Overlap between breeding season distribution and wind farm risks: a spatial approach

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While the interactions between wind turbines and birds have been studied comprehensively in recent years, large scale assessments on likely effects of the current development status of the wind energy sector on sensitive species are often missing. To mitigate wind farm related risks for birds, the Working Group of German State Bird Conservancies published species-specific minimum distances of wind turbines to breeding sites that should be kept free from turbines. Using these recommendations the overlap between the breeding distribution and areas of wind farm related risks was estimated as well as the proportions of bird populations potentially influenced by the current state of wind energy production. The assessment was carried out based on the distribution and abundance information of the recently published second Atlas of German Breeding Birds, land use information of the Corine Land Cover data base and location information for operational onshore wind turbines on German territory. The results indicate a considerable overlap between the breeding season habitat and areas of wind farm related risks for various sensitive species. Especially the group of open landscape species regularly face potential disturbance of 9 to 13 % of their breeding season habitat. For individual species, often with only regional distribution in Germany, even considerable higher potential habitat disturbance figures are found with values up to 55 %. For most species, values for percentage habitat disturbance and estimates on the proportion of the national population to be influenced by wind turbines were relatively similar.

Keywords: wind turbines, potential habitat disturbance, distance recommendations, sensitive species, overlap

1. Introduction

In 2015 gross wind energy production, on- and offshore, accounted for 13.3 % of the energy production in Germany and while there is a recent strong increase in wind energy generated offshore, the majority of wind energy is produced by nearly 26,000 onshore wind turbines (strom-report.de).

The effects onshore wind turbines impose on various bird species have been studied comprehensively in recent years and collision risk, habitat loss due to displacement and barrier effects have been identified as key impacts (e.g. Percival 2005, Drewitt & Langston 2006, Pearce-Higgins *et al.* 2012, Bellebaum *et al.* 2013). To mitigate wind farm related risks for birds, the Working Group of German State Bird Conservancies (LAG VSW) defined species-specific core activity zones around nesting sites that should be kept free from onshore wind turbines. These distance recommendations were informed by knowledge on species-specific sensitivity and home range size during the breeding season. Moreover, density hotspots of sensitive species should receive increased attention during the planning and approval process for wind turbines to secure source populations (LAG VSW 2014).

These species-specific distance recommendations should be considered at the planning stage and were used to estimate the overlap between potential breeding season habitats (breeding as well as foraging habitat during the breeding season) of sensitive species and areas of increased disturbance potential due to wind energy production. The assessment is based on the assumption that wind turbine related risks, respectively habitat devaluation, is likely to occur within the recommended distances irrespective of whether such zones around wind turbines are used as nesting sites or foraging habitat.

Species-specific breeding distribution was defined based on data of the recent Atlas of German Breeding Birds (Gedeon *et al.* 2014) and potential habitat within the respective distributional range determined using Corine Land Cover classes (CLC 2012). Wind turbine locations were buffered by species-specific distance recommendations to estimate the percentage spatial overlap between habitats and wind farm risk areas. This allows a cumulative assessment of the habitat disturbance associated with wind energy production across the entire German breeding range of sensitive species.

2. Data and methodology

The study assessed the overlap between breeding season habitat and wind farm related risks for those species identified by LAG VSW to be sensitive to wind farms (see Table 1) based on the assumption that wind turbines impose certain risks (displacement, collision, barrier effect) on these species within the recommended species-specific distances. A similar spatial analysis approach was followed e.g. by Telleria (2009). Moreover, population percentages potentially affected (not impacted) were estimated.

2.1 Breeding season distribution

The Atlas of German Breeding Birds (Gedeon *et al.* 2014) allows a precise definition of the current breeding season distribution of birds in Germany. The atlas is based on data collected between 2005 and 2009 and provides information on presence and absence of species as well as their abundance at the spatial resolution of the topographic map 1 : 25,000 (grid cells measuring approx. 11 x 11 km). Species abundance classes are provided for each grid cell.

2.2 Species-specific habitat classes

Individual species show specific habitat preferences and accordingly do not occur everywhere within the grid cells identified by Gedeon *et al.* (2014) as populated/occupied. To better understand the potential distribution within individual grid cells and identify potential habitats with relevance for the respective species, land use information was obtained. We used the Corine Land Cover (CLC) 2012 data set, providing land cover information at a geographic accuracy of 25 ha minimum mapping units and 100 m minimum mapping width (EEA 2007). For each species all CLC classes used to describe German territory were divided in those representing potential habitat for the respective species and those where regular usage for foraging or nesting appeared unlikely. This assignment process was informed by the Methodological Manual for Surveying Breeding Birds in Germany (Südbeck *et al.* 2005), listing typical habitats for each species, the result of a research and development project carried out by the Federation of German Avifaunists (DDA) defining ecological bird gilds (Wahl *et al.* 2014) and expert judgments.

This assignment process led to the exclusion of a few species from the assessment. For Osprey *Pandion haliaetus* and White-tailed Eagle *Haliaeetus albicilla* for example a suitable assignment of CLC classes to define the breeding season habitat was not feasible. Both species are strongly related to (especially inland) water bodies, but can breed in various kinds of habitats as long as suitable natural or artificial structures for nesting are available, and they overfly various habitats when commuting between breeding and foraging sites. Accordingly, it would be difficult to discard CLC classes to potentially represent habitat probably aside of strongly urbanized areas, while in fact the species are unlikely to regularly occur at larger distances of water bodies during the breeding season. Also Bittern *Botaurus stellaris* and Little Bittern *Ixobrychus minutus* were excluded for methodological reasons. For both species it was not always possible to indicate suitable habitats based on the CLC classes, leading to situations where Gedeon *et al.* (2014) indicates a breeding season occurrence in a particular grid cells, while those CLC classes identified to represent Bittern habitat (e.g. inland marshes and peat bogs) did not occur within those grid cells. Accordingly, the chosen approach was not suitable to identify and narrow down the potential breeding season habitat, likely because both species of bittern sometimes inhabit habitat patches too small to be mapped at CLC resolution.

Moreover, colonial breeding heron, gull and tern species, listed as sensitive to wind turbines (LAG VSW 2014), were excluded from the assessment, because the chosen approach was not deemed suitable to consider the strong concentrations of colonial breeding species in limited sectors of potentially suitable habitats as indicated by the CLC classes.

Nonetheless, it was possible to narrow down the potential breeding season habitats for 30 species for which minimum distances to wind turbines have been recommended. Table 2 illustrates the results of this assignment process for a few example species.

2.3 Wind farm locations and buffers

Based on these species-specific distance recommendations (LAG VSW 2014; see Table 1) the overlap between potential breeding season habitat and areas of increased risks due to wind energy can be assessed under the precondition that sufficient information on the wind turbine locations is available.

Geographic coordinates of wind turbine locations were enquired from the respective responsible authorities of all German federal states and data were obtained from all states with the exception of Berlin, where only single wind turbines have been built. The currentness of data (12/2014 to 01/2016), status information and data format differed considerably among the federal states. After combining and synchronizing data sets the locations of 24,011 operational onshore wind turbines could be visualized in the Geographic Information System (GIS). The German Agency for Renewable Energy (AEE) names a number of 25,821 onshore turbines in Germany by the end of 2015 (AEE 2016), without explicitly stating that all of these would be operational. Assuming this, we were able to collate point data for about 93 % of the operational onshore wind turbines (status 2015).

In a next step the wind turbine locations were buffered by species-specific distance recommendations, to identify those areas of potential habitat devaluation. By overlaying potential habitat within breeding season distribution with wind turbine buffers the spatial overlap between habitat and wind farm risk areas was estimated.

This allowed a cumulative assessment of the habitat disturbance potential associated with wind energy production across the entire German breeding range of sensitive species. Based on the species-specific percentage potential habitat disturbance calculated for each grid cell populated by the respective species it was possible to roughly estimate the proportion of the populations of sensitive species likely to be influenced by the presence of wind turbines. Therefore we calculated the geometric mean of the abundance

Table 1: Overview on recommended minimum distances of wind turbines to breeding sites of bird species sensitive to wind turbines. In brackets recommended ranges of verification around wind farms for frequently used feeding sites, roosts or other significant habitats (based on LAG VSW 2014). – *Übersicht über fachlich empfohlene Mindestabstände von Windenergieanlagen (WEA) zu Brutplätzen bzw. Brutvorkommen WEA-sensibler Vogelarten. Der in Klammern gesetzte Prüfbereich beschreibt Radien, innerhalb derer zu prüfen ist, ob Nahrungshabitate, Schlafplätze oder andere wichtige Habitate der betreffenden Art bzw. Artengruppe vorhanden sind, die regelmäßig angeflogen werden (basierend auf LAG VSW 2014).*

Species, species group – ***Art, Artengruppe***	**Minimum distance of wind turbines (range of verification) –** ***Mindestabstand der WEA (Prüfbereich in Klammern)***
Grouse species – *Raufußhühner*: Capercaillie *Tetrao urogallus*, Black Grouse *Tetrao tetrix*, Hazel Grouse *Tetrastes bonasia*, Ptarmigan *Lagopus muta*	1,000 m around areas of occurrence; corridors between neighbouring areas of occurrence should be kept free. – *1.000 m um die Vorkommensgebiete; Freihalten von Korridoren zwischen benachbarten Vorkommensgebieten.*
Bittern *Botaurus stellaris*	1,000 m (3,000 m)
Little Bittern *Ixobrychus minutus*	1,000 m
Black Stork *Ciconia nigra*	3,000 m (10,000 m)
White Stork *Ciconia ciconia*	1,000 m (2,000 m)
Osprey *Pandion haliaetus*	1,000 m (4,000 m)
Honey-buzzard *Pernis apivorus*	1,000 m
Golden Eagle *Aquila chrysaetos*	3,000 m (6,000 m)
Lesser-spotted Eagle *Aquila pomarina*	6,000 m
Hen Harrier *Circus cyaneus*	1,000 m (3,000 m)
Montagu's Harrier *Circus pygargus*	1,000 m (3,000 m); density hotspots should be considered irrespective of the current location of breeding sites. – *Dichtezentren sollten insgesamt unabhängig von der Lage der aktuellen Brutplätze berücksichtigt werden.*
Marsh Harrier *Circus aeruginosus*	1,000 m
Red Kite *Milvus milvus*	1,500 m (4,000 m)
Black Kite *Milvus migrans*	1,000 m (3,000 m)
White-tailed Eagle *Haliaeetus albicilla*	3,000 m (6,000 m)
Hobby *Falco subbuteo*	500 m (3,000 m)
Peregrine *Falco peregrinus*	1,000 m; tree breeders population 3,000 m – *Brutpaare der Baumbrüterpopulation 3.000 m*
Crane *Grus grus*	500 m
Corncrake *Crex crex*	500 m around regular breeding sites; density hotspots should be considered irrespective of the current location of breeding sites. – *500 m um regelmäßige Brutvorkommen; Dichtezentren sollten insgesamt unabhängig von der Lage der aktuellen Brutplätze berücksichtigt werden.*
Great Bustard *Otis tarda*	3,000 m around breeding areas; wintering ranges; all corridors between areas of occurrence should be kept free. – *3.000 m um die Brutgebiete; Wintereinstandsgebiete; Freihalten aller Korridore zwischen den Vorkommensgebieten.*
Golden Plover *Pluvialis apricaria*	1,000 m (6,000 m)
Woodcock *Scolopax rusticola*	500 m around display territories; density hotspots should be considered irrespective of the current location of breeding sites. – *500 m um Balzreviere; Dichtezentren sollten insgesamt unabhängig von der Lage der aktuellen Brutplätze berücksichtigt werden.*
Eagle Owl *Bubo bubo*	1,000 m (3,000 m)
Short-eared Owl *Asio flammeus*	1,000 m (3,000 m)
Nightjar *Caprimulgus europaeus*	500 m around regular breeding sites – *500 m um regelmäßige Brutvorkommen*
Hoopoe *Upupa epops*	1,000 m (1,500 m) around regular breeding sites – *1.000 m (1.500 m) um regelmäßige Brutvorkommen*
Endangered meadow bird species sensitive to disturbance: Snipe *Gallinago gallinago*, Black-tailed Godwit *Limosa limosa*, Redshank *Tringa totanus*, Curlew *Numenius arquata* and Lapwing *Vanellus vanellus*	500 m (1,000 m); in case of the Lapwing this also applies to regular breeding sites in arable land, when at least of regional importance. – *500 m (1.000 m); gilt beim Kiebitz auch für regelmäßige Brutvorkommen in Ackerlandschaften, soweit sie mindestens von regionaler Bedeutung sind.*
Colony breeders – *Koloniebrüter*: Herons – *Reiher* Gulls – *Möwen* Terns – *Seeschwalben*	1,000 m (3,000 m) 1,000 m (3,000 m) 1,000 m (min. 3,000 m)

Table 2: Selection of CLC classes to define breeding season habitat (used for breeding and foraging during the breeding season) for a selection of bird species sensitive to wind turbines. “X” indicates “no breeding season habitat”, “0” indicates “breeding season habitat”. – *Auswahl der CLC Landnutzungsklassen zur Eingrenzung des Brutzeitlebensraums (Bruthabitat und während der Brutzeit aufgesuchte Nahrungshabitate) für einige windkraftsensible Beispielarten. „X“ steht für „kein Brutzeitlebensraum“, „0“ steht für „Brutzeitlebensraum“.*

CORINE Land Cover classes – *CORINE Landnutzungsklassen*		Black Stork – *Schwarzstorch*	Lesser Spotted Eagle – *Schreiadler*	Montagu‘s Harrier – *Wiesenweihe*	Red Kite – *Rotmilan*	Snipe – *Bekassine*	Lapwing – *Kiebitz*
Urban fabric	1.1.1 Continuous urban fabric – *Durchgängig städtische Prägung*	x	x	x	x	x	x
	1.1.2 Discontinuous urban fabric – *Nicht durchgängig städtische Prägung*	x	x	x	0	x	x
Industrial, comercial and transport units	1.2.1 Industrial or commercial units – *Industrie- und Gewerbeflächen*	x	x	x	0	x	0
	1.2.2 Road and rail networks and associated land – *Straßen, Eisenbahn*	x	x	x	0	x	x
	1.2.3 Port areas – *Hafengebiete*	x	x	0	0	x	x
	1.2.4 Airports – *Flughäfen*	x	x	0	0	x	0
Mine, dump and construction sites	1.3.1 Mineral extraction sites – *Abbauflächen*	x	x	0	0	x	0
	1.3.2 Dump sites – *Deponien und Abraumhalden*	x	x	0	0	x	0
	1.3.3 Construction sites – *Baustellen*	x	x	x	x	x	x
Artificial, non-agricultural vegetated areas	1.4.1 Green urban areas – *Städtische Grünflächen*	x	x	x	x	x	x
	1.4.2 Sport and leisure facilities – *Sport- und Freizeitanlagen*	x	x	x	0	x	x
Arable land	2.1.1 Non-irrigated arable land – *Nicht bewässertes Ackerland*	x	0	0	0	x	0
Permanent crops	2.2.1 Vineyards – *Weinanbauflächen*	x	x	x	0	x	x
	2.2.2 Fruit trees and berry plantations – *Obst- und Beerenobstbestände*	x	0	x	0	x	x
Pastures	2.3.1 Pastures – *Wiesen und Weiden*	0	0	0	0	0	0
Heterogeneous agricultural areas	2.4.2 Complex cultivation patterns – *Komplexe Parzellenstrukturen*	x	0	0	0	x	0
	2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation – *Landwirtschaft und natürliche Bodenbedeckung*	x	0	0	0	x	0
Forests	3.1.1 Broad-leaved forest – *Laubwälder*	0	0	x	0	x	x
	3.1.2 Coniferous forest – *Nadelwälder*	0	x	x	0	x	x
	3.1.3 Mixed forest – *Mischwälder*	0	0	x	0	x	x
Scrub and/or herbaceous vegetation associations	3.2.1 Natural grasslands – *Natürliches Grünland*	0	0	0	0	0	0
	3.2.2 Moors and heathland – *Heiden und Moorheiden*	0	0	0	0	0	0
	3.2.4 Transitional woodland-shrub – *Wald-Strauch-Übergangsstadien*	0	0	0	0	x	x
Open spaces with little or no vegetation	3.3.1 Beaches, dunes, sands – *Strände, Dünen und Sandflächen*	x	x	0	x	x	0
	3.3.2 Bare rocks – *Felsflächen ohne Vegetation*	x	x	x	x	x	x
	3.3.3 Sparsely vegetated areas – *Flächen mit spärlicher Vegetation*	x	0	0	0	x	0
	3.3.4 Burnt areas – *Brandflächen*	x	0	x	0	x	x
	3.3.5 Glaciers and perpetual snow – *Gletscher und Dauerschneegebiete*	x	x	x	x	x	x
Inland wetlands	4.1.1 Inland marshes – *Sümpfe*	0	0	0	x	0	0
	4.1.2 Peat bogs – *Torfmoore*	0	0	0	0	0	0
Maritime wetlands	4.2.1 Salt marshes – *Salzwiesen*	x	x	0	x	0	0
	4.2.3 Intertidal flats – *In der Gezeitenzone liegende Flächen*	x	x	x	x	x	0
Inland waters	5.1.1 Water courses – *Gewässerläufe*	0	x	x	0	x	x
	5.1.2 Water bodies – *Wasserflächen*	x	x	x	x	x	x
Marine waters	5.2.1 Coastal lagoons – *Lagunen*	x	x	0	x	0	0
	5.2.2 Estuaries – *Mündungsgebiete*	x	x	x	x	x	x
	5.2.3 Sea and ocean – *Meere und Ozeane*	x	x	x	x	x	x

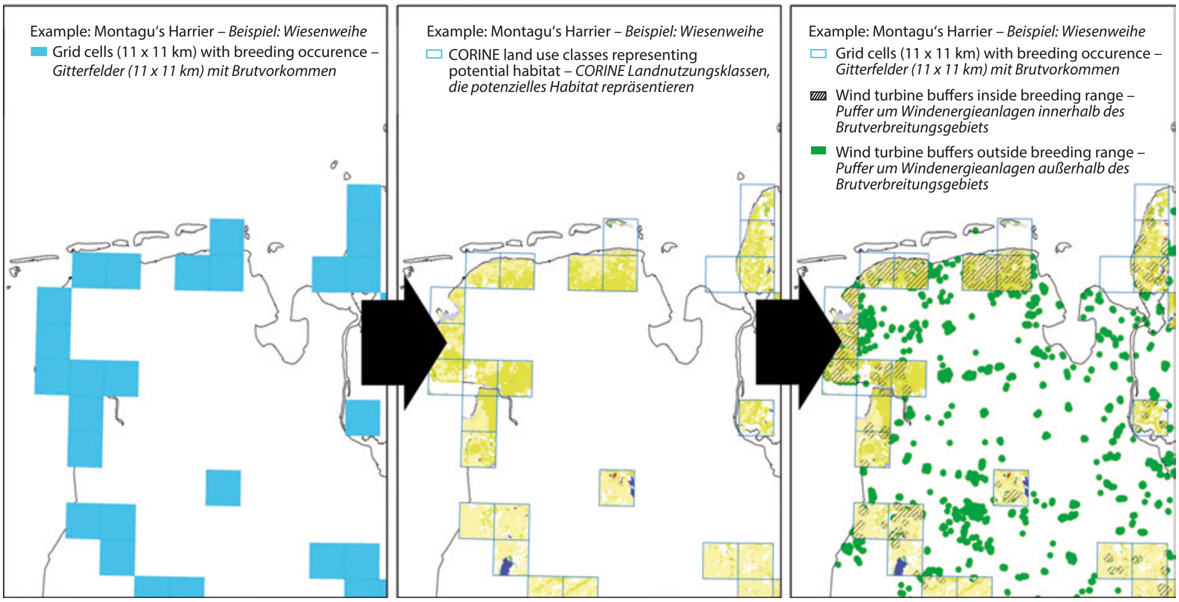


Fig. 1: Illustration of methodological approach: Within grid cells with breeding occurrence (left map) CLC classes representing potential habitat were identified (central map) and overlaid with wind farm locations buffered by the LAG VSW distance recommendation (right maps). – *Veranschaulichung des methodischen Ansatzes: Innerhalb der Gitterfelder mit Brutzeitvorkommen (linke Karte) wurden CLC Landnutzungsklassen identifiziert, die potenzielles Habitat darstellen (mittlere Karte), und dieses mit den, entsprechend der LAG VSW Empfehlungen, gepufferten Windkraftstandorten überlagert (rechte Karte).*

classes defined in Gedeon *et al.* (2014) for each grid cell and sensitive species and multiplied the grid cell specific population estimate by the percentage potential breeding season habitat identified to be disturbed by wind turbines (i.e. overlaid by a species-specific buffer based on the LAG VSW (2014) distance recommendations). Grid cell specific population estimates identified to potentially be affected by wind farm related risks were summed and compared with the national population estimates (sum of geometric means of abundance classes of all grid cells).

2.4 Testing for correlation

Based on a generated gridded dataset of wind turbine locations and presence/absence as well as abundance information of Gedeon *et al.* (2014) at the same spatial resolution, it was possible to test for correlations between the observed frequency of wind turbines and 1) the number of sensitive bird species per grid cell and 2) the mean number of breeding pairs of all sensitive species assessed per grid cell. As statistical tests concluded that the correlated characteristics are not normally distributed, we used a non-parametric Spearman's rank correlation.

3. Results

The assessment resulted in maps visualizing the degree of potential habitat disturbance due to wind turbines for individual species as well as overview maps indicating the distribution of overall habitat disturbance potential across species. Moreover, it was possible to estimate the proportions of populations of sensitive species potentially affected.

3.1 Species-specific maps

Species-specific maps visualizing the degree of potential habitat disturbance due to wind turbines (see Fig. 2) were generated for all 30 sensitive species assessed. For each grid cell with breeding occurrence the percentage overlap between habitat and wind farm risk areas can be read from those maps, allowing local assessments of existing potential pressures on sensitive species while providing a national overview at the same time. The maps represent a valuable tool for species conservation because they enable a quick overview of the regional strength of pressures from wind energy generation and make it easy to assess and compare pressures e.g. across different population strongholds or e.g. between Special Protection Areas (SPAs) and their surrounding respectively other regions.

Results can be best explained looking at an example species. Fig. 2 presents the species-specific map for Montagu's Harrier *Circus pygargus*. For this species highest overlaps between habitat and wind farm risk areas occur in grid cells bordering the North Sea coast of Lower Saxony and Schleswig-Holstein. Here, regularly more than 50 % (and up to 78 %) of potentially suitable habitat is disturbed by wind farm related risks. Besides collision risk (Langgemach & Dürr 2016) also displacement of Montagu's Harrier has been proven for particular subpopulations (Joest *et al.* 2013, LAG VSW 2014). Looking at population strongholds in Germany (in case of Montagu's Harrier regions in which several bordering grid cells support abundances

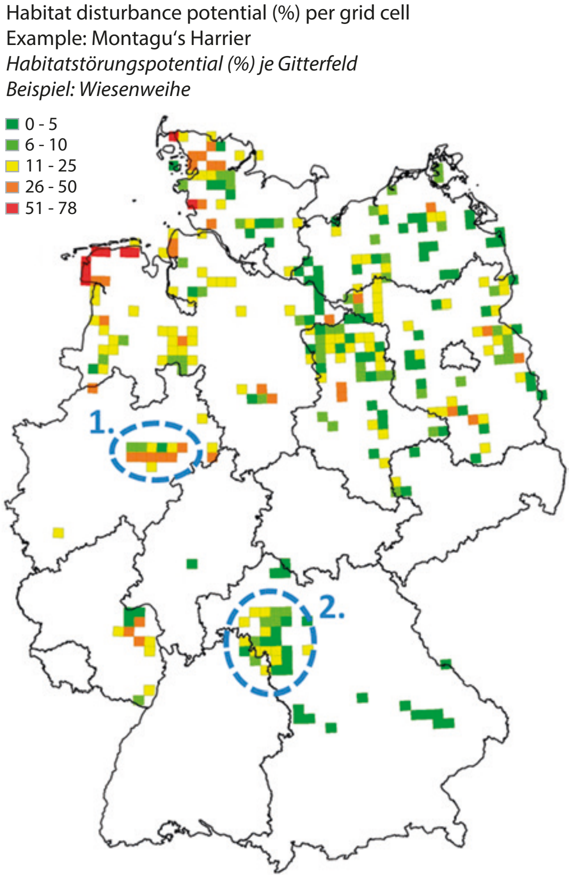


Fig. 2: Percentage overlap between potential Montagu's Harrier breeding season habitat and wind farm related risks in grid cells with breeding occurrence according to Gedeon *et al.* (2014). Circle 1 (Hellwegbörde, North Rhine-Westphalia) and circle 2 (Mainfranken, Bavaria) represent the two German population strongholds with comparably high abundances, respectively. – *Prozentuale Überlappung zwischen potenziellem Brutzeithabitat der Wiesenweihe und windkraftinduzierten Risiken innerhalb von Gitterfeldern mit Brutvorkommen nach* Gedeon et al. *(2014). Markierung 1 (Hellwegbörde, Nordrhein-Westfalen) und Markierung 2 (Mainfranken, Bayern) repräsentieren die beiden deutschen Vorkommensschwerpunkte der Art mit jeweils vergleichsweise hohen Bestandsdichten.*

of 8-20 pairs according to Gedeon *et al.* (2014)) interesting differences can be detected. Besides the coastal grid cells supporting breeding Montagu's Harriers, the 'Hellwegbörde' (see Fig. 2), one of two key regions for the species in Germany, represents the region with the highest percentage of potential habitat disturbance for the species. For half of the grid cells supporting this local population stronghold 26-50 % of potentially suitable habitat is overlaid with wind farm risk areas and also other grid cells of this hotspot are strongly disturbed. The second population stronghold 'Mainfranken', so far, is less influenced by wind turbines. Nonetheless, also in this region several grid cells indicate potential habitat disturbance between 11-25 %. Considering the request formulated by LAG VSW (2014) to secure sufficiently large wind farm free zones to preserve source populations, further development of wind turbines especially within the population strongholds already strongly affected has to be questioned.

3.2 Potential habitat and population level disturbance at national scale

To get a general overview and compare the relative strength of wind farm related risks sensitive species are currently facing in Germany, national figures for percentage potential habitat disturbance have been calculated (see Table 3). The analysis identified a considerable habitat disturbance potential for particular species and subsets of sensitive species respectively. By combining the results on percentage habitat disturbance obtained with abundance data available at grid cell scale (geometric means of abundance classes of Gedeon *et al.* (2014)) is was possible to estimate the proportion (%) of the German population likely to be affected by wind farm related risks.

For most species values derived for potential habitat disturbance and proportion of the population influenced by wind energy were relatively similar. As expected, correlations between both figures occurred especially in relatively equally distributed species, inhabiting comparably large territories (e.g. Black Kite *Milvus migrans*, Eagle Owl *Bubo bubo*, Hobby *Falco Subbuteo*, Montagu's Harrier, Red Kite *Milvus milvus* etc.). For some species with comparably small territories considerable differences between habitat and population level effect were detected (e.g. Lapwing *Vanellus vanellus*). Here effects at population level were higher than one would expect looking only at the percentage overlap between wind turbine buffers and potential breeding season habitat, indicating a concentration of the respective population within areas of increased wind energy generation.

Moreover, for species with very small ranges and/or very small populations considerable differences between potential habitat and population level effects were found (e.g. Golden Plover *Pluvialis apricaria*, Great Bustard *Otis tarda*, Hen Harrier *Circus cyaneus*, Hoopoe *Upupa epops*). Those results should be treated with caution and are likely to be a consequence of the chosen methodology (grid cells of approx. 11 x 11 km) not being applicable to identify potential effects at such fine scale.

To support the assessment of the potential effects identified it can be helpful to consider the results in light of the proportions of sensitive species occurring within SPAs (Wahl *et al.* 2015) (see Table 3). For certain species this clearly facilitates the assessment of wind farm related risks. For example, for some species of grouse one may conclude that the current state of

Table 3: Overview on species-specific potential percentage habitat disturbance due to wind turbines applying the LAG VSW distance recommendations; the percentage population of the respective sensitive species likely to be affected by wind farm related risks; to assess the disturbance potentials identified percentage populations occurring within designated SPAs as well as species-specific distance recommendations are presented. – *Übersicht zur potenziellen prozentualen Störung von Habitaten durch Windkraftanalagen unter Anwendung der LAG VSW Abstandsempfehlungen, sowie beeinflusste Populationsanteile als sensitive eingestuften Arten; zur besseren Einordnung und Bewertung der identifizierten Störungspotenzials werden zudem der jeweilige Populationsanteil innerhalb von EU-Vogelschutzgebieten, sowie die geltenden Abstandsempfehlungen dargestellt.*

Species – *Art*	**Habitat disturbance potential (%)** – *Habitatstörungs-potenzial (%)*	**Population potentially influenced by wind energy (%)** – *Potenziell beeinflusster Populationsanteil (%)*	**Population occurring within SPAs (%)** – *Populationsanteil innerhalb von EU Vogelschutzgebieten (%)*	**Species-specific distance recommendation** – *artspezifische Abstandsempfehlung*
Black Grouse – *Birkhuhn*	0.0	0.0	63.1	1,000 m
Black Kite – *Schwarzmilan*	5.0	4.6	28.3	1,000 m
Black Stork – *Schwarzstorch*	19.1	20.4	29.0	3,000 m
Black-tailed Godwit – *Uferschnepfe*	3.9	4.6	79.2	500 m
Capercaillie – *Auerhuhn*	0.9	0.3	61.5	1,000 m
Corncrake – *Wachtelkönig*	3.4	2.8	58.8	500 m
Crane – *Kranich*	3.3	2.6	41.4	500 m
Curlew – *Großer Brachvogel*	4.1	4.5	40.2	500 m
Eagle Owl – *Uhu*	5.3	5.5	18.6	1,000 m
Golden Eagle – *Steinadler*	1.0	0.7	73.1	3,000 m
Golden Plover – *Goldregenpfeifer*	7.9	12.0	100.0	1,000 m
Great Bustard – *Großtrappe*	18.0	6.0	100.0	3,000 m
Hazel Grouse – *Haselhuhn*	2.1	1.0	58.2	1,000 m
Hen Harrier – *Kornweihe*	11.7	5.4	95.4	1,000 m
Hobby – *Baumfalke*	2.3	2.2	n.a.	500 m
Honey-buzzard – *Wespenbussard*	3.0	3.1	25.1	1,000 m
Hoopoe – *Wiedehopf*	7.5	5.3	55.7	1,000 m
Lapwing – *Kiebitz*	3.6	5.9	24.5	500 m
Lesser Spotted Eagle – *Schreiadler*	54.6	49.7	82.3	6,000 m
Marsh Harrier – *Rohrweihe*	9.1	8.9	27.8	1,000 m
Montagu's Harrier – *Wiesenweihe*	13.0	14.4	50.2	1,000 m
Nightjar – *Ziegenmelker*	0.9	1.2	55.6	500 m
Peregrine – *Wanderfalke*	3.6	3.0	40.8	1,000 m
Ptarmigan – *Alpenschneehuhn*	0.0	0.0	87.3	1,000 m
Red Kite – *Rotmilan*	9.3	9.8	18.6	1,500 m
Redshank – *Rotschenkel*	3.4	4.1	74.0	500 m
Short-eared Owl – *Sumpfohreule*	13.9	13.6	100.0	1,000 m
Snipe – *Bekassine*	2.1	1.4	48.9	500 m
White Stork – *Weißstorch*	7.1	6.5	34.4	1,000 m
Woodcock – *Waldschnepfe*	0.7	0.9	n.a.	500 m

wind farm development does not represent a considerable threat, e.g. 61.5 % of the German Capercaillie *Tetrao urogallus* population occur within designated SPAs and only a fraction of the national population (0.3 %) was estimated to may potentially be affected by habitat disturbance potentials associated with wind energy. In terms of a species such as Black Stork *Ciconia nigra* the situation is entirely different. While only 29 % of the national population benefits from the protection offered by SPAs, a similar proportion of the population (20.4 %) was assessed to face wind farm related risks within its breeding season habitat. In this context it is important to mention that SPAs do not represent wind farm free zones. Nonetheless, one would expect that bird conservation needs have a higher priority within wind farm approval processes deciding about the construction of wind turbines within SPAs designated to support populations of wind farm sensitive species.

3.3 Distribution of wind farm related risks across species

Moreover, the results derived at species level were combined across all species analysed by calculating a mean percentage habitat disturbance value based on the species-specific figures per grid cell (irrespective of the total species-specific habitat extent per grid cell). The resulting map identified the distribution and potential strength of habitat disturbance effects considering the assemblage of wind farm sensitive species (see Fig. 3, B & C). Clearly, the general distribution of habitat disturbance potential is predefined by wind turbine frequency (see Fig. 3, A; due to map resolution single turbine locations are sometimes indistinguishable). Nonetheless, regions with increased conflict potential between bird conservation and the wind industry, mainly as a result of a high diversity of impacted species in particular

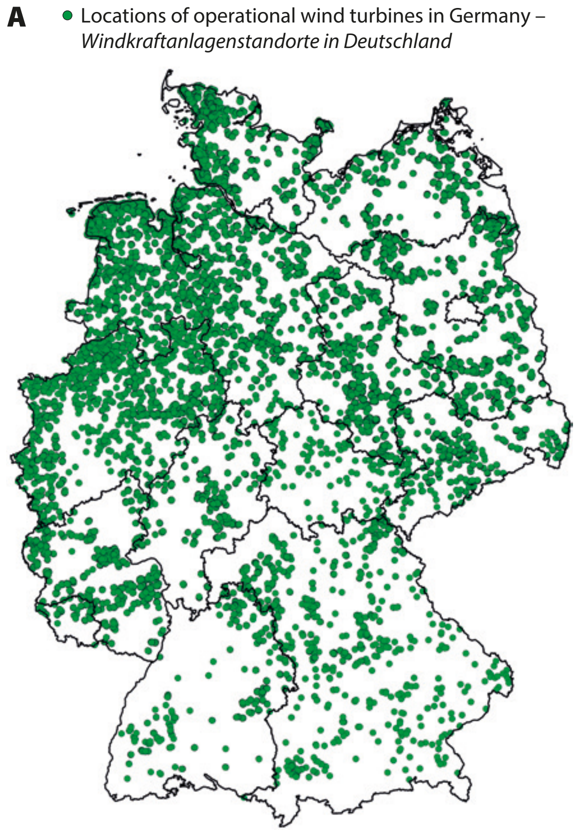
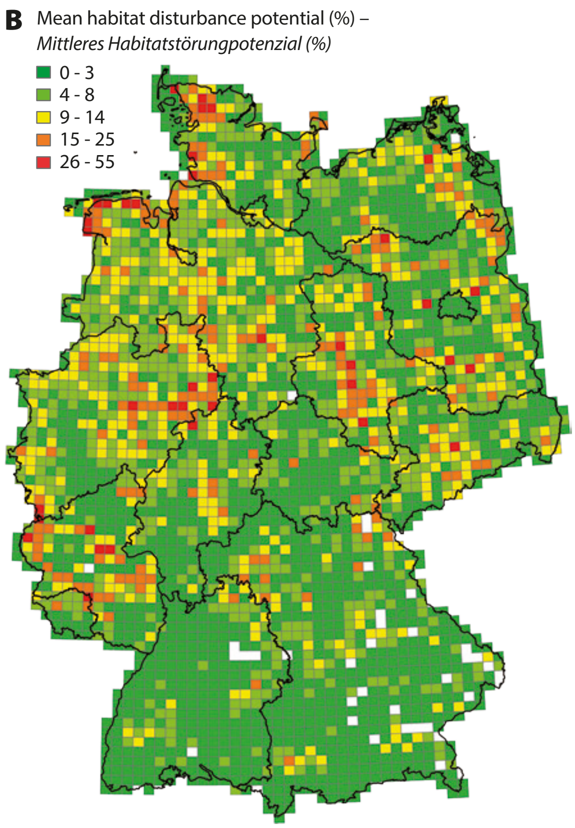
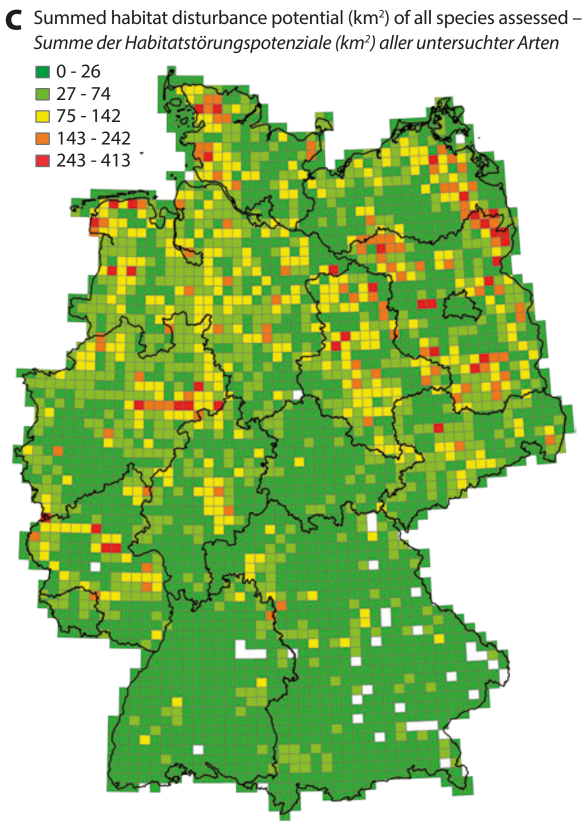


Fig. 3: A: Distribution of operational wind turbines across Germany, status 2015. **B**: Mean percentage habitat disturbance across the 30 sensitive species assessed per grid cell. **C**: Summed spatial habitat disturbance potential (km²) across the 30 sensitive species assessed per grid cell. – **A**: *Standorte operative Windkraftanlagen in Deutschland, Stand 2015.* **B**: *Prozentuale Habitatstörung, gemittelt über die 30 untersuchten sensitiven Vogelarten je Gitterfeld.* **C**: *Summe des potenziell gestörten Habitats (km²) über die 30 untersuchten sensitiven Vogelarten je Gitterfeld.*





regions, were identified. Especially the North Sea coast and its hinterland, as well as the fertile and open 'Börde' landscapes in central Germany are strongest disturbed by wind farms. Moreover, strong interactions between sensitive species and wind turbines occur in the western low mountain ranges of Eifel and Hundsrück. Generally, the relative concentration of turbines in North Rhine-Westphalia and Lower Saxony is clearly visible on the mean habitat disturbance map (see Fig. 3, B).

To ensure the results obtained a second approach was tested, avoiding the calculation of a mean value per grid cell. This was done to assure that in cases where e.g. only a single species occurring in a grid cell faces large scale potential habitat disturbance while additional sensitive species only face small effects within the same grid cell, considerable effects on one species are not relativized by small or no effects on other species. In this second approach, the spatial extents (km^2) of the potentially disturbed breeding season habitats of all sensitive species occurring in a respective grid cell were summed (see Fig. 3, C). Both approaches to derive an overview map on the distribution and strengths of wind farm related pressures on the assemblage of wind farm sensitive species identified very similar patterns, considering that mean potential habitat disturbance (%) is compared with summed potentially disturbed habitat (km^2). Moreover, data were classified by natural breaks in GIS, a classification scheme that aims at grouping similar values and maximise differences between classes by dividing features into classes whose boundaries are set where relatively big differences in data values occur.

3.4 The case of Red Kite

For one species, the Red Kite, it was possible to attempt to validate the assessment methodology. A nationwide Red Kite survey carried out in 2011 and 2012 reported the spatially explicit location of 6,840 Red Kite nests across the species range within Germany (DDA, unpublished data). Gedeon *et al.* (2014) report a national population of 12,000 – 18,000 pairs (mean 15,000 pairs). Thus the control sample comprised about 45.6 % of the likely German nesting sites of Red Kite. Combining nesting locations and wind turbine locations in GIS and buffering the nest locations with the recommended 1,500 m concluded that 626 nesting locations, representing 9.15 % (626 / 6,840 * 100) of the recorded nesting sites of Red Kite, occurred within 1,500 m of operational wind turbines. In this context it is important to note that until publication of the current recommendations (LAG VSW 2014) a 1,000 m distance was recommended for Red Kite (LAG VSW 2007) and several federal states still make use of this superseded distance recommendation within approval processes.

High consistency among the results obtained using the different assessment approaches was achieved (see Table 4). All methods indicated that about 9 % of the species habitat and population face wind farm related risks based on the current state of wind energy usage in Germany.

3.5 Testing for correlations

In a further analysis step we tested for correlations between the observed frequency of wind turbines and the number, respectively diversity, of sensitive bird species per grid cell, and between wind turbine frequency and mean number of breeding pairs across all sensitive species per grid cell (using the geometric mean of the respective abundance classes published in Gedeon *et al.* (2014)). As this analysis did not require the consideration of CLC classes, also species excluded from the other assessments for methodological reasons (colony breeding heron, gull and tern species as well as

Table 4: Comparison of assessment results for potential influence of wind energy production on Red Kite. – *Vergleich der Ergebnisse zum Einflusspotenzial der Windenergieproduktion auf den Rotmilan.*

Method – *Methode*	**Result** – *Ergebnis*	**Description** – *Beschreibung*
Potentially disturbed breeding season habitat in Germany – *Potenziell gestörtes Brutzeithabitat in Deutschland*	9.3 %	Definition of potential breeding season habitat using CORINE land use classes and calculating overlap with 1,500 m buffers around operational wind turbines – *Eingrenzung des potenziellen Brutzeithabitats über CORINE Landnutzungsklassen und Berechnung der Überlagerung mit 1.500 m Puffern um Windkraftstandorte*
Proportion of national population influenced – *Anteil der beeinflussten nationalen Population*	9.8 %	Multiplying % potential habitat disturbance with geometric mean of abundance class from Gedeon *et al.* (2014) at grid cell level and adding up those figures for entire Germany – *Multiplikation der potenziellen % Habitatstörung mit dem Geomittel der Abundanzklassen nach* Gedeon et al. *(2014) auf Ebene der Gitterfelder und Summierung dieser Werte für ganz Deutschland*
Nesting locations with operational wind turbine within 1,500 m distance – *Neststandorte mit Windkraftanlage innerhalb einer Distanz von 1.500 m*	9.2 %	Buffering of known nesting sites by the recommended 1,500 m exclusion zone and assessing overlap with operational turbines – *Pufferung der bekannten Neststandorte mit dem empfohlenen Mindestabstand von 1.500 m und Überprüfung der Überschneidung mit im Betreib befindlichen Windkraftanlagen*

Osprey, White-tailed Eagle, Bittern and Little Bittern) were included in this test for correlations. Obviously, species are defined to be sensitive to wind energy when they occur in or commute through areas where wind farms have been erected/built and behavioural observations or the discovery of collision victims proof an interaction with the turbines. Accordingly, a certain correlation between both parameters was expected.

We found highly significant though relatively week correlations between the investigated characteristics. Spearman's rank correlation identified a rho (Spearman's rank correlation coefficient) = 0.19 for wind turbine frequency and diversity of sensitive species and a rho = 0.22 for wind turbine frequency and the mean number of breeding pairs of sensitive species. The results indicate a high variance in the data. While the high significance of the correlations proofs a relationship between the correlated characteristics and indicates that areas with high turbine frequency can overlap with diversity hotspots respectively high breeding populations of sensitive species, there seems to be no general concentration of wind farms inside diversity and/or population hotspots when looking at the overall assemblage of sensitive species.

4. Discussion

The results indicate a strong overlap between wind farm related risks and the potential breeding season habitats of the majority of bird species identified to be sensitive to the operation of wind turbines in the vicinity of their breeding sites.

A few methodology-induced aspects, influencing the results obtained, need to be considered when interpreting e.g. the figures on percentage potential habitat disturbance. Species for which comparably big wind turbine free buffers are recommended regularly show considerable overlaps between breeding season habitat and wind farm related risks (e.g. Lesser-spotted Eagle *Clanga pomarina* (54.6 %), Black Stork (19.1 %) and Great Bustard (18.0 %)). The same applies to species with small distributional ranges in Germany (e.g. Golden Plover (7.9 %), Hen Harrier (11.7 %) and Short-eared Owl *Asio flammeus* (13.9 %)). Observed habitat disturbance potential is greatest when both aspects are combined, as can be observed in case of the Lesser-spotted Eagle. The species shows a restricted distribution in the North-East of Germany (Gedeon *et al.* 2014) and due to its high conservation concern and high vulnerability to both, collision with wind turbines and displacement from foraging habitat in vicinity of wind turbines (LAG VSW 2014), 6,000 m between breeding sites and wind turbines have been recommended as a spatial buffer. For Lesser-spotted Eagle the assessment concluded that more than half (54.6 %) of the species breeding season habitat is overlaid by wind farm related risks.

Moreover, there is a group of comparably widespread species with medium-sized recommended wind turbine exclusion zones between 1,000-1,500 m (Marsh Harrier *Circus aeruginosus* (9.1 %), Montagu's Harrier (13.0 %), Red Kite (9.3 %) and White Stork *Ciconia ciconia* (7.1 %)) that also face the potential disturbance of considerable proportions of their breeding season habitats. Interestingly, this group exclusively comprises species foraging mainly in open landscapes. The strong interaction indicates an extensive spatial influence of wind energy generation as widespread species appear to be affected across their distributional ranges. The fact that especially Montagu's Harrier and Red Kite show effects of a very similar strength in terms of habitat and population level disturbance (see Table 3) indicates a less clumped distribution of these species. Their comparably large territories prevent the occurrence of very high densities achieved by species with small territories and leads to a comparably even spread of individuals across the distributional range. In consequence, the estimated figures for habitat and population level disturbance are relatively similar.

Also the group of meadow-breeding waders should be mentioned (Black-tailed Godwit *Limosa limosa* (3.9 %), Curlew *Numenius arquata* (4.1 %), Lapwing (3.6 %), Redshank *Tringa totanus* (3.4 %) and Snipe *Gallinago gallinago* (2.1 %)). Considering the small recommended exclusion zones of 500 m, the potential disturbances of 2 to 4 % of the breeding season habitat indicates that wind energy imposes a pressure on this species group. Several meadow-breeding wader species showed considerable breeding range reductions in Germany during the period 1985-2009. A 21-50 % breeding range loss is recorded for Black-tailed Godwit, Curlew and Snipe (DDA, unpublished data). In this context the identified overlap between wind farm related risks and potential breeding season habitat indicates a relevant additional pressure on the remaining potential habitats of these species. Moreover, the comparably high habitat specialization of several meadow breeding waders has to be taken into account when assessing the results obtained. Due to specialization on wet open habitats comparably few CLC classes are defined to represent potential breeding season habitat. For example arable land, covering about 33 % of the overall German territory (BMEL 2014), has not been considered to represent potential breeding season habitat for Black-tailed Godwit, Redshank and Snipe. For such more specialized species for which comparably small potential breeding season habitat was identified the disturbance of comparably small percentages of that habitat may have another effect than for species using a large variety of habitats, because for specialized species less alternative switchover habitats are available. Moreover, especially for Lapwing considerable differences between habitat disturbance potential (3.6 %) and the population percentage potentially influenced

(5.9 %) were identified, indicating a concentration of the Lapwing population within areas heavily use for wind energy generation.

While montane and forest species, so far, seem to be less affected by the current state of wind farm development, plans to foster the construction of wind turbines in forested areas may impose increasing risks on these species in the future. Forest breeding birds like the Black Stork, also using open habitats in the surrounding of woodlands for foraging, today already show considerable interaction with habitats overlaid with wind farm related risks.

The LAG VSW (2014) recommend minimum distances of wind turbines to breeding sites of sensitive bird species, while the presented assessment used those distances to buffer wind turbines locations rather than breeding sites as such data are lacking for nearly all species, except Red Kite, at national scale. Accordingly, the achievement of very similar results when assessing the proportion of the Red Kite population influenced by wind farm related risks with and without consideration of the nest locations known for nearly half of the German population indicates that the chosen approach, applying the recommended minimum distances from operational turbines rather than breeding sites, appears suitable.

It should be noted that we do not assess the strength of the wind farm related population level impacts that may arise as a consequence of the operation of wind turbines inside potential breeding season habitats. The present study only indicates the likely proportion of potential breeding season habitat, as well as the proportion of the national population of sensitive species, that is likely to be disturbed by the current state of wind energy development in Germany. For impact assessments, especially at population level, a whole range of detailed species- and region-specific information would be required (species- and region-specific collision rates and/or displacement distances, exact nesting locations, data on mortality rates and recruitment etc.) that are currently not available. Nonetheless, our assessment for the first time estimates the spatial overlap between the habitats of sensitive species and wind farm related risks at the German national scale, helping to better understand the spatial implications of the current state of onshore wind farm development.

5. Conclusions

The findings of our study indicate a strong overlap between wind farm related risks, such as collision risk and displacement, and the potential breeding season habitats of the majority of bird species identified to be sensitive to the operation of wind turbines in the vicinity of their breeding sites. Montane and forest species seem least and open landscape species most affected by the wind farm development stage documented for the year 2015 in Germany. The spatial extent of bird habitats potentially disturbed and/or devaluated by onshore wind turbines is, at least for particular species, alarming and more detailed studies of particular subpopulations are required to quantify the population level impacts of the spatial risks identified in this study.

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The wind turbine locations used in frame of our assessment are based on data from the land use planning register of the federal state of Saxony-Anhalt with approval from the Ministry for Land Development and Transport, approval no.: MLV44/037/15. Moreover, data were provided with kind approval from the competent authorities of the other German federal states.

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6. Zusammenfassung

Busch, M., S. Trautmann & B. Gerlach 2017: Überlappung zwischen Brutzeithabitat und Windkraftrisiken: Ein räumlicher Ansatz. Vogelwelt 137: 169–180.

Während die Interaktionen zwischen Windenergieanlagen (WEA) und Vögeln in den vergangenen Jahren in vielfältiger Weise untersucht wurden, gibt es nur wenige großflächige Untersuchungen zu den möglichen Auswirkungen des bereits realisierten Ausbaustands des Windenergiesektors auf windkraftsensitive Arten. Um die von WEA ausgehenden Risiken für Vögel abzuschwächen, wurden in Deutschland durch die Länderarbeitsgemeinschaft der Vogelwarten (LAG VSW) Abstandsempfehlungen für WEA zu bedeutenden Vogellebensräumen sowie Brutplätzen ausgewählter, windkraftsensitiver Vogelarten definiert. Diese Abstandsempfehlungen wurden genutzt, um basierend auf dem aktuellen Ausbaustand der Windenergienutzung die Überlagerung von Brutzeitlebensräumen mit windkraftinduzierten Risiken als auch die potenziell beeinflussten Populationsanteile windkraftsensitiver Arten abzuschätzen. Die hier vorgestellte Untersuchung basiert auf Verbreitungs- und Häufigkeitsinformationen des aktuellen Atlas Deutscher Brutvogelarten (ADEBAR), Landnutzungsinformationen der Corine Land Cover Datenbank sowie Standortdaten zu im Betrieb befindlichen onshore WEA in Deutschland. WEA-Standorte in Gebieten mit Brutvorkommen windkraftsensitiver Arten wurden mit den artspezifischen Abstandsempfehlungen gepuffert und so die Überlappung mit potenziellen Brutzeit-

lebensräumen, die durch ihre Zugehörigkeit zu bestimmten Landnutzungsklassen identifiziert wurden, berechnet. Die Ergebnisse zeigen für die verschiedenen als windkraftsensitiv eingestufte Arten eine erhebliche Überlappung zwischen Brutzeitlebensräumen und Bereichen, in denen potenziell windkraftinduzierte Risiken auf diese Vogelarten einwirken. Insbesondere die Gruppe der Offenlandarten scheint vergleichsweise stark betroffen. Das identifizierte Habitatstörungspotenzial liegt hier regelmäßig bei Werten zwischen 9 und 13 % des Brutzeitlebensraums. Für einzelne Arten, oft mit nur kleinräumiger Verbreitung in Deutschland, werden darüber hinaus aber auch erheblich höhere Werte von bis zu 55 % des Brutzeithabitats im Einflussbereich von WEA erreicht. Für die meisten untersuchten Arten waren die Werte zur möglichen prozentualen Habitatstörung bzw. -beeinflussung und Schätzungen der durch WEA beeinflussten Populationsanteile recht ähnlich. Eine Validierung der angewandten Methode war zudem durch die Ergebnisse einer bundesweiten Rotmilankartierung 2011/12 möglich. Die Pufferung der in diesem Rahmen zusammengetragenen Neststandorte mit der artspezifischen Abstandsempfehlung erzielte im Hinblick auf das identifizierte Beeinflussungspotenzial eine gute Übereinstimmung mit den Ergebnissen die auf der Pufferung des WEA-Standorte basierten. Demnach scheint sich das räumliche Beeinflussungspotenzial von WEA auf Vogellebensräume auch ohne Brutplatzdaten, die zumeist nicht flächig vorliegen, recht gut abschätzen zu lassen.

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