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NINA Report

# Repowering Smøla wind-power plant

## An assessment of avian conflicts

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NINA

Norwegian Institute for Nature Research

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Dahl, E.L., May, R., Nygård, T., Åstrøm, J. & Diserud, O.H. 2015. Repowering Smøla wind-power plant. An assessment of avian conflicts. - NINA Report 1135. 41 pp.

Trondheim, June, 2015

ISSN: 1504-3312
ISBN: 978-82-426-2757-5

AVAILABILITY
Open access

PUBLICATION TYPE
Digital document (pdf)

EDITION
Espen Lie Dahl

QUALITY CONTROLLED BY
Arne Follestad

SIGNATURE OF RESPONSIBLE PERSON
Research director Signe Nybø (sign.)

CLIENT(S)/SUBSCRIBER(S)
Statkraft

CLIENTS/SUBSCRIBER CONTACT PERSON(S)
Harald Kristoffersen

COVER PICTURE
Aurora borealis over turbine 1 in Smøla wind-power plant. Photo: Espen Lie Dahl

KEY WORDS
- Norway, Smøla, Smøla wind-power plant
- Repowering, wind energy
- White-tailed eagle, birds
- impact assessment

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# Abstract

Dahl, E.L., May, R., Nygård, T., Åstrøm, J., Diserud, O.H. & Reitan, R. 2015. Repowering Smøla wind-power plant. An assessment of avian conflicts. - NINA Report 1135. 41 pp.

Both through ongoing and previous studies of the conflict between birds and wind turbines carried out in the Smøla wind-power plant, the white-tailed eagle, *Haliaeetus albicilla*, has been identified as the most vulnerable species. The Smøla wind-power plant has an impact on the white-tailed eagle both through increased disturbance as well as increased mortality from collisions with turbines.

The assessments are based on a set of different data sources and different analyses. (i) Monitoring data on reproductive success and nest locations for the white-tailed eagle. (ii) Data on eagle night roosts. (iii) Analysis of flight activity levels and collision risk modelling. (iv) Sensitivity analysis for birds in general based on data from the Merlin avian radar and (v) analysis of turbine-related collision risk sensitivity from bird fatality data. Together these data sources form a solid basis for assessing the potential impacts of a repowered Smøla wind-power plant.

In general, we expect the layout with 30 5MW turbines to have lowest conflict level for the white-tailed eagle. The modeled collision risk of a repowered wind power plant with 30 turbines are expected to have approximately 32% of the collision risk compared to the existing wind-power station, i.e. significantly less than in the existing wind-power plant. A renewed wind-power plant with 50 3MW turbines is expected to have a collision risk that is approximately 71% of that of the existing wind-power plant. The reduced risk of a power plant with 30 turbines compared to the existing wind-power plant and the 50-turbine layout is due to both the reduction of the number of turbines, and better individual turbine siting.

Also, when assessing the impact on the breeding performance of the eagles, the 30-turbine layout is expected to have a lower conflict level compared to the 50-turbine layout. This is mainly due to fewer turbines and greater distances between turbines and nest sites in the southwestern part of the wind-power plant. For other parts of the area we expect minor differences for the two layouts compared to the existing wind-power plant.

Considering the distance to night roosts there are minor differences between the two proposed layouts. North of the wind-power plant, there are several important night roosts that are being used by a relative large number of eagles. However, both proposed layouts have increased distances between the turbine locations and these roosts compared to the existing wind-power plant. The proposed 50-turbine layout will have a higher density of turbines in in southwest and thus a higher risk for the eagles in this area.

A summed vulnerability map for white-tailed eagles was developed, based on data on reproductive success, nest location, flight activity levels and night roost locations. According to this summed vulnerability map, the eagles have the highest vulnerability is present in the outer edges of the proposed layouts, as well as in an area in the south west between the two westernmost turbine strings. Other parts of the wind-power plant will have less vulnerability compared to the existing wind-power plant. Overall, the 30-turbine layout is expected to have least impact to the summarized white-tailed eagle vulnerability.

Analysis of the radar data provides a picture of the bird activity in general and not only for the white-tailed eagle. The results show that the lowest vulnerability is expected for the 30-turbine layout. The radars reduced ability to track objects close to the existing turbines make it difficult to compare the two proposed layouts with the existing wind-power plant.

An analysis of the potential variables that can explain where the white-tailed eagle collisions take place in the existing wind-power plants, shows that collisions among adult white-tailed eagle are

more likely to take place at turbines that are further from the nest sites than those that are close. However, there is greater likelihood of collision at turbines that have several nest sites within 1 km distance. A possible explanation for this could be that territorial adults inside the wind-power plant keep other eagles away from their own nest site.

Based on modeling of collision risk at the individual turbines for the 50-turbine layout, it is expected that the turbines 1, 13 and 19 in the northern part, turbine 22 and 23 in the southwest have the highest collision risks. For the 30-turbine layout it is predicted that turbines 1, 9, 10, and 13 will have the highest collision risks. All of these turbines are located in the northwestern corner of the wind-power plant. From the analyses of the summed vulnerability based on multiple data sources, the turbines located along the western turbine string and in the southwestern corner are expected to be the most sensitive turbines for both proposed layouts.

We recommend that an adaptive management plan is established as a follow-up program that regularly assesses the conflict level with the white-tailed eagle and whether mitigation measures should be initiated. This requires monitoring of the conflict level in the post construction period. The ongoing project INTACT working on identifying potential mitigation measures. Results from the INTACT project will be ready well in advance of the construction phase of a repowered Smøla wind-power plant, and should be taken into account in the follow-up program. In addition to mitigation measures, compensation measures could be used to compensate for e.g. bird mortality in the repowered wind-power plant.

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# Sammendrag

Dahl, E.L., May, R., Nygård, T., Åstrøm, J. & Diserud, O.H. 2015. Repowering Smøla wind-power plant. An assessment of avian conflicts. - NINA Report 1135. 41 pp.

Gjennom pågående og tidligere forskning på effekter av vindkraft på fugl i Smøla vindpark, er havørn identifisert som den mest sårbare arten. Smøla vindpark påvirker havørn både gjennom økt dødelighet som følge av kollisjoner og gjennom nedsatt reproduksjon som følge av forstyrrelser. NINA er bedt av Statkraft om å vurdere konsekvensene av en fornyet Smøla vindpark på fugl. NINA har mottatt ulike utkast til layout for et fornyet vindkraftverk. Felles for alle utkastene er at antall turbiner reduseres fra dagens 68 turbiner. Etter å ha justert layoutene basert på resultater av våre analyser endte Statkraft opp med to ulike versjoner; en layout med 50 3MW turbiner og en layout med 30 5MW turbiner. I våre vurderinger av konsekvensene for havørn, har vi lagt disse to layoutene til grunn for analysene og vurdert hvordan disse påvirker dødelighet og forstyrrelser på havørn.

Vurderingene er basert på en rekke ulike datakilder og analyser; reproduksjonsdata og reirlokaliseringer for havørn, overnattingsplasser for havørn, analyser av fluktaktivitet og kollisjonsrisikomodellering basert på data fra satellittsendere montert på unge havørner, samt sårbarhetsanalyser for fugl generelt basert på data fra fugleradar og analyser av turbin-baserte risikofaktorer tilknyttet kolliderte havørn. Alle disse datakildene gir til sammen et solid grunnlag for å vurdere effektene av foreslåtte turbinplasseringer og turbinstørrelser på risiko for kollisjoner og forstyrrelser hos havørn.

Generelt vil en layout med 30 stk. 5MW turbiner gi det minste konfliktnivået for havørn. Den modellerte kollisjonsrisikoen for et fornyet vindkraftverk med 30 turbiner med foreslåtte lokaliseringer forventes å være cirka 32% av risikoen i eksisterende vindkraftverk, dvs. en betydelig reduksjon. Et fornyet layout med 50 turbiner på 3MW med foreslåtte lokaliseringer forventes å ha en kollisjonsrisiko som er cirka 71% av risikoen i det eksisterende vindkraftverket. Den reduserte risikoen for et kraftverk med 30 turbiner sammenligna både med det eksisterende kraftverket og med 50-turbiners layout skyldes både en reduksjon av antall turbiner, men også at hver enkelt turbin har en bedre lokalisering med lavere modellert risiko.

Smøla har en høy tetthet av hekkende havørn. Tettheten i vindkraftverket har avtatt etter utbygging, men det finnes fortsatt hekkende havørnpar inne i vindkraftverket. Utenfor kraftverket har tettheten økt. Layouten med færrest antall turbiner er å foretrekke med tanke på forstyrrelse av hekkende havørn, særlig på grunn av at denne vil gi færre turbiner og noe større avstand fra nærmeste turbin til reirplasser i sørvest. I dette området ligger de to territoriene som de siste 10 årene har produsert flest unger. For resten av området, lengre østover og nordover, forventes begge de foreslåtte layoutene å gi liten eller ingen forskjell sammenlignet med eksisterende kraftverk.

Med tanke på nærhet til overnattingsplasser, såkalte nattekvister, er forskjellen mellom de to layoutene marginale. Nord for vindkraftverket er det flere nattekvister som benyttes av et relativt høyt antall havørn. Forskjellen mellom de to foreslåtte layoutene er liten i dette området. Layouten med 50 turbiner vil gi en noe høyere tetthet av turbiner i sørvest, og derfor noe større sårbarhet for to nattekvister i dette området. Den viktigste nattekvisten nært vindkraftverket er i det nordvestre hjørnet, begge de to foreslåtte layoutene vil gi større avstand fra turbiner til denne nattekvisten enn den samme avstanden i eksisterende kraftverk.

Basert på data på reproduksjon, reirlokalisering, fluktaktivitet og nattekvister ble et sumkart utviklet for å vise samlet sårbarhet basert på alle datakildene. Størst sårbarhet finnes i ytterkanten av de foreslåtte layoutene, samt i et område i sørvest mellom de to vestligste turbinstrengene. I dette området i sørvest forventes begge de nye layoutene å komme noe nærmere det mest sårbare området sammenligna med eksisterende kraftverk. I det nordvestre hjørnet vil begge de

nye layoutene ligge lengre fra det mest sårbare området sammenligna med eksisterende kraftverk. Totalt sett forventes layouten med færrest antall turbiner å gi minst sårbarhet med hensyn til summert havørnsårbarhet.

Analysene av radardata gir et bilde på aktivitet for fugl generelt og ikke kun for havørn. Resultatene viser at lavest sårbarhet forventes for layouten med færrest antall turbiner. Radarens egenskaper gjør det vanskelig å sammenligne de to foreslåtte layoutene med eksisterende kraftverk.

Analyser av de potensielle variablene som kan forklare hvor havørnkollisjoner finner sted i eksisterende vindkraftverk, viser at kollisjoner blant voksne havørn er mer sannsynlig mot turbiner som er lengre fra kjente reirplasser. Samtidig er det større sannsynlighet for kollisjon mot turbiner som har mange reirplasser innenfor 1km avstand. En mulig forklaring på dette kan være at voksne territorielle fugler inne i kraftverket holder andre ørner aktivt unna sitt eget reirområde.

Basert på modellering av kollisjonsrisiko ved enkeltturbiner for layouten med flest antall turbiner (50 stk. 3MW) forventes det at turbinene 1, 13 og 19 i den nordlige delen samt turbinene, 22 og 23 i sørvest vil ha størst risiko for havørnkollisjoner. For layouten med færrest antall turbiner (30 stk. 5MW) forventes turbinene 1, 9, 10 og 13 å ha størst risiko for havørnkollisjoner. Alle disse turbinene ligger i det nordvestlige hjørnet.

Fra analysene av samlet sårbarhet for havørn basert på flere datakilder forventes turbinene som ligger langs den vestlige turbinstrengen, samt i det sørvestlige hjørnet å være de mest sårbare turbinene.

Vi anbefaler at det etableres et oppfølgingsprogram som jevnlig vurderer konfliktnivå med havørn og om avbøtende tiltak skal tas i bruk. Dette forutsetter en overvåkning av konfliktnivå i etterkant av fornying av kraftverket. Det pågående prosjektet INTACT har til hensikt å identifisere potensielle avbøtende tiltak. Resultater fra INTACT vil være klart i god tid før det nye kraftverket settes i drift og disse resultatene bør tas i bruk i den fornyede vindparken om de viser seg å være effektive. Potensielle tiltak kan være maling av turbinblad og/eller turbintårn, bruk av UV-lys og kameradeteksjons- og varslingssystem. I tillegg bør selektiv stopping av turbiner i kritiske perioder og på kritiske lokaliteter vurderes. Tiltak for å kompensere for dødelighet hos havørn er også mulig å gjennomføre, for eksempel reduksjon av elektrokusjonsdødelighet langs kraftlinjer på Smøla- Når de gamle turbinene med deres infrastruktur fjernes, bør områdene som er berørt av dette tilbakeføres gjennom en restaureringsprogram.

Begge de to foreslåtte layoutene for en fornyet Smøla vindpark forventes å ha redusert negativ effekt på havørn i forhold til dagens vindpark. Dette gjelder både med tanke på kollisjonsrisiko, nærhet til overnattingsplasser og i forhold til forstyrrelse av hekkende havørn. Layouten med 30 stk. 5MW turbiner forventes å være den som kan gi størst redusert samlet sårbarhet for havørn. Resultater fra våre analyser gir til dels turbinspesifikk informasjon som muliggjør en prioritering av enkeltturbiner hvis antall turbiner i et fornyet kraftverk vil være mellom 30 og 50 turbiner. Turbiner i vest og sørvest bør prioriteres tatt ut om dette er at aktuelt scenario. Selv om datagrunnlaget som ligger til grunn for vurderingene er til dels svært gode er det ikke mulig å fastslå de eksakte effektene av et fornyet vindkraftverk. Vi anbefaler derfor et oppfølgingsprogram som gjør det mulig å ta i bruk nye avbøtende tiltak dersom konflikter skulle oppstå.

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# Contents

# Foreword

This report was ordered by Statkraft, with the aim of assessing the potential impacts on birds from a repowered Smøla wind-power plant. It was agreed, based on the knowledge and experiences gathered in previous studies in the area, that the assessment in this report should focus on the white-tailed eagle. NINA received several layout drafts of a repowered wind-power plant, and common to all layouts has been a reduction of todays 68 turbines. After adjusting the layout based on the results of our analysis, Statkraft ended up with two different layouts; one layout with 50 3MW turbines and one layout with 30 5MW turbines. We have based our impact assessments for the white-tailed eagle on these layouts and considered how these will affect mortality and disturbance of the white-tailed eagle.

Trondheim February 2015
Espen Lie Dahl

# 1 Background

## 1.1 A “new” Smøla power plant

The existing wind-power plant at Smøla was built in two stages, the first stage including 20 turbines was completed in 2002 and the second stage including another 48 turbines was completed in August 2005 (Statkraft 2008). The total installed capacity of the power plant is 150MW. The Smøla wind power plant was licensed for 25 years. However, in 2014 Statkraft presented their plans for repowering of the Smøla wind-power plant within 2020 to ensure the inclusion of the new turbines in the green certificate market (Ministry of Petroleum and Energy 2010)[1]. NINA has conducted comprehensive research on the conflicts between birds and wind turbines at Smøla, mainly through the research program BirdWind (Bevanger et al. 2010) and the ongoing INTACT-project (Ministry of Petroleum and Energy 2010; Norge 2012). Based on the results and knowledge obtained in research carried out in connection with the Smøla wind-power plant, NINA was asked by Statkraft to perform an impact assessment of the repowering of Smøla wind-power plant. Together with Statkraft, it was decided that the EIA should focus mainly on the white-tailed eagle, as this is the species identified to be the species in most conflict with the wind-power plant at Smøla. The assessment therefore focuses on the white-tailed eagle. Details on the conflict level of other bird species in the Smøla wind-power plant area can be found in the final report of the BirdWind project (Bevanger et al. 2010).

NINA received a set of two different layouts of a repowered Smøla wind-power plant when the assessments started. One 30-turbine layout and another 50-turbine layout. After giving input based on the findings when analyzing the vulnerability of these two layouts, an adjusted 50-turbine layout (3MW turbines) and one 30-turbine (5MW turbines) layout were received from Statkraft. Results and recommendations in this report are based on the adjusted layouts received by mid-January 2015.

## 1.2 Wind energy and birds

There are two main types of impact from wind-power generation on birds; disturbance potentially leading to displacement or loss of habitat and collisions with turbines leading to increased mortality (Drewitt and Langston 2006; Hötker et al. 2006). In addition, there is a potential for barrier effects from wind-power plants on migrating birds (Fox et al. 2006; Huppop et al. 2006). An increasing amount of studies is focusing on disturbance effects. Pearce-Higgins et al. (2009) found that a range of breeding bird species occurred at lower densities close to wind turbines compared to further away from turbines. The study observed reduced breeding bird abundance in a range of species within a 500-meter buffer from the turbines, with wading birds being most affected, as well as reduced flight activity close to turbines among raptor species. Garvin et al. (2011) investigated the response of raptors to wind-power plants and found that the abundance of raptors was reduced by 47 % post-construction compared to pre-construction. Most attention, however, has been directed towards monitoring of collision mortality in different species. Among different groups of birds, raptors are regarded as being particularly vulnerable to wind-power plants (Barrios and Rodriguez 2004; Bevanger et al. 2010; de Lucas et al. 2012; Smallwood and

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[1] In May 2015 Statkraft postponed the plans for repowering of the Smøla wind-power plant, by which this will not be realized prior to 2020.

Thelander 2008). Significant numbers of collision fatalities are reported among raptors from several parts of the world (Bevanger et al. 2010; de Lucas et al. 2012; Smallwood et al. 2009b).

Efforts in collision studies, so far, have largely been directed towards estimating annual mortality rates as well as towards assessing behavioral changes (Larsen and Guillemette 2007; Madsen and Boertmann 2008; Smallwood and Thelander 2008). The numbers of casualties recorded at power plants differ considerably between different sites and species (Kuvlesky et al. 2007). In general wetlands, coastal sites, ridges and cliff edges are reported to have more collision victims per turbine than agricultural areas and inland locations (Rydell et al. 2011). Collision risk is highly species-specific, and large soaring birds, e.g. eagles and vultures, seem to be particularly vulnerable (Bevanger et al. 2010; de Lucas et al. 2012; Shimada and Matsuda 2007; Smallwood and Thelander 2008). Even though small numbers of collision victims per turbine are reported among raptors, it is important to note that most raptorial species have slow reproduction, high annual survival and long life-span (k-strategists) (Newton 1979). These demographic features make them vulnerable to increased mortality, in particular mortality among adult individuals (Sæther and Bakke 2000). Therefore, even low collision mortality rates for such species could lead to population level impact (Orloff and Flannery 1992; Thelander and Rugge 2000).

Studies focusing on long-term population effects from wind-power plants on birds are scarce, yet much needed. Population-level effects from wind turbines on birds are mainly connected to increased mortality from collisions with turbines. Collision mortality could potentially lead to population decrease among some species. The impact from increased mortality is however, highly species-specific and dependent on both population size and life-history traits (Desholm 2009; Sæther and Bakke 2000). Carrete et al. (2009) found that even small reductions in survival rates associated to wind-power plants among territorial birds can strongly affect population viability in long-lived species. To assess the long-term population effect from increased mortality from turbine collisions for a given species, long-term population monitoring and population modeling is needed.

The research carried out in the Smøla wind-power plant has focused both on the impact from collisions and disturbance effects (Dahl et al. 2011; Dahl et al. 2013; May et al. 2013). Two species in particular have been identified to be in conflict with the wind-power plant at Smøla: the willow ptarmigan, *Lagopus lagopus*, and the white-tailed eagle (Bevanger et al. 2010). While it has not been possible to detect any population-level impacts from the ptarmigan mortality the studies focusing on the white-tailed eagle have identified population-level impacts. A PhD-thesis (Dahl 2014) studying the population dynamics in white-tailed eagle in the Smøla wind-power plant, found that increased mortality from collisions with turbines together with reduced reproductive success led to a reduced growth rate in the population caused by the wind-power plant development, with the part of the population breeding close to the wind-power plant being most affected. There was a clear spatial component in the impact from the wind-power plant on the white-tailed eagle population. The impact from mortality had a wider spatial component compared to the impact from disturbance. The impact from increased mortality among adult eagles was traced in territories out to 5 km from the turbines, while the reproductive success was reduced in territories out to 1 km from the turbines. This study concluded that it is highly important to take into consideration both disturbance and mortality when planning future wind-power plants.

## 1.3 Repowering of wind power-plants

The potential for repowering is expected to be extensive and has already been commenced in Denmark, Germany, Spain, California and India (del Río et al. 2011). Repowering allows the re-design of the wind-power plant layout within the existing footprint, thus further minimizing environmental impacts in the landscape. However, repowering also necessitates partial restoration of the wind-power plant footprint with respect to discontinued structures. There is however, limited information on the effect from repowering of wind-power plants on birds, as relative few power plants have been repowered. In Gotland, Sweden, a 58-turbine wind-power plant was repowered to a 28 turbine wind-power plant producing four times the amount of energy compared to the old wind-power plant (Hjernquist 2014). This study compared old vs. new turbines and the mortality rates and distribution of breeding and resting birds. In general, the study found no significant increased impact on breeding and wintering bird distribution. The study found that 1.77 times more birds collided per turbine per year after repowering compared to before, but when one accounted for the reduced number of turbines after the repowering, the numbers of birds colliding in total was reduced by 19%, going down from 1700 birds per year to 1500 birds per year. The amount of energy produced in the repowered wind-power plant increased fourfold, leading to the reduction of the number of birds killed per MW by 80 % after the repowering. Also in the Altamont Pass Wind Resource Area (APWRA), California, a repowering study have been conducted (Smallwood and Karas 2009). Here they found that raptor fatalities were reduced by more than 50 % when repowering the Diablo Wind part of APWRA. In general, fewer and larger turbines are thought to be preferred over many small turbines with regard to minimizing collision risk to birds. Primarily in wind-power plants in the USA, modern, larger tubular-towered turbines replaced old-generation turbines with lattice towers and/or smaller turbines. Repowering has been observed to lead to reduced bird mortality in the Altamont Pass Wind Resource Area (Hunt 2002; Smallwood 2006; Smallwood 2008; Smallwood 2010; Smallwood and Karas 2009). Other studies have however shown little (Krijgsveld et al. 2009) or even opposite effects (de Lucas et al. 2008) on fatality rates. From the existing literature, although limited, it may seem as repowering of wind-power plants with fewer but larger turbines may reduce the total number of collision fatalities, even though the number of collision victims per turbine may increase. It is important to note that too few studies have been carried out to conclude on this. Repowering may also allow for a re-evaluation of turbine localisation and wind-power plant design based on predictive modelling using existing data on bird mortality and behaviour (Smallwood et al. 2009a).

# 2 Methods

## 2.1 Analysis of collision risk factors

The first dead white-tailed eagle was found in August 2005. Since 1 August 2006 searches for dead birds has been carried out using dogs trained to search for both feathers and dead birds (Bevanger et al. 2010). Of the 68 turbines in the Smøla wind-power plant, 25 were searched weekly throughout the year within a radius of approximately 100 meters from the base of the turbine tower. The other 43 turbines were searched once each month during periods with expected high activity of birds, mainly March-June, and less intensively during winter (0-2 times depending on snow conditions). In addition, dead white-tailed eagles found by Statkraft personnel and the public have been immediately reported and collected as well. All dead white-tailed eagles have been autopsied and X-rayed to verify cause of death.

Potential mammalian scavengers are absent on the island of Smøla except for American mink (*Neovison vison*). The main scavengers on bird carcasses on Smøla seem to be white-tailed eagle, hooded crow (*Corvus cornix*) and raven (*Corvus corax*). Although parts of a carcass may be removed, some remains may be present for many months. The main potential bias at Smøla wind-power plant may be crippling bias (Bevanger 1999; Bevanger et al. 2010), i.e. injured birds may survive a collision, but are able to move and die outside the search area.

Altogether, 54 dead or injured white-tailed eagles have been found at Smøla wind-power plant during the period August 2005 – December 2013. During these years, on average 7.2 dead white-tailed eagles were found per year. This equals on average 0.11 dead white-tailed eagles per turbine per year (0.05/MW/year). Half of the collision victims were found during the searches, while the other half was found by Statkraft personnel and the public. The age distribution of the 54 birds found was 29 (54%) adults and 25 (46%) subadult and juvenile birds. The adults were mainly found during spring or autumn, subadult birds mainly in spring, and juveniles in the autumn and their first spring.

The spatial distribution of the recorded collision victims was analyzed using a generalized linear model with a Poisson distribution, while controlling for search effort by including an offset on number of searches per turbine (Crawley 2007). This assumes that all collided birds are found during the searches, and independence among turbines. Possible non-linear effects were tested using generalized additive models. Parameters included in the analysis were (i) search effort, (ii) distance to closest nest, (iii) number of nests within 1km), (iv) distance to closest roost), (v) topography, (vi) distance to closest turbine, (vii) end-of-string turbines, (ix) turbine string – north and (x) turbine string – south.

## 2.2 White-tailed eagle nest sites and reproduction

Data from yearly visits of all known eagle territories and nest sites in the wind-power plant area during the last ten breeding seasons (2004-2013) have been used in this report. White-tailed eagles in the study area nest both on the ground and in trees. Each pair of mated birds can have one or more nests within their home range, thus data from all known nest sites have been used. During the visits, data on territory occupancy and chick production were collected. From 2006 and onwards, molted adult feathers from the nest sites and plucked feather from chicks were collected to do DNA profiling of the birds. These data have given a better understanding of the structure of the eagle territories in thewind- power plant area.

Chick production data from nest sites that were recorded as active during the last breeding seasons was visualized using ArcGIS version 10.1. The density maps are calculated using Kernel densities in Spatial Analyst Tool in ArcGIS.

## 2.3 Eagle night roosts

Night roosts have been mapped based on data from satellite-tagged sub-adult eagles. Only positions recorded between sunset and sunrise have been used in the analysis. The use intensity of the roost sites are presented both as number of positions recorded within each roost and as number of satellite-tagged individuals that have used the roost. The actual number of individuals using the roost is therefore higher than the numbers given here, as only a small proportion of the total amount of eagles at Smøla have been satellite-tagged. The maps shown here are still judged to be good indicators of the use intensity of the different roosts.

## 2.4 Flight activity and collision risk modelling

Flight activity was obtained from 43 satellite-tagged subadult white-tailed eagles. Only positions representing an actual relocation were included, which was assumed to be the case with distances moved from last position >20 meters (*n*=38,508). The manufacturer, Microwave Telemetry, Inc., states a GPS accuracy of +/- 18 meters. Only data from September 1$^{st}$ during their first year-of-life and onwards was included to avoid an overrepresentation of areas directly surrounding their nest sites; prior to and directly after fledging. Flight activity was estimated by modelling the expected distribution of movement corridors using the Brownian bridge movement model (kernelbb in the R package adehabitatHR, R version 3.1.0). This was modelled for each individual separately, and "bursts" of activity therein. A burst indicates a more-or-less continuous sequence of activity with less than 24 hours between relocations. Each burst's utilization distribution was normalized to indicate the proportion of time spent within each pixel (resolution of 25m) by dividing each pixel's value with the sum over all pixel values for the entire utilization distribution. Individual flight maps were produced by summing over all burst, weighted after the number of relocations they represented. Thereafter all individual flight maps were summed, divided by the number of individuals and multiplied by the population size of the Smøla archipelago. This overall flight map was then adjusted for the surface area each pixel represented. This resulted in the estimated total flight activity/hour/km2.

Based on the near-turbine flight activity (<100m) within the rotor swept zone (RSZ) and turbine characteristics, the expected collision risk was modelled by employing the so-called Band collision risk model (CRM). CRM was executed for each layout separately, including the current design (Table 1). Flight activity within 100 meters surrounding each turbine was multiplied by the proportion of time eagles spent in active flight within the rotor swept zone. This proportion depends on the actual hub height and rotor blade length (R) of the (proposed) turbines. The number of birds to transit the volume swept by the rotor blades was calculated as the bird occupancy multiplied by the "risk volume" and mean bird speed (32 km/h). Bird occupancy represents the flight activity multiplied by the surface area (A) surrounding each turbine (<100m). The risk volume equals the ratio between the summed rotor swept areas ($N \cdot \pi \cdot R^2$) for all turbines (N) divided by the rotor swept volume at the focal turbine ($A \cdot 2R$). This "risk volume" enables assessing the collision risk for each turbine relative to all others within each design, irrespective of time. This number of bird transits was thereafter multiplied by the probability of a bird being hit when making a transit through the rotor swept zone. This hit probability depends on the breadth (=max. chord) and pitch of the turbine blades, the rotation speed of the turbine, the size of the bird (both length (=0.8m) and wingspan (=2.3m)), and the flight speed of the bird. The calculation of the hit probability assumes that all birds approach a turbine up- or downwind (50-50%). See May et al. (2011) for more details on the modelling approach.

***Table 1.*** *Input variables for the different designs*.

| Variable | Current design | Repowering design1 | Repowering design2 |
|---|---|---|---|
| Capacity | 2.0/2.1 MW | 3 MW | 5 MW |
| Number of turbines | 68 | 50 | 30 |
| Hub height (m) | 70 | 92 | 95 |
| Rotor blade length (m) | 40 | 58 | 64.5 |
| Max. chord (m) | 3.296 | 4 | 4 |
| Pitch (degrees) | 10 | 8 | 8 |
| % flights within RSZ | 0.135 | 0.136 | 0.156 |
| Hit probability | 0.105 | 0.096 | 0.092 |

It is known that the Band model has some limitations with regard to **absolute** estimates of number of expected collisions (Chamberlain et al. 2006; May et al. 2010; May et al. 2011). Conversely, the Band-model is an appropriate tool to gain insight into the **relative** effects of different design scenarios and tradeoffs between them. On this basis, the expected mortality due to collisions is estimated for both the current (reference) situation and alternative design options, this both with respect to the turbine characterization (hub height, rotor blade length, etc.) and configuration (number and location of turbines). Following comparative analyses allow assessing **relative** difference between design options, and possible “high-risk” turbine locations.

## 2.5 Summed white-tailed eagle risk map

Based on the distribution of nest sites (§ 2.1), night roosts (§ 2.2) and flight activity (§ 2.3) a summed risk map for white-tailed eagles was produced. For nest sites and night roosts the risk was assumed to decrease linearly with distance up to 1 kilometer, this distance is chosen as there is no negative impact on reproductive success beyond 1 kilometer distance to the turbines in the Smøla wind-power plant (Dahl 2014). Each nest site and night roost was buffered up to a distance of 1 kilometer where each cell (resolution of 25m) indicated the reciprocal distance (i.e. 1000 at the nest site or night roost, to 0 at 1 kilometer or further away) to indicate risk. Each nest site was weighted for their number of successful reproductions during the last 10 years, all nest sites summed and thereafter normalized. Each night roost was weighted for the number of individuals utilizing it, all night roosts summed and thereafter normalized. Flight activity was only normalized. Normalization was done as follows: [value – min] / [max – min]; rendering values ranging between 0 and 1. Finally all three risk maps were summed and normalized again to obtain an overall risk map [0 – 1].

## 2.6 Radar data analysis of bird flight in Smøla wind power plant

Avian radar can provide near real-time information on bird activity. This may be used to identify areas with increased risk potential. The MERLIN Avian Radar System (model: XS2530, DeTect, Inc.) is an automated processor of radar data enabling the continuous recording of bird activity

24/7. The system is based on cost-effective off-the-shelf hardware, using standard T-bar ship radars (Japan Radio Co.). The radars in the system are standard S- and X-band ship radars with nominal frequencies of 3050 MHz (JMA-5330) and 9410 MHz respectively (JMA-5320). They are operated independently from each other. The S-band radar is used in normal horizontal surveillance mode, while the base of the X-band antenna is tilted 90° giving a vertical scan pattern which enables height measurements in a narrow sector. The ship radars have antennas which gives horizontal polarisation of the transmitted electromagnetic wave. Since the X-band antenna in this case is mechanically tilted 90°, the X-band polarisation will be vertical. The analyses are however solely based on the horizontal S-band radar. Although the radar hardware is not designed specifically to capture small flying objects such as birds; the developed data extractor is especially designed to extract small flying objects from the radar signals. The output data, representing successive positions (i.e. successful detections) within tracks, has gone through several processing algorithms. The target data extractor has two main functions; detection and tracking. The detection process establishes the automatic detection thresholds on a combined background of clutter and system noise, and for each antenna scan, detects any signal level above this threshold as a target. The tracker takes the detections as input and, based on the movement characteristics of birds, performs scan to scan processing to identify and combine successive detections of the same target. Detections from several antenna scans found to be from the same moving target, are stored together as a "target track" in the target database. The entire system is mounted on a trailer and can thus be moved to any desired location for data collection. All data is automatically downloaded and stored in a SQL Server database. Each observed target detected by the radar is recorded for each scan as a separate observation in the database. For each observation its location (latitude, longitude), date and time stamp, speed and heading, size and shape are recorded. This database, however, contains both bird tracks and false alarms (e.g. cars/aircraft, moving rotor blades, interference). Prior to analyses all data is filtered using tailored multiple-criteria track recognition algorithm developed in the Microsoft Clustering Algorithm of the SQL Server 2008 Analysis Services.

The ability of the Merlin avian radar to track birds decreases with decreasing distance to the radar. Advanced methods to correct for this effect are being developed, and a preliminary method has been used for this report. The correction implemented in the analysis is based on the assumption that all areas within the wind-power plant has the same density of bird flights, irrespective of distance to the radar. The number of bird tracks in each pixel is thus corrected to give an equal mean track density in all areas covered by the radar. This was done by splitting the radar coverage into 100 meter circular bands ranging from 50 meters to 3700 meters outwards from the radar. Next, the number of bird tracks in each pixel was scaled relative to the number of tracks within each 100 meter circular band, and to the relative size of the area within each 100 meter band. The result is a “flat” radar image with equal bird track density for all distances to the radar. Even though this method is an objective representation of the bird flights in the area covered by the radar, it is likely to have some limitations. Firstly bird flight density in the power plant may fluctuate across the monitored area in and around the wind-power plant. Secondly directly surrounding and in close vicinity of most turbines in the current power plant there are “empty” areas without bird tracks due to high radar returns from the large turbines and but also bird avoidance behaviour. Finlaly topography and the operating turbines (moving blades) create shadowing effects affecting the radar’s ability to detect bird flights equally across all areas. Still we think that this method is useful to analyze the amount of bird movements around the turbines, in particular when comparing the two suggested layouts for a repowered Smøla wind-power plant.

# 3 Results

## 3.1 Analysis of collision risk factors

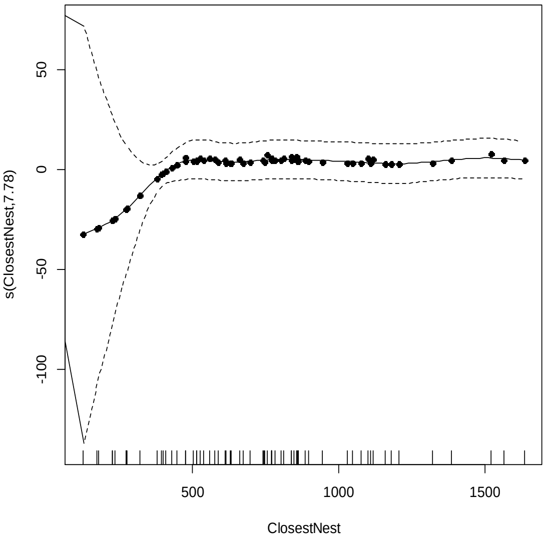
Collision victims of all age classes were positively related to distance to closest nest site; in addition to search effort for victims found by NINA personnel (Table 2). When modelling all white-tailed eagle collisions (not only those found by NINA personnel), adult collisions which were more probable at turbines located farther away from nest sites, and at the same time at turbines with more nest sites within 1km distance (all victims taken together). This positive relationship may be found because non-territorial adults are chased from active nest sites. When investigating possible non-linear effects in distance to closest nest site for all age classes, a strong increase in the collision rate is found within the first 500 meters from the nest site (Figure 1). In addition, the collision rate was higher in the northern and southern parts of the power plant, as well as with smaller inter-turbine distances. Adult collision victims found by NINA personnel were also more probable with smaller inter-turbine distances, and were lower at turbines with much public activity. Juvenile collisions were more probable at turbines in rugged terrain and at end-of-row turbines. Incidentally found collision victims were more probable closer to the nearest roost and in the central parts of the wind power plant. The nearest roost lies northwest of turbine 21; there a walking trail frequently used of the public enters the power plant. The central parts of the power plant are also used more frequently by both the public and Statkraft personnel.

***Table 2.*** *Z-scores and significance levels for the variables which were included in the best explanatory generalized linear (or: additive, for column 6) models for white-tailed eagle (WTE) collision rate at the Smøla wind-power plant. The last two rows indicate the $R^2$ and % deviance explained by the model.*

| Factor | All WTE collisions | | | NINA searched WTE collisions | | | | Incidentally found WTE collisions | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | all age classes | juveniles | adults | all age classes | | juveniles | adults | all age classes | juveniles | adults |
| | (N = 54) | (N = 25) | (N = 29) | (N = 27) | *-non-linear-* | (N = 17) | (N = 10) | (N = 27) | (N = 7) | (N = 19) |
| Search effort | | | | $1.545^{ns}$ | $1.349^{ns}$ | | | | Too few data | |
| Distance to closest nest | 2.148* | | 2.786** | 2.298* | $0.384^{ns}$ | | 2.625** | | | |
| Number of nests within 1km | | | 2.387* | | | | | | | |
| Distance to closest roost | | | | | | | | -2.336* | | -2.629** |
| Topography (rugged versus flat terrain) | | -2.097* | | | | -2.077* | | | | |
| Turbines with public activity | | | | | | | $-1.583^{ns}$ | | | |
| End-of-row turbines | | 2.612** | | | | 2.704** | | | | |
| Distance to closest turbine | | | | | -1.912 | | $-1.617^{ns}$ | | | |
| Row - North (reference = Middle) | | | | | $1.625^{ns}$ | | | -2.456* | | -2.234* |
| Row - South (reference = Middle) | | | | | 2.052* | | | -2.907** | | -2.480* |
| $R^2$ | 0.08 | 0.15 | 0.16 | 0.12 | 0.34 | 0.16 | 0.07 | 0.18 | | 0.19 |
| Deviance explained | 9 % | 15 % | 13 % | 12 % | 49 % | 17 % | 20 % | 18 % | | 23 % |

***Note:*** *numbers give the effect size and their direction for each variable in the best explanatory model. One, two and three asterisks indicate P<0.05, P<0.01 and P<0.001 respectively. No asterisks indicate P<0.10. "ns" indicates non-significant effect but neccessary part of the best model.*

***Figure 1.*** *Non-linear effects of distance to closest nest site in relation to collision rate using a generalized additive model on NINA searched white-tailed eagle collision victims at the Smøla wind-power plant for all age classes.*



## 3.2 Vulnerability of white-tailed eagle nest sites and reproduction

Distribution of nest sites and reproduction is shown both as exact locations of nest sites and their reproductive output as well as density maps. The maps showing exact locations are confidential and only for internal use. In the public version of the report, only the density maps will be shown.

During the ten last breeding seasons, most chicks in the wind-power plant area have been produced outside the power plant (Figure 2a and 2b). In particular, two nest sites in the southwestern parts of the area in close proximity to the turbines have been productive, west of the western string of turbine and in the southwestern corner of the proposed layouts. Of all nest sites in the wind-power plant area, these two sites are most sensitive to new turbines when it comes to chick production. Four nest sites east of the power plant area belonging to the same territory have in total experienced high chick production during the last ten breeding season. These nest sites are, however, further away from the proposed turbine locations and hence less sensitive. In some of the nest sites within the wind-power plant there has also been recorded chick production during the last ten years. However, these have been less productive than the ones outside the existing wind-power plant, probably due to disturbance and mortality effects (Dahl et al. 2012). Based on this knowledge, and as these nest sites are already the ones being most disturbed, the least sensitive areas when it comes to chick production are the areas within the existing wind-power plant and the repowered wind-power plant should as much as possible be restricted to the existing layout.

The density of nest sites (Figure 3a and 3b) show, as shown for chick production, that the areas south-west and east of the power plant area has the highest density of nest sites. Thus, the most vulnerable areas concerning nest sites are more or less the same areas as for chick production (Figure 2a & 2b, 3a & 3b, & 4a & 4b).

***Figure 2a.*** *Accumulated number of chicks produced within and close to the Smøla wind-power plant area (3MW layout) during the last ten breeding seasons with a 1km buffer around the nest sites.*

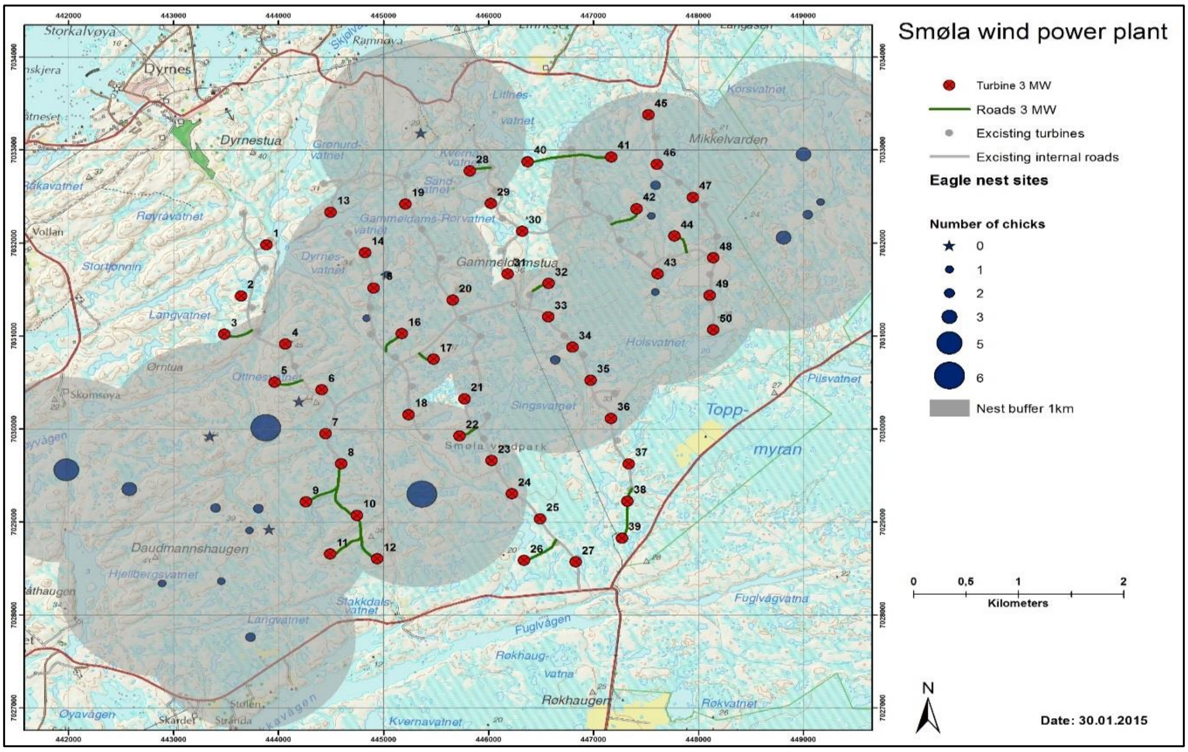


***Figure 2b.*** *Accumulated number of chicks produced within and close to the Smøla wind-power plant area (5MW layout) during the last ten breeding seasons with a 1km buffer around the nest sites.*

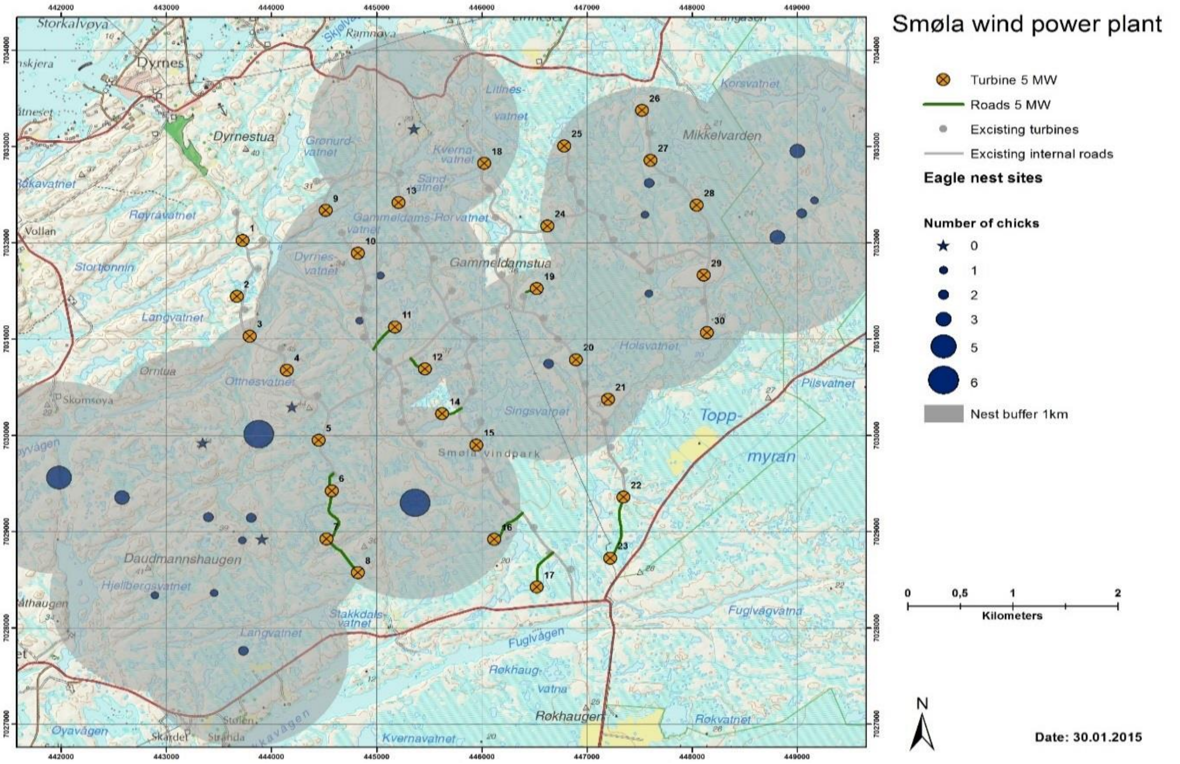


***Figure 3a.*** *Density of white-tailed eagle nest sites active during the last 10 breeding seasons in the Smøla wind-power plant area (3MW layout). The darker the color the higher the density.*

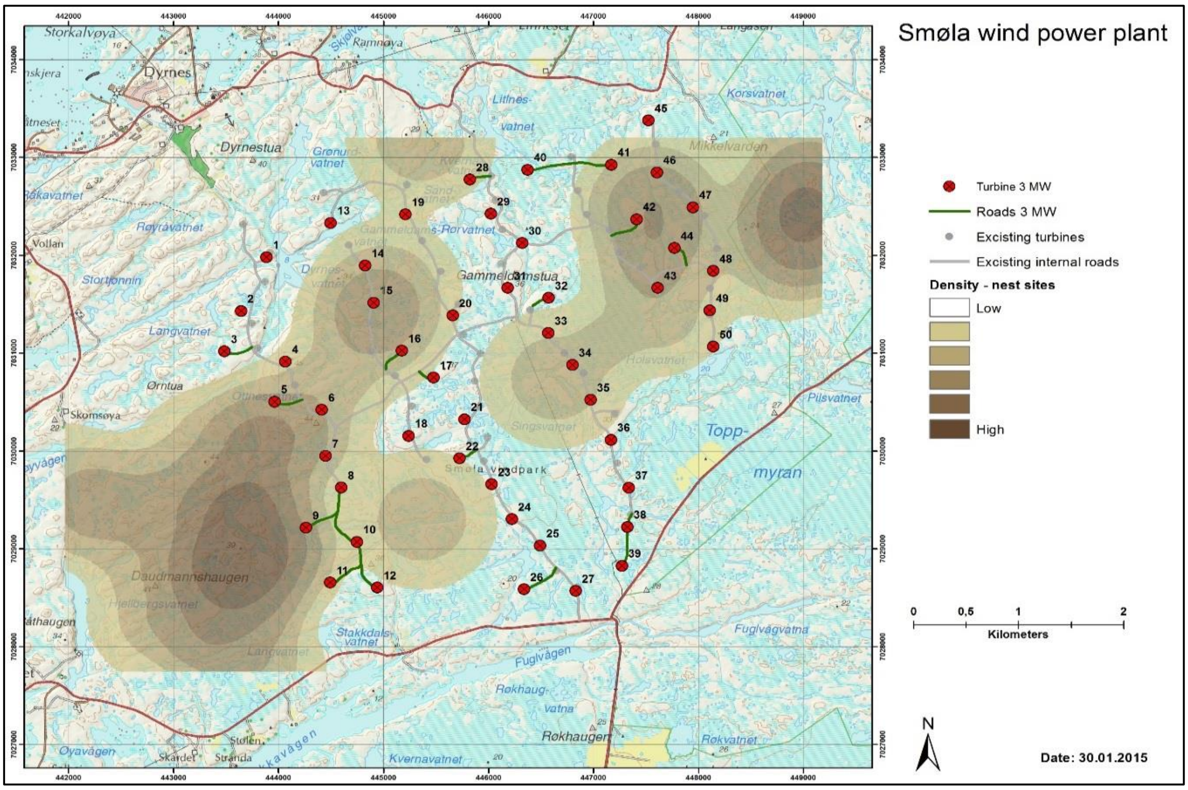


***Figure 3b.*** *Density of white-tailed eagle nest sites active during the last 10 breeding seasons in the Smøla wind-power plant area (5MW layout). The darker the color the higher the density.*

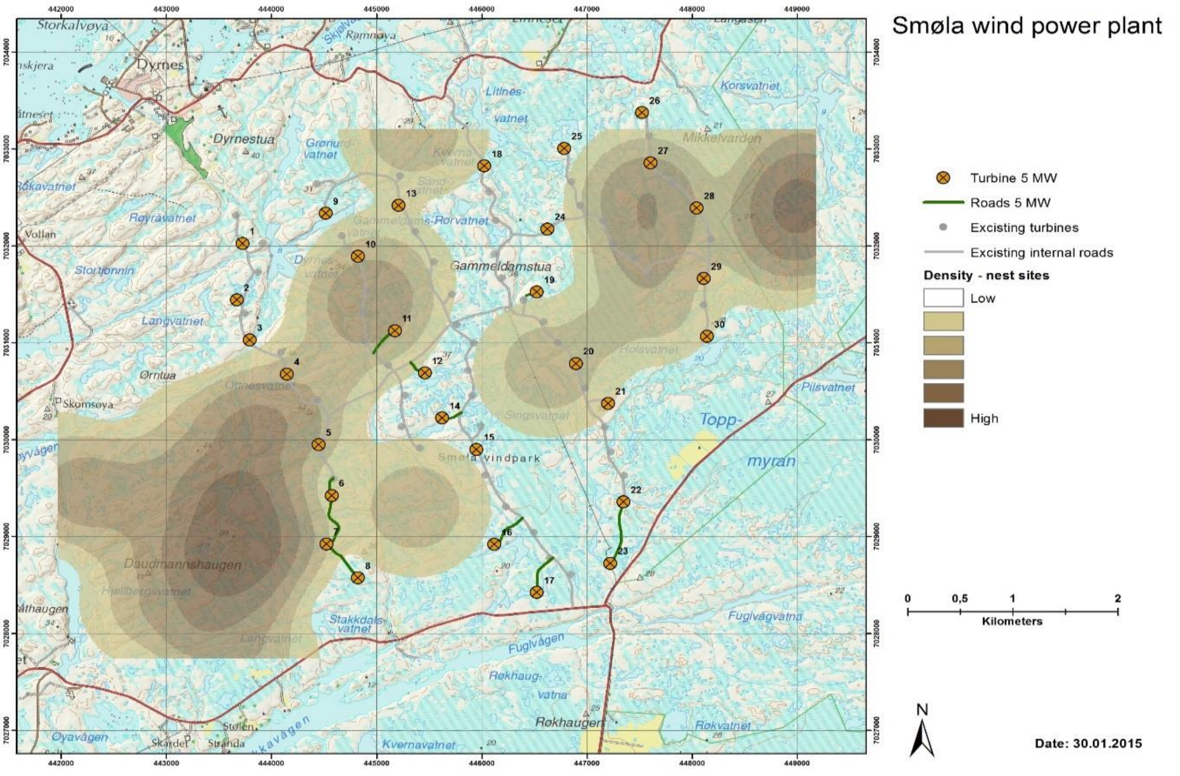


***Figure 4a.*** *Density of white-tailed eagle chick production during the last 10 breeding seasons in the vicinity of the Smøla wind-power plant (3MW layout). The darker the color the higher the chick production.*

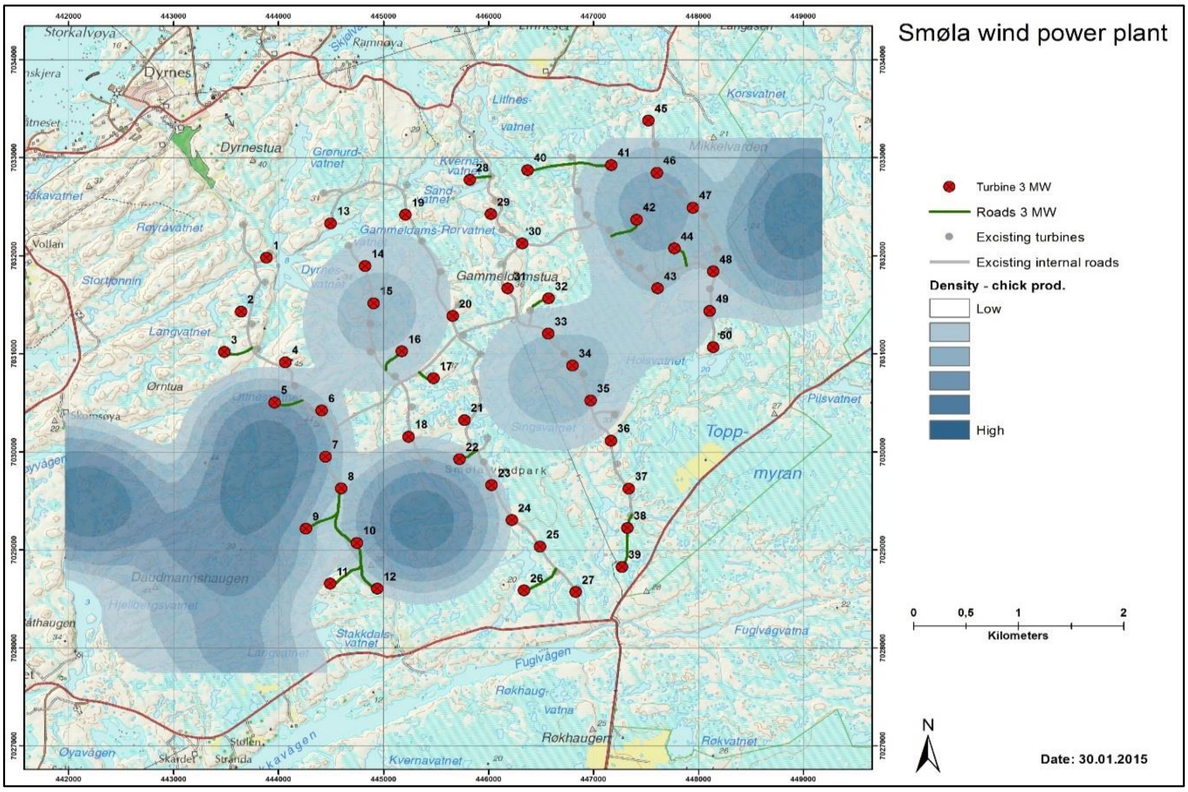
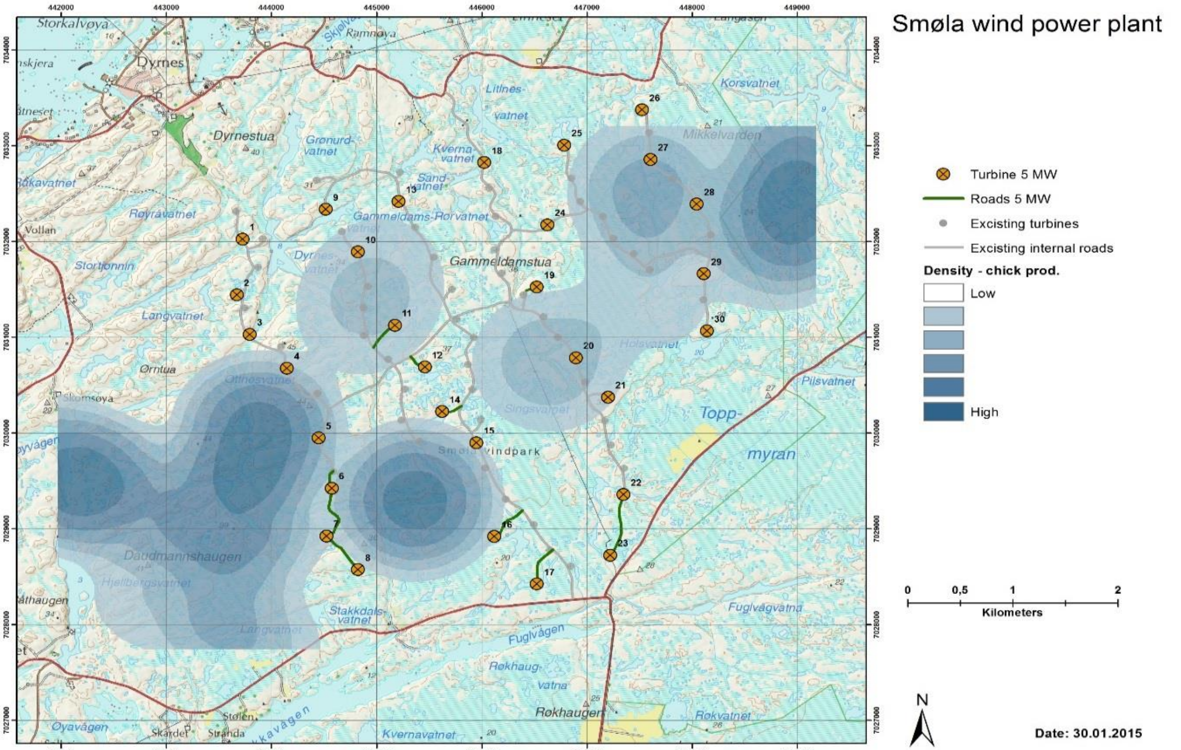


***Figure 4b.*** *Density of white-tailed eagle chick production during the last 10 breeding seasons in the vicinity of the Smøla wind-power plant (5MW layout). The darker the color the higher the chick production.*



## 3.3 Vulnerability of eagle night roosts

White-tailed eagles spend the dark part of the day at roost sites, where several individuals often roost together in a communal roost. Eagles enter and leave these roost sites during dusk and dawn and may therefore be vulnerable to collisions with turbines when entering and leaving the roost sites. Based on data from 68 satellite-tagged eagles the location of the night roost have been investigated. Most roosts identified in the Smøla wind power plant area (Figures 5a & 5b) are in trees, while some are located in small cliffs. The extent, number of individuals and number of positions recorded in the roost sites are shown in Figures 5a & 5b and 6a & 6b. The roost in the northwestern part of the wind-power plant area (close to suggested turbine 1 in both layouts) is the roost used by most eagles in the proximity of the wind-power plant area. In addition, two other roost sites were identified north of the wind-power plant area, used by five and 13 individual satellite-tagged eagles. One concentrated roost south of proposed turbine 12 in the 3MW layout and turbine 8 in the 5MW layout, have been used by 15 satellite-tagged eagles. However only 34 positions in total were recorded at this roost (Figure 6a & 6b), while up to 161 positions were recorded in the roost sites in the northwestern parts of the wind-power plant area.

***Figure 5a.*** *Number of different satellite-tagged eagles recorded at each night roost in the vicinity of the Smøla wind-power plant (3MW layout).*

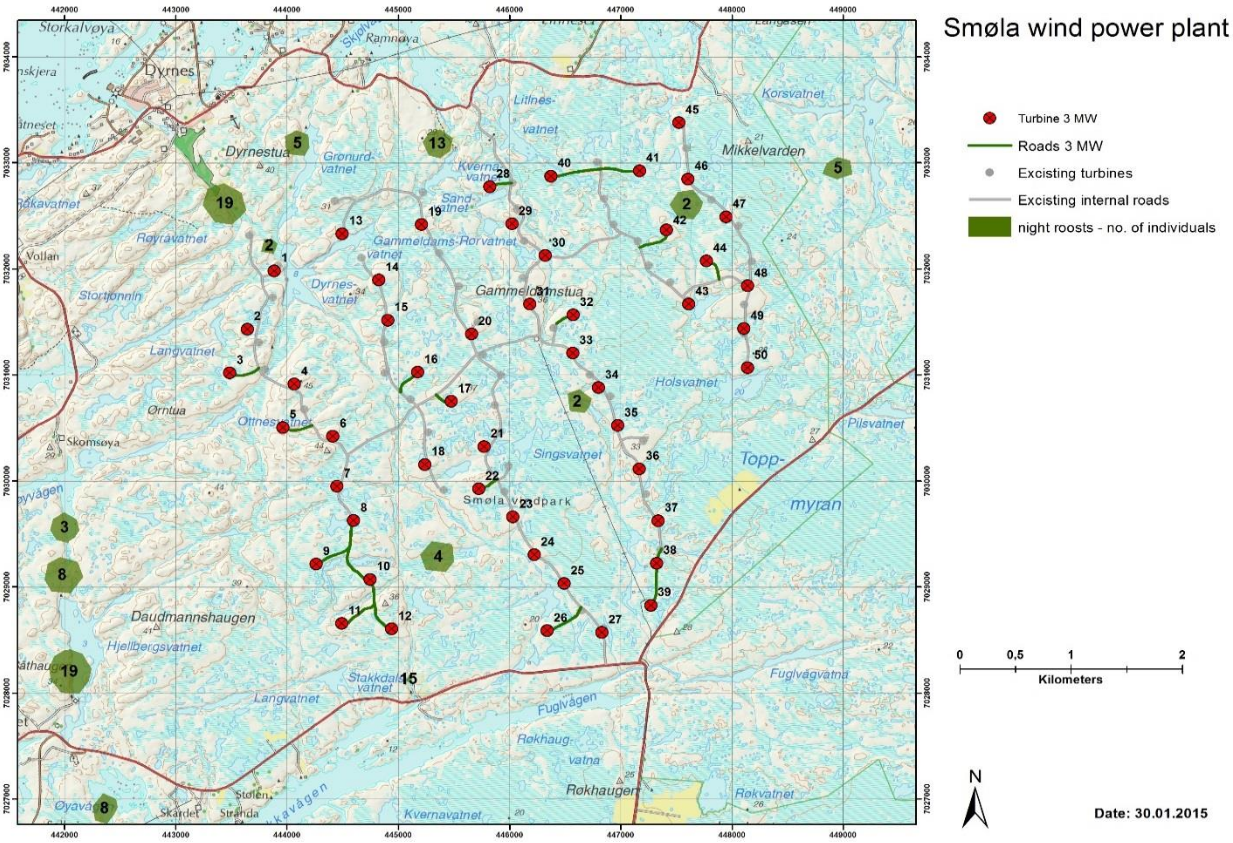
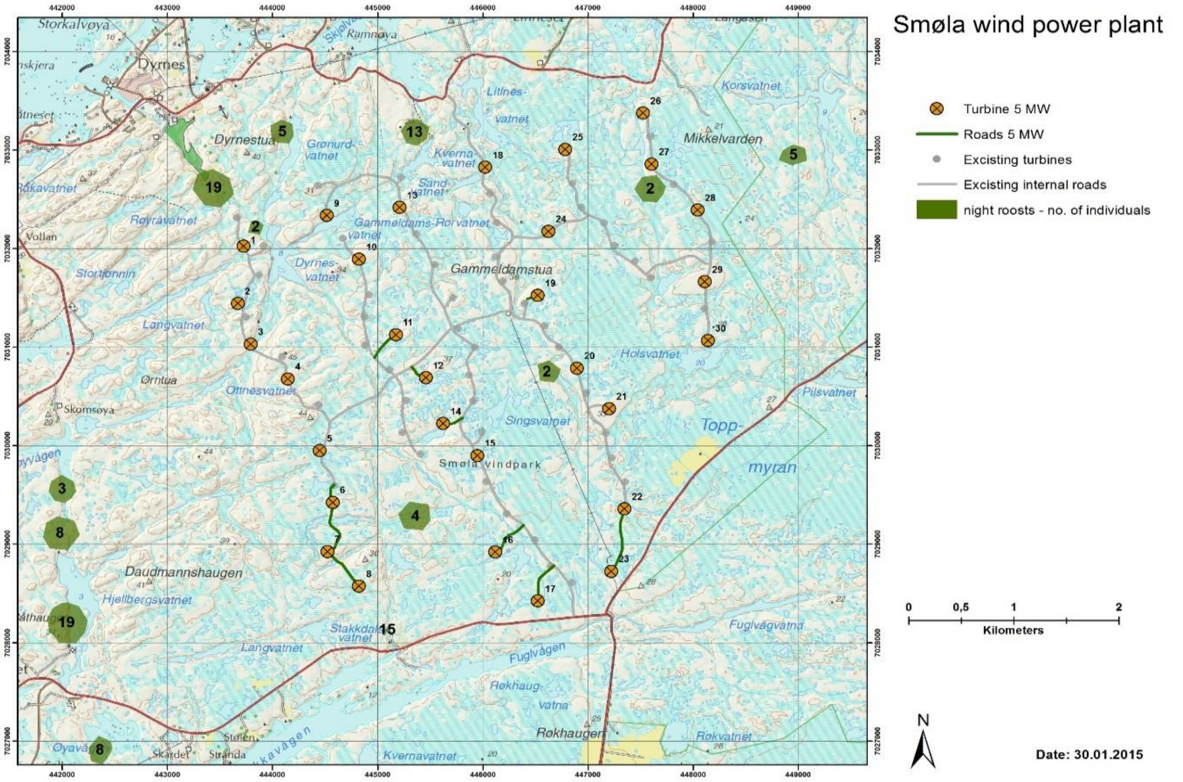


***Figure 5b.*** *Number of satellite-tagged eagles recorded at each night roost in the vicinity of the Smøla wind-power plant (5MW layout).*



Most attention should be given to Figure 5a & 5b (number of individual eagles using the roosts) as the different transmitters are programmed different and some transmitters may send only a small number of positions per day (or night), while other transmitters are recording a large number of positions per day (or night). The best representation of the intensity of use of the night roosts is therefore number of individuals. It is also important to note that the total number of birds using the roost sites are very likely to be higher than the numbers shown in Figure 5a & 5b, as this is the number of individuals carrying a satellite-transmitter. Not all eagles from the wind-power plant area are satellite-tagged; approximately 20% of the eagle chicks hatched in the Smøla archipelago during the last decade have been satellite-tagged. In addition, there are also adult birds using the communal night roosts. The actual number of birds using the roost sites is therefore likely to be much higher than the numbers given in Figure 5a & 5b; still the map may give a good indication of the relative importance of the different night roosts. The roost in the northwestern corner of the wind-power plant (Dyrnesdalen) is among the most widely used roost sites in the Smøla archipelago.

Attention should be given to the northern part of the wind-power plant as well as the southwestern corner as these have the most important roost sites. Under the current proposed wind-power plant layouts, turbines in the northern parts of the wind-power plant will have greater distance to the roosts compared to the current wind-power plant layout. Some turbines in the southwestern part of the proposed layouts will be located closer to roosts compared to the same area in the current wind-power plant.

***Figure 6a.*** *Number of positions from the satellite-tagged eagles recorded each night roost in the vicinity of the Smøla wind-power plant (3MW layout).*

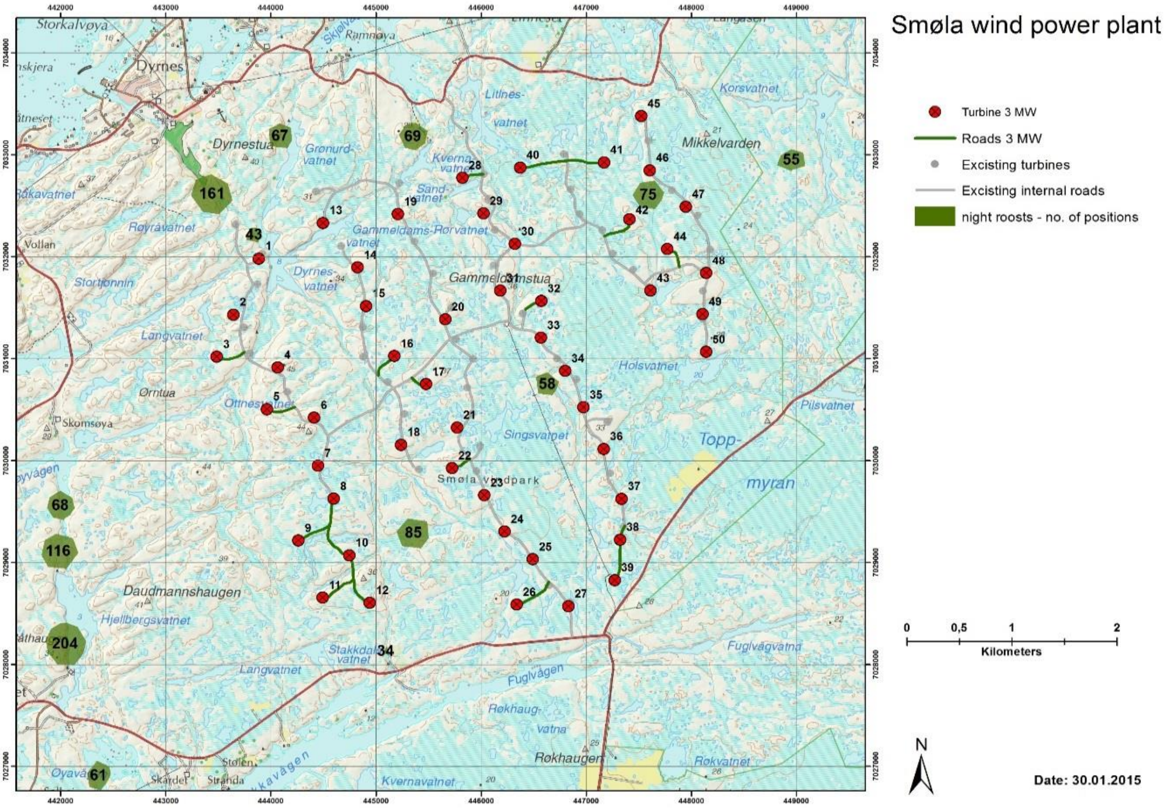
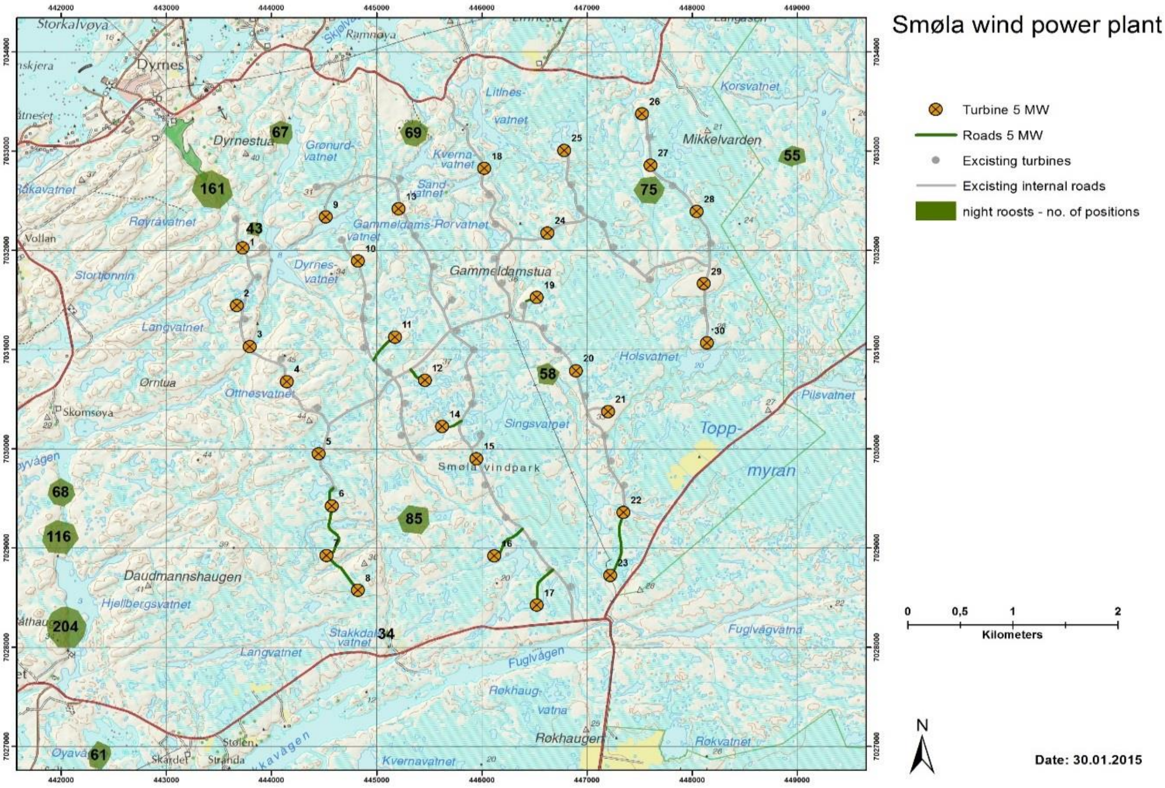


***Figure 6b.*** *Number of positions from the satellite-tagged eagles recorded each night roost in the vicinity of the Smøla wind-power plant (5MW layout).*



## 3.4 Flight activity and collision risk modelling for white-tailed eagle

The collision risk modelling is based on the flight activity level data delivered by the satellite-tagged eagles. The satellite-transmitters also deliver data on flight height, and results shows that flight activity is concentrated to low altitudes (Figure 7). This means that using larger turbines will most likely reduce the collision risk. Approximately 13 % of the flights were within the rotor-swept zone of the current turbines, and 55 % below. Larger turbines with larger ground-to-wing distance are therefore expected to reduce collision risks.

***Figure 7.*** *Flight altitudes of satellite-tagged white-tailed eagles in the Smøla archipelago. The box shows the rotor swept altitudinal band (adjusted for ground elevation) of the current turbines.*

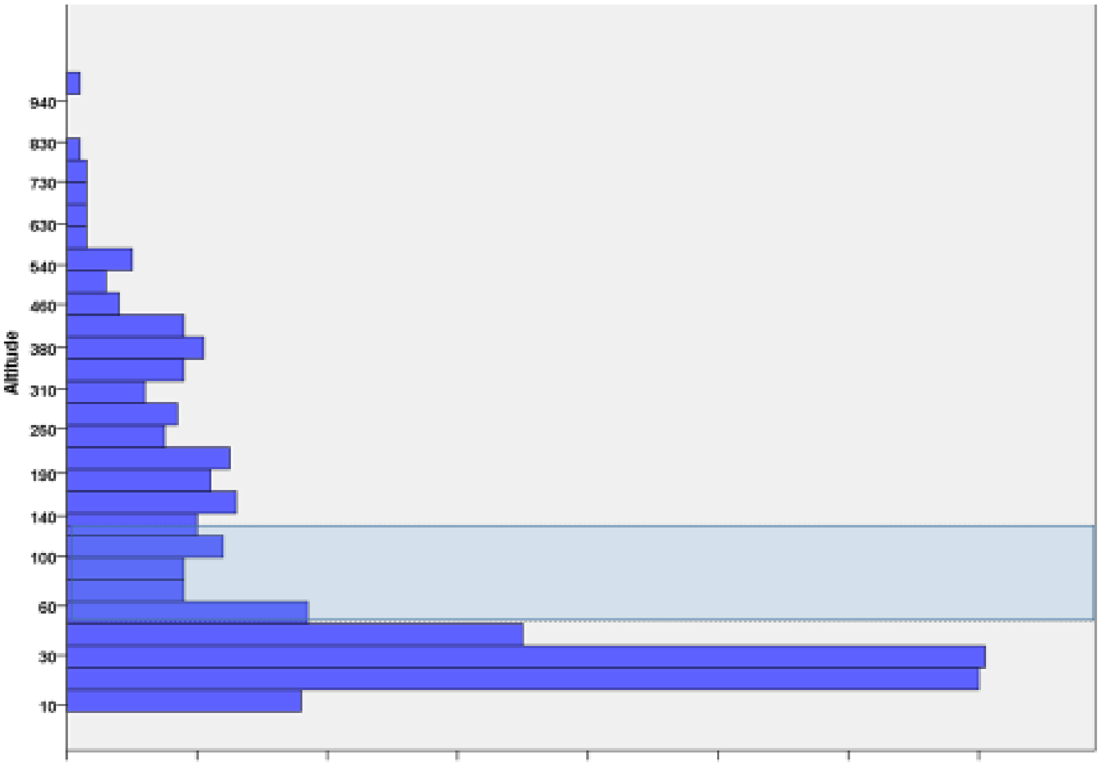


***Figure 8a.*** *Estimated flight activity at the Smøla wind-power plant (3MW layout), derived from satellite-tagged white-tailed eagles.*

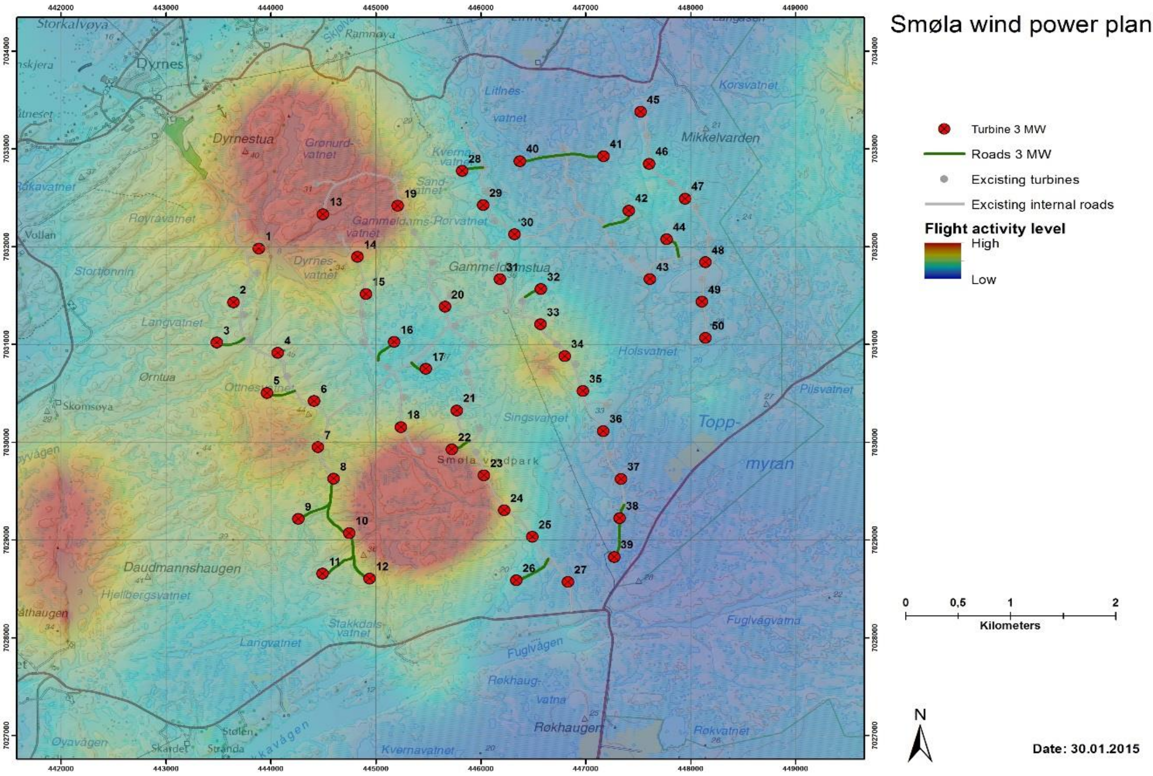
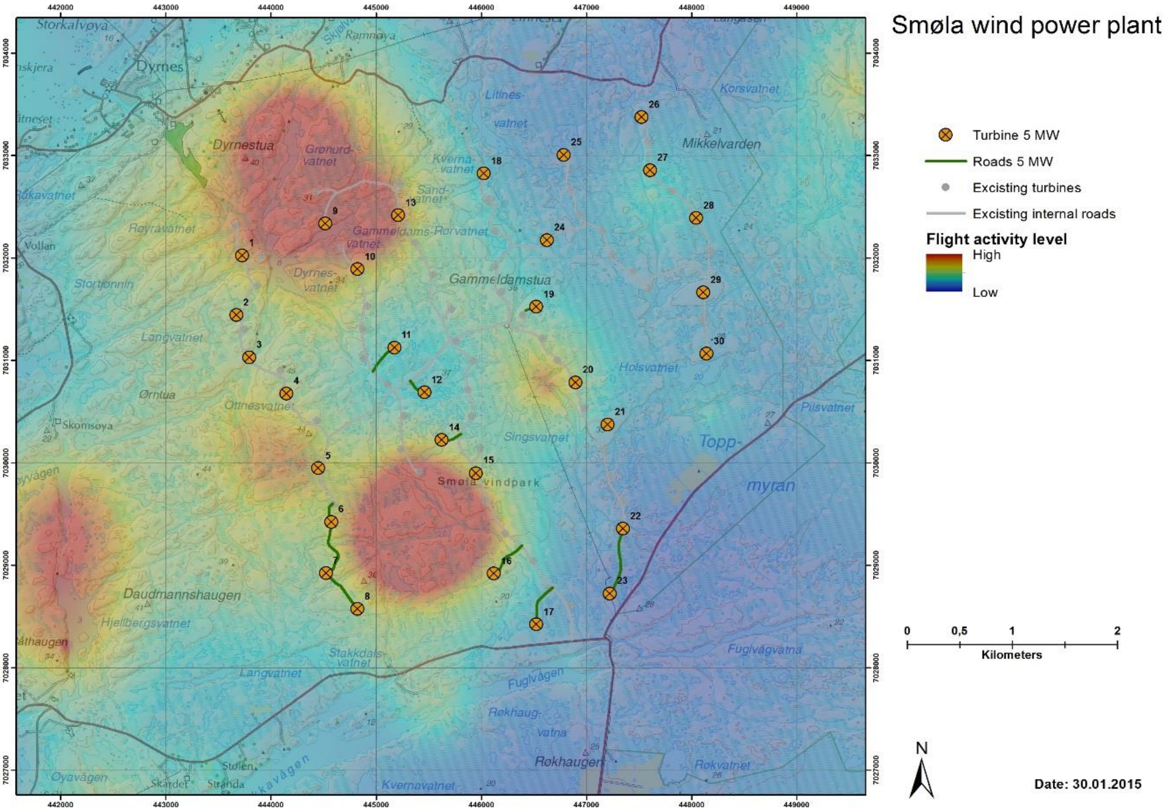


***Figure 8b.*** *Estimated flight activity at the Smøla wind-power plant (5MW layout), derived from satellite-tagged white-tailed eagles.*



Based on data from 42 satellite-tagged white-tailed eagles flight activity levels and collision risk have been analyzed. Turbine-specific flight activity per hour per km$^2$ are shown in Figures 8a & 8b and these data are the fundament for the collision risk modelling shown in Figures 9a, b and c and Table 3. In the proposed 3MW layout (50 turbines) turbines 13, 19 and 22 are the three most risky turbines, in the 5MW layout (30 turbines) turbines 9, 13 and 1 are the three most risky turbines. For a full list of the 10 most risky turbines in both proposed layouts as well as for the existing wind-power plant see Table 4. This list should be used when prioritizing turbines to be excluded or relocated if the layout of the proposed wind-power plant is to be changed.

***Figure 9a.*** *Calculated flight activity levels for white-tailed eagles for the individual turbines in the proposed 3MW (50-turbine) repowered layout for Smøla wind-power plant. Values calculated based on satellite-tagged individuals.*

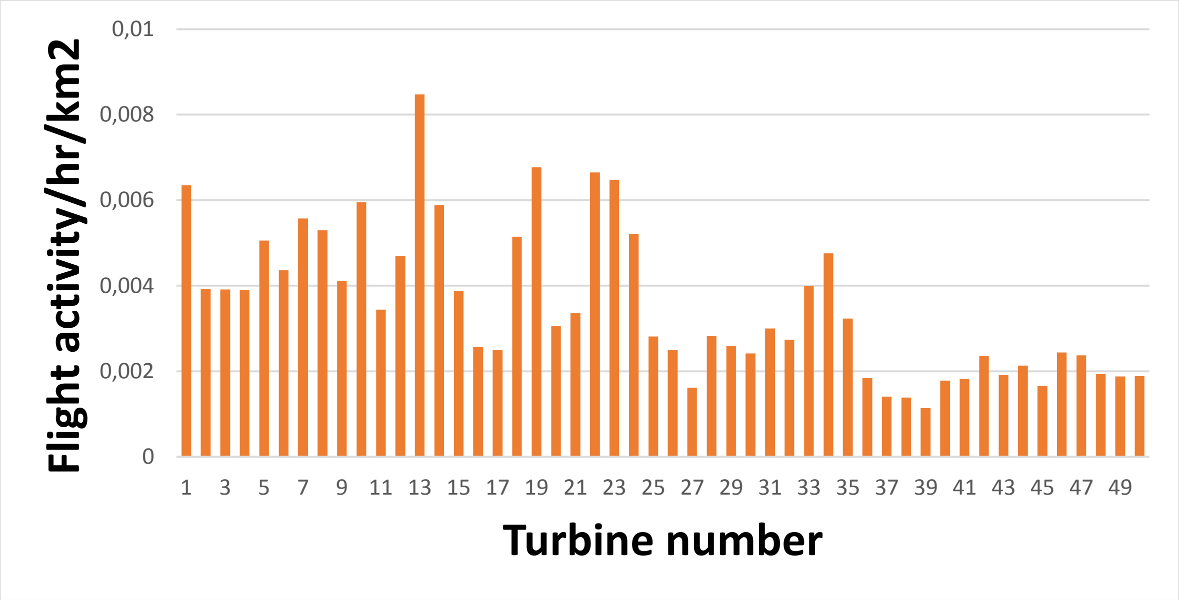
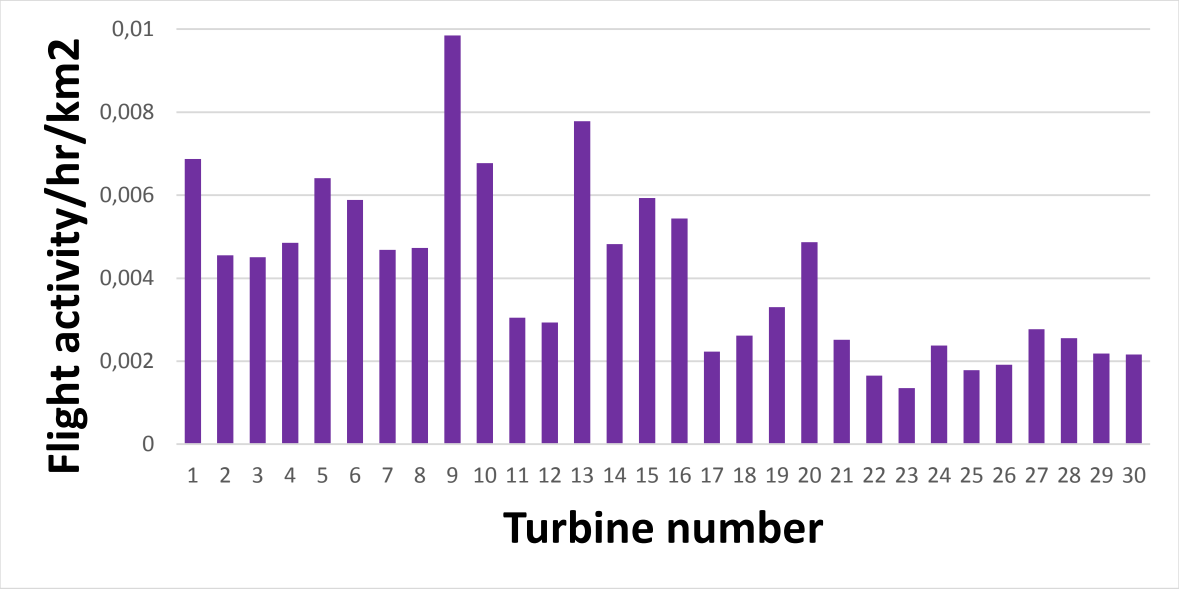


***Figure 9b.*** *Calculated flight activity levels for white-tailed eagles for the individual turbines in the proposed 5MW (30-turbine) repowered layout for Smøla wind-power plant. Values calculated based on satellite-tagged individuals.*



Even though the modelled collision risk are shown here as number of killed eagles per turbine (Figures 10a, 10b & 10c, Table 3), the results should be interpreted as risk relative to other turbines within the layout and relative to turbines in the other layouts. From Figure 10a it is clear that there are more high-risk turbines in the existing wind-power plant compared to the proposed 50-turbine layout (Figure 10b) and indeed the proposed 30-turbine layout (Figure 10c). From Table 2 it can be seen that the total modelled collision risk (the total amount of eagles colliding) in the proposed 3MW (50-turbine layout) is circa. 71% of the risk in the existing 68-turbine wind-power plant. For the 5MW (30-turbine layout) the total risk is 32% of the risk in the existing wind-power plant. This reduced risk is a result of both fewer turbines as well as better-located turbines reducing the risk for each single turbine (mean risk per turbine, existing: 1.65, 3MW: 1.58 and 5MW: 1.18).

***Figure 10a.*** *Modelled collision risk for white-tailed eagles for the individual turbines in the existing Smøla wind-power plant. Risk values give number of killed eagles from the modelling, but should be seen as relative numbers and compared to the proposed layouts (Figures 10b, 10c, Table 3) rather than actual expected number of killed eagles.*

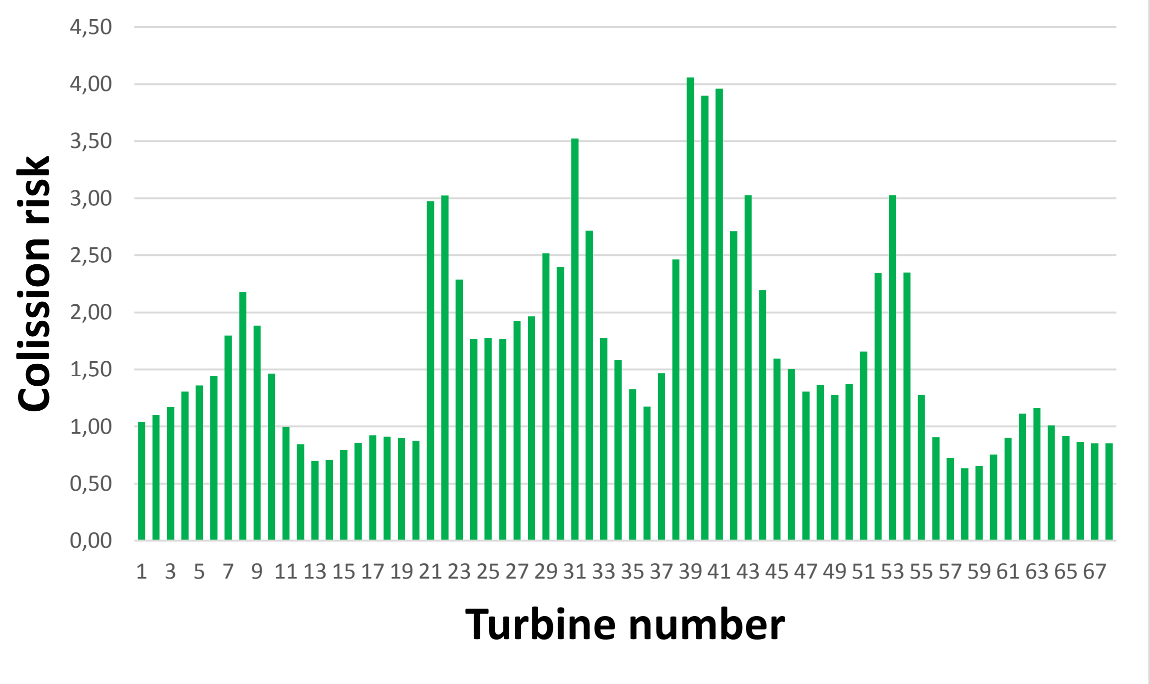


***Figure 10b:*** *Modelled collision risk for white-tailed eagles for the individual turbines in the proposed 3MW layout (50 turbines) of the Smøla wind-power plant. Risk values give number of killed eagles from the modelling, but should be seen as relative numbers and compared to the existing power plant and the 5MW layout (Figures 10a and 10c, Table 3) rather than actual expected number of killed eagles.*

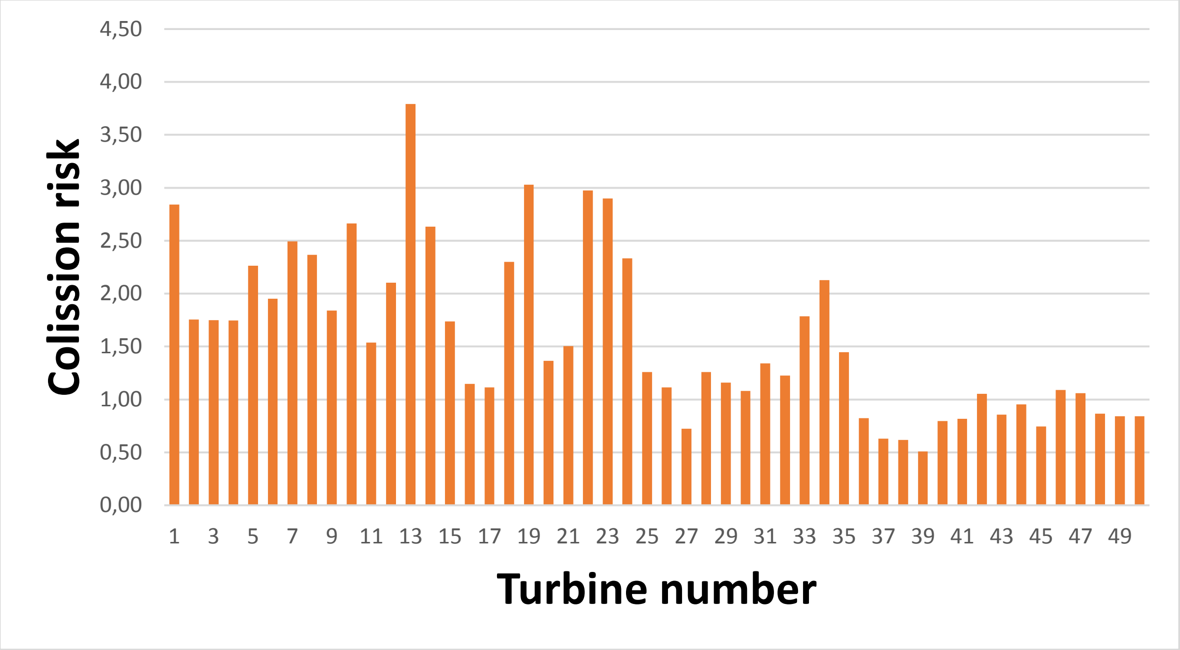


***Figure 10c.*** *Modelled collision risk for white-tailed eagles for the individual turbines in the proposed 3MW layout (50 turbines) of the Smøla wind-power plant. Risk values give number of killed eagles from the modelling, but should be seen as relative numbers and compared to the existing power plant and the 5MW layout (Figures 10a and 10b, Table 3) rather than actual expected number of killed eagles.*

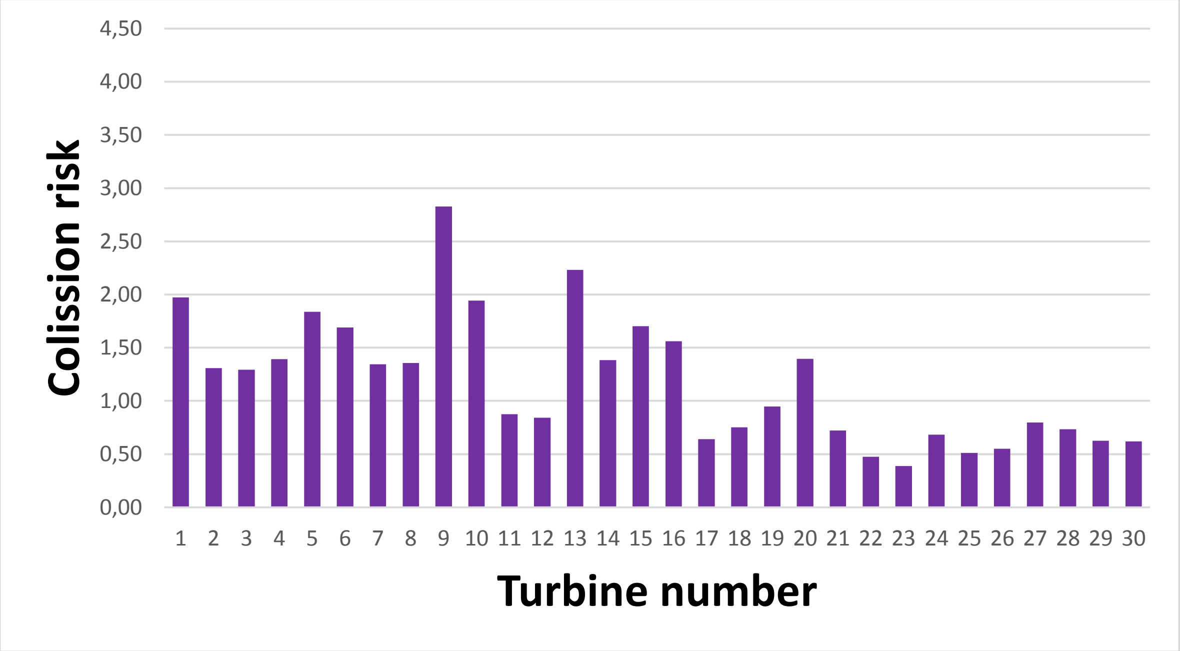


***Table 3.*** *The modeled collision risk (**relative** values summed for all turbines, mean, min and max values) in the current 68-turbine of the Smøla wind-power plant compared to the proposed re-powered 30-turbine (5 MW) and 50-turbine (3 MW) wind-power plant layouts.*

| **Modelled collision risk (CRM)** | | | |
|---|---|---|---|
| **Layout** | **Current** | **3 MW** | **5 MW** |
| *Sum* | *111.98* | *79.15* | *35.40* |
| *Mean* | *1.65* | *1.58* | *1.18* |
| *Min* | *0.63* | *0.51* | *0.39* |
| *Max* | *4.06* | *3.79* | *2.83* |

***Table 4.*** *Individual turbine modelled collision risk for the 10 most risky turbines for the turbines in the current layout, the 30-turbine (5 MW) proposed layout and the 50-turbine (3MW) proposed layout of a repowered Smøla wind-power plant.*

| **Individual turbine risk - 10 most risky turbines** | | | | | |
|---|---|---|---|---|---|
| **Current layout** | | **5 MW layout** | | **3 MW layout** | |
| **Turbine ID** | **CRM** | **Turbine ID** | **CRM** | **Turbine ID** | **CRM** |
| *39* | *4.06* | *9* | *2.83* | *13* | *3.79* |
| *41* | *3.96* | *13* | *2.23* | *19* | *3.03* |
| *40* | *3.90* | *1* | *1.97* | *22* | *2.97* |
| *31* | *3.52* | *10* | *1.94* | *23* | *2.90* |
| *53* | *3.03* | *5* | *1.84* | *1* | *2.84* |
| *43* | *3.03* | *15* | *1.70* | *10* | *2.66* |
| *22* | *3.02* | *6* | *1.69* | *14* | *2.63* |
| *21* | *2.97* | *16* | *1.56* | *7* | *2.49* |
| *32* | *2.72* | *20* | *1.40* | *8* | *2.37* |
| *42* | *2.71* | *4* | *1.39* | *24* | *2.33* |

## 3.5 Summed risk map for the white-tailed eagle

As an attempt to sum up the different vulnerabilities (nest sites and reproduction, use of night roosts, and flight activity and collision risk) a summed sensitivity map was developed. As this is a combination of several very different vulnerabilities, these maps (Figure 10a and 10b) should be seen as maps showing the sensitivity of areas relative to other areas on the map. Still, the summed sensitivity maps give guidance for the detailed planning of the wind-power plant. As seen in Figures 10a and 10b, the areas in the outskirts of the proposed layouts are the most sensitive areas. In addition, there are a sensitive area in southwest.

***Figure 10a.*** *White-tailed eagle relative sensitivity map at the Smøla wind-power plant (3MW layout) summed for the data sources: nest site, chick production, flight activity and collision risk. The more red the color the higher relative sensitivity compared to lighter areas in the map.*

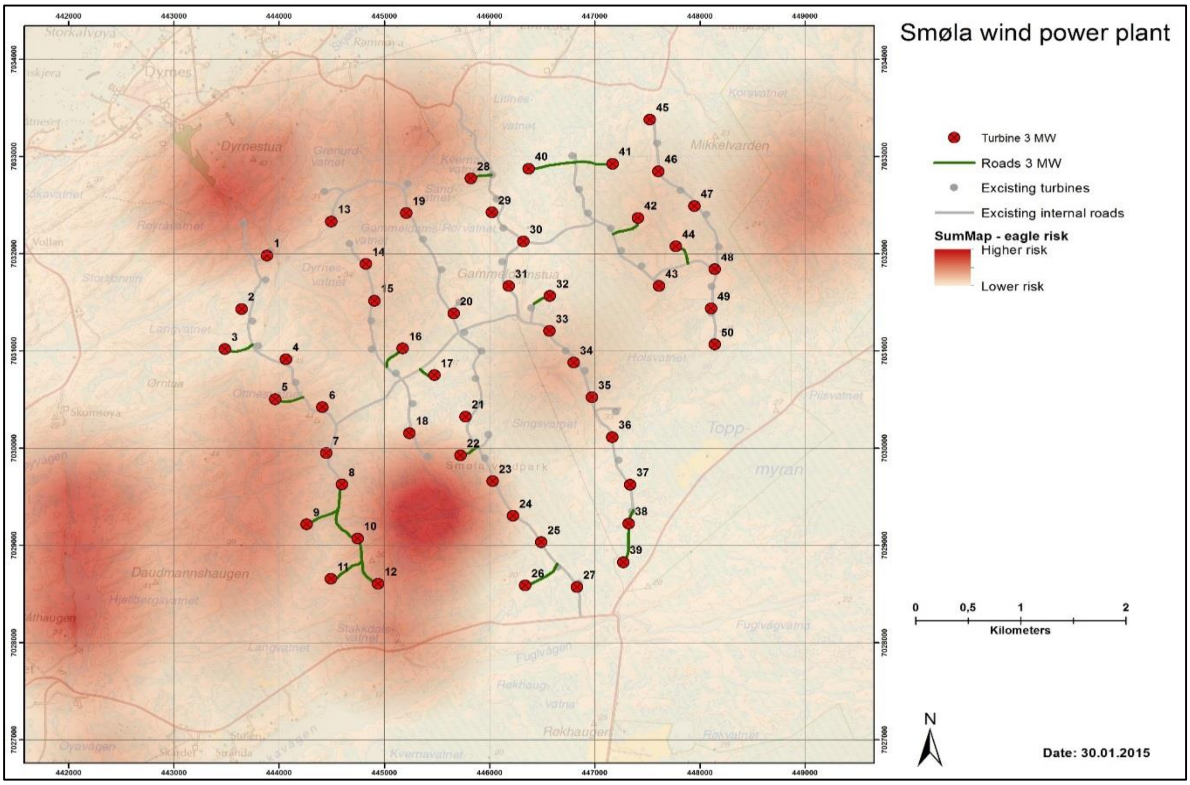
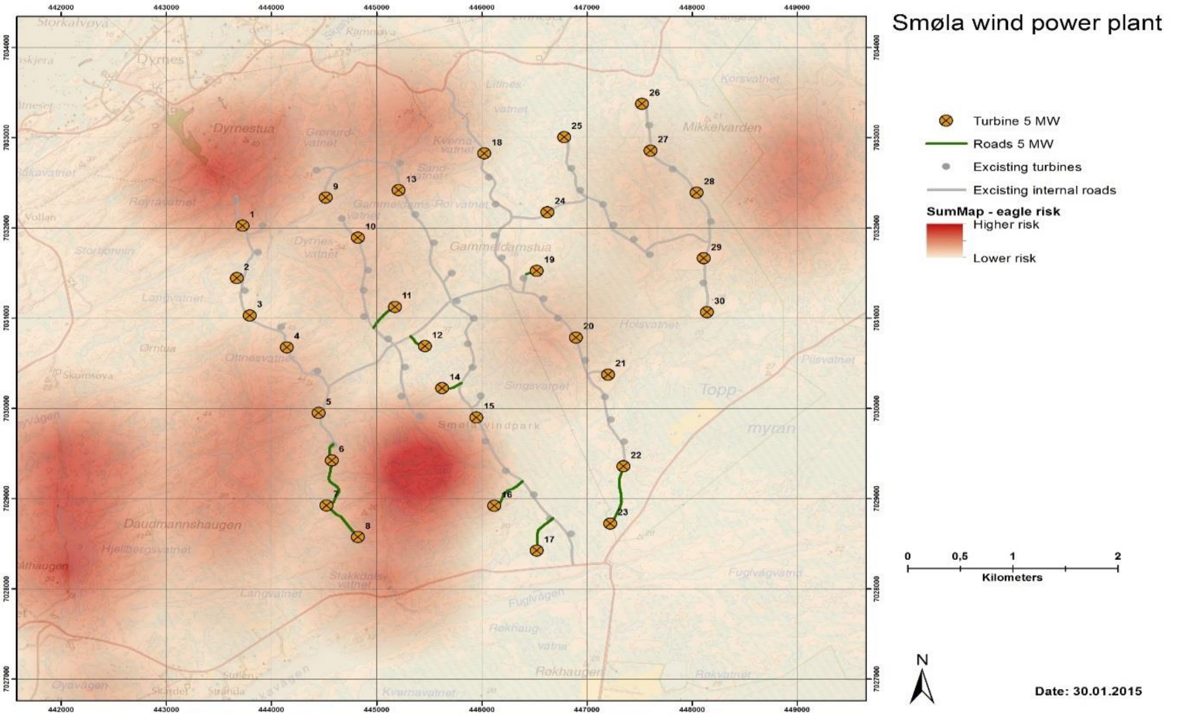


***Figure 10b.*** *White-tailed eagle relative sensitivity map at the Smøla wind-power plant (5MW layout) summed for the data sources: nest site, chick production, flight activity and collision risk. The more red the color the higher relative sensitivity compared to lighter areas in the map.*



## 3.6 Radar data analysis of bird flight in Smøla wind power plant

In total a dataset of circa 790,000 bird tracks in the area covered by the vertical radar were used (period: 21.06.2013 – 05.08.2014). Each track could represent single birds or a flock of birds. For the analysis tracks falling within 100m buffers around the turbines were included. The tracks have not been sorted according to species, so the data represent bird activity in general. See Bevanger et al. (2010) for more detailed description of the data sampled by bird radar in Smøla wind-power plant.

***Figure 11a.*** *Heatmap showing the track intensity in the existing Smøla wind-power plant. The darker the color the higher intensity of bird tracks.*

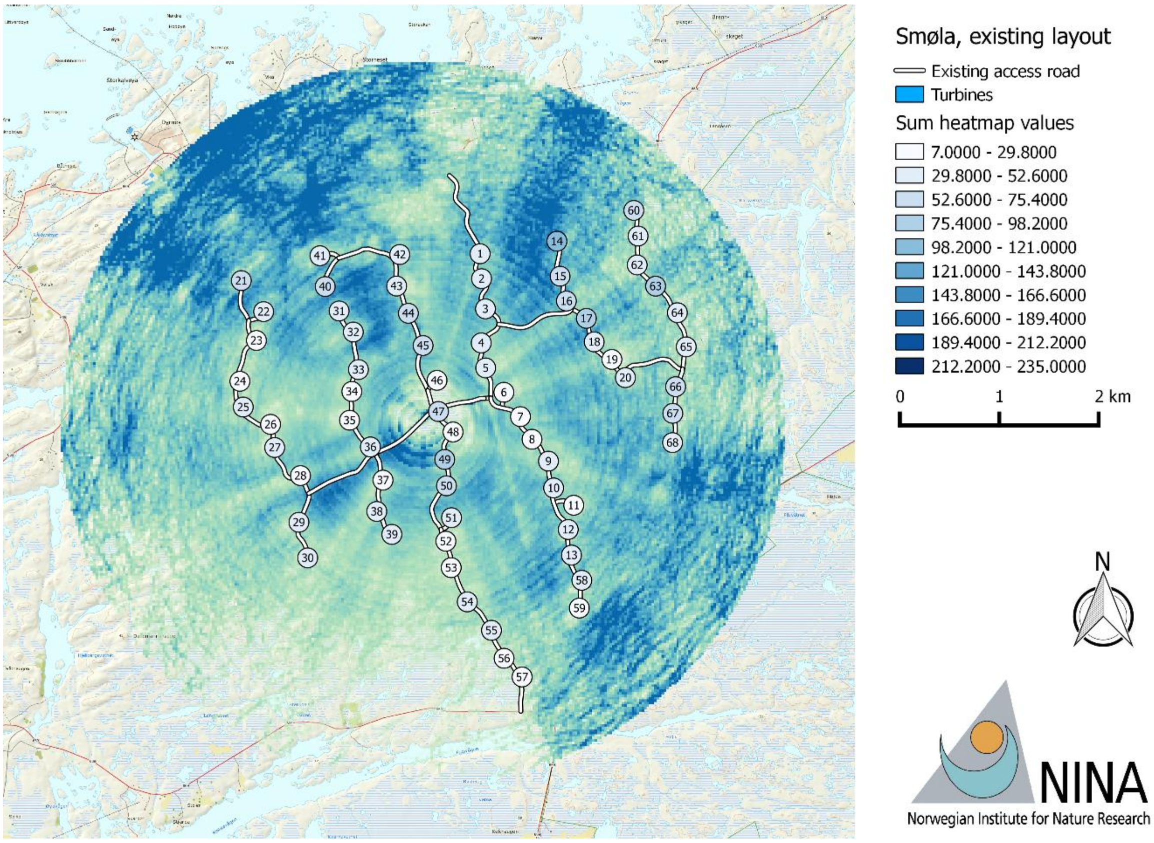


***Figure 11b.*** *Heatmap showing the track intensity in the in the proposed Smøla wind-power plant with 3MW turbines. The darker the color the higher intensity of bird tracks.*

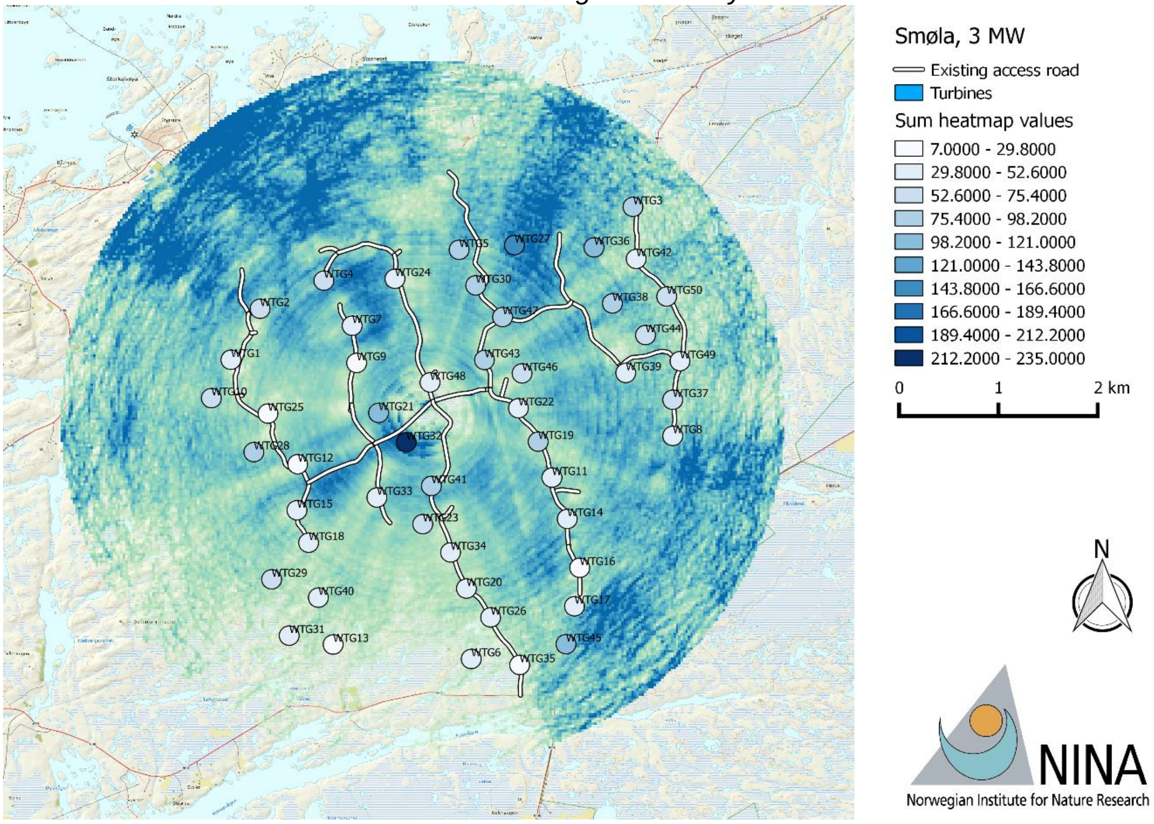
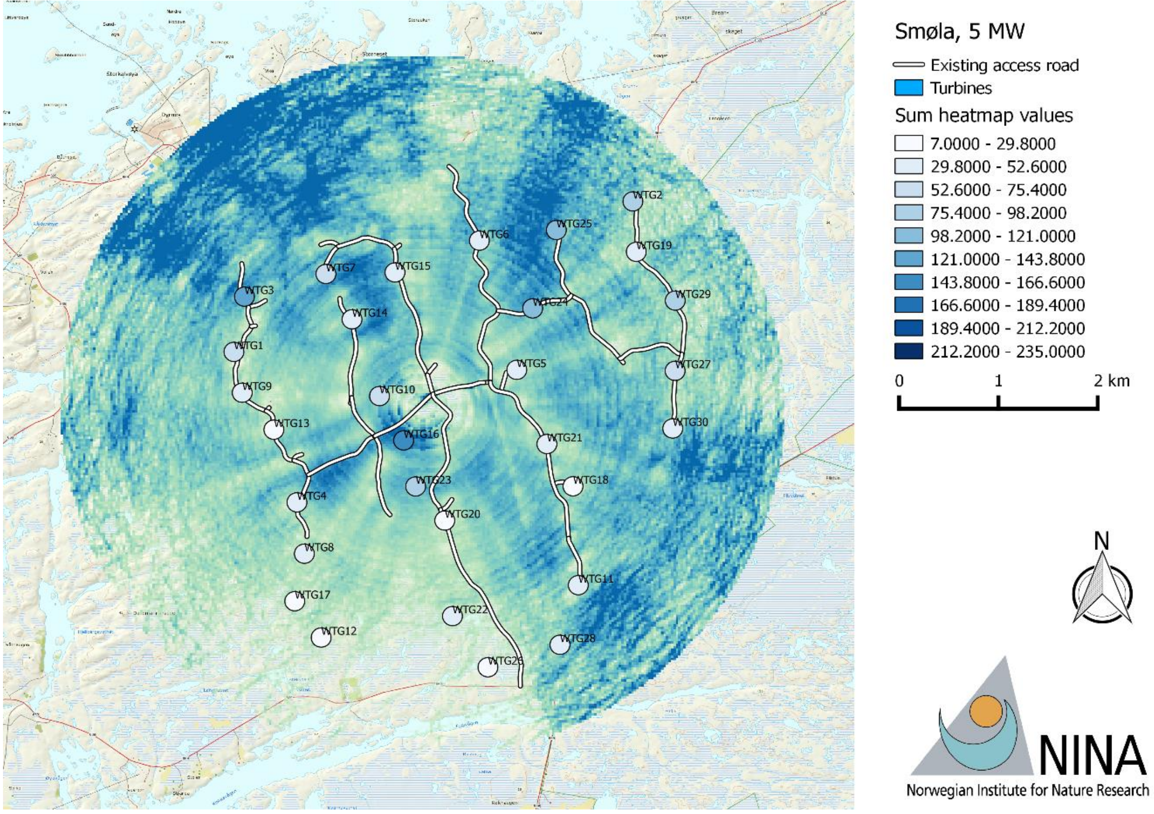


***Figure 11c.*** *Heatmap showing the track intensity in the in the proposed Smøla wind-power plant with 5MW turbines. The darker the color the higher intensity of bird tracks.*



Because the existing turbines create shadowing effects to the radar beam, track intensity around the existing turbines are most likely underestimated. Thus, it is not correct to compare the track intensity in the current wind-power plant with the proposed layouts. However, comparing the intensity in 100m buffers around the proposed turbine locations in the two repowered layouts is possible. The summed heatmap values of all turbine locations in the 5MW layouts has 55% of the track intensity compared to the 3MW layout (Table 5), while the 5MW layout has less turbines compared to the 3MW layout (30 versus 50 turbines, respectively). The reduced total track intensity in conflict with the 5MW layout is therefore gained from the reduced number of turbines. Also the per-turbine track intensity is lower in the 5MW layout compared to the 3MW layout (54.6 and 59.4, respectively).

***Table 5.*** *Heat map values from the radar data analysis for each turbine in the current Smøla wind-power plant and the proposed 5MW and 3MW layout. Larger values indicate higher bird flight activity in a 100m buffer around the turbine.*

| ***Turbine ID*** | **Sum heatmap value**<br>**Existing** | **3MW layout** | **5MW layout** |
|---|---|---|---|
| ***1*** | 46 | 69 | 142 |
| ***2*** | 48 | 49 | 56 |
| ***3*** | 49 | 53 | 40 |
| ***4*** | 35 | 22 | 27 |
| ***5*** | 36 | 82 | 34 |
| ***6*** | 24 | 25 | 52 |
| ***7*** | 25 | 34 | 19 |
| ***8*** | 29 | 38 | 25 |
| ***9*** | 43 | 67 | 59 |
| ***10*** | 31 | 33 | 34 |
| ***11*** | 24 | 30 | 59 |
| ***12*** | 46 | 7 | 153 |
| ***13*** | 49 | 59 | 36 |
| ***14*** | 106 | 34 | 91 |
| ***15*** | 73 | 26 | 21 |
| ***16*** | 59 | 110 | 35 |
| ***17*** | 86 | 235 | 28 |
| ***18*** | 45 | 39 | 36 |
| ***19*** | 20 | 36 | 35 |
| ***20*** | 43 | 42 | 41 |
| ***21*** | 75 | 91 | 24 |
| ***22*** | 40 | 61 | 32 |
| ***23*** | 27 | 31 | 45 |
| ***24*** | 17 | 46 | 111 |
| ***25*** | 40 | 31 | 106 |
| ***26*** | 29 | 33 | 76 |
| ***27*** | 31 | 11 | 40 |
| ***28*** | 27 | 98 | 85 |
| ***29*** | 34 | 92 | 53 |
| ***30*** | 39 | 96 | 44 |

| ***Turbine ID*** | **Sum heatmap value**<br>**Existing** | **3MW layout** | **5MW layout** |
|---|---|---|---|
| ***31*** | 43 | 80 | |
| ***32*** | 34 | 58 | |
| ***33*** | 33 | 45 | |
| ***34*** | 27 | 78 | |
| ***35*** | 22 | 31 | |
| ***36*** | 35 | 46 | |
| ***37*** | 26 | 18 | |
| ***38*** | 38 | 37 | |
| ***39*** | 45 | 102 | |
| ***40*** | 59 | 154 | |
| ***41*** | 34 | 114 | |
| ***42*** | 49 | 81 | |
| ***43*** | 36 | 49 | |
| ***44*** | 59 | 57 | |
| ***45*** | 70 | 76 | |
| ***46*** | 23 | 40 | |
| ***47*** | 56 | 66 | |
| ***48*** | 23 | 49 | |
| ***49*** | 88 | 63 | |
| ***50*** | 57 | 44 | |
| ***51*** | 37 | | |
| ***52*** | 26 | | |
| ***53*** | 27 | | |
| ***54*** | 46 | | |
| ***55*** | 31 | | |
| ***56*** | 22 | | |
| ***57*** | 15 | | |
| ***58*** | 31 | | |
| ***59*** | 13 | | |
| ***60*** | 53 | | |
| ***61*** | 33 | | |
| ***62*** | 40 | | |
| ***63*** | 86 | | |
| ***64*** | 51 | | |
| ***65*** | 34 | | |
| ***66*** | 53 | | |
| ***67*** | 63 | | |
| ***68*** | 33 | | |
| ***Sum*** | **2827** | **2968** | **1639** |

# 4 Mitigation measures

## 4.1 Adaptive management

The main purpose of this impact assessment has been to identify locations for the new turbines less sensitive to birds than the existing turbines, both with regards to collision risk and disturbance potential. However, it is not possible to construct wind-power plants that are entirely without conflicts to birds. Predictions in this report are based on a solid data foundation, rendering information on the conflict level relative to the existing Smøla wind-power plant. It is, however, not possible to predict the exact conflict level of the new, repowered wind-power plant. An entirely new design of the Smøla wind-power plant may also adjust the behavior of the birds compared to the present power plant layout. We therefore strongly recommend an adaptive management approach of the repowered wind-power plant. Included in this adaptive management approach is the ability to adapt to the spatio-temporal conflict level in the repowered wind-power plant, i.e. where, when and to what extent will there be conflicts between birds and turbines in the new wind-power plant. This allows for implementing mitigation measures at risky turbine locations and/or specific times of the year (e.g. contrast painting rotor blades, operational adjustments, video-based warning systems). The fundament of an adaptive management approach is a follow-up of parts of the research activities and monitoring carried out at the Smøla wind-power plant. We recommend in particular continued searches for collision fatalities at the new turbines for at least a five-year period after construction.

We also recommend continued population monitoring of the white-tailed eagle population at Smøla following the established methods for population monitoring. This includes visiting every territory once every year to record territorial activity including collection of DNA-profiles for detailed monitoring of adult survival rates and origin of collision fatalities. The time-series of these data collected at Smøla is unique, and a continued DNA-monitoring will give very detailed information not possible to collect using other methods. Due to the life-history traits of the species(Dahl et al. 2012), this should also be carried out at least for a five-year period after construction of the new power plant. Another long and valuable time-series of data established at Smøla from the BirdWind and INTACT projects is satellite tagging of juvenile white-tailed eagles. We recommend that eagle chicks hatched within or in the close proximity of the wind-power plant are satellite-tagged. Data from these satellite-transmitters give detailed information on e.g. the use of night roosts and flight paths, and the data from the GPS units are the basis of collision risk modelling. A continuation of these monitoring projects will secure a knowledge-based management of the power plant, and it will make effective mitigation measures possible. Without a continued monitoring and sampling of the most crucial data, adaptive management of the wind-power plant will be difficult.

## 4.2 Implementation of new mitigation measures

There has been several mitigation measures suggested to reduce collision risk among birds, among them is increased visibility of turbines and turbine rotor blades, warning sounds and/or lights to scare birds, and shut-down or adjusted cut-in speeds of turbines and wind-power plants during periods with increased risk. So far there are few clear results to prove the efficiency of such measures (May et al. 2014; Rydell et al. 2011). The on-going INTACT project(Norge 2012) is testing mitigation measures *in situ* at the Smøla wind-power plant, including: painting of turbine blades and tower bases, ultraviolet lights, and options for selective shut-down. Final results from the INTACT project are not yet ready, but will be ready before the repowering of Smøla wind-power plant will be carried out. These findings, including possible effective mitigation measures, should be implemented during the final planning of the repowered Smøla wind-power plant. If painting of turbine rotor blades proves an effective mitigation measure this should be implemented in the repowered Smøla wind-power plant. Another part of the INTACT project is monitoring of daytime bird activity in the surroundings of two selected turbines using the DT-Bird camera system (May et al. 2012). This system has several modules: the first module is detecting and video-recording bird activity within a pre-defined distance from the turbines. The second module is activated and sends out a loud warning signal if the bird approaches the turbine within a pre-defined distance, less than the distance under module one. The third and last module includes stopping of the turbine as the bird approaches the turbine at an even closer distance than under module two, and is activated if the second module is not effective in changing the flight path of the bird. At Smøla, currently only module one is implemented, while the last two modules are only virtually operative in the DT-Bird system to give information on the amount of bird flights that would have caused module two and three to have been activated. A detailed review of the data sampled by this system, together with data from the collision fatality searches will give information on the reliability of the system. Implementation of the second and third module of DT-Bird, as well as implementation of the system on more turbines should be kept as an option under the suggested adaptive management regime of the repowered Smøla wind-power plant.

From the data sampled during searches for collisions fatalities in the BirdWind project it is established that a large proportion of the eagle collisions is taking place during a relative limited period during the spring (Bevanger et al. 2010). Further, collision risk modeling carried out on the Smøla white-tailed eagle population using visual observations and data from satellite-tagged birds further identifies the most vulnerable periods of the year as well as the most sensitive areas within the wind-power plant (May et al. 2010; May et al. 2011). The bird radar operating in the Smøla wind-power plant has recorded several of the eagle collisions. Also, several of the satellite-tagged eagles have been found as collision victims. Finally, humans have visually observed a handful of the eagle collisions that have been recorded in the Smøla wind-power plant. All of these different data sources add up to a relative good understanding of the spatio-temporal collision pattern in white-tailed eagle in the Smøla wind-power plant. Selective stopping of turbines have been successfully used as an active mitigation measure in other wind-power plants, de Lucas et al. (2012) found a 50% reduction in mortality rate in griffon vulture after implementation of a selective stopping regime, with a consequent reduction in energy production of only 0.07%. An analysis targeted at identifying high-risk conditions in the Smøla wind-power plant are expected to be relative specific. Selective stopping of turbines under conditions identified as risky should therefore be included as an option under the adaptive management regime.

Collisions may be reduced by changing the cut-in speed, possibly at specific turbines, at low wind speeds; when power output is marginal. Several studies have shown the highest activity of birds at low wind speed (Bevanger et al. 2010; de Lucas et al. 2012). For large soaring birds that use thermal updrafts, the measure may specifically reduce the risk in such situations. Such a reduction of the risk window may come at relatively low costs because energy generation at low wind speed is limited (de Lucas et al. 2012). INTACT will develop the methodology for options to adjust operation regimes to reduce collisions; including a quantification of the potential loss in power production. The generic model should be robust enough to be able to detect risky situations in time and space. Preliminary results show that aerial bird activity drops at wind speeds above 8 m/s (Barrios and Rodriguez 2004; Smallwood et al. 2009b). Hence, adjusting turbine operation regimes when winds are low and bird activity high (e.g. on sunny days in spring) will reduce collision risk considerably at relatively low production loss.

## 4.3 Restoration and compensation

Finally, we would like to underline the importance of conducting restoration when repowering the Smøla wind-power plant. Repowering allows the re-design of the wind-power plant layout within the existing footprint, thus further minimizing environmental impacts in the landscape. However, repowering also necessitates partial restoration of the wind-power plant footprint with respect to discontinued structures. The current turbine fundaments and road system that will be replaced in the repowered version of the wind-power plant should thus be restored at least to their original state, pre-construction of Smøla wind-power plant. For guidance on how to conduct sound restoration at wind-power plants see Welstead et al. (2013).

Some guidelines for wind-energy developers suggests the “avoid-mitigate-compensate” hierarchy (Langston and Pullan 2003) where ecological impact from wind-power plants should be avoided when planning new sites. If impact still occurs the next step is to do mitigation measures to reduce the conflict. The last step in the hierarchy is ecological compensation where the ecological damage is compensated through environmental compensation, aiming to restore or replace the lost resources from the ecological damage. Among the challenges when doing ecological compensation is to make a clear link between the ecological injury and the gains created through the compensation project. Scaling the compensation effort to meet the level of the injury is another challenge during compensation programs, as the lost resource (e.g. dead birds from collisions) needs to be restored at the same level as the injury (Cole 2011). There is also a lack of studies to prove the efficiency of compensation measures. However, the “avoid-mitigate-compensate” hierarchy can potentially provide effective incentives to prevent impacts from wind-power developments and, if necessary, initiate mitigation measures or compensation projects to restore lost ecological resources (Dunford et al. 2004; Zafonte and Hampton 2007).

Cole and Dahl (2013) identified electrocution prevention measures as a possible compensation project for the eagle mortality in the existing Smøla wind-power plant. This study gives detailed information on the amount of compensation that needs to take place to compensate completely for the observed mortality and at what economical cost. We recommend that compensation is included as a possible part of the adaptive management regime for the repowered Smøla wind-power plant. After careful planning and possible mitigation measures have taken place, compensation through electrocution prevention measures can be an alternative approach. For this approach to be effective and accurate, it is fundamental that the suggested research activities under the adaptive management regime is conducted. If not, it will not be possible to do accurate compensation.

# 5 Conclusion and recommendations

Both the 3MW layout and the 5MW layout are expected to give reduced negative disturbance and mortality impacts on the white-tailed eagle compared to the existing wind-power plant. This is a result of reduced collision risk, increased distances to important night roost for the eagles and less disturbance of breeding eagles. The layout with 30 5MW turbines is expected to give less combined vulnerability compared to the layout with 50 3MW turbines. The results from the analysis reveal turbine-specific information on vulnerability making it possible to prioritize exclusion of single turbines if the number of turbines in a repowered wind-power plant is between 30 and 50 turbines. In general, turbines in the western and southwestern parts of the wind-power plant should be prioritized excluded if this is a realistic scenario. Even though the data from which the assessments in the reports is based on are very solid, some uncertainty exists, and it is therefore not possible to predict the exact impacts of a repowered wind-power plant. Therefore, we recommend an adaptive management plan. Included in this adaptive management approach is the ability to adapt to the spatio-temporal conflict level in the repowered wind-power plant, i.e. where, when and to what extent will there be conflicts between birds and turbines in the new wind-power plant. This allows for implementing mitigation measures at risky turbine locations and/or specific times of the year (e.g. contrast painting rotor blades, operational adjustments, video-based warning systems).

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ISSN: 1504-3312
ISBN: 978-82-426-2757-5

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