights) may well have lowered breeding success in densely populated areas, including the Archipelago Sea (Helander and Herrmann 2016). Another possibility is that pairs with less breeding experience, thus with a potentially lower productivity (Evans et al. 2009), happened to breed closer to a wind-power plant. Unfortunately, this possibility could not be tested, because the identity of the breeding individuals was unknown.

As regards territory occupancy, it appears that the distance to a wind-power plant does not play a significant role in determining whether a pair will attempt to breed in a given year. Similarly, I found that the presence of turbines did not lead to birds nesting at increasing distances over time. This result contrasts with the major role of disturbance in the displacement of breeding white-tailed eagles on the island of Smøla (Dahl et al. 2012). Nevertheless, I should note that the lack of displacement does not completely exclude the role of disturbance on the pairs that stayed and attempted to breed in the study areas. Disturbance (e.g. from turbine maintenance and increased access to a previously undisturbed area) can indeed affect the body condition of breeding birds (Gove et al., 2013). The potential effect of proximity was not detected in the analysis of post-fledging survival. It is possible that the young eagles that fledged closer to an installation faced no greater collision risk than those that fledged farther away, perhaps because their space use did not overlap, or overlapped only to a negligible extent, with the existing turbines.

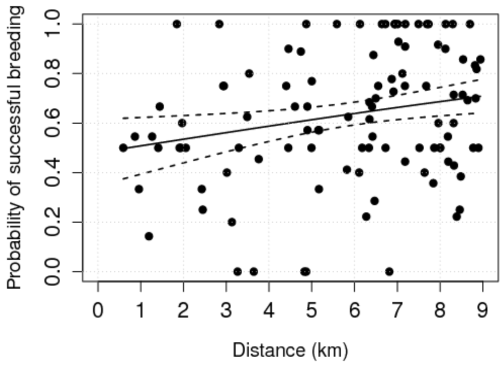

Figure 2 Probability of successful breeding in relation to the distance to the nearest wind-power plant. Each data point represents a territory with either a single or multiple breeding attempts.

3.2 Post-fledging white-tailed eagles: ranging behaviour in relation to turbine deployment

In chapter **II**, I made use of satellite tracking to study the movements of 14 white-tailed eagles from fledging to dispersal, with a particular focus on their ranging behaviour in relation to a hypothetical scenario of turbine deployment around the nests. Fledging and dispersal took place at the respective age of 71-86 and 115-244 days, which are consistent with the literature (Hardey et al. 2013). I found that the maximum distance covered during a day increased with time after fledging, meaning that areas that are farther away are increasingly explored as the eagles become more independent from the parents (Fig. 3). Presumably, the longer an individual remains in the natal area, the higher the risk of its being affected by a wind turbine or associated infrastructure. In general, eagle movements occurred within short distances from the nest, with average 50 and 95% home ranges equalling 0.7 and 8 km^2, respectively. Accordingly, the probability of a fledging visiting the vicinity of a wind turbine, and thus potentially being at risk of collision, decreases with deployment done at increasing distances from the nest (Fig. 3). For instance, the probabilities at the distances of 1, 2 and 3 km are 0.8, 0.5 and 0.3, respectively. I also found that, although the eagles spent only a small proportion of the time in flight, most of their flights were within 200 m above ground level, *i.e.* within the vertical range of modern turbines. The above results suggest that site selection can play a major role in the interactions between young white-tailed eagles and wind energy, with a clear potential to minimise or avoid undesirable effects by installing turbines sufficiently far from the nests. In Finland, a current proposal is a buffer of 2 km for the deployment of onshore turbines around active nests (WWF Finland 2011). Although a buffer of this dimension encompasses a relatively large area, with a potential to reduce conflicts, attention should also be given to nearby foraging habitats. In the case of nests located close to the sea, I found that the young eagles used a narrow strip of coastal area in a significant manner. In terms of wind-energy development, this means that deployment should be carefully planned or completely avoided in the space between a nest and important coastal habitats.

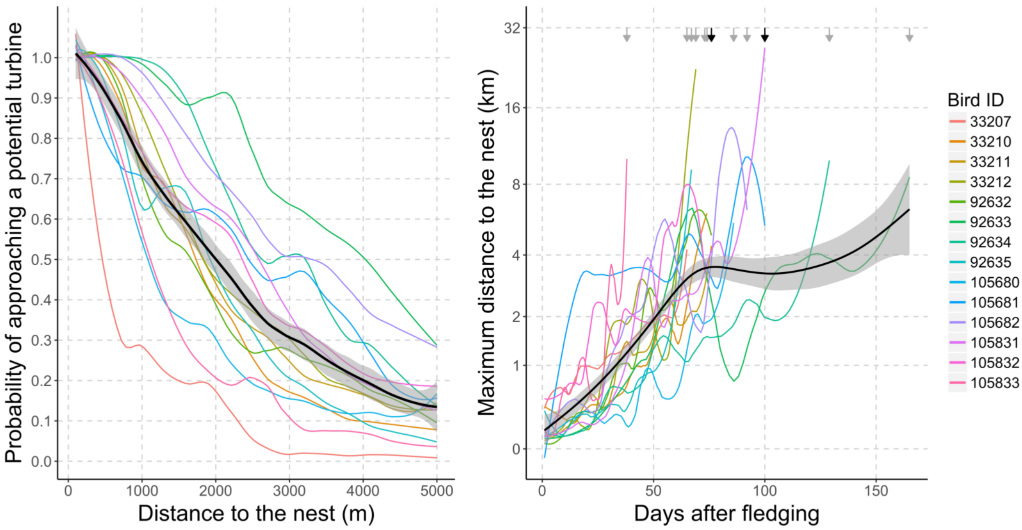

Figure 3 In the first plot, probabilities are shown for a white-tailed eagle during the post-fledging period approaching a turbine that is installed at an increasing distance to the nest. In the second plot, the maximum daily distance from the nest is presented in relation to the number of days after fledging. Each arrow at the top of the plot indicates the day of departure from the natal site of one individual (grey arrow) or two individuals (bold arrow).

3.3 Post-fledging white-tailed eagles: habitat use in a conservation context

In chapter **III**, I evaluated habitat use in detail during the post-fledging period, classifying resource units into one of several categories to estimate selection ratios. In this way, I was able to address some of the major threats faced by the species which are connected with different land uses. Of the habitats considered available to the eagles, I found that forests (42%) and waterbodies (13%) were the most abundant, followed by semi-natural areas (7%), agricultural areas (5%), wetlands (2%), and artificial surfaces (2%); the remaining percentage corresponded to unavailable waterbodies. The eagles were shown to select semi-natural areas and avoid artificial surfaces, agricultural areas and roads. Semi-natural areas consisted primarily of transitional woodland/shrub, while artificial surfaces consisted of urban fabric, mineral extraction sites, industrial and commercial units, and summer cottages. I note that all habitats associated with a considerable degree of human disturbance, namely artificial surfaces, agricultural areas, and roads were avoided, a pattern which is line with similar studies (Scholz 2010; May et al. 2013). Forests were abundant in all the study areas, and were in absolute terms used more than any other habitat. Therefore, a non-significant selection ratio only informs us that the use of forests did not exceed the proportional use expected from their great availability in the landscape. Naturally, this great availability reflects in part the parental choice of nesting site and does not allow us to discard the importance of forests to the young. When using forested patches, the eagles selected young tree stands (0-10 years old), and were also more likely to be closer to waterbodies than would be expected by chance. Because power lines were either absent or present only in small amounts, I was not able to test the response of young white-tailed eagles to this landscape feature, which appears to be a primary cause of mortality among Finnish white-tailed eagles (Saurola et al. 2013) and a major source of general avian mortality (Ferrer 2012).

3.4 Dispersing white-tailed eagles: potential conflict with wind energy at the landscape scale

In chapter **IV**, I reported on the dispersal movements of pre-breeding white-tailed eagles with a particular focus on wind energy, assessing the suitability of site selection of existing turbines and proposed wind farms in light of a large-scale eagle space use. More than 80000 eagle positions were collected within Finland during the study period (2009-2015). Although the eagles wandered widely across the country, they occurred primarily and were most often located along the coast and nearby areas, restricted to where human infrastructure was present only at very small amounts. A correlation matrix revealed that power production potential was highly correlated ($> |0.7|$) with sea distance and waterbody distance. Wind energy has greater potential towards the sea, and generally lower potential towards lakes and rivers owing to their distribution in relation to the coastline. Given the general aims of this study, we retained power production potential and excluded the other two variables. Because of the distribution of wind resources, the most frequently used areas by the eagles contained considerable potential for power production. The eagles visited most of the areas with an existing or proposed wind farm. However, the areas with an existing or proposed wind farm did not appear to have a higher-than-average relocation frequency, suggesting that their site selection would not pose an elevated threat to dispersing eagles. Nevertheless, caution should be taken against interpreting that co-occurrence poses no potential threat at any given site.

In general, the eagles flew at low to intermediate elevations over the sea ($\bar{x} = 90$ m) and land ($\bar{x} = 198$ m). A considerable proportion of the over-sea (21%) and over-land flights (37%) were at a rotor-swept zone of 50-200 m, and around 43% of all flights occurred within 50 m above ground level. These estimates suggest that considerable time is spent at elevations that pose a risk of collision with poorly-sited onshore and offshore installations. Considering the wind farm projects investigated here, I found that the approval of approximately 25% of their proposed capacity would be sufficient to achieve the current national goal on wind energy, i.e. to produce 8 TWh by 2030. Based on the estimated area of a project with 21 turbines, Zakeri *et al.* (2015) noted that the average land required for a 2-MW turbine is 1.5 km^2 or 75 ha/MW (including an area not directly disturbed by the installation). Assuming these estimates to be representative, the installed capacity expected for 2030 would claim *ca.* 2335 km^2 (or 0.7% of the national land area). However, it should be noted that, as wind energy is expected to play an increasing role in electricity generation in Finland in a more distant future, site selection will likely continue to be a critical step in the planning process.

4. CONCLUSIONS

In this thesis, I studied various aspects of the white-tailed eagle and addressed issues and concerns related to its future conservation in Finland, particularly with respect to wind energy. Given data availability on its different developmental stages, I was able to give the thesis a logical structure by focusing almost exclusively on the breeding (**I**), post-fledging (**II-III**), and dispersal periods (**IV**) in separate chapters, which allowed me to make inferences in a holistic manner.

Compared to many European countries, Finland still has a modest installed wind-energy capacity. Nevertheless, my results suggest that the presence of wind turbines within the territories of white-tailed eagles may have contributed to breeding failure: pairs holding a territory closer to an installation were less likely to breed successfully (**I**). This raises the question of whether the non-binding recommendation of a 2-km buffer is enough to ensure little or no interference in breeding performance, given the unsuccessful breeding attempts reported at longer distances. Supported by strategic planning, the adoption of a sufficiently large buffer appears to be necessary to specifically protect breeding adults. Systematic carcass searches at wind resource areas, especially along the coast, are needed to estimate mortality and thus have a better understanding of the potential impacts of current and future developments.

Based on high-precision telemetry data, I found the space use of white-tailed eagles to be largely restricted to the nest surroundings in the post-fledging period, with a remarkable pattern in the probability of a fledgling visiting sites at increasing distances from nest (**II**). The greater the distance, the lower the probability of a site being visited. This means that the distance at which a turbine is installed from the nest has an influence on the chances of a harmful interaction with young eagles. Another critical consideration is the relative use of the surrounding habitats, which closely relates to the broader issue of land use. In line with similar studies, I showed that all habitats with a considerable degree of human disturbance, namely artificial surfaces, agricultural areas and roads, were avoided in a consistent manner (**III**). Moreover, I found that the eagles tended to use areas close to the sea and other waterbodies (**II-III**). Given this pattern of space use, it may be concluded that sites that are already environmentally disturbed, or located away from *e.g.* important coastal habitats, are a suitable alternative (at least from a conservation standpoint) for the construction of wind farms. Also, the conversion of natural habitats into human infrastructure such as roads, industrial areas, and summer houses, leads to greater encroachment of unfavourable areas for the white-tailed eagle.

The post-fledging period ends when the juvenile eagles disperse from the natal areas, usually travelling long distances over many years. Mapping avian distribution or space use at the landscape scale allows the identification of areas containing vulnerable species, priority habitats or major flight paths, which clearly has implications for conservation. Using long-term data on the dispersal movements of pre-breeding white-tailed eagles, I found that the most frequently used areas were located along the coast and on islands, where the potential for power production is considerable (**IV**). However, the areas targeted for wind-energy development did not coincide with the eagles' highest relocation frequency, suggesting that they do not represent an elevated threat to dispersing eagles. Nevertheless, it should not be concluded that co-occurrence poses no threat to dispersing eagles. A number of intensively-used areas overlapped with proposed wind farms, notably in the coastal region of Ostrobothnia. Under a scenario of widespread developments and future proposals, a greater sample of birds from less restricted locations would be required for further investigation.

The conservation of a target species requires an understanding of the relative importance of its available resources. In view of the growing conflicts between biodiversity conservation and human activities due to changes in land use, such a knowledge appears to be indispensable. In this thesis, I focused primarily on wind energy, a form of land use whose impact is dependent on a combination of factors. Clearly, site selection is paramount to avoid or minimise undesirable impacts not only on the white-tailed eagle, but also on other species vulnerable to wind energy. A sensitivity map based on population-related and ecologically relevant information, such as breeding density, home range and foraging habitats, is needed to provide early locational guidance for developers and other stakeholders. As white-tailed eagle populations continue to recover and expand after a drastic decline in the 1960s and 1970s, land-use planning will play an increasing role in the protection of nesting sites and surrounding areas identified as important for their normal activities (Probst and Gaborik 2011), such as coastal habitats.

Acknowledgements

I would like to start the acknowledgements by expressing my gratitude to my supervisors, Toni Laaksonen and Jon E. Brommer, who have given me the opportunity to study one of Finland's most emblematic species. During the course of my studies, Toni encouraged me to think bigger and become a more independent researcher. He kindly introduced me to the WWF White-tailed Sea Eagle Working Group, for which I presented my individual studies at their annual meetings, and with whose members I developed a friendly and respectful relationship. Jon, with his wisdom and foresightedness, provided the basis on which to build my confidence and inner strength to overcome minor and major difficulties. In sum, their trust, support and expertise were essential for the completion of this thesis.

The white-tailed eagle data used in all the chapters are directly linked to the long-term efforts of many volunteers from the WWF White-tailed Sea Eagle Working Group, who have committed themselves to the study and protection of this magnificent species. To all of them I express my sincere gratitude. I take this opportunity to also thank my co-authors, some of whom belong to the same working group.

For the task of pre-examining this thesis, I would like to thank Miguel Ferrer and Torgeir Nygård, who have been actively engaged in the noble cause of nature conservation. In addition, I am very grateful to Professor Oliver Krüger for readily and kindly accepting the invitation to examine this thesis at a public defence.

A Brazilian scholarship, CAPES, was my source of continuous funding for four years, and I feel privileged for having had this opportunity. Such opportunities will likely become more difficult in a precarious world fuelled by competition and utilitarianism. I am equally grateful for the funding received from the University of Turku, which kindly provided the resources I needed in the final stages.

Hadi, who is seventeen years old, kindly produced the drawing that you can appreciate on the cover of this thesis. I hope that, after enduring a perilous journey towards a wealthier and safer place, he can have a prosperous and wonderful life in Finland.

I would like to thank all the BGG students and members of staff with whom I have had the chance to share a meaningful experience, engage in an interesting conversation, or simply have lunch or coffee in the kitchen. I thank Barbara, with whom I have shared an office for more than four years. With sympathy, I must acknowledge my vast indebtedness to all the people who supported me during the last months of the past year. In particular, I would like to thank three great mothers, Gabriela, Mirkka, and Mariana, for their profound sense of solidarity.

I would like to thank my parents and my sister, who live very far away from Finland, in Brazil, for always believing in me more than I do it myself. I must express my deepest gratitude to my wife, for her natural courage, strength, and optimism, and for being part of every aspect of my life. In 2016, we became parents for the first time, and since then our daily life has been filled with greater joy. My family is my primary source of motivation and inspiration. Without its unifying force of love, it would have been impossible for me to find the necessary strength to finalise this thesis. The presence of my wife and our daughter is a constant reminder of what really matters in life. The simple, true happiness of a child is endlessly powerful, and a lesson to us all.

References

Barrios, L., and A. Rodríguez. 2004. Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines. *Journal of Applied Ecology* **41**: 72–81.

Bevanger, K., F. Berntsen, S. Clausen, E. L. Dahl, Ø. Flagstad, A. Follestad, D. Halley, F. Hanssen, et al. 2010. *Pre- and post-construction studies of conflicts between birds and wind turbines in coastal Norway (Bird-Wind)*. 620. NINA Report. Trondheim, Norway.

BirdLife International. 2015. BirdLife International. *Data Zone*.

Cramp, S., and K. E. L. Simmons. 1980. *Handbook of the Birds of Europe, the Middle East and North Africa: Hawks to Bustards*. Vol. II. Oxford, UK: Oxford University Press.

Dahl, E. L., K. Bevanger, T. Nygård, E. Røskaft, and B. G. Stokke. 2012. Reduced breeding success in white-tailed eagles at Smøla windfarm, western Norway, is caused by mortality and displacement. *Biological Conservation* **145**: 79–85.

Dahl, E. L., R. May, P. L. Hoel, K. Bevanger, H. C. Pedersen, E. Røskaft, and B. G. Stokke. 2013. White-tailed eagles (*Haliaeetus albicilla*) at the Smøla wind-power plant, Central Norway, lack behavioral flight responses to wind turbines. *Wildlife Society Bulletin* **37**: 66–74.

De Vos, J. M., L. N. Joppa, J. L. Gittleman, P. R. Stephens, and S. L. Pimm. 2015. Estimating the normal background rate of species extinction. *Conservation Biology* **29**: 452–462.

Directive 2009/147/EC. 2009. *DIRECTIVE 2009/147/EC of the European Parliament and of the Council on the conservation of wild birds*.

Drewitt, A. L., and R. H. W. Langston. 2006. Assessing the impacts of wind farms on birds. *Ibis* **148**: 29–42.

Erickson, W. P., G. D. Johnson, and D. P. J. Young. 2005. A summary and comparison of bird mortality from anthropogenic causes with an emphasis on collisions. In: Ralph, C. John; Rich, Terrell D., Editors 2005. Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference. 2002 March 20-24; Asilomar, California, Volume 2 Gen. Tech. Rep. PSW-GTR-191. Albany, CA: U.S. Dept. of Agriculture, Forest Service, Pacific Southwest Research Station: P. 1029-1042.

Evans, R. J., J. D. Wilson, A. Amar, A. Douse, A. Maclennan, N. Ratcliffe, and D. P. Whitfield. 2009. Growth and demography of a re-introduced population of White-tailed Eagles Haliaeetus albicilla. *Ibis* **151**: 244–254.

FAO. 2001. *Global Forest Resources Assessment 2000*. Main report 140. FAO Forestry Paper. Rome.

Ferrer, M. 2012. *Birds and power lines. From conflict to solution*. Endesa SA and Fundación Migres. Sevilla, Spain.

Finnish Energy Industries. 2017. Tuulivoima.

Finnish Wind Power Association. 2016. Tuulivoimalaitokset ja tuulivoimahankkeet Suomessa.

Global Wind Energy Council. 2015. *Global Wind Report: Annual Market Update*.

Gove, B., R. H. W. Langston, A. McCluskie, J. D. Pullan, and I. Scrase. 2013. *Wind farms and birds: an updated analysis of the effects of wind farms on birds, and best practice guidance on integrated planning and impact assessment*. Report prepared by BirdLife International on behalf of the Bern Convention. Convention on the Conservation of European Wildlife and Natural Habitats: Bern Convention Bureau Meeting. Strasbourg, France.

Hanski, I. 2016. *Messages from Islands: a global biodiversity tour*. Chicago: The University of Chicago Press.

Hardey, J., H. Crick, C. Wernham, H. Riley, B. Etheridge, and D. Thompson. 2013. *Raptors: a field guide to survey and monitoring*. Norfolk: TSO (The Stationery Office).

Helander, B., and C. Herrmann. 2016. *White-tailed eagle productivity*. HELCOM Indicators.

Helander, B., and T. Stjernberg. 2002. *Action Plan for the conservation of White-tailed Sea Eagle (Haliaeetus albicilla)*. Prepared on behalf of BirdLife International Sweden. Convention on the Conservation of European Wildlife and Natural Habitats. Strasbourg, France.

Helander, B., C. Herrmann, and T. Stjernberg. 2013. *White-tailed eagle productivity*. HELCOM Core Indicator of Biodiversity.

Herrmann, C., O. Krone, T. Stjernberg, and B. Helander. 2011. *Population Development of Baltic Bird Species: White-tailed Sea Eagle (Haliaeetus albicilla)*. Helsinki Commission - Nature Protection and Biodiversity Group. HELCOM Indicator Fact Sheet. Kotka, Finland.

Hunt, G. 2002. *Golden eagles in a perilous landscape: predicting the effects of mitigation for wind turbine blade- strike mortality*. Consultant report prepared for PIER - Environmental Area. California, USA: California Energy Commission.

Kenward, R. E. 2001. *A manual for wildlife radio tagging*. London: Academic Press.

Kirby, J. F., A. J. Stattersfield, S. H. M. Butchart, and M. I. Evans. 2008. Key conservation issues for migratory land- and waterbird species on the world's major flyways. *Bird Conservation International* **18**: S49–S73.

Krone, O., and C. Scharnweber. 2003. Two white-tailed sea eagles (Haliaeetus albicilla) collide with wind generators in northern Germany. *Journal of Raptor Research* **37**(2): 174–176.

Krone, O., T. Langgemach, P. Sömmer, and N. Kenntner. 2003. Causes of mortality in white-tailed sea eagles from Germany. In *Proceedings of the Swedish Society for Nature Conservation*, ed. B. Helander, M. Marquiss, and W. Bowerman, 211–218. Stockholm, Sweden.

Loss, S. R. 2016. Avian interactions with energy infrastructure in the context of other anthropogenic threats. *The Condor* **118**: 424–432.

de Lucas, M., M. Ferrer, M. J. Bechard, and A. R. Muñoz. 2012. Griffon vulture mortality at wind farms in southern Spain: Distribution of fatalities and active mitigation measures. *Biological Conservation* **147**: 184–189.

Mace, G. M., H. Masundire, and J. E. M. Baillie. 2005. Biodiversity. In *Ecosystems and Human Well-being: Current State and Trends, Volume 1*. The Millennium Ecosystem Assessment Series. Washington D.C.: Island Press.

Mäkisara, K., M. Katila, J. Peräsaari, and E. Tomppo. 2016. *The Multi-Source National Forest Inventory of Finland–methods and results 2013*. 10. Natural Resources and Bioeconomy Studies. Natural Resources Institute Finland (Luke).

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. *Resource selection by animals: statistical analysis and design for field studies*. Nordrecht, The Netherlands: Kluwer.

May, R., T. Nygård, E. L. Dahl, and K. Bevanger. 2013. Habitat utilization in white-tailed eagles (Haliaeetus albicilla) and the displacement impact of the Smøla wind-power plant. *Wildlife Society Bulletin* **37**: 75–83.

Mikkola-Roos, M., J. Tiainen, A. Below, M. Hario, A. Lehikoinen, E. Lehikoinen, T. Lehtiniemi, A. Rajasärkkä, et al. 2010. Birds. In *The 2010 Red List of Finnish Species*, ed. P. Rassi, E. Hyvärinen, A. Juslén, and I. Mannerkoski, II:320–331. Helsinki: Ympäristöministeriö & Suomen ympäristökeskus.

National Energy and Climate Strategy. 2013. *National Energy and Climate Strategy*. Government Report to Parliament on 20 March 2013.

Neu, C. W., C. R. Byers, and J. M. Peek. 1974. A Technique for Analysis of Utilization-Availability Data. *The Journal of Wildlife Management* **38**: 541–545.

Newton, I. 1998. *Population limitation in birds*. San Diego, California, USA and London, UK: Academic Press.

Probst, R., and A. Gaborik. 2011. *Action plan for the conservation of the white-tailed eagle (Haliaeetus albicilla) along the Danube*. Convention on the Conservation of European Wildlife and Natural Habitats. Strasbourg, France.

Sala, O. E., F. Stuart Chapin, III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, et al. 2000. Global Biodiversity Scenarios for the Year 2100. *Science* **287**: 1770–1774.

Saurola, P. 2008. Monitoring Birds of Prey in Finland: A Summary of Methods, Trends, and Statistical Power. *AMBIO: A Journal of the Human Environment* **37**: 413–419.

Saurola, P., J. Valkama, and W. Velmala. 2013. *The Finnish Bird Ringing Atlas*. Vol. I. Helsinki, Finland: Luonnontieteellinen Keskusmuseo, Ympäristöministeriö.

Scholz, F. 2010. Spatial use and habitat selection of white-tailed eagles (*Haliaeetus albicilla*) in northern Germany. PhD Thesis, Berlin: Freie Universität Berlin.

Seppälä, J., M. Melanen, T. Jouttijärvi, L. Kauppi, and N. Leikola. 1998. Forest industry and the environment: a life cycle assessment study from Finland. *Resources, Conservation and Recycling* **23**: 87–105.

Smallwood, K. S., and C. Thelander. 2008. Bird Mortality in the Altamont Pass Wind Resource Area, California. *The Journal of Wildlife Management* **72**: 215–223.

Stewart, G. B., A. S. Pullin, and C. F. Coles. 2007. Poor evidence-base for assessment of windfarm impacts on birds. *Environmental Conservation* **34**: 1–11.

Stjernberg, T., J. Koivusaari, J. Högmander, T. Ollila, and H. Ekblom. 2005. Population trends and breeding success of the White-tailed Sea Eagle Haliaeetus albicilla in Finland, 1970–2005. In *Proceedings of the Workshop on the Status of Raptor Populations in Eastern Fennoscandia*. Kostomuksha, Karelia, Russia.

Tammelin, B., T. Vihma, E. Atlaskin, J. Badger, C. Fortelius, H. Gregow, M. Horttanainen, R. Hyvönen, et al. 2011. Production of the Finnish Wind Atlas. *Wind Energy* **16**: 19–35.

Thomas, D. L., and E. J. Taylor. 1990. Study Designs and Tests for Comparing Resource Use and Availability. *The Journal of Wildlife Management* **54**: 322–330.

Thomas, D. L., and E. J. Taylor. 2006. Study Designs and Tests for Comparing Resource Use and Availability II. *Journal of Wildlife Management* **70**: 324–336.

Tiainen, J., M. Mikkola-Roos, M. Below, A. Jukarainen, A. Lehikoinen, T. Lehtiniemi, J. Pessa, A. Rajasärkkä, et al. 2016. *Suomen lintujen uhanalaisuus 2015 – The 2015 Red List of Finnish Bird Species*. Ympäristöministeriö & Suomen ympäristökeskus.

Tosh, D. G., W. I. Montgomery, and N. Reid. 2014. *A review of the impacts of onshore wind energy development on biodiversity*. Report Prepared by the Natural Heritage Research Partnership (NHRP) between Quercus, Queen's University Belfast and the Northern Ireland Environment Agency (NIEA) for the Research and Development Series No. 14/02.

Ueta, M., Y. Fukuda, and R. Takada. 2010. Difference in flight behavior between White-tailed and Steller's Sea Eagle in Hokkaido. *Bird Research* **6**: A43–A52.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study* **46**: S120–S139.

Worton, B. J. 1989. Kernel Methods for Estimating the Utilization Distribution in Home-Range Studies. *Ecology* **70**: 164–168.

WWF Finland. 2011. *WWF Suomen kanta: Ekologisesti kestävä tuulivoima*.

Young, J., A. Watt, P. Nowicki, D. Alard, J. Clitherow, K. Henle, R. Johnson, E. Laczko, et al. 2005. Towards sustainable land use: identifying and managing the conflicts between human activities and biodiversity conservation in Europe. *Biodiversity & Conservation* **14**: 1641–1661.

Zakeri, B., S. Syri, and S. Rinne. 2015. Higher renewable energy integration into the existing energy system of Finland e Is there any maximum limit? *Energy* **92**: 244–259.

Zieliński, P., G. Bela, and A. Marchlewski. 2011. *Report on monitoring of the wind farm impact on birds in the vicinity of Gnieżdżewo (gmina Puck, woj. pomorskie)*. Gdańsk, Poland: PRO ORNIS.

Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. *Mixed Effects Models and Extensions in Ecology with R*. Springer.

Annales Universitatis Turkuensis

Turun yliopisto
University of Turku

Painosalama Oy, Turku , Finland 2018

ISBN 978-951-29-7144-2 (PRINT)
ISBN 978-951-29-7145-9 (PDF)
ISSN 0082-6979 (PRINT) | ISSN 2343-3183 (ONLINE)