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Sensitivity mapping informs mitigation of bird mortality by collision with high-voltage power lines

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Abstract
Mapping the relative risk of impact on nature by a human infrastructure at a landscape scale ("sensitivity mapping") is an essential tool for minimising the future impact of new development or for prioritising mitigation of existing impacts. High-voltage power lines ("transmission lines") are known to increase bird mortality by collision. Here we present a method to derive a high resolution map of relative risk of transmission line impacts across one entire country, Belgium, from existing bird distribution data. First, all the bird species observed in Belgium were systematically assessed using literature and casualty records to select those to be included in the sensitivity map. Species were selected on the basis of their intrinsic susceptibility to collision and the conservation relevance of avoiding additional mortality for that species in Belgium. Each of the selected species was included in one or several spatial layer constructed from existing data, emerging from citizen science bird monitoring schemes. The resulting 17 layers were then combined into one final sensitivity map, where a "risk score" estimates the relative collision risk across Belgium at a 1×1 km resolution. This risk score is relatively robust to the subtraction of any of the 17 layers. The map identifies areas where building new transmission lines would create high risk of collision and, if overlapped with existing power lines, helps to prioritise spans where mitigation measures should be placed. Wetlands and river valleys stand out as the most potentially dangerous areas for collision with transmission lines. This sensitivity map could be regularly updated with new bird data or adapted to other countries where similar bird data are available.

Keywords
Belgium, bird, mitigation, sensitivity mapping, strategic planning, transmission lines, waterbird

Introduction

Power lines have been identified as one of the major causes of man-induced mortality in birds (Loss et al. 2015). Direct mortality by collision with overhead wires is known to occur with any type of lines but has been especially studied for the so-called transmission grid, or high-voltage power lines (Bernardino et al. 2018), while medium-voltage lines (the so-called distribution grid, from 1 to 30 kV in Belgium) additionally induce electrocution risk for larger birds (Guil and Pérez-García 2022). Flying birds might collide with wires especially under low visibility conditions during crepuscular or nocturnal movements or during bad weather. Despite the difficulties inherent to such quantification, casualty numbers are undoubtedly very high. An annual estimate of 8–57 million birds killed by collision with transmission lines was made for the USA alone (Loss et al. 2014). Despite these impressive figures, only in very few instances has a link been established between population dynamics (e.g. the decline of a given population of a single bird species) and power line mortality (Bernardino et al. 2018; D'Amico et al. 2018). Possible demographic impacts mostly concern endangered species: 12% of the entire Blue Crane *Anthropoides paradiseus* population was estimated to be killed annually by collision with power lines in South Africa (Shaw et al. 2010). On the other hand, low mortality rates do not mean that no significant impact exists, e.g. by historical depletion of local populations (Ascensão et al. 2019). Even if a population effect of power line mortality cannot be readily established, it is important to reduce this human-induced mortality as much as possible in an attempt to minimise the impact of this ever-growing infrastructure. An estimated 65 million kilometres of medium- to high-voltage lines was already covering the world a decade ago (Jenkins et al. 2010). With the anticipated change towards a more decentralised production, transmission grids are expected to grow constantly in the near future (Barov 2011; Bio Intelligence Service 2012; Biasotto and Kindel 2018). Therefore, minimising bird fatalities on both existing and future power lines is critical and a prerequisite to increase public support for such a development.

Construction of underground lines is the best solution to prevent any further casualties. However, this is not always possible from a technical point of view or economically viable, especially when existing aerial lines have to be brought underground. Wire marking in order to increase visibility of the cables for birds is therefore the most widespread measure to reduce mortality. A recent review of wire-marking effectiveness (Bernardino et al. 2019) concluded that mortality rates on average are reduced by half (95% confidence interval: 40.4–58.8% across 35 studies).

Strategic planning has been proposed as a first necessary step to mitigate power line impact, both to avoid building new power lines in vulnerable areas and to act on mitigation measures on existing dangerous lines (Bernardino et al. 2018; D'Amico et al. 2018). Sensitivity mapping is routinely used in several instances of interaction of fauna with human infrastructure as a basic planning tool when new infrastructure has to be built (Allinson et al. 2020). It also helps to prioritise where mitigation measures should be taken (European Commission 2018). However, there are very few examples of sensitivity maps for a countrywide transmission line network (but see (D'Amico et al. 2019) for Portugal and Spain). Here, we present a method based on large-scale citizen science data to map the relative collision risk associated with transmission lines for birds, for any given location in Belgium. We also propose a prioritisation process to mitigate the risks associated within the existing 5,614 km of aerial transmission lines (70–380 kV) in Belgium.

Identifying existing transmission lines presenting a high collision risk for birds or drawing attention to potentially harmful future lines can be attempted at a regional scale by looking at some natural habitat features or spatial characteristic (Martín Martín et al. 2019), but mapping areas where collision-susceptible species are particularly abundant would always give a better assessment of the risk, especially on a larger scale. Indeed, not all species are facing the same risk when confronted with power lines since some species are more prone to collisions than others (Bevanger 1998). These susceptible species could congregate in large numbers at specific places used on a daily basis, like communal night roosts or breeding colonies, hence increasing the number of potential casualties around those areas. Besides the intrinsic probability of collision for a given species, the conservation value (for example, their IUCN status) or demographic sensitivity to higher adult mortality could also guide the choice of lines to be targeted for mitigation.

The building of the collision risk map in Belgium followed several steps. First, a list of bird species prone to collision with power lines has been compiled based on a review of the literature and casualty records in Belgium. This list was then matched with available recent data on bird distribution and abundance, provided by different schemes of large-scale bird monitoring and a citizen-science portal. Several layers of spatial information on birds were then combined using a scoring system to create a sensitivity map at a resolution of 1×1 km. When overlapped with the existing transmission line network, this map highlights power line spans presenting high collision risk for birds and is now used by the transmission system operator in Belgium, Elia, to define priority sectors for mortality surveys and, more importantly, mitigation actions. Furthermore, the risk map allows for the planning of new developments of the transmission grid minimising collision risk, but not precluding the necessity of environmental impact assessment to detect possible collision issues before any new line construction.

Methods

Study area

Belgium is a low-lying country in North-Western Europe, characterised by a landscape gradient ranging from densely populated flat areas in the northern part, largely occupied by intensive farmland and urban areas, to hilly parts in the South, culminating slightly under 700 m, with a more forested and rural landscape. Including rare and vagrant species, but excluding introduced or escaped species, about 460 different wild bird species have been reported in Belgium. Although a small and densely populated country, Belgium hosts no fewer than 184 regular breeding bird species, of which 62 are of European Conservation Concern (BirdLife International 2017). During the winter, waterbird populations of international importance (several species of geese and ducks) are observed, especially in Flanders. For example, the coastal polder complex between Bruges and Ostend is home to 30% of the total biogeographic population of Pink-footed Geese *Anser brachyrhynchus* (Devos and Kuijken 2020). On average, an estimated 374,000–594,000 waterbirds -gulls not included- winter in Belgium, mostly in Flanders (Paquet et al. 2019). Due to its central position in Europe and along the southern edge of the North Sea, millions of birds also travel across Belgium during prenuptial and postnuptial migrations, some of them even without a stop or roosting only for a few hours or days.

Belgium has a long industrial history and is a very densely populated country, equipped with a dense power line network: 5,614 km of aerial high-voltage lines (voltage of 70–380 kV, here after "transmission network") are managed by Elia, the transmission system operator for Belgium, additionally to more than 5,000 km of aerial medium voltage power lines managed by several electricity distributors (Synergrid 2022). The medium-voltage transmission network (30–36 kV) is largely underground. The density of aerial transmission lines in Belgium (about 18 km/100 km^2) is similar to the one in France but higher than in Spain (about 8.3 km/100 km^2) and in Germany (about 9 km/100 km^2; Data: ENTSO-E). In the present study, we focused only on the transmission network, for which a detailed map in vectorial format was provided by Elia. The vectorial format of the transmission network is composed of more than 22,000 linear segments of lines between two pylons (named "spans" in the rest of the study). Spatially explicit vectorial data on the distribution grid for the whole of Belgium was not available for this study.

Sensitivity map development

The development of the collision-risk map followed the general guidance for wildlife sensitivity mapping (Allinson et al. 2020), which was established primarily for renewable energy development but is also relevant for any potentially impactful large-scale infrastructure.

Identification of susceptible bird species

Several criteria were used to select bird species that need to be considered as prone to collision with power lines (those species are named "susceptible species" in the rest of this study), for which we therefore need to include information about numbers and distribution in the next steps of this process.

The species list that we considered (Suppl. material 1: Table S1) is the reference list used in the reporting under Article 12 of European Union Directive 2009/147/EC, known as the "Birds Directive". This list follows the taxonomy of BirdLife (BirdLife International 2021) and contains all the breeding bird species, the species that winter in large numbers and some abundant passage migrants in Belgium. Intrinsic susceptibility to collision of individual bird species was evaluated. Not all bird species are equally susceptible to collision with the horizontal cable structures; birds with poor manoeuvrability, i.e. small wings related to body weight, are more prone to collision (Bevanger 1998). Other factors like poor eyesight may also play a role (Martin and Shaw 2010; D'Amico et al. 2019). However, some species groups which are expected to present a low collision risk given their body aspect or physiology are frequently encountered as victims: this is the case for gulls, probably because of their social behaviour and frequent movements in crepuscular conditions when commuting between their feeding grounds and their communal nocturnal roosts (Bevanger 1998). Based on these studies, several lists of collision susceptible species have been published (Bern Convention on the Conservation of European Wildlife and Natural Habitats 2004; Prinsen et al. 2011) and these lists were used as a basis for our own sensitive-species list.

In order to optimally adapt our approach to our local conditions, information about collision frequency in Belgium was also examined. Statistics of bird casualties resulting from probable collision cases with power lines were taken from two sources: Firstly, 719 cases of dead birds found opportunistically under high-voltage power lines recorded in the most popular nature recording platform in Belgium (named Waarnemingen.be in Dutch and Observations.be in French) were examined. This relatively high number of cases is due to an active promotion campaign since 2016 among the public of nature conservation organisations to record such casualties. From this list of 91 species, we retained those with more than 4 cases as being susceptible to collision (Suppl. material 2: Table S2). Secondly, a wounded bird found under high-voltage power lines recorded by wild bird care centres in Belgium was used in the same way (Suppl. material 2: Table S3) to refine the list of susceptible species. By this process, bird species from Belgium were classified into three "collision susceptibility" categories: 0 – Null, almost never cited in mortality studies or in review, never found as victims in Belgium; 1 – Sometimes cited in studies as found injured or dead, but not regularly in Belgium; 2 – Regularly cited in studies or encountered in Belgium as injured or dead by collision with power lines (see Suppl. material 1: Table S1, column J).

Along with the concept of susceptibility to collision, the "conservation relevance" of preventing collision was considered for each species. If the conservation status of a species is already degraded, any supplementary mortality is important to avoid. The most recent regional red lists of endangered birds in Wallonia, Flanders and Europe (Devos et al. 2016; BirdLife International 2021; Paquet et al. 2021) were used to classify the species according to their conservation relevance: in Belgium: 0 – not red listed in any of the three lists considered no; 1 – listed as "Neath-threatened – NT" in at least one of the three lists; 2 – Red listed (at least Vulnerable) in at least one of the three lists. A few species were also listed as "2" because Belgium is hosting an important part of the global population (wintering arctic geese); in that case, reducing mortality in Belgium is also of conservation interest.

Susceptible species (value of 2 for that criteria) and of high relevance for conservation (value of 2 for that criteria) were retained for building the risk map thanks to spatially explicit information about that species (the "spatial layers"), but some exceptions are to be noted: waterbird species often congregating in large numbers or in large communal roosts in winter and migrant birds known to fly over Belgium in very large numbers, sometimes a significant part of the overall European population, such as for the Common Crane *Grus grus* (Kever et al. 2018). All these exceptions are detailed in Suppl. material 1: Table S1 (column N).

Compiling and preparing the bird spatial layers

In order to capture the actual spatial risk of collision for a selected species within the collision risk map, different types of geographical information were used, according to distribution patterns of the species and the behaviour increasing the risk. For the selected species with a diffused distribution pattern across the country, the relative bird density was calculated at high spatial resolution (1×1 km). Bird species which are naturally concentrated on a few sites e.g. waterbirds during wintering or migration period were treated differently. For those species, using site perimeters, we evaluated the relative importance of these sites using individual numbers of each species regularly counted inside these perimeters. A special case is the social species. They breed or roost together in relatively small areas, sometimes in very large numbers. However, they can also disperse over larger areas to forage. The social congregations add a supplementary risk of collision because of the commuting habits for many birds at the same time. Therefore, the spatial location of roosts and breeding colonies was used, rather than their dispersed distribution when foraging.

Table 1 is describing the different bird layers used in the compilation of the collision risk map. Some susceptible species are treated in more than one geographical layer (see Suppl. material 1: Table S1); this could be the case if a species has a breeding population at risk but also a wintering population that congregate in roosts or in important wintering sites for waterbirds. Some layer types are included in the collision risk map as one synthetic layer for several species, while others are declined in several individual layers, one for each species (for further explanation see Table 1).

Here we describe how each of the spatial layers was derived from the raw data. Bird data from the period 2010–2019 were used, except when mentioned differently.

"Important waterbird sites" were derived from mid-monthly counts of wintering waterbirds carried out in Belgium for several decades by hundreds of volunteers (Devos et al. 2019; Jacob et al. 2019). For this spatial layer, Flanders and Wallonia administrative regions were considered separately, as we wanted to assess the importance of the sites at the regional (and not national) level. Each participant counted all the waterbirds present from a specific wetland (or watercourse) on a specific weekend (the closest to the 15th of the month from October to March in Flanders and from November to

Table 1. Description of the spatial layers containing bird distribution or abundance information used in sensitivity mapping.

Bird layer type	spatial information type	Explanation	Number of layers included in the collision risk maps	Species concerned (see also Suppl. material 1: Table S1)
Important waterbird sites	Site perimeters and distance buffer around these sites (several species in one synthetic layer; see table 2 for the buffer distances)	Layer based on regular surveys performed at specific sites, during which all present waterbirds are counted. Each site may be used by several sensitive species and the relative risk associated with the sites depends on the number of species and individuals regularly seen at the site, compared to the regional estimated population of those species.	1	48 species of wintering waterbirds
Important roosts	Buffers around a point location (several species in one synthetic layer; see table 2 for the buffer distances)	These layers are based on the distance from a specific location (point) where a colony or a roost of a sensitive species is established. The closer a colony or roost is to a power line, the higher the collision risk, because of the flight trajectory to and from the site.	1	10 sensitive species regularly forming roosts
Important colonies			1	11 sensitive species breeding in colonies
Foraging goose areas	Presence or absence of each of the considered species at a 1×1 km spatial resolution	Maps at 1-km² resolution indicating the presence or absence of sensitive species, estimated by a spatial model constructed on the basis of raw data of species presence (extracted from citizen science data portals; see text) combined with environment variables. Sensitive species are deemed 'present' in a given 1-km² area if the probability of occurrence of the species (estimated by the spatial model) is above a cut-off value. The use of spatial modelling reduces the risk of bias associated with observers' tendency to visit certain locations and the lack of data in other locations, where few people are recording birds.	3	Goose species wintering in large numbers: Greylag, Pink-footed and Greater White-fronted Goose
Widespread breeding birds			5	5 species of widespread breeding birds (Grey Partridge, Green Woodpecker, Black Woodpecker, Middle Spotted Woodpecker, European Turtle Dove)
Woodcock areas			1	Areas where displaying Eurasian Woodcock are present
Plover group areas			3	Charadriidae species with a tendency to form large groups in very open countryside: Eurasian Dotterel, Golden Plover, Northern Lapwing
Rare bird areas	Number of rare breeding species in 1×1 km square (several species in one synthetic layer)	Maps at 1-km² resolution with a count of the number of species (in our case, rare breeding bird species) recorded in that cell.	1	22 species of susceptible rare bird with high conservation value
Migration corridors	Low resolution very large perimeters (several species in one synthetic layer)	Very low-resolution maps of the main 'corridors' for large numbers of migrant birds in transit	1	Migration corridors for general migrants (coastline) and two very abundant migrants: Woodpigeon and Common Crane

February in Brussels and Wallonia). Maximum counts per winter, for each species and each site, were calculated. The regional wintering population for each species was estimated using a multiple imputation method to account for missing values (Onkelinx and Devos 2019). Only species with a mean regional population of at least 10 individuals were taken into account. To assess the relative importance of a counting site, the total number of individuals (all species together) and the relative importance of the site population for a given species were considered. For each species, the winter maximum for any given site was compared with the regional population estimate. A site is deemed as "fairly important" If between 100 and 1,000 individuals are regularly counted. A site was deemed "important" if 2% of the regional population of at least one waterbird species or more than 1,000 individuals (all species taken together) are regularly recorded. A site was deemed "very important" if 15% of the regional population of at least one species is regularly recorded (Everaert et al. 2011). Here, "regularly" means at least half of the years in which one count was available (some sites were not counted every year). Non-indigenous species and gulls were excluded from all calculations here.

"Important roost or colonies" counts were extracted from the databases of coordinated counts of roosts and colonies maintained by the Research Institute of Nature and Forest in Flanders and Natagora in Brussels and Wallonia. These data were complemented by records extracted from the main nature observations recording portals used by birdwatchers in Belgium, named www.observations.be in French and www.waarnemingen.be in Dutch (Paquet et al. 2013). Colonies and communal night roosts can be specifically recorded in this data portal so that all relevant records can be easily extracted. Communal roosts are defined as "very important" if more than 1,000 individuals. or at least 2% of the regional population, are counted in at least half of the available counts during the period 2010–2019. They are deemed as 'important' if between 100 and 1,000 individuals are regularly (i.e. for half of the available counts) counted. Colonies were defined 'important' if 10 to 100 breeding pairs are regularly counted (i.e. at least 50% of the available counts; when several counts are available for one season, the highest count is taken into account), and 'very important colonies' if more than 100 breeding pairs are regularly recorded or if it holds at least 2% of the regional breeding population.

Layers of presence-absence of the considered species at 1 km^2 resolution were obtained by spatial modelling. Observational data for the target species were extracted from the portal www.observations.be/www.waarnemingen.be during the period 2012–2019. To model the distribution of the species considered at a resolution of 1×1 km, 20 environmental variables were calculated for each grid cell of 1×1 km across Belgium. These variables describe land use (calculated from the 2006 version of the CORINE land cover map, published by the European Topic Centre on Land Use and Spatial Information) and bioclimatic variables calculated from the WordClim dataset (Hijmans et al. 2005). MaxEnt, a presence-only technique widely used in distribution work (Phillips et al. 2006), was used to model the presence-absence of the considered species. MaxEnt uses the square where the focus species was observed (redundant observations in the same square are discarded) as the training dataset for modelling the relationship between the presence of the species and its environment as described by the 20 variables. The projected result of the model is a map estimating the probability of occurrence of the target species (ranging from 0 to 1) for every 1×1-km square in the model's grid. The model was created based on 75% of the data, leaving out 25% for validation. This modelling procedure was repeated 10 times, with the final model providing the average of the 10 repetitions. A species is considered 'present' in a given square if the probability of occurrence is above a certain cut-off value. This cut-off is proposed by MaxEnt and corresponds to the probability value for which the omission rate is closest to 20% (meaning that the model omits 20% of the actual occurrence in the validation set). This should help to keep the risk of false negatives (stating that the species is absent when it is actually present) at around 20% while minimising the total range predicted for the species (and therefore minimising the risk of false positives). Observational data used as raw data in these modelling procedures were selected to correspond to the behaviour of the targeted species (i.e. territorial behaviour for breeding bird species, large groups for foraging geese). If the raw data used to build the model corresponds to a particular criterion (i.e. 'groups larger than 10 individuals'), then the model also reflects the chance of presence of the same form of bird presence (groups rather than just the simple presence of an exemplar).

The list of species identified as being prone to collision with power lines includes several rare breeding bird species. For some species, all known breeding sites are monitored each year. Point records of breeding rare birds were extracted from data portals; records were selected on the basis of breeding evidence given by the observers (i.e. a territorial behaviour, the presence of a nest or pulli, or behaviour indicating a nest). The number of breeding species of this particular list for each 1×1 square in Belgium was retained for the layer type "rare breeding bird".

Mapping specific corridors for seasonal bird migration is especially difficult in a low-lying country. While in mountainous areas clear migrant funnels can be observed, Belgium lacks such strong geographical bottlenecks. As a result, millions of migrant birds fly over the country, crossing a wide area each year. However, some concentrations of migrating birds are observed along the North Sea coastline or along some river valleys. To consider migration in a layer, we started from migration corridors already defined for wind-farm sensitivity mapping in Flanders (Everaert et al. 2011) and we added approximated corridors for the main migration of the Common Crane *Grus grus*, known to migrate in rather well-defined corridors, and one of the most abundant migrant birds, the Wood Pigeon *Columba palumbus*, as deduced from migration counts recorded in the portal trektellen.org (Troost and Boele 2019).

Combining bird layers into a risk map

The bird layers were combined into a risk map using a scoring system (Table 2), with the intention of providing an assessment of the relative risk of bird collisions, in other words 'weighting' spatial units in relation to bird collision risk with power lines. As explained above, we hypothesised that the most detrimental power line effects would be close to important waterbird areas, especially roost sites and colonies, as they involve regular movements of large numbers of birds entering and leaving these areas. We also postulated that focusing on mitigation efforts for lines crossing sensitive rare bird areas would be relevant, as it makes sense in terms of concentrating on conservation measures, given that regional authorities as well as nature-conservation organisations are often already investing in these areas to protect target species. Other sensitive species, like widespread breeding species and migrating birds in certain corridors, are also present around some power lines but because power lines probably pose a 'diluted' risk for these species, we advocate handling these factors only as a secondary priority criterion.

Table 2. Priority scoring system for the spatial units in the final map.

Spatial layer considered (Table 1)	Distance buffer from the site				
	Inside the site	Less than 1 km	Between 1 and 3 km	Between 3 and 5 km	Over 5 km
Important waterbird site	If very important, 30; if important, 25; if fairly important, 20	14	9	4	0
Important roosts	If very important, 25; if important, 20	14	9	4	0
Important colonies	If very important, 25; if important, 20	14	9	4	0
	(no buffer considered below)				
Rare-bird area	10 points for an area with one rare species, 20 for an area with two or three rare species, 25 for an area with four or five rare species, and 30 for an area with more than five species				
Migration corridor	8 points if inside, 12 if it is the coastal corridor				
Plover staging area	5 points for each of the three species, when presence cut-off is reached				
Widespread breeding bird	4 points for each species, when presence cut-off is reached				
Woodcock area	4 points if Woodcock presence cut-off is reached				
Geese foraging area	5 points in the areas of occurrence defined by the spatial models				

All these considerations are reflected in the scoring system. The bird layers and the score system were combined, adopting the following procedure. We used a regular 31,472 km^2 grid covering Belgium – in fact, the same 1×1-km grid used to build the bird layers in Table 1. The highest possible score for a given layer intersecting each square was selected for that square and summed over all layers. For the score depending on the distance to waterbird sites, the distance from the centroid of the square to the nearest important site was used. Therefore, each 1×1-km^2 square received a final score made up of 17 sub-scores corresponding to all the possible bird layers.

Checking the risk map robustness

The importance of the different spatial layers and their effect on the final risk score of the grid cells was calculated by comparing the results from the complete risk map with the map resulting from reduced maps in which a single data layer was removed. Since the risk map is designed to identify the most vulnerable locations, the main interest of the reduced risk maps is to study how consistently these vulnerable locations are identified when removing a single data layer from the global risk map. To examine this, the grid cells within the top 10 percentile highest-risk scores were identified, next we examined how many of these grid cells were also classified as among the top 10 percentile most dangerous in each of the reduced risk maps.

Results

The list of susceptible species to be considered for collision risk with transmission lines amounts to 83 bird species in Belgium (see Suppl. material 1: Table S1 for the complete list). This represents 38.4% of all regularly observed bird species in Belgium. Thanks to regular coordinated monitoring of wintering waterbirds, colonial breeding birds and some socially roosting species, together with a very popular bird recording system (about 2 million bird records in Belgium every year), a large number of data could be used to draw the 17 thematic layers (all presented as Suppl. material 4: Figs S1–S17).

The application of the scoring system resulted in a map at 1×1 km spatial resolution for collision risk with power lines for Belgium, presented in Fig. 1. This map is independent of the presence of actual power lines; it represents a hypothetical risk based on the additive presence of the identified sensitive species.

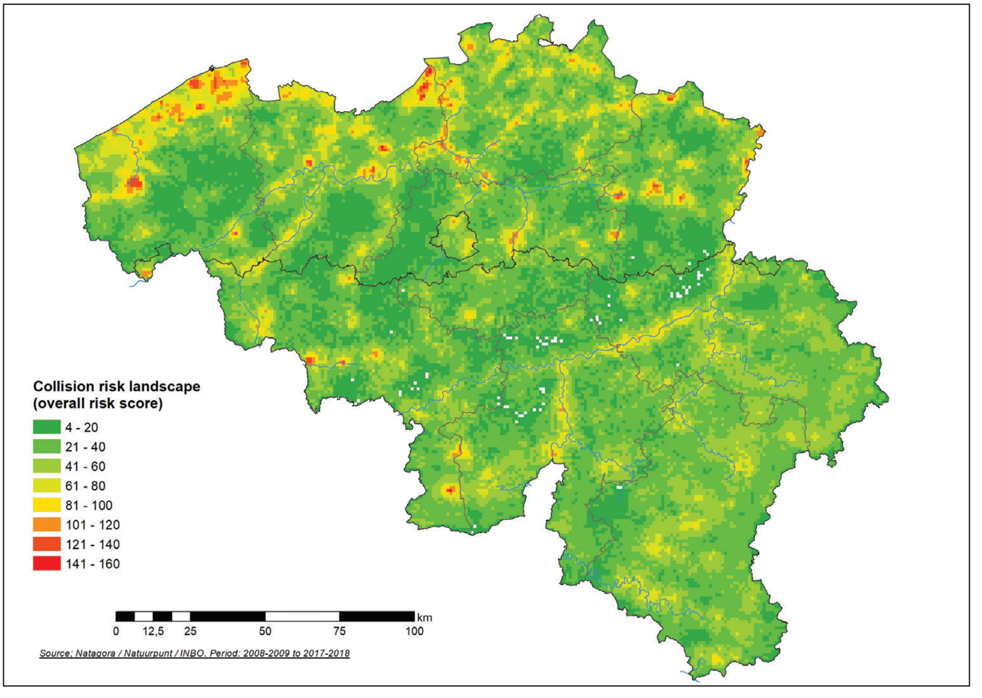

Figure 1. The transmission lines collision risk map for the whole of Belgium, shows the risk at any location in the country. This is a theoretical score not accounting for the current presence/absence of a power line, based only on the additive presence or high abundance of the sensitive species.

Combining all the possible maximum scores for each layer, the theoretical highest possible score is 176. In our present assessment, the highest observed score is 153. There is a clear gradient of risk from the lowlands in northern Belgium, where most wetlands are located, to southern, more elevated parts of the country, where risk is more diffused except along the main river valleys. The polder areas are the most critical areas as these are major concentration sites for waterbirds. Inland wetlands are also focal points for collision risk.

When overlapped with the risk maps, power-line spans (the linear segment of lines between two pylons) can be classified according to the relative risk they represent to birds (Fig. 2). The most dangerous span in the present assessment is predicted to be the line crossing a nature reserve along a major tributary of the Scheldt river, with a score of 133.

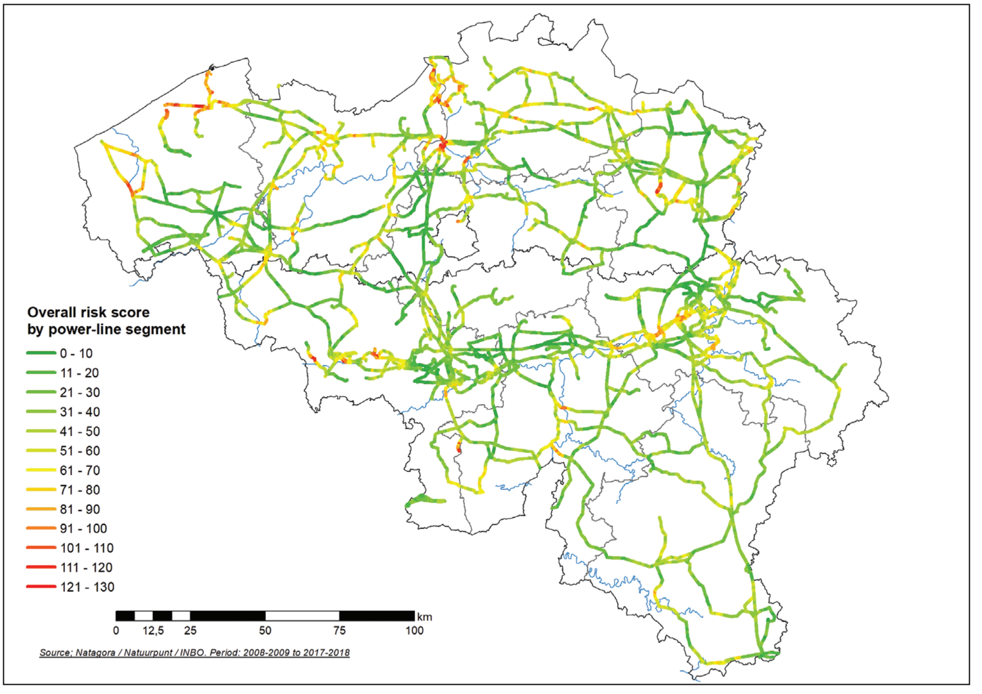

Figure 2. Map of the existing transmissions lines, colour-coded according to the bird collision risk they represent. Most of the high-priority lines are close to important waterbird sites, but numerous segments are also located in the central part of the country, in the historically industrial river valleys.

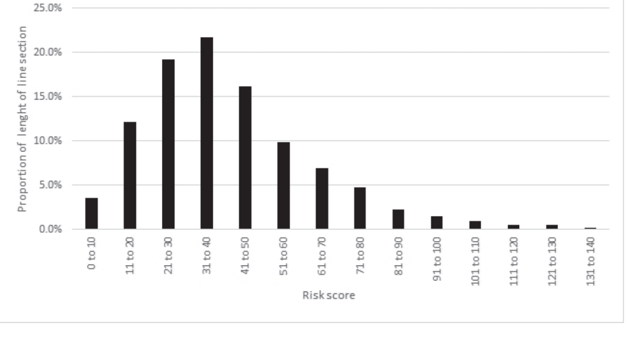

Figure 3. Frequency distribution of grouped risk scores for the total length of overhead line spans (for the whole of Belgium).

Most of the lines run through medium- or low-risk score areas (Fig. 3). Looking at the grid as a whole, 5.8% of the total length has a score above 80.

Depending on which data layer was removed, 81.6% – 90.1% of the most dangerous grid cells (as identified by the complete risk map) remained within the top 10% of the most dangerous grid cells (according to the reduced risk maps, Suppl. material 3: Table S4). This indicates a certain robustness from the collision risk map to the removal of one specific data layer.

Discussion

Reducing the risk of bird mortality along transmission lines is an important goal to achieve in a context where electricity transport system will inevitably expand throughout the world. Here we propose a method based on existing bird data to identify the "dark spot" where collision risk is relatively higher at a country scale, the scale at which the transmission line companies are operating. We believe that such an approach could inform the strategic planning of new transmission lines to be installed but more directly could be used to target mitigation actions – wire marking – on existing lines, once the existing network is overlapped with our risk map. A similar sensitivity mapping approach was developed previously in Spain and Portugal, taking into account susceptible breeding bird distribution at the scale of 10×10 km (D'Amico et al. 2019). Here, both breeding and wintering bird abundances were brought into the map at a resolution of 1×1 km, thanks to the spatially explicit data provided by several citizen-science schemes.

Our results indicate that the risk of bird collisions with high-voltage power lines is unequally distributed over Belgium. This knowledge is important for multiple reasons. Firstly, for existing power lines, it contributes to focusing efforts to mitigate effects as efficiently as possible, where every investment has the highest return translated into prevented collision casualties. Secondly, the country wide risk assessment (independent of the presence of a transmission line) can be used to compare potential trajectories of new proposed power lines.

The collision risk map was entirely based on data about the avifauna. However, the risk of bird collision is not only depending on the species richness and the abundance of birds, but also on the technical configuration of the pylons and consequently the power lines. Spacers, which separate the lines of the phase, can increase visibility (Bevanger 1994). The height of the power line is also likely to affect the bird collision risk, as is the number of vertical wire levels, the wire diameter and the presence of an earth wire (Bernardino et al. 2018). Although currently not available nationwide (Mortier, J. pers. comm.), the addition of a technical data layer to combine with the risk derived from the avifauna data could refine the current results. Furthermore, there is the possible effect of the surrounding landscape. A power line located in a heavily forested habitat with power pylon height lower than the average tree height poses limited risk to possibly susceptible species since they are forced to fly above the trees and the power lines (Jenkins et al. 2010). We suggest taking these landscape elements into consideration for fine-tuning of the wire marking once mitigation has been targeted with the help of the countrywide risk map. However, even with a further refinement of this theoretical approach, it should not replace a detailed field survey of mortality along existing lines or the necessary field expertise necessary for a proper Environmental Impact Assessment.

A key issue in this sensitivity mapping approach is the availability of bird data at a country-wide scale. Our study area, Belgium, benefits from a high density of amateur birdwatchers and long-term coordinated monitoring schemes. But we think that our approach could be used even in less surveyed regions. Spatial modelling techniques are now available to produce reliable predictive spatial models based on citizen-science records, taking into account strong spatial bias in their collections (Tang et al. 2021). These citizen-science records are now starting to accumulate almost everywhere in the world and are generally available as open source data (Callaghan and Gawlik 2015; de Vries and Lemmens 2021). In our case, for species with a low detection rate, as Eurasian Woodcock, we could use the limited number of available data to estimate the total range at 1×1 km resolution. Scarcity of data should not prevent attempting to perform a risk map analysis in other regions of the world as we have shown that prioritised segments are rather constantly highlighted by the risk maps, even when removing one layer.

A common problem with many conservation assessments published is that they often do not result in any conservation action (Knight et al. 2008; Arlettaz et al. 2010; Schuwirth et al. 2019). Our sensitivity mapping was commissioned by Elia, the transmission lines operator in Belgium. An earlier version of the risk map (Derouaux et al. 2012) was already used by the company to prioritise mitigation actions and to equip with wire marking around 115 km of lines until 2021 across Belgium (around 2% of all lines; data Elia). Some of this wire marking already took place before the production of the first version of the risk map, but already 7.4% of the transmission lines with a risk score higher than 80 are now equipped with wire marking (Elia data). In several of these spans, before-after control impact treatment involving field searches of bird casualties are now under way. Future field work analyses will allow for an assessment of the effectiveness of the prioritised wire markings but also will provide an evaluation of the theoretical mapping approach presented here.

Once established, our risk map analysis could be easily updated with new data, as bird monitoring and data collecting programs involved are running continuously and bird numbers and distributions are often susceptible to rapid changes. Another potential use of our risk analysis method is to assess further needs in wire marking (or burying) in the case of major natural wetlands restoration programmes (Decleer et al. 2016) that could result in large-scale bird distribution changes (Bregnballe et al. 2014) and thus changing the collision risk associated with existing transmission lines.

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Supplementary material 1

Table S1

Authors: Jean-Yves Paquet, Kristijn Swinnen, Antoine Derouaux, Koen Devos, Dominique Verbelen

Data type: Excel table

Explanation note: List of all considered bird species in Belgium with the classification into several categories according to the type of presence in Belgium, the susceptibility to collision with transmission lines, the conservation relevance. The type of spatial layer where the data from the considered species was used is also indicated.

Link: https://doi.org/10.3897/natureconservation.47.73710.suppl1

Supplementary material 2

Table S2, S3

Authors: Jean-Yves Paquet, Kristijn Swinnen, Antoine Derouaux, Koen Devos, Dominique Verbelen

Data type: Excel table

Explanation note: List of species recorded as victim of collision with power lines in Belgium: Table S2. From data portal. Table S3. From care centre in Belgium in 2010 and 2011 (source: Vogelbescherming VL).

Link: https://doi.org/10.3897/natureconservation.47.73710.suppl2

Supplementary material 3

Table S4

Authors: Jean-Yves Paquet, Kristijn Swinnen, Antoine Derouaux, Koen Devos, Dominique Verbelen

Data type: docx. file

Explanation note: Robustness of the final risk map, estimated by removal of one of the bird information layers.

Link: https://doi.org/10.3897/natureconservation.47.73710.suppl3

Supplementary material 4

Figures S1–S17

Authors: Jean-Yves Paquet, Kristijn Swinnen, Antoine Derouaux, Koen Devos, Dominique Verbelen

Data type: Maps in a docx document

Explanation note: Individual maps of all the spatial layers contributing to the final sensitivity map of the collision risk for birds with transmission power lines in Belgium.

Link: https://doi.org/10.3897/natureconservation.47.73710.suppl4