Temporary Halting of Wind Turbine Rotors to Mitigate Effects on Birds

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Abstract
This study assesses the viability of temporarily halting wind turbine operations as a mitigation measure to protect bird populations during migration periods. Conducted in the northern Baltic, it examines the migration patterns, timings, and altitudes of various bird species, aiming to identify the most critical times for implementing turbine stoppages. Utilizing statistical analyses, including F-tests to evaluate migration intensity differences among species, the report proposes that strategic, short-duration shutdowns can significantly reduce avian collisions. The research emphasizes the importance of species-specific approaches and evaluates the cost-effectiveness of various bird collision reduction techniques, such as blade painting and thermal detection for dynamic shutdowns. This approach seeks to balance the ecological impact of wind turbines with the necessity for renewable energy development, offering practical solutions that could enhance biodiversity conservation efforts without substantially compromising energy production efficiency.
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1. Introduction

1.1 Background
As the World moves away from a fossil-fuel-based economy to mitigate climate change, new technologies are developed to keep up with increasing energy demand (Ekonomifakta 2023) while simultaneously reducing the emissions of greenhouse gasses. Sweden has set goals to ensure 100% renewable energy by the year 2040. This will probably lead to large development of wind farms since it is the most competitive option (Naturvårdsverket & Energimyndigheten 2018). The development of wind power in Sweden is not necessarily in direct conflict with the environmental goal of sustaining vital bat and bird populations, but planning is needed to consolidate these goals (Rydell et al., 2017). Enabling an extensive expansion of the current wind power production capabilities in Sweden will require considerable effort which will most likely include the construction of offshore wind farms in the northern Baltic. To make this development possible while minimizing the impact on local bird populations, studies are needed on the behaviour of those birds. While there has been some research on the behavioural patterns of birds in relation to wind turbines, there are currently no studies published as far on this relationship in the northern Baltic.

It has been known for a long time that wind farms do not pose a significant increase in collision risk above other man-made structures, unless built in a high-risk area such as along bird migration routes. However, it should be noted that most of the collision risk studies focusing on structures other than wind turbines were made in response to a perceived problem and are therefore not necessarily representative of the average (Erickson et al. 2001). Bird collisions with artificial buildings is a phenomenon that has been known and written about for over 100 years (Götke, 1891). Many species of birds that live and migrate in an offshore environment are long-lived species with low reproductive rates, such as most seabirds, waterfowl, and waders. Low reproductive rates can make their populations especially vulnerable to even small increases in mortality (Exo et al. 2003). During poor sight conditions, which are common at sea, collision risk with turbine blades is most likely at its highest since avoidance behaviour cannot be used by the birds (Wang et al. 2015). While mortality rates by wind turbines are much lower than some other widely deployed power generation methods such as fossil-fuel plants and nuclear power plants, there is a possibility that if wind parks are deployed on a mass scale, they will lead to a significant loss of biodiversity when it comes to birds (Wang et al. 2015).

The mortality rates at different turbines vary greatly and are highest around turbines located in wet environments (Rydell et al. 2017). Data also shows that larger turbines kill more birds than smaller ones. Even though data is lacking on mortality rates on offshore farms, the combination of the marine environment, placement in migration routes, and the larger size of offshore turbines make for a troubling forecast for their effect on bird populations (Rydell et al. 2017; Loss et al. 2013). However, a study conducted by Smallwood (2013) showed that larger turbines lead to decreased mortality per MW of installed effect. Most wind turbines kill very few birds, while a select few kill many (variation between 0 and 60 birds killed per year and turbine). This emphasizes the importance of planning and placement of new wind turbines (Rydell et al. 2017; Loss et al. 2013; Zimmerling et al. 2013).
As wind farms grow larger, which is especially pertinent when it comes to offshore projects, the appropriate placing of said wind farms become more important. The research that exists can aid tremendously in the planning stages of a wind farm development. However, collecting data will virtually always be a necessity to account for local variations in migration and numbers. To be effective, wind farms need to be in areas exposed to high winds on a regular basis. This causes them to be proposed in high elevation areas, or coastal and offshore areas meaning that they have potential overlap with important habitat, migration routes, and wintering areas for birds. Large birds such as swans, cranes, and geese with poor dexterity are generally at higher risk for collisions with man-made structures. Displacement of birds from potential nesting and resting area is an issue associated with the construction and operation of wind farms, again stressing the importance of proper placement of the site. The displacement occurs both in habitat loss, and loss of breeding areas as birds seem to avoid breeding in direct association with the farm site. Wind farms could also be causing a barrier affect, causing birds to change migration routes and flight paths (Drewitt och Langston 2006).

For shutdowns of wind turbines to be realistic (i.e. effective and economically viable), three things need to be considered. Firstly, energy demand needs to be considered as it would be unfeasible to shut down an entire wind farm during peak energy demand to save a few birds. Secondly, there has to be a reasonable risk of collision for the species in question for a shutdown to be called for. The species that have been selected for this study are species that are often in question during the planning stages of a wind farm in Västerbotten. If a species flies within the rotor sweep zones (RSZ) of the wind turbines, it is at risk for collision. The RSZ for turbines planned in the Baltic are usually 65-365 meters (Eolus Vind AB 2023). Thirdly, the shutdowns must be limited to a time period that will not significantly impact the total energy production of the wind park. If shutdowns are limited to two 17-day periods per year during peak fall and spring migrations, with an average shut down time of 210 minutes per day, it would equal roughly 1% of total operation time. If this shutdown time could be combined with planned maintenance, it would further reduce the impact of these periods on power production. Combined with the fact that electricity demand is usually lower in the spring and fall due to the availability of hydroelectric power, this could be a cost effective method to mitigate bird collision rates with wind turbines.

1.2 Purpose and thesis
This project aims to analyse if it would be possible to pause operation of wind parks during certain times of the year and certain times of the day to minimize wind farms' impact on birds in the area while avoiding significant effects on power production and economics. This will be tested through analyzing the difference in migration timing between certain problem species: crane (Grus grus), bean goose (Anser fabilis), arctic tern (Sterna paradisaea), herring gull (Larus fuscus), and rough-legged buzzard (Buteo lagopus). For the aforementioned species, overlap in average flight height with RSZ will also be investigated.

2. Method & materials

2.1 Data
Data collected from the Swedish Species Information Centre (www.artportalen.se) was processed by selecting migrations for the selected species (crane, bean goose, arctic tern, herring gull, and rough-legged buzzard) during the period 2000-2023 in the coastal area in
Västerbotten. A polygon was drawn from Obbola just south of Umeå, all the way to Bjuröklubb just south of Skellefteå. The polygon stretched between the highway E4 in the west to the Finnish border in the Baltic Sea to the east. All data collected from artportalen without exact timestamps was disregarded. The flight height data collected by me and others were taken from several different locations around the Baltic, both on the Swedish and Finnish side.

2.2 Analysis
The analysis chosen for the data was an F-test where I tested the variation and if there is a significant difference between migration intensity between the species at risk for collision. I selected a 17-day period in both spring and fall to encompass as much as possible of the migratory peaks without stretching them out unreasonably long in time to avoid too much effect on the energy production of the wind parks. I then looked at the spread over day for the species too see at when the migration occur to avoid shutdowns of wind turbines during hours of low migrations. A 210-minute window per day was selected for the same reason as the 17-day period.

Flight heights will be summarized using a 95% confidence interval.

2.3 Area of study
The flight height data was collected as described below during 2023 at four different locations for the aforementioned species. An undisclosed location outside Pori, Finland (the exact location is undisclosed since the project associated with the data is not yet public and will hereafter be referred to as location 1), Holmön (outside Umeå, Sweden), Gumboda, and Ratan (between Umeå and Skellefteå).

2.4 Boat-based transect survey and fixed-point visual survey
Boat-based transect surveys (hereafter boat-based surveys) were used as the primary method for surveying seabirds for several decades (Thaxter et al. 2016). While this approach followed guidelines set by Camphuysen et al. 2004, we have opted for a slightly altered method combining boat-based surveys with laser rangefinders. This method allowed us to increase the accuracy of the flight heights compared to traditional boat-based surveys where flight height is estimated visually into flight height bands. The laser range-finder used was a SAFRAN Vectronix vector IV which is the most widely used laser rangefinder for commercial wind farm surveys. The rangefinder has a range of up to 6 km. Unpublished preliminary results suggest a tendency to overestimate flight height of birds in flight when assigning them to flight height bands as described in the standard method set by Camphuysen et al. (2004). Furthermore, there is evidence that observers assign birds to incorrect flight height bands 50-70% of the time using visual observation (Thaxter et al. 2016). Even though these results are by no means established, the use of laser rangefinders completely circumvents this potential issue. During the boat-based survey, all birds within 500 m of the vessel were identified and their activity was noted as either foraging or migrating. If migrating, flight heights were also measured. This method has a close to 100% rate of correct identification of species and in combination with laser rangefinders it offers reliable height data as well (Thaxter et al. 2016). All measurements were made during the spring and fall migration 2023. Boat-based surveys were used in location 1. At all locations other than location 1, fixed point surveys were utilized where all birds flying directly over land or very
near land were measured. Approximately 10% of the data was collected by me, the rest was collected by colleagues at Grouse Expeditions and EcoGain.

During the fixed-point visual survey, an observer was placed at Holmön, Gumboda, and Ratan. At these locations, all birds flying over land were recorded both by species and flight height. The same kind of laser rangefinders were used for fixed point surveys as the boat-based surveys. Provided that weather allowed, after a transit time of one hour (roughly 20 nautical miles) to the site at location 1 by boat, we were usually on site at around 07:30 a.m. and drove the boat along transects, which were evenly spaced through the project area, for around 8 hours. For the fixed-point surveys, observations would begin as soon as it was light enough to see, around 06:00 a.m. Depending on weather conditions and bird activity, some observation sessions (days) might only last roughly one hour and some several more. There is usually an easily identifiable sharp dropoff in bird activity at some point after sunrise, the identification of which was left up to the observers. All flight height data for both fixed-point and boat surveys was collected between April and October 2023.

3. Results

As shown in table 1, the flight heights of all species other than crane and bean goose put them outside the rotor-sweep-zone (RSZ) and were hence excluded from further analysis within the scope of this study. The data used from artportalen shows that migration activity is temporally limited both on a seasonal and daily basis, especially in the spring. On average over the 23 years of data collected, 88% of cranes and 65% of bean goose migrated past the study area between April 9 and April 26 during the spring. During fall, it was 48% for cranes and 59% for bean goose on average between September 17 and October 4. Furthermore, about half of all observations were made in a 210-minute window on average over all years. For bean goose, 48.6% of all observations were made between 05:00 and 08:30. For cranes, 55.1% of observations were made between 06:30 and 10:00.

The F-test showed that there is a difference in the timing of migration between bean goose and cranes both in the spring and fall. The P-value for the spring was P < 0.01 while the P-value for the fall was P = 0.036. 21 flocks consisting of a total of 1126 cranes were measured to fly at altitudes between 29–885 meters based on 249 individual measurements. There was much less data for bean geese with 5 flocks consisting of a total of 331 bean geese that were measured to fly at altitudes between 25–120 meters based on 5 measurements. The other species mentioned were only observed to fly occasionally within the RSZ.

Table 1. Flight height measured for different species during migration in the area of study. 95% confidence intervals rounded to nearest positive integer.

<table>
<thead>
<tr>
<th>Species</th>
<th>Flight height average (m)</th>
<th>Flight height 95% CI (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>crane (Grus grus)</td>
<td>293</td>
<td>189-397</td>
</tr>
<tr>
<td>rough-legged buzzard (Buteo lagopus)</td>
<td>48</td>
<td>31-65</td>
</tr>
<tr>
<td>arctic tern (Sterna paradisaea)</td>
<td>12</td>
<td>7-17</td>
</tr>
<tr>
<td>bean goose (Anser fabilis)</td>
<td>54</td>
<td>1-119</td>
</tr>
<tr>
<td>herring gull (Larus fuscus)</td>
<td>13</td>
<td>10-15</td>
</tr>
</tbody>
</table>
4. Discussion

Studies show that bird mortality rates caused by wind turbines are highly dependent on season, weather conditions, and location. An example of a high collision risk time would be migrations during low visibility conditions (Wang et al. 2015). Therefore, the planning stages of wind farms are probably where the biggest differences can be made. If high collision risk conditions can be identified during certain times of the year and day, it may be possible to temporarily disable turbines to allow birds to pass undisturbed.

Operating wind turbines during conditions of low visibility near migration routes constitute the highest risk for bird collisions. Examples of such conditions are fog, rain, and night (Sovacool, 2009), although nighttime activity is most likely much lower than daytime (Skov et al. 2018).

Birds that fly more often within the RSZ of wind turbines will have a higher risk of collision as they are at risk of being struck by a turbine blade when in reach of them. As shown in table 1, only bean geese and cranes had a meaningful spread (1-119m and 189-397m respectively) within the RSZ (65-365m). The other species only had a few individuals observed inside the RSZ. There is of course still a small risk of collision with the turbine tower itself, although this could not be mitigated by halting of the turbines. It should be noted that the flight height data for bean goose is much too sparse but was unfortunately all that could be collected. However, flight height for bean goose has previously been investigated and found to be similar to the data collected here (Hilgerloh 2022).

In the diagrams below (figure 1-10), one can see stark differences in temporal activity between different species. While there is some difference in the timing of the spring migration, this has the least variance as all species seem to arrive around the end of April or early May. The fall migrations south are far more varied, with rough-legged buzzard’s southern migration peak happening as late as October 11 while the arctic tern peaks as early as July 28. The differences here could be attributed to life history and migration strategy. The differences in time of day migration are interesting and also provide needed information for the eectivization of the halting of turbine blades. To target protection toward species in need of it, the timing of migration peaks during the day are a necessary component to measure in order to recommend effective shut-down periods. The later migration of for example cranes is most likely attributable to their use of thermal air currents to carry them higher which usually do not occur until later in the day (Pekarsky et al. 2023).

4.1 Collision risk factors

4.1.1 Time windows
Migration peaks both in spring and autumn (Fig 1; Hüppop et al. 2006). If higher migration activity leads to higher collision risk, migration peaks are the highest-risk timing for bird collisions with wind turbines.

4.1.2 Weather conditions

Strong winds have been shown to increase risk of collision. However, since wind speed is directly correlated with power production, it is unlikely that this is a condition that can be
accounted for unless electricity prices are exceptionally low (Marques et al. 2014). As shown by Hüppop et al. 2006, poor visibility during two nights accounted for half the collisions of the entire study which lasted for just over 6 months (all during peak migratory periods) (Hüppop et al. 2006).

4.1.3 Other risk factors
Most of the time, wind farms will trigger avoidance behaviour. However large-scale offshore wind farms might even attract migrating birds that use updrafts. Skov et al. 2016 speculate that this may be due to the migrating birds mistaking wind farms for land (where updrafts are found) which could in turn lead to higher collision risk as local flight activity increases.

4.2 Mitigation
In terms of mitigation, relatively few attempts have been made to reduce collision risk. There are some low-cost alternatives that have been shown to be effective. May et al. 2020 showed that painting the turbine blades black led to a 70% reduction in collision risk. While this study is limited to a few wind farms and should thus be interpreted cautiously, it had a long data series with over seven years of data for the control turbines and over 3 years for the impact turbines. Raptors had the largest reduction in collision risk which may be relevant for land-based wind farms in the Baltic area (May et al. 2020). Studies like these demonstrate that it is possible to mitigate collision risk cost-effectively.

Given the high predictability and intensity of migration both on a seasonal (fig. 1-5) and hourly (fig. 6-10) basis, it may be possible to turn off the wind farms during certain times of the day and year to reduce collision risk with limited loss of electricity production since migration is concentrated in time to relatively few days every year for any given species. During days of high migratory activity, there is an even smaller subset of hours in which the majority of migration occur.

Temporary shutdown of wind turbines is a method that has been used previously but have then relied on visual observers, making it infeasible in terms of general, long-term use (May et al. 2015; Marques et al. 2014). Mitigation efforts such as these could be especially important on offshore farms, as the species in those areas are most sensitive to extra mortality (Exo et al. 2003). Since there are no wind farms in the Baltic yet, but many projects planned and given permit, it would be prudent to incorporate some of these mitigation actions now. For example, painting the turbine blades before construction on site would be much cheaper than painting them at after operation begins. The great benefit of turning the farms off during certain times is that it can be implemented easily after operation begins, at no additional cost other than the potentially lost production.

4.3 Conclusion

Based on the results, there is a significant difference between the percentage of the total migration within the most active 17-day period (April 9 and April 26 for the spring and September 17 and October 4 in the fall). This result highlights that different species require different turbine halting periods. For both species, roughly half of the migration occurred during a 210-minute time window during each day. It is important to note that there was significant variation in the amount of migration happening within the same 17-day period.

This means that to have an effective mitigation strategy using halting of turbines during certain times of the year and day, the shutdowns have to be dynamic and adapt to the number of migrating birds and conditions on any given day. If shutdowns are static, there is risk that
shutdowns are ineffective if for example there is low migration activity on a day within the shutdown period simultaneously as electricity demand is high. There are some methods that have been developed for this reason in form of thermal detection systems, but they must be further developed to be deployed at scale cost effectively (Desholm 2006). Furthermore, not all species of birds are in need of wind park shutdown, therefore it is crucial to continue the research focused on identifying which species are most affected.

While this study has shown that it is difficult to have a static time period in which most bird collisions could be avoided, it highlights that migrations happen over a short and intense period during which large parts of collision risk could be avoided (fig. 1 and 2).

As wind turbines continue to be developed globally on larger scales, the importance of collision risk mitigation grows. New technologies can possibly be used to have a dynamic response to flight activity in terms of turbine halting. This study shows that it could be possible to halt turbine movements during short periods to mitigate their impact on bird populations while simultaneously minimizing the halting’s effect on profitability of the wind parks.

Overall, the results of this study, both in the F-test and as shown in the diagrams, illustrate the importance of tailoring any potential shutdowns for wind parks in order to effectively target the desired species while minimizing the negative impact of energy production. Furthermore, it highlights that to have a “one-size fits all” solution is highly unlikely to be effective as different species have different behaviours. Continued research is needed to establish which species are in need of protection from turbine collision, and when the shutdown should be initiated and for how long to have the desired effect.
Acknowledgments

I would like to give a special thanks to my supervisors Bent Christensen and Martin Rydberg Hedén, for the support, help and knowledge lending during all stages of this work. Thanks for always being there! I would also like to thank the many people that worked on the data collection for this project, without which it would not have been possible. Lastly, thanks to my partner, family, and friends for your support.
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Appendix

Fig 1. Number of migrating bean geese (*Anser fabilis*) per day. Data from artportalen.se year 2000-2023.

Fig 2. Number of migrating arctic terns (*Sterna paradisaea*) per day. Data from artportalen.se year 2000-2023.

Fig 3. Number of migrating rough-legged buzzards (*Buteo lagopus*) per day. Data from artportalen.se year 2000-2023.
Fig 4. Number of migrating herring gulls (*Larus fuscus*) per day. Data from artportalen.se year 2000-2023.

Fig 5. Number of migrating cranes (*Grus grus*) per day. Data from artportalen.se year 2000-2023.

Fig 6. Number of migrating bean geese (*Anser fabelis*) over the day (cumulative). Data from artportalen.se year 2000-2023.

Fig 7. Number of migrating arctic terns (*Sterna paradisaea*) over the day (cumulative). Data from artportalen.se year 2000-2023.
Fig 8. Number of migrating rough-legged buzzards (*Buteo lagopus*) over the day (cumulative). Data from artportalen.se year 2000-2023.

Fig 9. Number of migrating herring gull (*Larus fuscus*) over the day (cumulative). Data from artportalen.se year 2000-2023.

Fig 10. Number of migrating cranes (*Grus grus*) over the day (cumulative). Data from artportalen.se year 2000-2023.