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Prognosis and assessment of bird collision risks at wind turbines in northern Germany (PROGRESS)

Joint research project, reference number (BMWi) 0325300 A-D

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The project „Prognosis and assessment of bird collision risks at wind turbines in northern Germany (PROGRESS)“ is a joint research project of the three consultancies BioConsult SH GmbH & Co. KG, ARSU GmbH, IFAÖ GmbH and the Department of Animal Behaviour of the University of Bielefeld.

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10 SUMMARY AND CONCLUSIONS

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Summary

The research project “Prognosis and assessment of collision risks of birds at wind turbines in northern Germany” (PROGRESS) deals with bird collisions, a central area of conflict between the development of further wind energy use and nature conservation. Since many bird and all bird of prey species are strictly protected by EU legislation, collisions present a legally important conservation aspect in the permission process. This research & development project focused on the extent of mortality at wind turbines. Based on this spatial planning background data for the prognosis and assessment of the collision risk with onshore wind turbines were developed.

So far, only locally conducted studies were available for Germany. Therefore, it was the aim of this project to collect a representative dataset on collision rates of birds with onshore wind farms by conducting a systematic field study across several federal states of Northern Germany and to then develop general statements and recommendations for the conflict assessment and conflict resolution as part of the site selection process for further wind energy development. Comprehensive systematic searches for fatalities and observation of flight patterns were performed at various wind farms.

The project extended previous studies in the field of bird collisions at wind turbines and allows an informed assessment of the development of wind energy utilization in Germany.

In the context of PROGRESS the North German lowland was investigated as a focus area for current and future use of wind energy in Germany. 46 windfarms throughout northern Germany were examined. Emphasis was placed on the federal states of Schleswig-Holstein, Lower Saxony and Mecklenburg-Western Pomerania and Brandenburg. As some windfarms were investigated more than once, a total of 55 data sets were generated (subsequently termed wind farm season). The determined target species were: birds of prey (occurrence in the VSW list), large birds (often small populations) and breeding and resting bird species (utilization of the wind farm area).

PROGRESS is a collaboration between the three consultancies BioConsult SH GmbH & Co.KG, ARSU GmbH and IfAÖ GmbH and the Department of Animal Behaviour of the University of Bielefeld.

The start of the project was the 1st of November 2011 for a period of up to the 30th of June 2015. A project accompanying group (PAG) met on the 22nd February 2012 at the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety and on the 22nd of January 2014 at the Federal Ministry for Economic affairs and Energy in Berlin. Two workshops with international participants were held (28./29. November 2012 in the BMU, Berlin and 09. March 2015 at the TU Berlin).

Presentations from the workshops and this final report can be found on the PROGRESS website (www.bioconsult-sh.de/projekte/progress).

The search for collision victims was conducted in five field seasons from spring 2012 to spring 2014 (three spring and two autumn field campaigns). In the context of PROGRESS 46 different WP were examined. Since some wind farms were examined more than once (two to three times), overall 55 wind farm seasons were recorded. Searches were carried out with a transect design where mostly two scientists searched for dead birds along predefined parallel transects that were 20 m apart. All retrievals within a search plot – with a radius of the height of the wind turbine– were classified as collision victims.

A total of 291 birds were found during the study period. The two most frequently found species were the common species Wood Pigeon (*Columba palumbus*) and Mallard (*Anas platyrhynchos*). Among the 15 most frequently found species are five target species of the project: Common Buzzard (*Buteo buteo*), Lapwing (*Vanellus vanellus*), Golden Plover (*Pluvialis apricaria*), Red Kite (*Milvus milvus*) and Kestrel (*Falco tinnunculus*). Waterfowl (ducks, geese/waders/gulls) represent half of the fatalities. The group of other non-passerines is the largest group due to doves which were frequently found. Birds of prey do not dominate the list. Nocturnal broad front migratory songbirds (especially thrush species) are hardly represented among the fatalities.

The total track length that was covered amounted to 7,672 km. With 291 birds found in total, this lead to an average of one bird found every 27 km.

The estimated total number of fatalities was extrapolated from the number of birds that were actually found by considering several correction factors. The rendered surface extent was determined by buffering the actual transect line in the search circle with 10 m wide strips on both sides.

The carcass removal rate (caused e. g. by predators) was determined experimentally by conducting 81 experiments in which 1,208 birds were laid out in 46 windfarms. The calculated daily probability of finding the bird ("survival probability") was high (usually over 90%).

The search efficiency was determined experimentally by placing birds (two conspicuousness classes) in different areas covering five vegetation classes. Under good search conditions about 50% of the inconspicuous birds and 72% of the more noticeable birds were found. The good agreement between the scientists (high observer reliability) justifies the general applicability of the survey results.

The expected distribution of collision victims was determined by placing the individually measured distances of the retrievals to the wind turbine in relation to the total rendered surface in that particular distance ring.

The proportion of collision victims outside the search circle was between 7 and> 20 %. However, for the collision victim estimate, only birds that were found within the search circle were taken into account, as the search effort can only be calculated for these finds. In order to avoid an underestimation of the number of actual collision victims, it is necessary to correct for the proportion of collision victims outside the search circle.

For the following species and species groups an extrapolation to each surveyed wind farm was carried out: Common Buzzard, Golden Plover, gulls, Kestrel, Mallard, Lapwing, Red Kite, waders, Wood Pigeon, Skylark (*Alauda arvensis*) and Starling (*Sturnus vulgaris*).

The relative uncertainty of these projections decreased only with more than ten actual finds, so that for five species or groups of species an extrapolation for the non-examined wind turbines and wind farms in the entire study area of PROGRESS (federal states NI, SH, MV und BB) was performed. These are shore birds, Common Buzzards, gulls, Wood Pigeon and Mallard.

An extrapolation of the results for the entire project area leads to numbers of around 7,800 Common Buzzards, 11,000 Wood Pigeons and 11,800 Mallards killed per year. Based on the breeding population in the project area this translates to 0.4 % of Wood Pigeons, 4.5 % of Mallards and 7 % of Common Buzzards (with floaters and migrating birds). Other estimates of anthropogenic fatality do not exist for Germany. In the US, LOSS et al. (2015) showed negligible numbers of wind energy fatalities compared to fatalities caused by cats, buildings, traffic, power lines and communication towers. In Germany, the actual dominating cause of death of (ringed) birds of prey is traffic (BAIRLEIN et al. 2014).

For comparison, the annual harvest by hunting is 12 times higher for the Mallard and 16 times higher for the Wood Pigeon. For the protected Common Buzzard, the reported kills in Schleswig-Holstein were in the range of 18 % of the breeding population with floaters and migrating birds until 1970.

In the context of PROGRESS, observations across 55 windfarm seasons were carried out in northern Germany to assess the spatial distribution of birds flying near or within windfarms and their avoidance behaviour in relation to wind turbines. We distinguished between target species (birds of prey, waders, geese, cranes and other large birds) and secondary species that were recorded with a varying degree of intensity.

The most abundant secondary species were Wood Pigeon and Starling. Most individuals observed within the rotor height were pigeons and swifts. Songbirds, gulls and ducks were predominantly observed below the rotor swept zone.

The largest share of sightings of target species consisted of raptors, while the most frequently observed group of birds were geese. The most frequently observed raptor species were Common Buzzards and Red Kites. Other raptor species only occurred in lower numbers.

For both geese and crane (*Grus grus*) avoidance of windfarms as well as a distinct avoidance behaviour could be observed. Birds of prey on the other hand were found disproportionately often in the vicinity of wind turbines and hardly displayed a recognizable avoidance behaviour. There is a mixed picture for waders.

Across 55 wind farm seasons, systematic collision victim searches were carried out and data on flight activity were collected for selected target species in parallel for PROGRESS. This approach allowed an analysis of the extent to which the number of estimated collision victims, based on the collision victim searches, is dependent on the determined flight activity. Furthermore, it was assessed whether the number of collision victims, based on the flight activity data and projected by the BAND-model, were consistent with the numbers determined by collision victim searches. This led to the following results:

- For the Common Buzzard and the Golden Plover, no significant influence of flight activity on the number of determined collision victims could be observed.

- On the basis of the recorded flight activity data, the projections of the BAND model led to a drastic underestimation of collision victims.

In this project, all parameters, assumptions and calculation steps that feed into the BAND-model were considered in terms of possible effects on this result. In summary, the mechanistic structure of the BAND-model cannot depict the inherent variability of the raw data. In particular, the stochasticity of flight activity in the danger zone (see chap. 5.4.2.4, 5.4.3.1 und 5.4.3.2) and a combination of uncertainty factors (see chap. 5.4.4) appear to be decisive for this.

The validation approach results of PROGRESS are in agreement with the critical discussion of the BAND-model in the literature (CHAMBERLAIN et al. 2006, MAY et al. 2010, 2011).

The inadequate results of the BAND model projections can partially be attributed to the flight activity observations that fail to depict it in adequate quantity or quality (very small sample size, high impact of individual events). However, chap. 5.4.2.2 shows that for a 'correct' projection, regarding the determined collision victims such a large amount of flight activity data would have to be recorded that in view of the knowledge about activity times of the observed species during the day, this has to be considered as unrealistic.

The observed discrepancy between the estimates based on the collision victim searches and the projections of the BAND-model is thus only partially attributable to methodological problems of the observation of spatial use. As shown, a number of inherent weaknesses in the BAND-model approach also contribute to this discrepancy. In addition, it is sensitive when changes are made to various input data (CHAMBERLAIN et al. 2006). Although technical parameters such as rotor diameter and total height are fixed, other parameters such as rotor speed or the angle of the tilt of blades are difficult to include precisely. Concerning bird behaviour, next to the proportion of activity in the danger zone, flight speed, flight height and wind direction are also subject to a high level of uncertainty.

Overall, the main problem of the calculations using the BAND-model seems to be largely the only vague relationship between the observable flight activity and the collision risk. The model assumes a linear relationship between the length of stay and danger, which does not apply in most cases (DE LUCAS et al. 2008). In addition, the collision model contains information about the avoidance rate in the form, which implies that a certain - but ultimately unknown - part of the projected birds on a collision course performs appropriate responses to avoid a potential collision. The model also assumes that this avoidance rate is constant over all individuals of a species (regardless of age), which has to be considered unlikely. Thus, the biggest limitation of the model is based on the many hardly substantiated assumptions about bird behaviour, simply because the BAND-model is a stochastic/mechanistic and not a behavioural model.

Given these results, it is assumed that the existing environmental stochasticity and irregular, but not necessarily rare sporadic events, which lead to a diversion of attention or a restriction of manoeuvrability (e. g. territorial conflicts, wind gusts), cannot adequately be represented using such a mechanistic model. This is particularly noticeable for the assumption that the probability of presence and thus the probability of collision of a bird is supposed to be identical at any given point within a height class of an area.

However, various studies have shown that single-detached or peripheral wind turbines often stand out as collision sites and specific wind turbine locations are associated with an increased risk (ORLOFF & FLANNERY 1992, BARRIOS & RODRÌGUES 2004, SMALLWOOD & THELANDER 2004, EVERAERT & STIENEN 2007, DREWITT & LANGSTON 2008, SMALLWOOD & KARAS 2009, SMALLWOOD et al. 2009, FERRER et al. 2012). Nevertheless, a majority of studies (mostly meta-analyses) cannot identify a distinct statistical connection between mortality rates and the characteristics of a given wind turbine (HÖTKER 2006, BARCLAY et al. 2007, PEARCE-HIGGINS et al. 2012). Furthermore, the majority of wind turbines do not cause fatalities (BARRIOS & RODRÍGUEZ 2004, DE LUCAS et al. 2012a).

Even though there might be complicated interrelationships between plant-specific characteristics, topography and species-specific behaviour (BARRIOS & RODRÍGUEZ 2004, SMALLWOOD et al. 2009, DE LUCAS et al. 2012b, SCHAUB 2012), it is likely that the location of the wind turbine within the surrounding landscape has a greater impact than particular turbine characteristics such as the hub height (Hötker 2006). Thus, there is a broad consensus in the literature that the risk of collision is mainly dependent on the location, the topography and the range of species (GOVE et al. 2013).

Other factors such as the prevailing wind conditions, other weather parameters or type and height of flight and the time of day additionally affect the risk, as well as the age of the animals, their behaviour (interactions etc.) and the time of the annual cycle of the species (LANGSTON & PULLAN 2003). Only if each of these aspects is taken into account, ideally, can the risk be assessed adequately.

Given the results, the suitability of the BAND-model for the evaluation of an anticipated collision risk for a planned windfarm at an 'average' onshore site is limited, since the projections do not forecast absolute collision victims at an adequate scale. However, the model allows standardized comparisons of relative risks, e.g. for the assessment of various repowering scenarios (DAHL et al. 2015) or to illustrate the influence of various distances to a breeding site (RASRAN & THOMSEN 2013).

Otherwise, it appears that the model can only be used sensibly, when the variability of flight activity is as low as possible, i.e. that there is a good predictability to the course, altitude, direction and intensity of the use of flight paths. For example, this might be the case for flights between breeding colonies of gulls, terns or herons and their foraging grounds, on concentrated migratory routes (guiding lines along a relief) or occasionally during foraging flights of Ospreys (*Pandion haliaetus*) and White-tailed Eagles (*Haliaeetus albicilla*) (high fidelity to breeding sites and consistent foraging areas). But even for large bird species the location of the used area in each year – and thus their spatial use – can change due to changing cultivation conditions (shown for the Lesser Spotted Eagle: LANGGEMACH & MEYBURG 2011). Also the actual or missing breeding success and not least the presence of possible neighbours and their breeding success (MEYBURG et al. 2006, LANGGEMACH & MEYBURG 2011, MELUR & LLUR 2013) play a crucial role for the anticipated flights through the area of a planned wind farm.

A further aim of the PROGRESS project was to model target species on the population level considering an additional mortality due to collisions with wind turbines based on the determined collision rates. Deterministic matrix models were used to simulate whether the additional mortality would affect the population trajectories of target species in a qualitative way. The analysed data allowed an assessment of the effects on the target species Common Buzzard (*Buteo buteo*), Red

Kite (*Milvus milvus*) and Common Lapwing (*Vanellus vanellus*), whereas the credibility interval for the estimated collision rate of White-tailed Sea Eagles (*Haliaeetus albicilla*) was so large that any interpretation of the simulation was deemed to be not meaningful. Two scenarios of wind turbine density were considered: first the actual density of wind turbines as of 2014 for the federal states of NI, SH, MV and BB, secondly the annual wind turbine dynamics for these federal states between 2000 and 2014. All simulations based on the median collision rate resulted in decreasing populations for the Common Buzzard, and four out of six simulations did so for the Red Kite, with two simulations predicting stable population. Based on these results, it is apparent that collisions with wind turbines will have effects that will lead to declining populations for these two species. For the Common Lapwing, potentially significant population effects are currently masked by the already very negative population dynamics, most likely caused by a very low reproductive rate. These conclusions seem to be relatively robust against changes in the assumptions underlying the models.

A multivariate analysis to explain variation between windfarms in the estimated collision rate for eleven species or species groups was conducted. The question was, whether certain windfarms are more prone to lead to collisions due to the surrounding habitat or the turbine characteristics of the wind turbine. The analyses were based on agricultural use data, distance of the windfarm to the next forest patch as well as turbine characteristics. Principal component analysis was conducted before multivariate model selection was performed, based on an information-theory approach. For the vast majority of species or species groups (eight out of eleven analyses), no robust correlate of variation in collision rate between windfarms could be found, and further analyses suggested that for two out of the three species or species groups, the found correlates were not robust against outlier removal. Hence, only for one species group (gulls), a robust correlate of variation in collision risk between windfarms was found. In conclusion, variation in the collision rate between windfarms could not be explained by the variables included in this analysis, or it could be that collisions with wind turbines are mostly a stochastic event that is hard to predict by any habitat variables.

The systematic collision victim searches for PROGRESS have demonstrated that collision victims are to be expected at almost any wind farm site (in only 6 of 55 wind farm seasons no collision victims were found, Chap. 2). In addition, it is apparent from the PROGRESS list of species and from the VSW list that in principle any species might collide with a wind turbine. However, there are marked and specific differences how different species are affected. In absolute terms, common species that stay within windfarms without a pronounced avoidance behaviour collide the most (e. g. Skylark, Starling, Wood Pigeon, Mallard, Common Buzzard, gulls). In relation to population size birds of prey and large birds collide disproportionately frequently.

With respect to legal species protection requirements during the planning of a wind farm site, it is necessary to examine whether species occur in the area that are “especially prone to be affected due to their behaviour”. The number of potential victims has to exceed a certain value so that a significantly increased killing risk can be asserted, and that can in turn be considered as significant in terms of population size and natural mortality. It is therefore necessary to assess in each case, taking specific local factors into account, whether for certain particularly collision prone species (due to their spatial use and behaviour) collision victims have to be expected to an extent that has to be considered as significant in the light of their sensitivity at the population level. This extent, as a criterion for a significantly increased killing risk, is species-specific and may vary from one individual (e. g. for the Lesser Spotted Eagle (*Aquila pomarina*)) to a larger number (e. g. Skylark or Mallard). However, it does not have to be that large that it already leads to adverse effects at the population level.

This threshold for a significantly increased collision risk is thus a quantitative measure, which can, however, not be expressed as tangible numbers for collision victims. This is primarily the case, due to the lack of a validated method to forecast the collision risk before the construction of a windfarm (Chap. 5), in part because a clear quantitative relationship between flight activity and collision risk has so far not been established for birds (Chap. 3), unlike for bats. This is especially true in the light of the long period of operation of a windfarm, within which there may be significant changes in the situation for the local population and thus the collision risk. In this respect there is no standard to check compliance or whether an o absolute threshold level has been exceeded.

Generalized statements for the occurrence of a significantly increased collision risk are therefore limited. For breeding birds the distance to the nesting site can be used as a first approximation, within which an increased flight activity or particularly collision prone behaviours (e. g. courtship and territorial flights) have to be expected for certain species. A tangible assessment of the collision risk is only possible for individual cases, for which a qualitative behavioural ecological assessment based on a spatial land use analysis is proposed. For this, however, the species-specific spatial-temporal variability of land use has to be considered, in the view of which it is to be assessed, whether the collected data represent only a snapshot and do therefore not constitute a reliable basis for assessing the operational span of the planned windfarm.

Thus, it is proposed to combine this approach with a stronger legal species protection operational support. This may be particularly necessary for those species that are already adversely affected on the population level by collision caused mortality due to the numbers of wind turbines that have significantly increased in Germany. According to current knowledge this is relevant for the Common Buzzard and the Red Kite (Chap. 6). However, it is to be expected that with continued expansion, these cumulative effects will also occur for other species.

Such a legal species protection operational support would be constituted in its core by three pillars of monitoring (inventory control), protective measures (e. g. habitat improvement, increasing breeding success) and possibly temporary operating restrictions - each depending on the target species and the local population trend. With regards to the additional costs, at least some could be absorbed by reducing the very complex spatial land use observations in the course of planning, provided a realistic assessment of the individual case would show that their value has already to be considered limited due to spatial and temporal variability.

It can be assumed that cumulative effects will become more significant with a further increasing number of wind farms. Accordingly, the demands on conflict resolution from a legal species protection point of view will increase. It will also have to be expected more frequently that legal species protection conflicts might not always be adequately resolvable for an individual project. Therefore, overarching solutions are required that accompany the further expansion of wind energy use and ensure that this does not lead to a severe decline of certain bird species that are particularly affected by collisions. Specifically, the following would have to be mentioned:

- Large-scale wildlife conservation programs e.g. for Red Kites and Common Buzzards that improve habits, particularly in terms of food availability and lead to a compensation of collision losses at the population level (increase in reproduction rate, reduction of other anthropogenic mortalities).

- Identification of species-specific density centres that are of particular importance as source populations, and assessing targeted measures to protect and promote them, e. g. by appropriate directed species relief measures, protection against collisions by having wind turbine free areas or by increasing requirements on the avoidance of losses (unless already protected by legal reserve categories).

- Development of concepts and practical testing of a legal species protection operational support in terms of their effectiveness and their economic effects.

- Increased research efforts in terms of scale and addressing cumulative effects.

- Increased research regarding the effectiveness of specific measures for the prevention and control of collision losses.

Conclusions

Collisions of birds (and bats) are a key area of conflict between the expansion of wind energy use and nature conservation. Although a large number of studies have already addressed this topic, there are only a few systematic studies that quantified the collision rates of birds and judged the importance at population level. This complicates the assessment of a possible conflict. With regard to strict legal species protection affecting planning permission for the construction of wind turbines, a lack of knowledge poses a potential obstacle for the intended expansion of wind energy use.

The project PROGRESS investigated for the first time on a large scale and quantitatively the collision rates of birds with wind turbines accompanied by visual flight activity surveys. The North German lowland was chosen as the study area, because of its particular importance for the use of wind energy in Germany and because approximately half of the wind turbines currently operating in Germany are located here (2014: 12,841 in the project area of PROGRESS (federal states Lowe Saxony / Schleswig-Holstein/ Mecklenburg-West Pomarania/ Brandenburg) of a total of 24,867 in Germany (https://www.wind-energie.de/themen/statistiken/deutschland)). Thus, representative statements on the collision risk of birds of Northern Germany are possible for all species. However, due to the relatively small numbers of fatalities found the extent of collisions can only be quantified for fewer species. The project is based on collision victim searches that were conducted with a considerable effort, and a simultaneous determination of detection errors, such as search efficiency and carcass removal of the collision victims as well as an accurate determination of the searched area. The determination of these factors allows an estimation of the actual collision victims for the investigated wind farms and the investigation period. It is a very important result of PROGRESS that the determined correction factors are relatively small, i.e. the search efficiency within the selected transects (20 m width) with a search efficiency of 50 to 70 % under good conditions and the persistence of carcasses of collision victims was quite high with a daily removal rate of < 10 %. These two correction factors only contribute little to the uncertainty in the estimation of the number of fatalities As searching along linear transects result in decreasing relative area coverage with increasing distance to the wind turbine, a larger correction for area coverage is necessary. Nevertheless, the method developed for PROGRESS is considered as very suitable for the estimation of collision victims. However, a naive transfer of the determined correction factors to other studies is not recommended, as they were derived for local conditions and with the particular methodology used. Given these assumptions and based on of this methodology for the determination of collision victims, we emphasise that:

1. the required effort is very high. For PROGRESS and under good search conditions (flat agricultural land with low vegetation) in a 20 m wide search strip, one collision victim was found for every27 km of transect line searched. With a total effort of 7,500 km of covered transect line 291 fatalities were found which were distributed among 57 species. The necessary effort to obtain robust data on species-specific collision rates is thus very high.

2. the possible investigation effort is limited by geographical features and vegetation structure. The search for collision victims in areas with a higher and/or denser vegetation than what has been accepted for PROGRESS would severely restrict search efficiency and significantly raise the necessary effort to obtain a sufficient sample size. Search effort in fullgrown cereal or maize fields as well as in forests was therefore deemed unacceptable during PROGRESS. This limits the applicability of the method, both seasonally and spatially. However, since no alternative methods, which would allow more efficient searches, are currently available, this is regarded as a tolerable restriction for the determination of collision rates, but it has to be considered when actual collision rates are projected.

3. the low finding rates – in accordance with the low collision rates of most species – impedes the formulation of quantitative statements, especially for rare species, because the necessary effort for these species is not workable cannot be rendered. However, since some particularly relevant species, e. g. birds of prey, have relatively low abundances, the necessity arises that other methodological approaches for the determination of collision rates have to be developed, too.

The overall low numbers of fatalities found allow a projection of collision numbers for the investigated windfarms for eleven species/ species groups and a projection for the entire study area of PROGRESS for five species/ species groups. Among the eleven frequent collision victims 71 % are accounted for by five species/ species groups: Skylark, Starling, Mallard, gulls and Wood Pigeon. It is noteworthy that these species account for only 28 % in the national reference database of Vogelschutzwarte Brandenburg (VSW-list). Birds of prey, which are represented in the national reference database with 35 %, account for only 11 % of fatalities according to PROGRESS data. This highlights the necessity for systematic studies with consideration of investigation effort and correction factors. Chance records of fatalities in unsystematic controls automatically lead to a bias for more noticeable species and species with higher public interest. This hampers the assessment of the actual degree to which the various species are affected.

In accordance with the accompanying visual observations the majority of collisions happen to abundant and non-endangered species of the agricultural landscape, which are resting or foraging in the wind farm. The collision risk is species specific, but a high similarity seems to exist for related species. This allows, at least within certain boundaries, a transfer of the assessment of the collision risk to species for which little data exists so far. Those species that collide frequently, as well as birds of prey, were found disproportionately often in the vicinity of wind turbines and displayed hardly recognizable avoidance behaviour. Geese and Crane, on the other hand, exhibit both macro and micro avoidance behaviour around wind turbines. Among the fatalities, nocturnally migrating species are significantly underrepresented and a threat by wind turbines to species of the nocturnal broad front migration of northern songbirds can be ruled out. Given the high investigation effort, it can be assumed that those species that are common in the study area, but were only detected in small numbers as collision victims, are not significantly affected by the recent expansion of wind energy in the North German lowland. For rare species, however, this conclusion cannot be drawn due to a limited sample size even in this investigation.

Overall it is noteworthy that collisions with wind turbines predominantly occur during the day and affect species with good flying capabilities, whereas species with poor manoeuvrability, such as geese or cranes, and nocturnal migrant species collide significantly less frequently with wind turbines. On the other hand, the exact time of the collision event is not known and may, in particular for the frequently found collision victim Mallard, which was observed only in small numbers during the day, have happened during the night. Reflecting of the results of the flight activity observations, the species composition of the collision victims indicates that the collision risk is largely determined by the behaviour of the birds towards the wind turbines. While some species apparently perceive wind turbines as disturbing structures, other species approach them without showing any avoidance behaviour at all and are thereby endangered by the rotors. Specific behaviours (courtship, territorial fights, foraging, etc.) can affect the perception of wind turbines. The accompanying flight activity observations of birds within the investigated wind farms, as well as a habitat analysis did not allow to conclude, under which circumstances collisions occur. This indicates that the risk of collision significantly arises from the situational behaviour of birds towards wind turbines, which currently cannot be generalized, so that the existing projection models cannot predict collision rates of birds based on their flight behaviour with satisfactory accuracy.

The population models indicate a negative effect on the population level for the Common Buzzard. This is a new and surprising result, since the Common Buzzard –the most common raptor in Germany - has so far not been considered in the planning process of wind farms. Considering the nationwide distribution and a generally increased collision risk for raptors, a population level effect for this species due to the expansion of wind energy utilization is plausible. The models show similar effects for the Red Kite, but in PROGRESS, the effects on the population of the Red Kite may have been even underestimated because the core distribution area of the species was not included.

Further investigations in Red Kite core areas are hence recommended. For the White-tailed Eagle, PROGRESS generated insufficient data to identify population effects. Only a limited number of variables of relevance for raptor populations can be incorporated into models and the population projections have rather large confidence intervals. However, other less abundant raptor species lacking sufficient data could well be affected on the population level by the already installed number of wind turbines in northern Germany. Factors being relevant at least at the local level cannot be ruled out for other species such as Lapwing.

The outcome of PROGRESS gives an all-clear signal of no concern for the majority of bird species of northern Germany. For other species, especially Common Buzzard and Red Kite, the results indicate that estimated fatality rates based on the current state of wind farm development could already lead to a population decline.

The outcomes of PROGRESS reveal difficulties to identity and use mitigation measures to reduce the risk of collision of endangered species in the planning process of wind farms. Previous approaches addressed primarily minimum distances from breeding sites of endangered species to reduce the collision risk. This is justified as the breeding site is an activity centre - at least in the breeding season and based on the assumption that the collision risk is correlated with frequency of flight movements.

The effectiveness of standard distance radii is however countered by the fact that flight activity of species is not evenly distributed across different habitats and that habitat use is rather variable throughout the year and over the years

All species showing frequent fatalities also occur outside the breeding season in northern Germany, some of the collision victims found only occur as staging birds. The number of fatalities was comparable between the spring and autumn seasons in single species – e. g. Skylark - the collision risk is influenced by specific flight activity pattern in the breeding season, but for most other species, there is no such evidence.

All species with frequent fatalities depend in their abundance on the actual type of land use which changes over seasons and years. Changes in land use result in changes of the breeding site and feeding and resting areas. This limits the possibilities for mitigation and avoidance at the project level to a great extent. As a consequence, the total number of fatalities depends on the total number of wind turbines installed across a larger area which cannot be addressed in the planning process of single wind farm or even wind turbine projects.

In the context of the proposed increase of wind energy use the following measures are recommended to (1) examine the consequences of collisions for bird populations of conservation concern in more detail, and to identify methods (2) how to avoid conflict and (3) support populations of conservation concern.

1. Comprehensive population studies on Common Buzzard, Red Kite and other potentially endangered species are recommended. Models should incorporate individual based modelling, (IBM), which include density-dependent processes, resources and other causes of mortality. Additional investigations applying PROGRESS methodology are recommended.

2. Compensatory measures must be established, not at individual project level, but within the framework of regional planning. As a consequence crucial core areas for breeding or staging of endangered species should have no or fewer additional wind turbines. Exclusion areas for wind energy use should also be protected legally. Repowering should be considered as potential mechanism to constrain the growth of, or even reduce, the number of wind turbines per unit area, especially in core areas of species of conservation concern.

3. Since most species of concern inhabit the agricultural landscape, a habit associated with strongest decrease among bird species in Germany, further intensification of agriculture should be constrained and the structural diversity of the agricultural landscape should be increased.

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