www.nina.no

NINA Report 910

Evaluation of the DTBird video-system at the Smøla wind-power plant

Detection capabilities for capturing near-turbine avian behaviour

Roel May
Øyvind Hamre
Roald Vang
Torgeir Nygård

NINA
Norwegian Institute for Nature Research

Cooperation and expertise for a sustainable future

NINA Publications

NINA Report (NINA Rapport)
This is a electronic series beginning in 2005, which replaces the earlier series NINA commissioned reports and NINA project reports. This will be NINA's usual form of reporting completed research, monitoring or review work to clients. In addition, the series will include much of the institute's other reporting, for example from seminars and conferences, results of internal research and review work and literature studies, etc. NINA report may also be issued in a second language where appropriate.

NINA Special Report (NINA Temahefte)
As the name suggests, special reports deal with special subjects. Special reports are produced as required and the series ranges widely: from systematic identification keys to information on important problem areas in society. NINA special reports are usually given a popular scientific form with more weight on illustrations than a NINA report.

NINA Factsheet (NINA Fakta)
Factsheets have as their goal to make NINA's research results quickly and easily accessible to the general public. The are sent to the press, civil society organisations, nature management at all levels, politicians, and other special interests. Fact sheets give a short presentation of some of our most important research themes.

Other publishing
In addition to reporting in NINA's own series, the institute's employees publish a large proportion of their scientific results in international journals, popular science books and magazines.

Evaluation of the DTBird video-system at the Smøla wind-power plant

Detection capabilities for capturing near-turbine avian behaviour

Roel May
Øyvind Hamre
Roald Vang
Torgeir Nygård

Norwegian Institute for Nature Research

May, R., Hamre, Ø., Vang, R. & Nygård, T. 2012. Evaluation of the DTBird video-system at the Smøla wind-power plant. Detection capabilities for capturing near-turbine avian behaviour. NINA Report 910. 27 pp.

Trondheim, December 2012

ISSN: 1504-3312
ISBN: 978-82-426-2514-4

AVAILABILITY
Open

PUBLICATION TYPE
Digital document (pdf)

EDITION

QUALITY CONTROLLED BY
Ole Reitan

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

CLIENT(S)/SUBSCRIBER(S)
Statkraft AS

CLIENTS/SUBSCRIBER CONTACT PERSON(S)
Bjørn Iuell

COVER PICTURE
Screenshots DTBird

KEY WORDS
Smøla wind-power plant, DTBird, video, collision risk, real-time monitoring, deterrence, warning, dissuasion, avoidance

NØKKELORD
Smøla vindpark, DTBird, video, kollisjonsrisiko, sanntids overvåking, avskrekkelse, advarsel, fraråding, unnvikelse

CONTACT DETAILS

NINA head office
Postboks 5685 Sluppen
NO-7485 Trondheim
Norway
Phone: +47 73 80 14 00
Fax: +47 73 80 14 01

NINA Oslo
Gaustadalléen 21
NO-0349 Oslo
Norway
Phone: +47 73 80 14 00
Fax: +47 73 80 14 01

NINA Tromsø
Framsenteret
NO-9296 Tromsø
Norway
Phone: +47 77 75 04 00
Fax: +47 77 75 04 01

NINA Lillehammer
Fakkelgården
NO-2624 Lillehammer
Norway
Phone: +47 73 80 14 00
Fax: +47 61 22 22 15

www.nina.no

Abstract

May, R., Hamre, Ø., Vang, R. & Nygård, T. 2012. Evaluation of the DTBird video-system at the Smøla wind-power plant. Detection capabilities for capturing near-turbine avian behaviour. NINA Report 910. 27 pp.

Collisions between birds and wind turbines can be a problem at wind-power plants both onshore and offshore, and the presence of endangered bird species or proximity to key functional bird areas can have a major impact on the choice of site or location of wind turbines. There is international consensus that one of the main challenges in the development of measures to reduce bird collisions is the lack of good methods for assessment of the efficacy of interventions. In order to be better able to assess the efficacy of mortality-reducing measures Statkraft wishes to find a system that can be operated under Norwegian conditions and that renders objective and quantitative information on collisions and near-flying birds. DTBird developed by Liquen Consultoría Ambiental S.L. is such a system, which is based on video-recording bird flights near turbines during the daylight period (light levels >200 lux). DTBird is a self-working system developed to detect flying birds and to take programmed actions (i.e. warning, dissuasion, collision registration, and turbine stop control) linked to real-time bird detection. This report evaluates how well the DTBird system is able to detect birds in the vicinity of a wind turbine, and assess to which extent it can be utilized to study near-turbine bird flight behaviour and possible deterrence. The evaluation was based on the video sequences recorded with the DTBird systems installed at turbine 21 and turbine 42 at the Smøla wind-power plant between March 2 2012 and September 30 2012, together with GPS telemetry data on white-tailed eagles and avian radar data. The average number of falsely triggered video sequences (false positive rate) was 1.2 per day, and during daytime the DTBird system recorded between 76% and 96% of all bird flights in the vicinity of the turbines. Visually estimated distances of recorded bird flights in the video sequences were in general assessed to be farther from the turbines compared to the distance settings used within the software configuration to define the moderate (warning) and high (dissuasion) collision risk area. This led to a high rate of triggered warning/dissuasion signals. The Dissuasion module of DTBird certainly is superior compared to any random activation system, however minimization of habituation necessitates that the system is only triggered by birds during the time they fly near the rotor swept zone of a turbine. Visually assessing the video sequences enables the identification of species (groups), flight behaviour and possible responses to warning/dissuasion signals. The DTBird system, enabling the monitoring of near-turbine flight behaviour in birds, presents a complementary technique to GPS telemetry and avian radar. In addition, the DTBird system may be utilized as a measure for mitigating collisions.

Roel May, Øyvind Hamre, Roald Vang & Torgeir Nygård. Norwegian Institute for Nature Research, P.O. Box 6585 Sluppen, NO-7485 Trondheim. Email: roel.may@nina.no

Sammendrag

May, R., Hamre, Ø., Vang, R. & Nygård, T. 2012. Evaluation of the DTBird video-system at the Smøla wind-power plant. Detection capabilities for capturing near-turbine avian behaviour. NINA Rapport 910. 27 s.

Kollisjoner mellom fugler og vindturbiner kan være ett problem i vindkraftverk både på land og til havs. Tilstedeværelsen av truede fuglearter samt nærhet til nøkkelarealer for fugler kan derfor ha stor betydning for lokalisering av vindturbiner. Det er internasjonal enighet om at en av hovedutfordringene ved utviklingen av tiltak for å redusere kollisjoner, er gode metoder for bedømmelse av de forskjellige tiltakene. For bedre å kunne evaluere effekten av avbøtende tiltak, ønsker Statkraft å finne et system som både fungerer under Nordiske forhold, og som gir objektive og kvantitative data om kollisjoner og nært-flygende fugler. DTBird utviklet av Liquen Consultoría Ambiental S.L. er ett slikt system. Dette systemet baserer seg på video opptak av fugleflyvninger nært vindmøllene på dagtid (lysnivå >200 lux). DTBird er en automatisert system utviklet for å oppdage flygende fugler og å ta programmerte handlinger (dvs. advarsel, fraråding, kollisjonsregistrering og turbin stopp kontroll) gjennom sanntids fuglegjenkjenning. Denne rapportens formål, er å evaluere hvor godt DTBird systemet er til å oppdage fugl i nærheten av den enkelte vindturbin, samt å vurdere i hvilken grad systemet kan benyttes til å studere fuglers adferd nær turbinene, her innbefattet effekten av avskrekkelse. Denne evalueringen er basert på videosekvenser fra vindturbinene 21 og 42 i Smøla vindkraftverk, i perioden 2. mars til 30. september 2012, sammen med GPS telemetri data fra havørn og fugleradar data. I gjennomsnitt ble videosekvenser feiltrigget (falsk positivraten) 1,2 ganger per dag, og DTBird systemet registrerte mellom 76 % og 96 % av alle fugleflukter i nærheten av turbinene. En visuell verifisering av opptakene av fugleflyvninger viser at oppdagede fugler generelt sett vurderes å være lenger unna turbinene sammenlignet med avstandene som blir brukt for å karakterisere moderat (advarsel) og høy (fraråding) risiko avstand i innstillingene til programvaren fra DTBird. Dette har ført til en stor andel advarsler og frarådings signaler. Selv om frarådingsmodulen til DTBird absolutt er overlegen i forhold til ett hvilket som helst tilfeldig aktiveringssystem, nødvendiggjør minimering av tilvenning til systemet at varslingen i systemet kun utløses av fugl som faktisk flyr i rotorsonen. Visuell vurdering av videosekvensene muliggjør identifisering av arter/artsgrupper, fluktatferd og mulige reaksjoner på varsling/fraråding signaler. DTBird systemet, som muliggjør overvåkning av fugleadferd nær vindturbiner, presenterer en utfyllende teknikk til GPS telemetri og fugleradar. I tillegg kan DTBird systemet blir brukt som et kollisjonsreduserende tiltak.

Roel May, Øyvind Hamre, Roald Vang & Torgeir Nygård. Norsk institutt for naturforskning, Postboks 6585 Sluppen, 7485 Trondheim. E-post: roel.may@nina.no

Contents

Foreword

Winter – spring 2012, two DTBird video-systems were installed at turbine 21 and turbine 42 within the Smøla wind-power plant to test their efficacy to monitor (near-)collisions and to deter birds through warning sounds. The evaluation of the DTBird video-system presented in this report was commissioned by Statkraft AS. We are grateful to the support received by personnel of Liquen Consultoría Ambiental S.L. to better understand their DTBird video-system. We are also grateful to the technical personnel at Smøla for providing power supply to the avian radar and notifying of power outages.

21.12.2012 Roel May

1 Introduction

Collisions between birds and wind turbines can be a problem at wind-power plants both onshore and offshore, and the presence of endangered bird species or proximity to key functional bird areas can have a major impact on the choice of site or location of wind turbines. Conflicts with birds can lead to demands for comprehensive pre-surveys, mitigation measures and monitoring programs. To reduce the risk of collisions, several mitigation measures have been proposed both to make the turbines more visible to birds and scaring birds away from the turbines. However, it is as yet unclear whether increased visibility will reduce the risk of collisions, and how quickly birds may habituate to measures that rely on scaring them away. A further challenge is the lack of suitable methods for evaluating the effectiveness of implemented mitigation measures. The latter is especially true in situations where there are relatively few birds being killed, e.g. on Smøla with between 2 and 11 recorded white-tailed eagle collision victims per year. The recorded number of birds killed is too small to use as the sole indicator of the impact of implemented measures within a practical timeframe.

There is international consensus that one of the main challenges in the development of measures to reduce bird collisions is the lack of good methods for assessment of the efficacy of interventions. An alternative way to go is to study the birds' behavioural response to such measures through visual observations or registrations. Manual field observations are laborious, weather-dependent and subject to biases and, thus necessitating some form of automated monitoring. In order to be better able to assess the efficacy of mortality-reducing measures Statkraft wishes to find a system that can be operated under Norwegian conditions and that renders objective and quantitative information. Such an automated system should to be able to record all collisions and near-flying birds, under virtually all conditions, and should to some degree be able to distinguish between types of birds (based on size). The monitoring system would primarily be used to detect (near-)collisions and to evaluate the effect of collision reduction measures through registration of flight behaviour. The system should be able to automatically recognize birds in flight, and filter out all other extraneous movement, such as rotor blades, vegetation, shifting clouds, passing aircrafts, etc. With a real-time detection scheme this can possibly be linked to automated systems for triggering of measures to scare away birds or the implementation of other measures. DTBird developed by Liquen Consultoría Ambiental S.L. (hereafter referred to as Liquen) is such a system, which is based on video-recording bird flights near turbines. A one-year pilot project was commenced to establish, calibrate the DTBird system and test its efficacy to fulfil the requirements set by Statkraft. The already available in-depth avifaunal knowledge at the Smøla wind-power plant, employing GPS-instrumented white-tailed eagles, on-going avian radar observations and systematic searches for dead birds, forms a good basis for comparing to the DTBird system.

In order to accomplish the requested pilot project, Liquen proposed to install the DTBird system in two wind turbines, in October 2011, and six months of operation at the Smøla wind-power plant, starting April 2012. DTBird is a self-working system developed by Liquen in order to control and reduce bird mortality in wind-power plants. DTBird system uses high definition image recognition techniques to detect flying birds in real time and takes programmed actions to reduce bird mortality: dissuasion of birds near wind turbines or wind turbine stoppage. DTBird system also controls bird collisions. DTBird has a modular design. Every module has a specific function and is connected to a shared Analysis unit. There are four modules available: Detection, Dissuasion, Stop Control and Collision Control:

- Detection module continuously monitors the surveillance area and detects flying birds in real time.
- Dissuasion module emits warning or (stronger) dissuasion signals as long as birds are detected flying in respectively moderate or high collision risk areas around the wind turbine.
- Stop Control module sends a stop signal to the wind turbine when migratory birds or birds of medium to big size, including most raptor species, are detected flying to collision risk areas.

- Collision Control module records potential collisions with wind turbine of medium to big size birds (including most raptor species).

The DTBird system as installed at the Smøla wind-power plant receives its input from two sets of visual light video cameras placed on the turbine tower; each with both a vertically and a horizontally placed camera. These cameras cover the rotor swept area upwards and the approach zone towards the turbine with a view angle of 90°. Each set also included two speakers for warning/dissuasion, placed on the turbine tower. At turbine 21 two opposite sectors were monitored with each its separate set of cameras at an azimuth of 43° and 248°. At turbine 42 the two opposite sectors had an azimuth of 169° and 333° (Fig. 1). The video input from the sensors is automatically analysed locally, and video sequences are automatically stored and uploaded to a web-based Database Analysis Platform (after June 18 2012). When an observed bird meets the distance criteria for warning/dissuasion (Table 1), the system automatically emits an audible signal. After installation the software was configured to emit a warning and dissuasion sound when white-tailed eagles were observed within the moderate/high collision risk area at respectively <150m and <75m from the turbine. The Dissuasion module was activated June 1 2012. Given their wing span (ca. 2.4 m), eagles were expected to be detected within a maximum surveillance range of circa 300m. To assess the efficacy of the DTBird system the following quantitative criteria were examined:

- Detectability, as measured by the percentage of detected birds by the total number of birds near the turbines, should be over 80%.
- The number of false positives, video sequences without birds, should be less than 2 per day.
- The percentage of falsely triggered video sequences should be less than 10%.
- The percentage of falsely triggered warnings and dissuasions should be less than 20%.

The aim of this evaluation was twofold. The first objective was to assess how well the DTBird system is able to detect birds in the vicinity of a wind turbine. This was addressed by both assessing the error rates and realized surveillance area. Error rates may be differentiated into true positives (TP: video sequences with birds), false positives (FP: video sequences without birds) and false negatives (FN: unrecorded birds near the turbines). These assessments were done by thoroughly analysing the video-database, and by comparing video-based observations with both data from GPS-equipped white-tailed eagles and avian radar bird tracks. The second objective was to assess to which extent the DTBird system can be utilized to study near-turbine bird flight behaviour and possible deterrence. This was done by analysing the information recorded by the DTBird system; such as flight duration, direction, altitude and distance, and behaviour. With regard to deterrence, the number of birds that visually responded their flight behaviour, and to which extent, as a result of the audible signals was assessed.

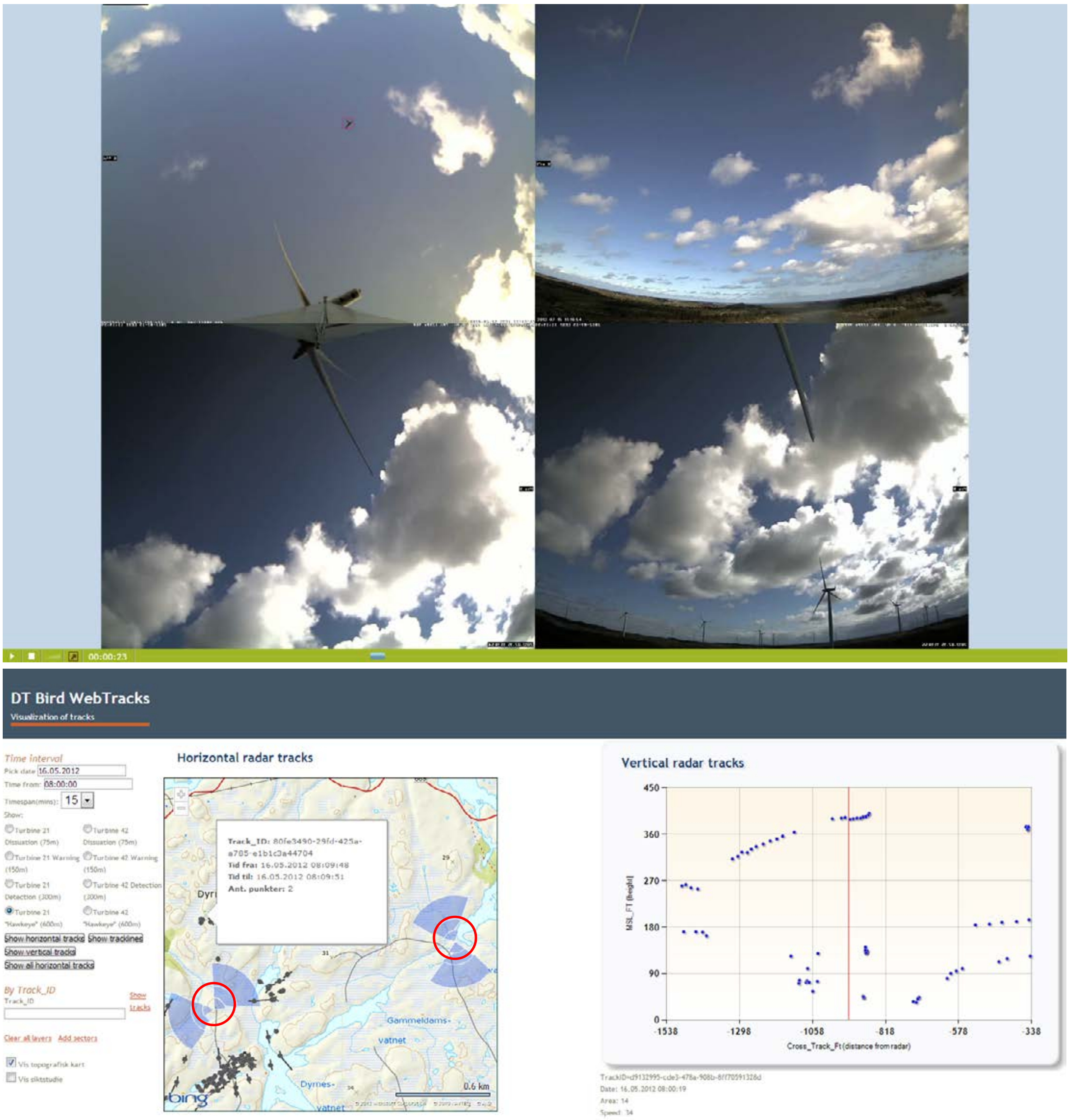
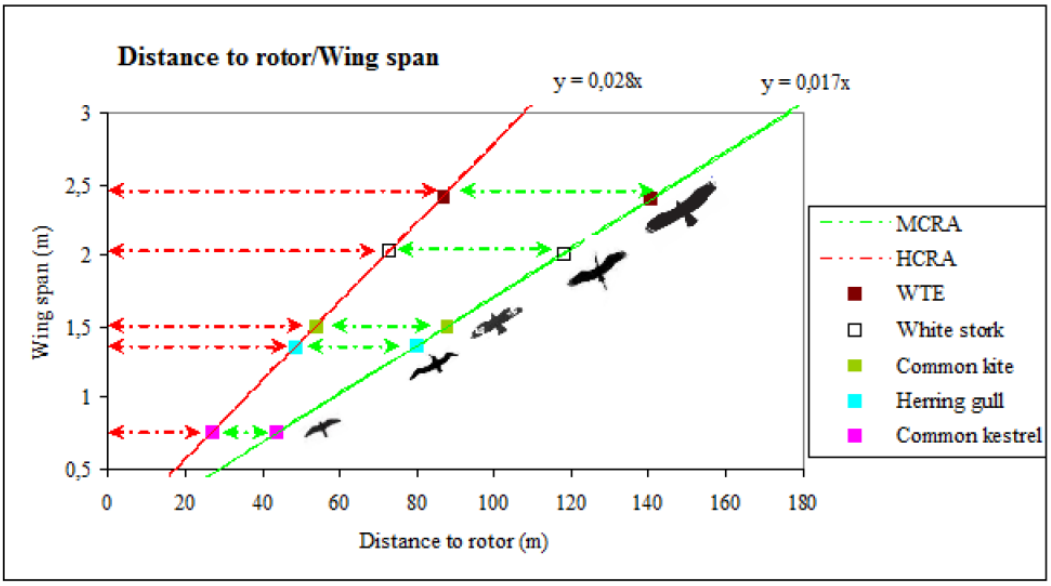


***Figure 1.** Screenshot of the composed video output from the four turbine sensors (top) and the web-based analysis tool developed by NINA (bottom) to connect DTBird video sequences to avian radar tracks. The blue sectors indicate the horizontal detection area of the DTBird visual light cameras; the red circle indicates the vertical detection area covering the rotor swept zone.*

***Table1.** Technical specifications of the DTBird system.*

Performance	
Daily service	light >200 lux[1]
Target Species	White Tailed Eagle - WTE
Target Species Maximum Detection Distance	200-300 m, depending on bird body position at the detection frame.
High collision risk area (HCRA) calculation	Area around a wind turbine between the rotor and a radius X, calculated according to the function X=Y/0,027, where X is the distance to the rotor, and Y is the wing span of the bird.
Moderate collision risk area (MCRA) calculation	Area around a wind turbine, between the high collision risk area and a radius X, calculated according to the function X=Y/0,017, where X is the distance to the rotor, and Y is the wing span of the bird.
Observations: [1] 400 lux corresponds to sunrise and sunset light on a clear day.	

Graphical example of the relation between the wing span of 5 bird species, and radius of moderate and high collision risk areas (MCRA and HCRA), producing warning and dissuasion signals, respectively.



Species (example)	Wing span (m)	HCRA radius (m)	MCRA radius (m)
WTE (Haliaeetus albicilla)	2,4	0-90	90-140
White stork (Ciconica ciconia)	2,00	0-70	70-120
Common kite (Milvus milvus)	1,50	0-55	55-90
Herring gull (Larus argentatus)	1,35	0-50	50-80
Common kestrel (Falco tinnunculus)	0,75	0-30	30-45

2 Material and methods

2.1 DTBird video-sequences

This evaluation was based on the video sequences recorded with the DTBird systems installed at turbine 21 and turbine 42 between March 2 2012 and September 30 2012 (Fig. 2). All recorded flights from June 18 2012 could be accessed through the web-based Database Analysis Platform (DAP). All data prior to this date were obtained directly from DTBird personnel and downloaded; no data was delivered during June 1-18 2012 due to the transition to DAP. For all video sequences additional information was visually assessed and registered: object type (bird, false positive (FP), false negative), species (group) and FP cause, flight duration and length, flight altitude band (below, at and over rotor swept zone (RSZ)), distance (<75m, 75-150m, 150-300m), flight direction (in 45° sectors), flight behaviour (irregular flight, circling/soaring, straight flight), warning and dissuasion (initiation and end time, duration), visible response to deterrence signals (yes/no). Thus a complete database with all recorded observations was obtained as basis for the evaluation. False positives were not saved before June 22 2012.

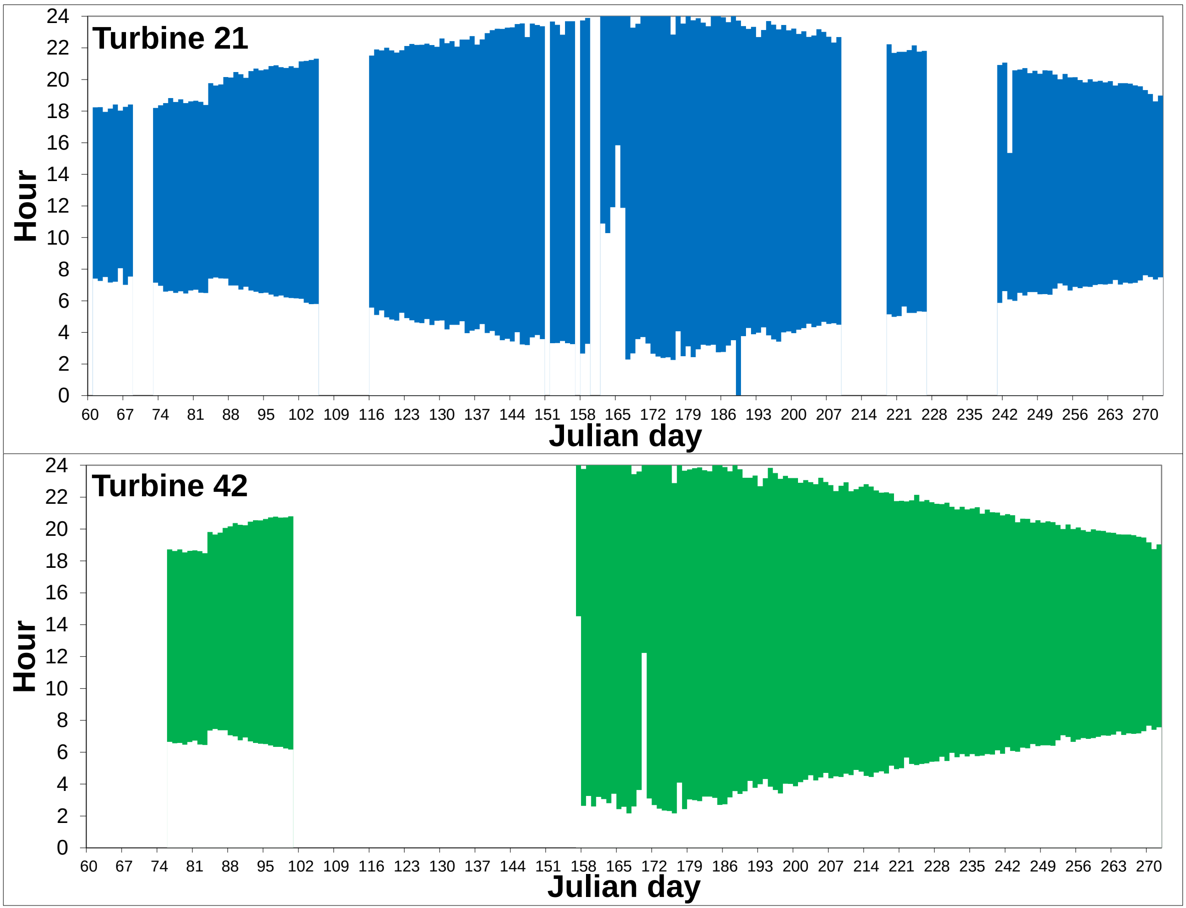


Figure 2. *Daily operation hours of DTBird at the Smøla wind-power plant installed at turbine 21 and turbine 42, between March 1 and September 30 2012 (Julian day 60 – 273). Although the system at turbine 42 was operational in May (Julian day 124 – 146), the Detection module was out of service.*

The observations from this completed database were assessed both temporally (months, time-of-day) and spatially. The distance classes followed the same classification as the original settings in the software configuration with regard to warning and dissuasion distances for white-tailed eagles (respectively 150m and 75m). Although also other species have been recorded with DTBird, this at least enables a relative assessment of observed distances. Distances were also visually assessed by one person directly from the video sequences, and thereafter compared to the set distance classes. We tested whether the observed number of video sequences within three distance (*D*: <75m, 75-150m, 150-300m) and altitude classes (*A*: below (<30m), at (30-110m) and over (110-300m) RSZ) compared to the expected number of relocations given the available surface area ($\pi \cdot D^2$) and volume ($\pi \cdot D^2 \cdot A$), respectively, using a Chi^2-test.

By analysing the raw detection data of the video sequences, obtained directly from Liquen, insight was obtained on possible responses due to the warning/dissuasion signals (here we did not distinguish between both types of signals). The raw detection data consisted of XY coordinates (measured in pixels from the image origin) and object size (measured in the number of pixels; hereafter called "Z coordinate") of detected object for each image frame (i.e. detection) of all video sequences. While X represents a proxy for the location perpendicular to the turbine, the meaning of Y and Z depend on whether a video sequence was captured with a horizontal or vertical placed camera. Z renders a proxy for respectively distance and altitude, Y provides the opposite. Those video sequences including more than one object were excluded from further analyses because it was beyond the scope of this study to develop a tracker to "connect-the-dots" into trajectories for each individual. For each detection, the relative change in heading angle from the previous detection ($H_{a,b}$) was calculated for the XY, XZ and YZ coordinate pairs (*a, b*) separately:

$$H_{a,b} = \frac{\left(1 - cos\left(\Delta atan2(\Delta b, \Delta a)\right)\right)}{2}$$

This rendered a measure ranging between zero (straight ahead) and one (reverse turn). Tortuosity (*T*) was thereafter calculated as the cube root of the product of these three measures:

$$T = \sqrt[3]{\prod H_{a,b}}$$

We employed a linear mixed-effects model, including a random grouping on sequence ID, to assess variation in tortuosity following a so-called Before-After-Control-Impact (BACI) approach. Here, "control" sequences were those which did not result in warning/dissuasion sounds (i.e. all "pre-warning"). "Impact" sequences were split into before and after warning/dissuasion initiation. For each video sequence the mean tortuosity was calculated before and after (if available) warning/dissuasion initiation.

2.2 GPS telemetry data for white-tailed eagle

As part of the BirdWind research project (Bevanger et al. 2010) over 50 individual ready-to-fledge white-tailed eagles have been captured and equipped with satellite transmitters (Nygård et al. 2010). During the period September 2003 through to October 2012, in total 57 individuals represented by 81,890 GPS relocations (max. hourly fix rate) were included in this report. Because relocations were obtained at an hourly fix rate, it was possible to obtain relocations on the ground near a turbine without data on the flight thereto. Therefore we included all relocations in the analyses to assess distance but only relocations in flight (instantaneous speed >0 m/s) for altitude. Of all relocations, 54 rendered information on their movements prior to fledging (29,094 relocations). In total 50 individuals, of the 57 individuals equipped with GPS transmitters, were followed also after fledging (52,796 relocations); some even for up to six years after capturing. These data enabled us to assess the temporal and spatial distribution of movement activity of marked white-tailed eagle individuals with regard to their vicinity of wind turbines. None of the relocations were found to be in the vicinity of turbine 21 and 42 during the period DTBird was in operation. We tested whether the observed number of relocations within three distance (*D*) and altitude (*A*) classes (<75m, 75-150m, 150-300m) compared to the expected number of relocations given the available surface area ($\pi \cdot D^2$) and volume ($\pi \cdot D^2 \cdot A$), respectively, using a Chi^2-test.

2.3 Avian radar data

NINA’s mobile avian radar system (Merlin Avian Radar System, Model XS2530e) was placed beside the maintenance road in-between turbine 21 and turbine 42 such as to obtain both horizontal and vertical radar data in the vicinity of both turbines (Fig. 3). The distance between the avian radar and turbine 21 and turbine 42 was 956m and 661m, respectively. Since April 26 2012 the radar has recorded bird activity continuously from this location. The radar system gathered data using a horizontal S-band radar and vertical (tilted) X-band radar. The radar images are automatically processed locally in real-time and detections are stored in MS Access databases, which are downloaded automatically once a day to NINA headquarters in Trondheim through a wireless broadband connection. The radar system detects and tracks birds (‘targets’) of various sizes on the horizontal plane within a circular area with a radius of 1.9km (1 nautical mile). The horizontal radar has a vertical beam width of 30°; resulting in a maximum detection altitude of 256m and 177m for turbine 21 and turbine 42 respectively. In addition flight altitudes up to 3km and a total range of 2.8km (1.5 nautical miles) were recorded within a 20° vertical beam width resulting in a detection sector of 337m and 233m at turbine 21 and turbine 42 respectively. The avian radar system was powered by the wind turbine nearest to the radar (turbine 41). The aim of operating the avian radar system next to the DTBird video-system was to obtain an independent dataset on bird movements near these two turbines which could be directly connected to each other (see also Fig. 1). This enabled both the assessment of frequency of near-turbine radar detections in space and time, as well as the comparative assessment of video versus radar observations and verification of detection distances. For the spatio-temporal assessment only radar tracks consisting of at least four plots (representing circa 12 seconds) and within 300m from either turbine were included. Connection of video sequences with birds to radar tracks also included radar tracks slightly beyond the 300m buffer to allow for possible systematic differences in distance measurement between video and radar. Connected video sequences and radar tracks enabled comparison of distances.

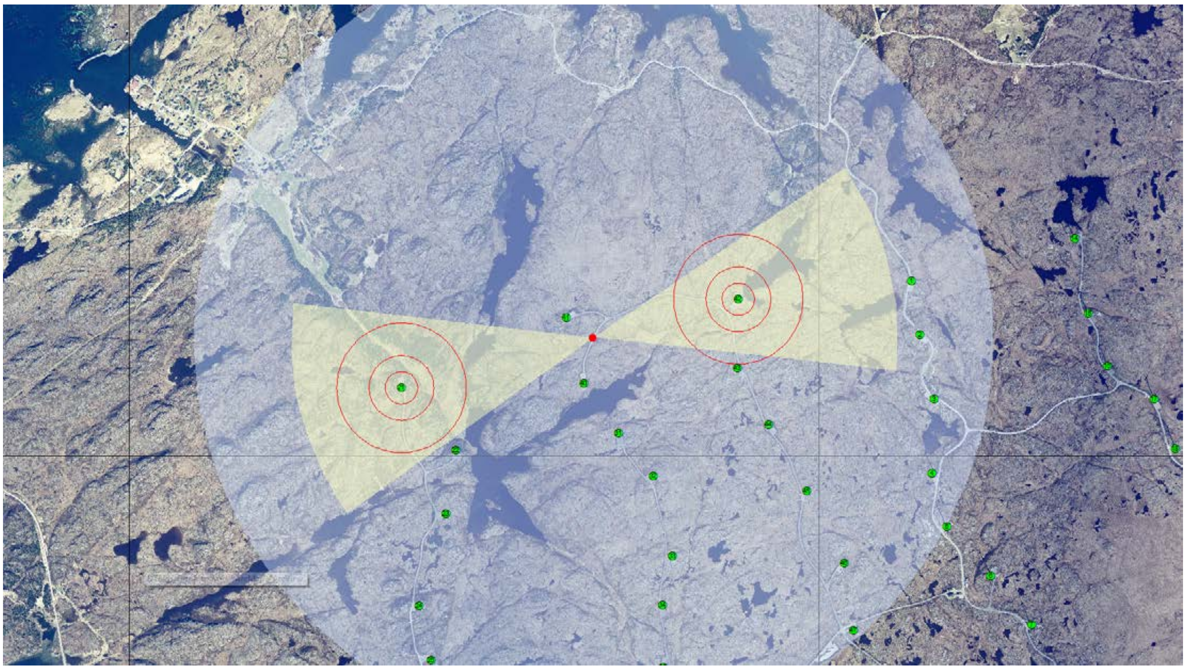


Figure 3. *Placement of the mobile avian radar system within the Smøla wind-power plant April 26 – September 30 2012. The red dot indicates the location of the radar, placed in-between the two turbines equipped with the DTBird video-systems (turbine 21 and turbine 42; respectively the left- and right-most turbine). The red circles indicate the set distances for the medium and high collision risk area (75m, 150m and 300m). The yellow segments indicate the approximate sectors covered by the vertical radar, while the blue circle indicates the surveillance area for the horizontal radar.*

3 Results

3.1 DTBird video-sequences

Between March 2 and September 30 2012, in total 711 video sequences were recorded by the DTBird system; 368 and 343 at turbine 21 and turbine 42 respectively. Of these, circa 40% were false positives (33% and 48% for turbine 21 and turbine 42 respectively) (Fig. 4 – left panel). The exceptionally high number of false positive at turbine 21 in July was the result of sky artefacts (e.g. moving clouds). At turbine 42, the higher number of false positives throughout the summer compared to turbine 21 was due to insects. The average number of recorded bird triggers varied over the year, ranging between below two and above three triggers per day (Fig. 4 – right panel). On average 1.40 (245 per 175 operating days) and 1.06 (179 per 169 operating days) bird triggers were produced at turbine 21 and turbine 42, respectively. During May no bird flights were recorded at turbine 42 because the Detection module was out of service during this month (see also Fig. 2). On average recorded bird flights lasted for 11.8 (± 1.2 S.E.) and 9.1 (± 2.5 S.E.) seconds at turbine 21 and turbine 42 respectively. Circa two-thirds of the video sequences captured single birds in flight; however numbers ranged between one and 50 birds. The DTBird system is operative when enough light is available (light levels >200 lux); in this case on average between 04:00 and 22:00. Most bird activity was observed between 11:00 and 18:00 (Fig. 5 – left panel). The observed direction of observed birds largely follows the orientation of the monitored sectors at the two turbines (Fig. 5 – right panel).

When excluding three events of malfunctioning video cameras rendering long-lasting video sequences, the total summed duration of all video sequences was 5,755 seconds and 3,039 seconds at turbine 21 and turbine 42, respectively. Circa half of this represented bird flights (2,888 seconds and 1,631 seconds at turbine 21 and turbine 42 respectively). Only from June 22 2012 information was stored on false positives. At turbine 42 insects posed a problem, while maintenance at turbine 21 created a fair number of false positives (Fig. 6). The difference in orientation between turbine 21 (generally north-south) and turbine 42 (generally east-west) might well explain the occurrence of false positives due to sky artefacts (stronger contrast of clouds due to the sun) and rain drops (inclement weather coming from the west). On average 1.56 (122 FP over 78 operating days) and 1.61 (161 FP over 100 operating days) false positives were generated per day at turbine 21 and turbine 42 respectively. When excluding false positives due to maintenance, one average 1.19 (93 FP over 78 operating days) and 1.52 (152 FP over 100 operating days) false positives were generated per day at turbine 21 and turbine 42 respectively. The higher FP/day at turbine 42 compared to turbine 21 was due to more frequent occurrence of false positives in June (3.67 FP/day), prior to fine-tuning.

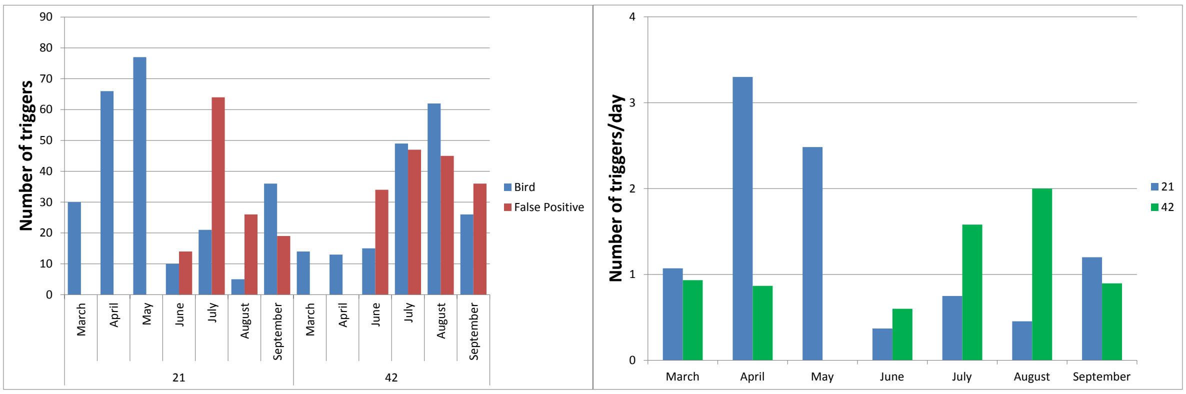


Figure 4. *Total number of monthly triggered video sequences (left panel) and average number of daily bird triggers (right panel) of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42.*

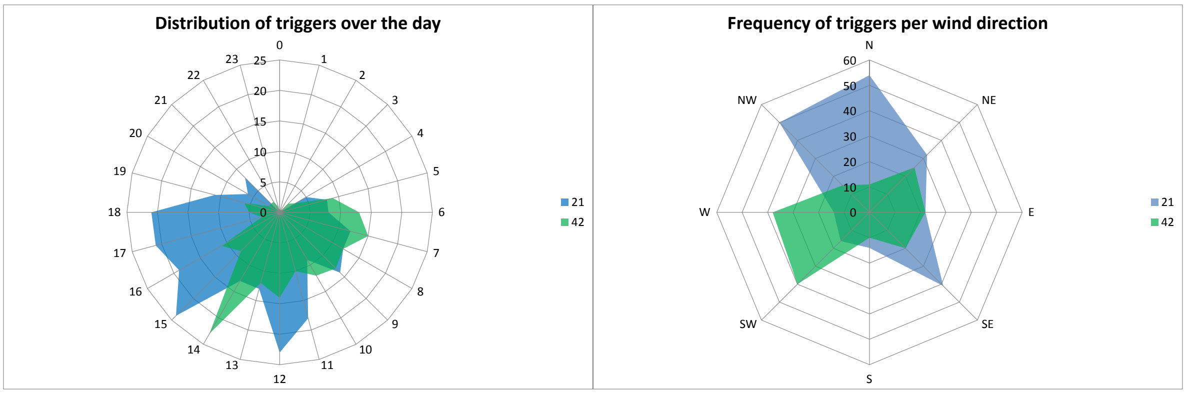


Figure 5. *Frequency distribution of triggered video sequences with birds per hour (left panel) and wind direction (right panel) of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42.*

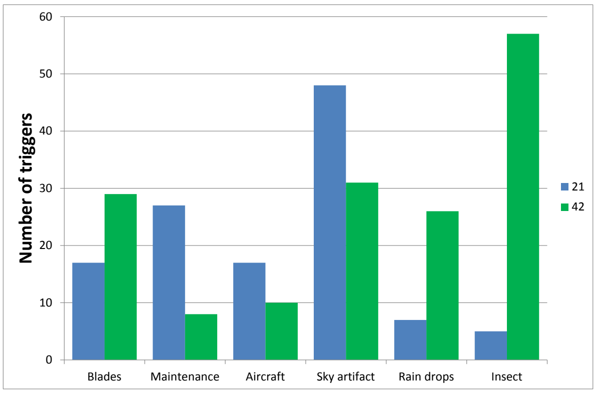


Figure 6. *Total number of falsely triggered video sequences per cause of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42.*

Bird species were visually determined from the video sequences. Due to the resolution and distance the birds were recorded, it was only possible to determine bird groups (eagle, falcon, corvid, gull, goose), or at larger distances only an indication of the bird's size (small, medium or large bird). Eagles (here it often was impossible to distinguish with certainty between white-tailed eagle and golden eagle) represented by far most observations with a peak during spring (Fig. 7). No observations were recorded at turbine 42 during May due to the Detection module being out of service. Most flights were categorized as straight flights, however also a significant part of the observed eagles were soaring/circling (Fig. 8). Only few of the flight represented smaller sized birds. Whether this was due to lack of flight activity within the surveillance area or due to limitations in detection due to size, is unclear. Most flight activity of small passerines may be expected to occur below RSZ; also their detection range may be limited.

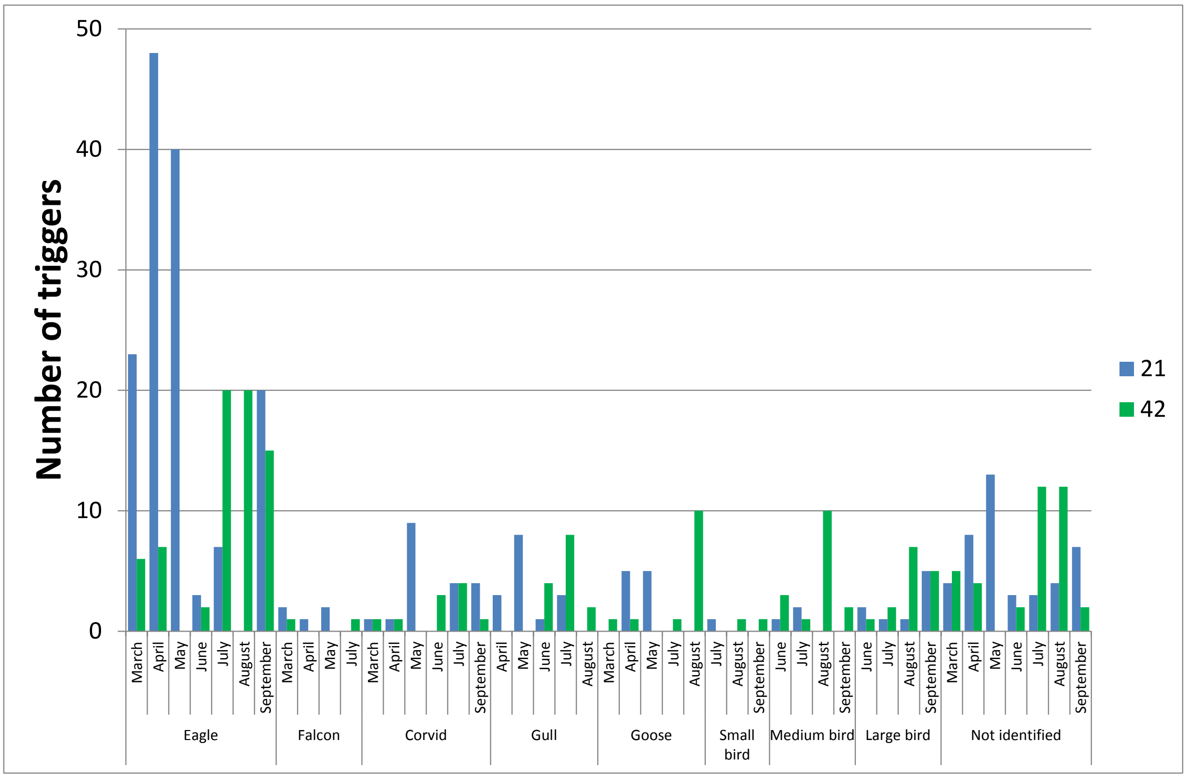


Figure 7. *Total number of triggered video sequences per month and species of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42.*

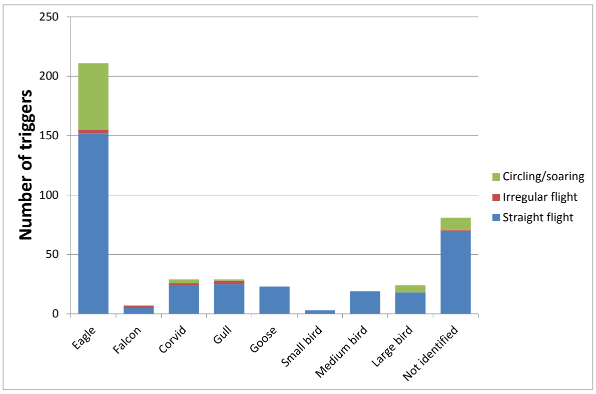


Figure 8. *Total number of triggered video sequences per species and flight behaviour of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42.*

For each bird flight, the distance to the turbine was visually assessed directly from the video sequences. It is important to stress that the visual assessment may be affected by the ability to assess distance correctly from a 2D video sequence, and is prone to observer bias even though it was done by one person. The DTBird software also renders an indication of distance through the software configuration used for defining the warning and dissuasion distances together with the approximate detection range. These settings were based on the wing span of a white-tailed eagle sized bird (2.4m). This, however, does not take into account factors affecting the distance determination: smaller-sized birds (e.g. the size of a nearby passerine is equal to a far-off white-tailed eagle), flapping (reducing the wing span) and orientation of the bird to the video camera. Thus neither the visual assessment nor the settings determine the *actual* distance; however it enables the *relative* comparison of the distribution of observations with distance. Birds were in general visually assessed to be farther away from the turbine than what was determined by DTBird (Fig. 9). This may indicate that the overall detection range actually is less than 300m. This is somewhat confirmed by the “correct” determination for eagles at turbine 21 (Fig. 9 – left panel).

Compared to an expected equal distribution of all bird flights over the available surface area/volume surveyed, bird flights were, for turbine 21 and 42 respectively, recorded 2 to 4 times more often within 150m from the turbines (turbine 21: $\chi^2 = 35$, $P < 0.001$; turbine 42: $\chi^2 = 149$, $P < 0.001$) and at lower altitudes (turbine 21: $\chi^2 = 1695$, $P < 0.001$; turbine 42: $\chi^2 = 2423$, $P < 0.001$) (Fig. 10). Flight altitudes below RSZ were utilized 75-100 times more often as expected. While altitudes at RSZ were utilized more often (5-8 times), fewer flights were recorded over RSZ (0.5-0.7 times). These results were the same also for eagles only. Possible rotor area crosses and collisions were only assessed for the video sequences from June 18 2012. In only four instances a flight was detected near or crossing the rotor swept zone. Two of these detections elicited a warning signal; the two others initiated dissuasion. In nearly 8% of all 226 flights a rotor swept area cross could not be determined with certainty; mainly when birds did not fly in the field-of-view of the vertically placed cameras. Birds with certain or undetermined rotor area cross nearly all were in straight flight. Although the DTBird system provides the possibility to visually record collisions, no such events were observed with certainty during the time of operation. In 7% of all flights a collision event could not be determined with certainty when the video sequence did not record the flight beyond the turbine in its entirety. During the same period regular searches for collision victims around the turbines were carried out using trained dogs; no collision victims were found at the two turbines. Once the dog marked a location at turbine 21, which is indicative of a bird in decomposition although no feather remains were found (pers. comm. Ole Reitan).

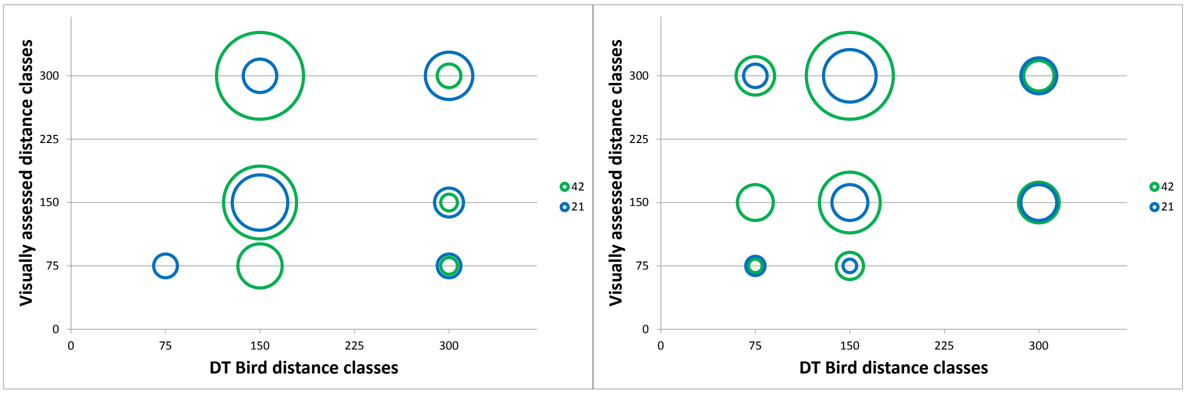


Figure 9. *Comparison of bird flight distances automatically derived from DTBird distance settings for white-tailed eagles (dissuasion: <75m; warning: <150m; maximum detection: 300m) and visually assessed bird flight distances; for eagles (left panel) and other bird species (right panel). The size of the circles indicates the relative distribution of triggered video sequences of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42.*

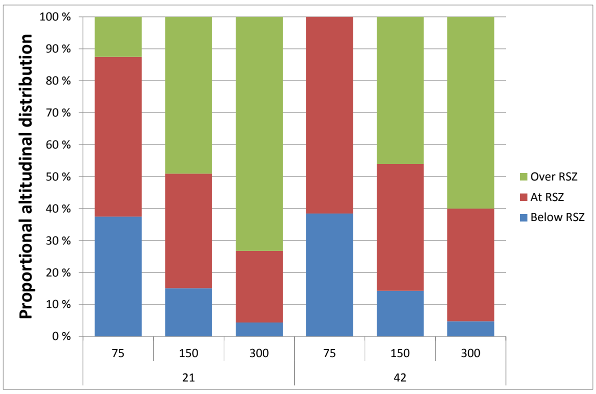


Figure 10. *Proportional altitudinal distribution (below, at and over the rotor swept zone (RSZ)) per DTBird distance class of the number of triggered video sequences with birds of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42.*

The DTBird system initiated the Dissuasion module, during the period it was activated (June 1 – September 30 2012), in total 426 times (of a total of 511 video sequences); both as a result of birds (45%) and false positives (55%). At turbine 21 and turbine 42, the rate of falsely triggered warnings/dissuasions was 66% and 48% respectively. Less than 15% of these falsely triggered events were due to turbine maintenance; without these the overall rate became nearly 50-50%. In circa 63% of the video sequences containing birds, warning was initiated; whereas dissuasion was initiated in circa 20%. In circa 17% of the cases the Dissuasion module was not activated. Whereas at turbine 42 warning was initiated throughout the summer, only in September warnings were common at turbine 21 (Fig. 11). It seems there was an overweight of warnings with respect to the visually assessed distances (Fig. 9). When a warning was initiated sounds were elicited for 13.3 (± 0.4 S.E.) and 12.7 (± 0.7 S.E.) seconds at turbine 21 and turbine 42 respectively (only after June 1 2012). Dissuasion lasted on average for 10.6 (± 0.3 S.E.) and 11.8 (± 0.6 S.E.) seconds at turbine 21 and turbine 42 respectively. In only 7% of all video sequences where warning/dissuasion was initiated, was a visible flight response observed. This was in most cases in response to the emitted warning signal (Fig. 12 – left panel). No flight responses were observed in the video sequences when both warning and dissuasion were initiated; however in circa half of the cases it could not be determined whether or not a response occurred. As was also mentioned before, the visually assessed distances did not always confirm to the software settings (see also Fig. 9). While most flights were visually assessed to be between 150 and 300m from the turbine at or over RSZ, the majority of visible flight responses were observed at RSZ and within 150m of the turbines (Fig. 12 – right panel). Lack of flight responses occurred more often farther from the turbines and at higher altitudes. Undeterminable responses mainly occurred when the birds did not fly in the field-of-view of the cameras long enough to ascertain their behaviour. Certain or undeterminable responses mainly occurred in straight flight.

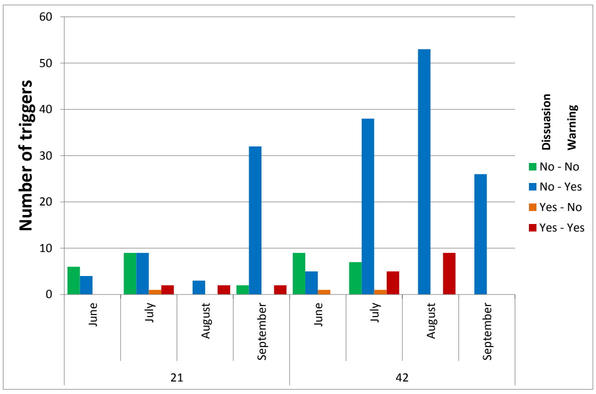


Figure 11. *Frequency of triggered video sequences with birds that activated the warning and/or dissuasion modules of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42.*

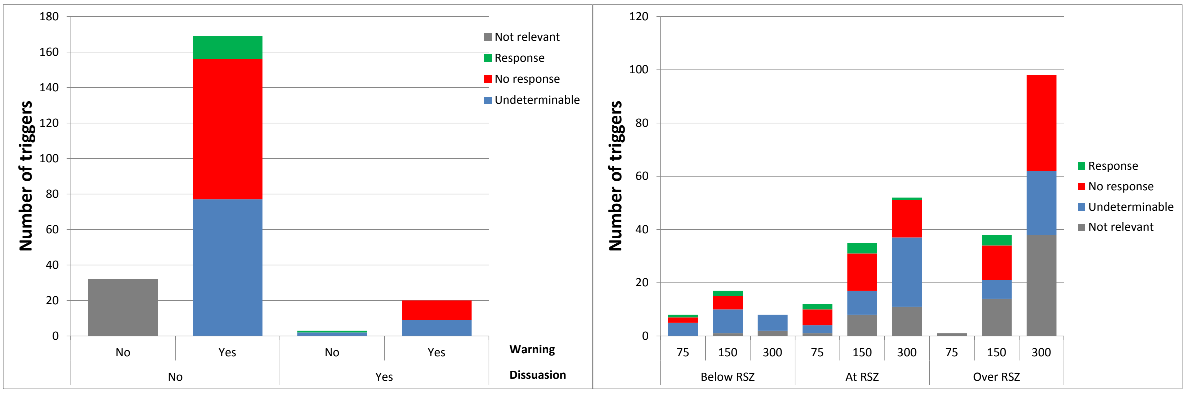


Figure 12. *Number of triggered video sequences with activated warning and/or dissuasion that elicited a visible flight response (left panel), distributed over visually assessed altitude bands and distance classes (right panel), of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42.*

Although there was no difference in tortuosity between control and impact sequences pre-warning ($F = 2.328$, $P = 0.128$), a significant 3.6-fold increase in tortuosity could be detected for the impact sequences post-warning ($F = 15.618$, $P < 0.001$; Fig. 13). The relative change in tortuosity, as measured by the tortuosity ratio before/after, indicated that those sequences that had a visually assessed flight response on average had a slightly higher ratio versus those without any visible response (0.82 vs. 0.79 respectively).

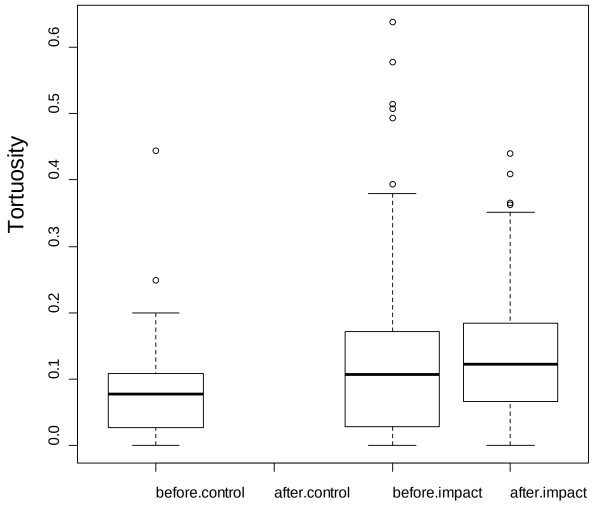


Figure 13. *Tortuosity of video sequences of DTBird at the Smøla wind-power plant; installed at turbine 21 and turbine 42. Median (thick line), 50%-percentile (block), 95%-percentile (whiskers) and outliers (dots) are shown for "control" sequences (without warning/dissuasion) and "impact" sequences before and after warning/dissuasion.*

3.2 GPS telemetry data

A temporal assessment of the GPS relocation data at the Smøla archipelago indicates an increased flight activity during spring (Fig. 14 – left panel). Throughout the year flights were mostly directed in a north-western to south-eastern axis (Fig. 14 – right panel). Flight activity within 300 m of wind turbines was more pronounced during the breeding season (March – September). Although all 68 turbines within the wind-power plant were considered, only four turbines represented over 50% of all GPS relocations within a 300-m radius, turbine numbers: 21, 29, 39 and 22. These turbines were visited respectively with 337, 126, 68 and 51 of a total of 1082 relocations within a 300-m radius of turbines. However, neither turbine 21 nor turbine 42 made it to the "most visited" turbines within a 150-m and 75-m radius (in total 179 and 45 relocations, respectively).

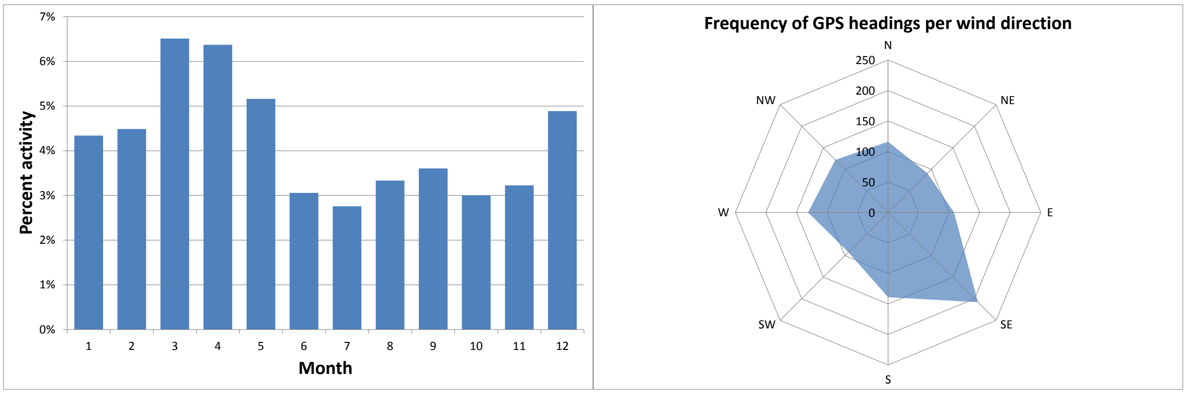


Figure 14. *Temporal distribution in flight activity (left panel) and heading (right panel) of sub-adult white tailed eagles equipped with GPS-transmitters at the Smøla archipelago.*

Compared to an expected equal distribution of relocations over the available surface area, white-tailed eagles utilized the area surrounding the turbines more prior to fledging (χ^2 = 633, P < 0.001), and less post-fledging (χ^2 = 41, P < 0.001; Fig. 15 – left panel). The increased utilization prior to fledging, with nearly three times as many relocations as expected within 75m, is likely due to juveniles born within the wind-power plant. Post-fledging the number of relocations was circa 0.7 times lower within a 150-m radius. Within a 300-m radius of turbines, white-tailed eagles utilized lower flight altitudes both prior to fledging (χ^2 = 97, P < 0.001) and post-fledging (χ^2 = 58, P < 0.001; Fig. 15 – right panel). Flight altitudes below RSZ were utilized 3.5 (post) to 6.1 (prior) times more often than expected from an equal distribution of relocations in flight (instantaneous speed >0 m/s) over the available volume. Few relocations were found in the vicinity of turbine 42 prior to and post-fledging (zero and nine relocations, respectively). Prior to fledging 183 relocations were found within 300m of turbine 21; with a significant decreased utilization (χ^2 = 40, P < 0.001). Also post-fledging white-tailed eagles utilized the turbine surroundings less 21 (χ^2 = 99, P < 0.001, N = 337). As for DTBird observations, the GPS-equipped white-tailed eagles utilized altitudes below RSZ more intensively. Contrary to the GPS-equipped individuals, DTBird video sequences indicated increased flight activity within the first 150m from the turbines.

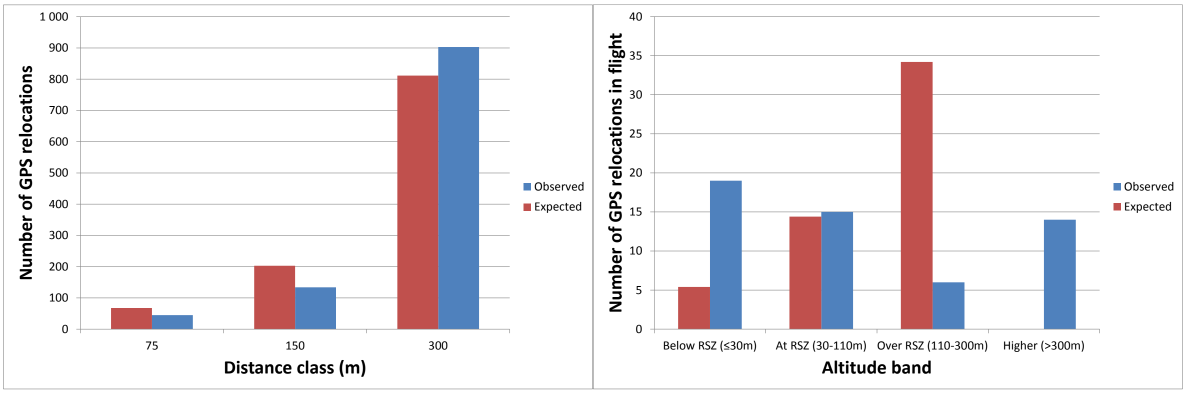


Figure 15. *Number of relocations of sub-adult white-tailed eagles near turbines within the Smøla wind-power plant (left panel), and the flight altitude within a 300-m radius surrounding turbines (right panel). The expected number of relocations assumes an equal distribution of relocations over the available surface area (left panel) and volume (right panel).*

3.3 Avian radar data

From April 26 2012 birds have been tracked with the Merlin avian radar system. The system was out of operation for three short periods: June 13-17, June 28 and July 13-22. From September 25, many birds migrated over the surveillance area (Fig. 16 – left panel). This can also be seen from the overweight of tracks which moved in south-westerly direction (Fig. 16 – right panel). Further analyses exclude this migration period. Within a radius of 80-120m from the turbines fewer birds were tracked (Fig. 17 – left panel). This is partly due to the inability of the radar to tracks small objects such as birds in the vicinity of large reflective objects such as the turbines. However, the observed distribution of recorded tracks were according to expected given the surface area encompassed by the three distance classes (turbine 21: χ^2 = 2.85, P = 0.793; turbine 42: χ^2 = 0.24, P = 0.241; Fig. 17 – right panel).

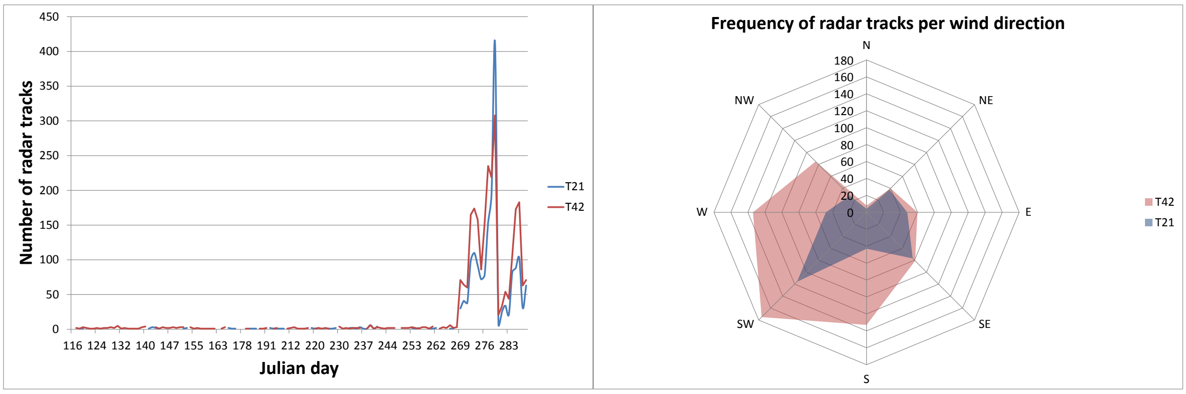


***Figure 16.** Frequency of bird tracks within a 300-m radius around turbine 21 and turbine 42 recorded by the horizontal avian radar at the Smøla wind-power plant between April 26 and October 15 2012 (left panel). Note the sharp increase after September 25 due to bird migration. The right-hand panel gives the frequency distribution per wind direction.*

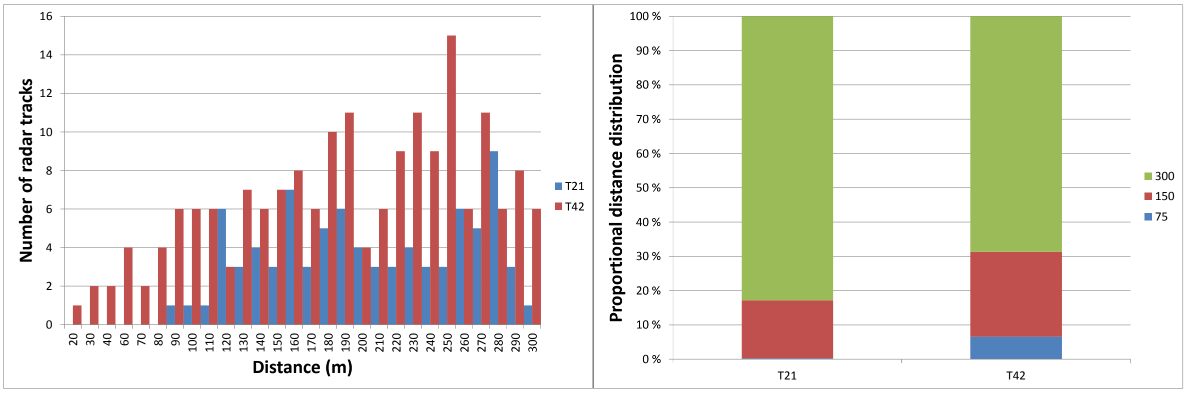


***Figure 17.** Number of radar tracks over distance from the turbine (left panel) and the proportional distribution over three distance classes (right panel). The graphs include all horizontal radar tracks recorded at the Smøla wind-power plant between April 26 and September 25 2012.*

For the vertical radar it is easier to track birds at varying distances from the turbines; also due to the fact that these only form a fraction of the total surveyed air space. However, more tracks were generated here due to the moving rotor blades (false positives). This can clearly be seen form the high number of tracks within the first 20-60m from the turbines (Fig. 18 – left panel). While the number of tracks at turbine 21 tapered off with increasing distances, the numbers remained stable at turbine 42 at on average 20 tracks per day. The altitudinal distribution of tracks showed a strong peak at rotor swept height (50-120m) due to the moving rotor blades creating false positives (Fig. 18 – right panel). Below the RSZ the radar could not track birds; here the large number of tracks in the first 10-m bin at turbine 21 is due to reflectivity due to terrain properties (i.e. ground clutter). Above the RSZ, most bird activity was recorded at altitudes below circa 300m. The shift in the form of the distribution between turbine 21 and turbine 42 is due to the altitude a.s.l. they are placed (21.5m and 11.0m respectively); the terrain at turbine 21 is higher. The number of recorded tracks differed significantly from expected given the volume within the different distance classes and altitude bands (turbine 21: $\chi^2 = 244376$, $P < 0.001$; turbine 42: $\chi^2 = 182949$, $P < 0.001$; Fig. 19 – left panel). Less tracks were recorded at distances 150-300m and below RSZ at both turbines, whereas more tracks were recorded at distances <75m. The average nearest distance to the turbine birds were tracked was lowest at RSZ (Fig. 19 – right panel). While the average nearest distance was equal at turbine 42 at the other altitude bands, the average nearest distance did increase with altitude band at turbine 21.

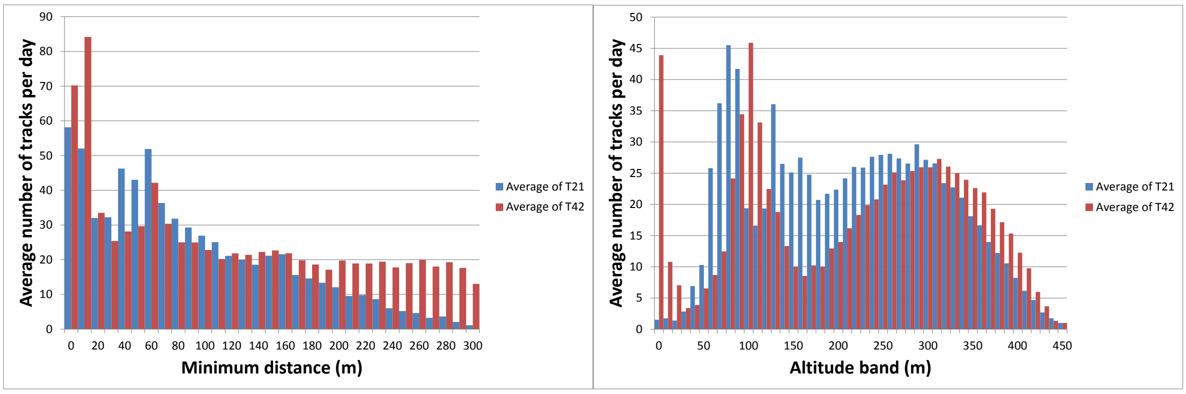


Figure 18. *Number of radar tracks over distance from the turbine (left panel) and at different altitude bands (right panel). The graphs include all vertical radar tracks recorded at the Smøla wind-power plant between April 26 and September 25 2012.*

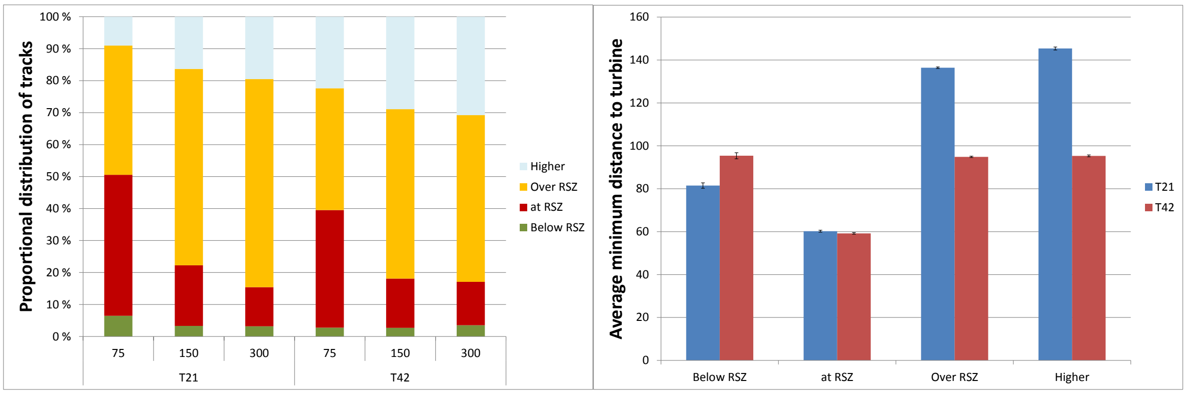


Figure 19. *Distance of recorded vertical radar tracks at turbine 21 and turbine 42 of the Smøla wind-power plant between April 26 and September 25 2012 below, at, over rotor swept zone (RSZ) or higher (respectively: <30m; 30-110m; 110-300m; >300m). The left-hand panel gives the proportional distribution over three distance classes (<75m; 75-150m; 150-300m); the right-hand panel gives the minimum recorded distance to the turbine (± S.E.) averaged over all tracks per altitude band.*

3.4 Comparative video – radar assessment

By comparing the video sequences recorded by DTBird with the tracks recorded by the avian radar, it is possible to get insight into the efficacy of the DTBird system with regard to false negatives. False negatives represent birds that were active near the turbines, but were not detected by DTBird. It is here important to stress that also the avian radar does not detect all bird flights; however it does provide an independent dataset on bird activity. The results here presented should therefore be seen as indicative. Visually comparing the frequency of video sequences and radar tracks shows that, short periods when either DTBird or the avian radar was out of order aside (see also Fig. 2), there was a fair overlap between the two datasets; especially at turbine 42 (Fig. 20). The video sequences that could be connected with, especially horizontal radar data, radar tracks showed that this was easier to find a match farther from the turbines (Fig. 21). This is due to the decreased detection capabilities of the radar close to large reflective objects such as turbines and below RSZ.

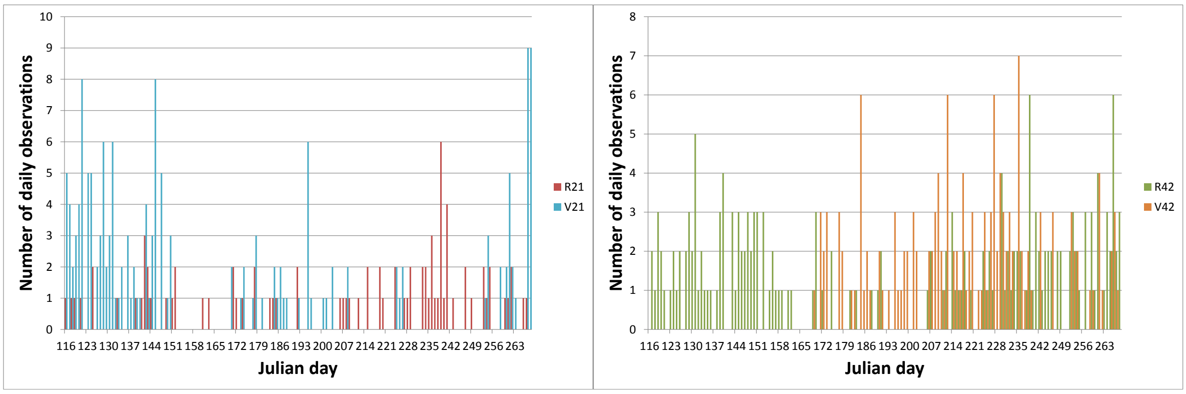


Figure 20. *Comparison between the number of recorded horizontal radar tracks (R) and the number of video sequences (V) recorded within 300m of turbine 21 (left panel) and turbine 42 (right panel) at the Smøla wind-power plant between April 26 and September 25 2012 (Julian day 116 – 268).*

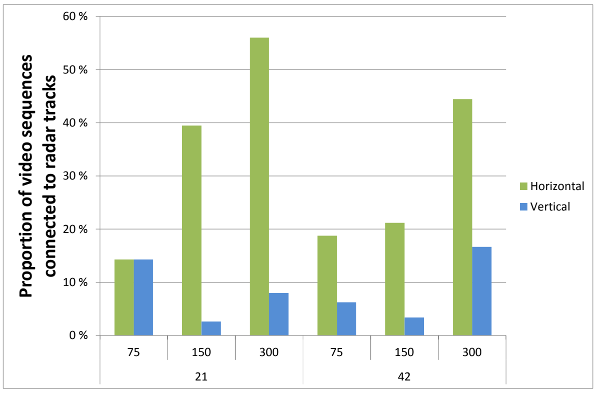


Figure 21. *Proportion of video sequences that could be connected to radar tracks within the three distance classes at turbine 21 and turbine 42 of the Smøla wind-power plant between April 26 and September 25 2012.*

Put together, this enables the assessment of the number of true positives (TP: recorded video sequences with birds), false positives (FP: recorded video sequences without birds) and false negatives (FN: radar tracks with birds, but no corresponding video sequence). This assessment only includes periods when both DTBird and the avian radar were operative, and assumes that all birds in the vicinity of the turbines were detected either by DTBird or the avian radar. The detectability measure (see also chapter 1), defined as the ratio of recorded bird flights (TP) by all birds near the turbines (TP and FN), and throughout the 24-hr day was 83% and 59% at turbine 21 and turbine 42, respectively (Table 2). When only considering the operative daytime period (light levels >200 lux) detectability increased to respectively 92% (14 FN) and 76% (43 FN) within a 300-m radius. When assuming a more conservative surveillance area radius of 150m, the detectability increased to 96% (6 FN) and 86% (22 FN) for turbine 21 and turbine 42, respectively. At turbine 21 the connectivity of DTBird with the avian radar was inferior relative to turbine 42. At turbine 21 only 28 video sequences could be connected to radar tracks, whereas at turbine 42 58 were connected. Also there were more video sequences with birds without matching radar tracks (126 versus 77). This was most likely due to the suboptimal performance of the avian radar at turbine 21 due to ground clutter. The DTBird system configuration was tuned for white-tailed eagles. Therefore the actual surveillance area for all birds may to a certain extent be overestimated.

T21		Bird: Yes	Bird: No
Video	Yes	154 (28)	117
Video	No	31 (126)	---

T42		Bird: Yes	Bird: No
Video	Yes	135 (58)	160
Video	No	95 (77)	---

Table 2. *Number of true positives (TP; upper left cells), false positives (FP; upper right cells), false negatives (FN; lower left cells) and true negatives (TN; lower right cells; per definition zero) recorded with the DTBird system and the avian radar within a radius of 300 m to turbine 21 and turbine 42 of the Smøla wind-power plant between April 26 and September 25 2012, throughout the 24-hr day (DTBird operates only when light >200 lux). For TP, between brackets the number of observations both recorded by DTBird and radar is given. FN is approximated by the number of radar tracks without corresponding DTBird video sequences; the opposite is indicated between brackets.*

4 Discussion

Overall the DTBird system concurred with two of four of the quantitative evaluation criteria. The detectability of birds met the 80%-criteria; the daily number of false positives was well below two. The percentage of falsely triggered warnings/dissuasions however was circa 50% (instead of 20%). At Smøla 40% of all video sequences were false positives (instead of 10%). Still, we have to take into account that this was the first time DTBird was installed and operated at Nordic conditions. Also it had the status of pilot project with the aim to install and calibrate the system; however when operationalized in full scale the evaluation criteria should be met by further fine-tuning the Detection module and system configuration. When assuming that all bird flights were detected either by DTBird or the avian radar, DTBird actually detected between 76% (within a radius of 300 m to the wind turbine) and 96% (150 m radius) of all daylight bird flights. When considering the entire 24-hr day, DTBird recorded 59%-80% of all bird flights in a radius of 300 m to the wind turbines. The number of detected smaller-sized birds (e.g. Northern wheatear, waders) was low; whether this was due to lack of flight activity within the surveillance area or due to limitations in detection due to size, merits further study. Although resource-demanding, this could be assessed through visual observations by recording distance and flight altitude using a rangefinder. The average number of false positives was below two per day (after fine-tuning circa 1.2 FP/day). DTBird thus did not generate large amounts of false positives; those generated are still manageable to filter out manually by viewing the video sequences.

Possible causes of missing flights (DTBird false negatives) may be because DTBird covers 100% the circumference of the turbine in a radius of circa 150 m, but only 50% in the distance range of 150 to 300 m (Fig. 1) while the avian radar covers (nearly) all at this latter range (Fig. 2). Also, the high definition image recognition algorithms of DTBird eliminates physical objects from the detection area, and uses filters to remove false positives generated by e.g. the rotor blades, insects or sky artefacts. The realized detection area may thereby be limited to a varying extent, depending on the local conditions and turbine operational mode (i.e. azimuth). To which degree this affects the detection of all near-flying birds is as yet unclear. This could be further assessed by identifying partial detection of flights (i.e. delayed initiation and/or premature termination). The DTBird system uses visual light cameras. Although most birds at the Smøla wind-power plant are day-active, those active before sunrise of after sunset (light levels <200 lux) could not be detected by DTBird. The avian radar, on the other hand, tracks birds irrespective of light levels.

According to the GPS telemetry data, white-tailed eagles utilized distances farther from the turbines more intensely. The DTBird system detected the majority of bird flights at closer range, often initiating the Dissuasion module. The visually estimated distances of recorded bird flights in the video sequences were, however, in general assessed to be farther from the turbines compared to the distance settings used within the software configuration to define the moderate (warning) and high (dissuasion) collision risk area. Apparently, the software estimated the distance, based on the wing span of the bird in question, to be nearer the turbine. This may well be a possible explanation for the high percentage of falsely triggered warnings/dissuasions. Although the Dissuasion module of DTBird certainly is superior compared to any random activation system, minimization of habituation necessitates that the system is only triggered by birds during the time they fly near the RSZ of a turbine. The Dissuasion module of DTBird is only triggered for short intervals; however, many of the false positives also initiated warning/dissuasion. Here it will be important that the emitted audible signal is perceived as unpleasant to the target species, cannot be heard beyond the collision risk areas, and preferably has biological meaning to the bird (e.g. alert calls). The assessment of detection distance versus actual distance merits further investigation, possibly through a field performance test using a model aircraft equipped with GPS. Also, the efficacy of the Dissuasion module may be further tested by comparing the flight data (minimum distance, flight responses) with this module enabled versus disabled.

All monitoring techniques come with their own specific limitations and strengths. GPS telemetry is limited by the number of individuals that can be tracked, but they can be continuously tracked for longer periods. Avian radar, on the other hand, is able to continuously survey a relatively large area; but is limited in identifying species and individuals, and tracking low-flying birds and close to turbines. The DTBird system enabling monitoring of near-turbine flight behaviour in birds presents a complementary technique. Although individual birds usually cannot be identified to species, they can most often be classified to species group (eagles, gulls, corvids, etc.). In addition, the DTBird system may be utilized as a measure for mitigating collisions. Active flight responses to the warning/dissuasion signal were visually detected in a limited number of video sequences. Taking into account that this evaluation encompassed three months of operation of the Dissuasion module, longer operation periods and further modelling of possible flight responses (such as distance and altitudinal estimation from raw detection data) will allow a more detailed analysis of system performance. Also, changes in both the number of detections and the spatial distribution of these, enable testing the possible efficacy of other mitigation measures implemented at specific turbines; following a so-called Before-After-Control-Impact (BACI) approach.

5 References

Bevanger, K., F. Berntsen, S. Clausen, E. L. Dahl, Ø. Flagstad, A. Follestad, D. Halley, F. Hanssen, L. Johnsen, P. Kvaløy, P. Lund-Hoel, R. May, T. Nygård, H. C. Pedersen, O. Reitan, E. Røskaft, Y. Steinheim, B. Stokke, and R. Vang. 2010b. Pre- and post-construction studies of conflicts between birds and wind turbines in coastal Norway (Bird-Wind). Report on findings 2007-2010. Report 620, Norwegian Institute for Nature Research, Trondheim, Norway.

Nygård, T., K. Bevanger, E. L. Dahl, Ø. Flagstad, A. Follestad, P. L. Hoel, R. May, and O. Reitan. 2010. A study of White-tailed Eagle Haliaeetus albicilla movements and mortality at a wind farm in Norway. Pages 1-4 in BOU Conference – Climate Change and Birds. BOU, Leicester, UK.

910

NINA Report

The Norwegian Institute for Nature Research (NINA) is Norway's leading institution for applied ecological research.

NINA is responsible for long-term strategic research and commissioned applied research to facilitate the implementation of international conventions, decision-support systems and management tools, as well as to enhance public awareness and promote conflict resolution.

ISSN: 1504-3312
ISBN: 978-82-426-2514-4

Norwegian Instutute for Nature Research
NINA head office
Postal address: P.O. Box 5685 Sluppen, NO-7485 Trondheim, NORWAY
Visiting address: Tungasletta 2, NO-7047
Phone: +47 73 80 14 00, Telefax: +47 73 80 14 01
E-mail: firmapost@nina.no
Organization Number: 9500 37 687

http://www.nina.no

Cooperation and expertise for a sustainable future