Reducing the risk of bird collisions with high-voltage power lines in Belgium through sensitivity mapping: 2020 update

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with the collaboration of Natuurpunt and the Flemish Research Institute for Nature and Forest (INBO)

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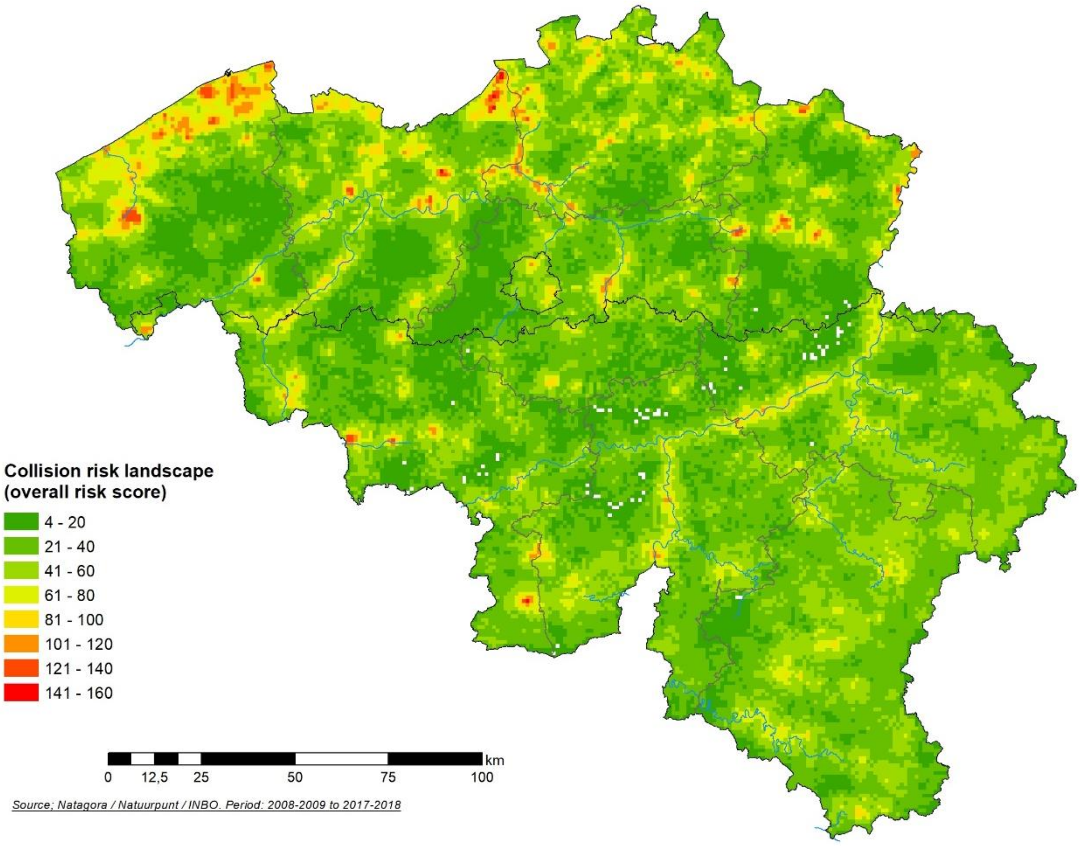

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Reducing the risk of bird collisions with high-voltage power lines in Belgium through sensitivity mapping: 2020 update

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Special thanks go out to the thousands of birdwatchers and ornithologists who count birds throughout Belgium and contribute to various databases and long-term monitoring projects. This work was only possible as a result of their input enhancing our knowledge of bird distribution and abundance. The portal *Observations.be/Waarnemingen.be* (a joint project run by Observation International, Natuurpunt and Natagora) played a key role in collecting accurate bird data.

Table of contents

1. Introduction 4
2. Update of the sensitive bird lists 5
3. From raw data to bird distribution layers 7
   3.1. Preliminary remarks 7
   Regional vs national criteria 7
   Temporal reference of the data used 7
   3.2. Wintering waterbirds 7
   3.3. Roosts of sensitive species 10
   3.4. Breeding colonies of sensitive species 11
   3.5. Widespread sensitive bird species 13
   3.6. Plover and Northern Lapwing staging areas 16
   3.7. Foraging areas for geese 18
   3.8. Rare breeding birds 20
   3.9. Migrants in large numbers 22
4. Combining the bird distribution layers into the risk map 24
5. Conclusion and next steps 29
6. Bibliography 30

1. Introduction

In 2012, a map of the collision risk between birds and high-voltage power lines – the first of its kind in Belgium and indeed, to the best of our knowledge, anywhere on a national scale[1] – was compiled and delivered to Elia, to enable the company to decide which power lines should be equipped with diverters to reduce the collision risk (DEROUAUX *ET AL.*, 2012). This risk map was drawn up on the basis of the best available knowledge about bird distribution in Belgium. A scoring system was developed to estimate the collision probability: a risk score was calculated for each pylon in the grid of electricity transmission system operator Elia, based on the local abundance of a selection of sensitive bird species. The sensitive species were selected using a combination of each species' susceptibility to collisions (as determined by a literature review), the impact on the conservation of this species of a potential surplus mortality rate due to such events and the gregariousness of the relevant species, leading to potentially mass mortality. Most of the distribution data used in this study dated from the period 2001-2010.

A decade after this first edition, we present an update of this collision risk map. This update was considered necessary for the following reasons:

- Data on bird distribution have become much more accurate and plentiful since 2008, thanks to the online recording platform www.observations.be/www.waarnemingen.be. For some species the availability of more data has resulted in a more detailed understanding of their distribution than 10 years previously.
- Environmental changes (climate change, large-scale habitat restoration, etc.) are constantly reshaping bird distribution and abundance, and so ten years after the initial assessment of the situation seemed to be an appropriate juncture for an update.
- New information from literature or casualty records could have an impact on the sensitive species list and hence the scoring system, regardless even of any change in bird distribution. This makes it important to periodically re-assess the sensitive species list. The change in which species are monitored could also be due to a shift in a species' status: for instance, recently the collision risk of migrating common cranes (*Grus grus*) with power lines in Belgium was assessed because of a dramatic increase in the numbers of these birds passing through Belgium during migration (DEROUAUX & PAQUET, 2018a).

Over the course of this decade, substantial progress was made on reducing the impact of energy infrastructure on birds and other wildlife. Several important guidance documents have been published (EUROPEAN COMMISSION, 2018; MARTÍN MARTÍN *ET AL.*, 2019). Thanks to the increased availability of data and relevant publications, it became easier to assess the efficiency of diverters in avoiding collisions (BERNARDINO *ET AL.*, 2019; FERRER *ET AL.*, 2020). In Belgium, an ongoing collaboration between Elia, nature-conservation NGOs Natuurpunt and Natagora led to more effective identification of particularly dangerous power lines, impact assessments at local sites and the accumulation of an extensive collection of casualty records through a 'citizen science' project. Several lines have recently been fitted with diverters, with more to follow soon. This report takes account of these developments and draws

[1] However, a risk map for bird electrocution on medium-voltage power lines was drawn up for Hungary in 2008 (see http://datazone.birdlife.org/sowb/casestudy/safer-powerlines-for-hungary's-birds).

on the more accurate knowledge regarding bird distribution, paying attention to some large-scale shifts in bird abundance.

The general principles applied when working out the risk map were the same as those used for the 2012 version. First, from the list of sensitive bird species (see section 2), we identified the data that needed to be extracted or obtained for the period 2010-2019 under consideration. From these raw data, we produced several map types (as explained in section 3), also called 'layers'. Then we combined all these layers using a scoring system, detailed in section 4, to produce a landscape map of the collision risk. Finally, this map was brought together with the locations of Elia power-line segments[2] and a risk score was assigned to each segment. The higher the score, the more dangerous the line segment in terms of bird collisions.

2. Update of the sensitive bird lists

Along with Natuurpunt (Dominique Verbelen) and the Flemish Research Institute for Nature and Forest (INBO) (Koen Devos), we re-examined the bird list compiled in 2012. To ensure that no species were missed, we also checked the list of species whose status Belgium is required by the EU Birds Directive to report on every six years. For species that were migrant and wintering species, we created two lines, one for each 'population'. Then, for all populations we assessed the availability of data from known sources and the ability to use these data without bias to update the risk map. Our final species list is presented in Annex I.

We also considered what type of analysis needed to be conducted to use the data with minimal bias in our assessment. Based on the analysis of bird distribution data, five different map types were used. These are explained in Table 1. The next section describes how we derived these maps from the raw data.

[2] In the 2012 version of the risk map, pylons were used as evaluation points for collision risks. In contrast, in the present study a risk score was calculated for each segment, i.e. each section of line between two pylons.

Table 1: Description of the different map (or 'layer') types used in sensitivity mapping

Map type	Explanatory remarks	Application
Important sites	These maps are based on surveys performed at specific sites (which are defined as a perimeter on a map), such as waterbird count sites. Each site may be used by several sensitive species and the relative risk associated with the sites (reflected in the risk score) depends on the number of species and individuals regularly seen at the site.	Important waterbird sites (at least 29 species affected) – see 3.2
Buffers around a specific location	These maps 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 power-line segment is to a colony or roost, the higher the collision risk, because of the flight trajectory to and from the site.	Important roosts or colonies (> 8 sensitive species affected) – see 3.3 and 3.4
Distribution models	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 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 little recording takes place.	Maps for widespread breeding species or staging groups of geese and plovers – see 3.5, 3.6 and 3.7
Species richness maps	Maps at 1-km² resolution with a count of the number of species (in our case, rare breeding bird species) recorded in that cell	Maps showing the richness of rare breeding birds – see 3.8
Migration corridors	Very low-resolution maps of the main 'corridors' for large numbers of migrant birds in transit	Bird migration corridors in Belgium – see 3.9

3. From raw data to bird distribution layers

3.1. Preliminary remarks

Regional vs national criteria

As Elia operates right across Belgium, it makes sense to determine the most critical areas for birds at national level. However, bird monitoring and conservation in Belgium are organised at regional level because nature conservation is a responsibility of the regional authorities and because the coordinating organisations mostly operate at this level. Therefore, to produce the initial map, it was decided to use regional criteria of importance for each site rather than national criteria (i.e. to set thresholds of importance for a site based on the proportion of the regional population present at this site, instead of taking the national bird population). We considered this the best way of resolving the dilemma of delineating important bird areas nationally, while taking into account regional priorities for nature conservation. This approach may inspire integrated work at a higher level (multi-country approaches), although additional research and testing would be necessary.

Temporal reference of the data used

The maps presented below are based on the most up-to-date bird distribution data available, dating from the period 2009-2018 for the waterbird census and 2010-2019 for most other data. We could have worked out most of the maps using a much shorter period (for example, the last three years instead of the last 10 years), but we believe that taking 10 years provides a clearer picture of the multi-annual importance of a given site. Some locations could temporarily harbour a very large number of birds because of particular circumstances (such as cold weather freezing other wetlands). However, we think that the relative collision risk of a site is linked to regular, long-term occupation of this site. By way of exception, for geese groups, only the last three years of data were taken into consideration because of the recent, significant changes in distribution observed for these species.

3.2. Wintering waterbirds

Belgium, and Flanders in particular, is home to large numbers of waterbirds, especially in winter. 'Waterbirds' is the name given to a multi-family group of species sharing a strong ecological link with wetlands and includes wildfowl, herons, rails, waders and gulls but traditionally excludes passerines also linked to water (like the Dipper *Cinclus cinclus*). Waterbird species are often regarded as particularly sensitive to power-line collisions. This sensitivity is further reinforced by their social behaviour (most species are highly social during migration and in winter and many breed in colonies, i.e. are social during reproduction). Large groups of waterbirds can easily be disturbed by humans or predators, often leading to a higher risk of collisions, caused by panic. Colonial and communal roosting behaviour involves regular 'commuting' trips between roosts/colonies and foraging sites. Note that some waterbirds (e.g. the Common Snipe *Gallinago gallinago*) may also use dispersed habitats (such as wet meadows and pastures).

Waterbirds are also probably the most closely monitored species group in the world, having been the subject of mid-winter counts organised throughout Europe for more than 40 years (WETLANDS INTERNATIONAL, 2012). In Belgium, every winter, mid-monthly counts of waterbirds are carried out in the country's three regions, aided by hundreds of volunteers. The counts are coordinated by INBO for Flanders (DEVOS *ET AL.*, 2019) and by Aves for Wallonia and Brussels (JACOB *ET AL.*, 2019). The procedure for these counts is simple (DEVOS *ET AL.*, 2020): each participant is assigned a perimeter of wetlands (described from here on as a 'waterbird site'). A waterbird site could be a pond, a lagoon or an artificial water body, or a stretch of river or canal. It could also be a complex of wet meadows. In a nutshell, it refers to any wetlands occupied by waterbirds in winter. Each participant should visit their site on a specific weekend (the closest to the 15th of the month from October to March in Flanders and from November to February in Brussels and Wallonia) and count all the waterbirds. Therefore, the final format of the data is a list of species with a total count for each visit. Data are entered and managed online. These datasets are used for a variety of purposes, of which a very important one is to make estimates of population trends. Here we used an extract from both databases encompassing all counts from 2008-2009 to 2017-2018. Maximum counts per winter for each species and each site were calculated. The site perimeters were copied from the INBO geographical database for Flanders and the Aves[3] database for Brussels and Wallonia (most of the boundaries of the sites are obvious from habitat maps or aerial views).

The regional population for each species was estimated using a multiple imputation methods to account for missing value (ONKELINX & DEVOS, 2019). Only the species with a mean regional population of at least 10 individuals were taken into account for this rest of this step. The winter maximum for each waterbird site for each species and each winter was then compared with the regional population estimate to check whether two arbitrary thresholds of 'importance' were reached, namely 2% and 15% of the regional population. These thresholds to establish the importance of sites were previously used in sensitivity mapping for wind turbines in Flanders (EVERAERT *ET AL.*, 2011). The importance criteria are reached for one site and one species if the threshold is reached for at least half of the years for which a count is available (some sites were not counted every year). We also calculated the total number of waterbirds counted at each site each winter and this was also used as a criterion for importance. Exotic species and gulls were not included. Table 2 explains how the criteria were applied to classify the sites in terms of their level of importance for wintering waterbirds.

Table 2: Criteria applied to work out the importance of wintering waterbird sites in the mapping process. In this table, 'Regularly' means at least 50% of the considered counts. Please note that exotic species (Canada goose, Egyptian goose, etc.) and gulls were not taken into account.

Importance for waterbirds	**Criterion**
Fairly important site	Regularly 100-1,000 waterbirds
Important site	Regularly more than 1,000 waterbirds **or** at least 2% of the regional wintering population of at least one species
Very important site	Regularly at least 15% of the regional wintering population of at least one species

The resulting map of critical areas for waterbirds in Belgium can be seen in Figure 1. As explained above, numerical criteria were applied on a regional basis to estimate the threshold. However, as

[3] Aves is the ornithological section of Natagora.

would be expected, the analysis reveals higher numbers of important waterbird sites in Flanders, especially in the polders and in the province of Antwerp. Given the higher numbers of waterbirds, there are more 'very important' and 'important' waterbird sites in Flanders than in Wallonia and the Brussels region. Brussels was considered together with Wallonia (as it is for the winter census); this was necessary because if Brussels had been considered on its own, many more sites would have reached the criterion of 2% of the regional population, although Brussels typically contains less than 2% of waterbirds wintering in Belgium.

We consider this regional approach to applying the threshold to be valid even to assess the relative importance of wintering sites nationally. This avoids regionally important sites being overlooked and, at the same time, suggests a clear priority for action for nationally important sites (in the case of waterbirds, most of these are in Flanders).

Sites were more precisely delineated than in the previous version of this map, and in some cases they were split. Overall, the map is more accurate, but this also means that as sites are smaller, one 'very important' site could now be divided into several 'important' sites. A very clear change from the previous version is the increasing importance of the Yser valley, where important habitat restoration work has been carried out, leading to higher average numbers of waterbirds.

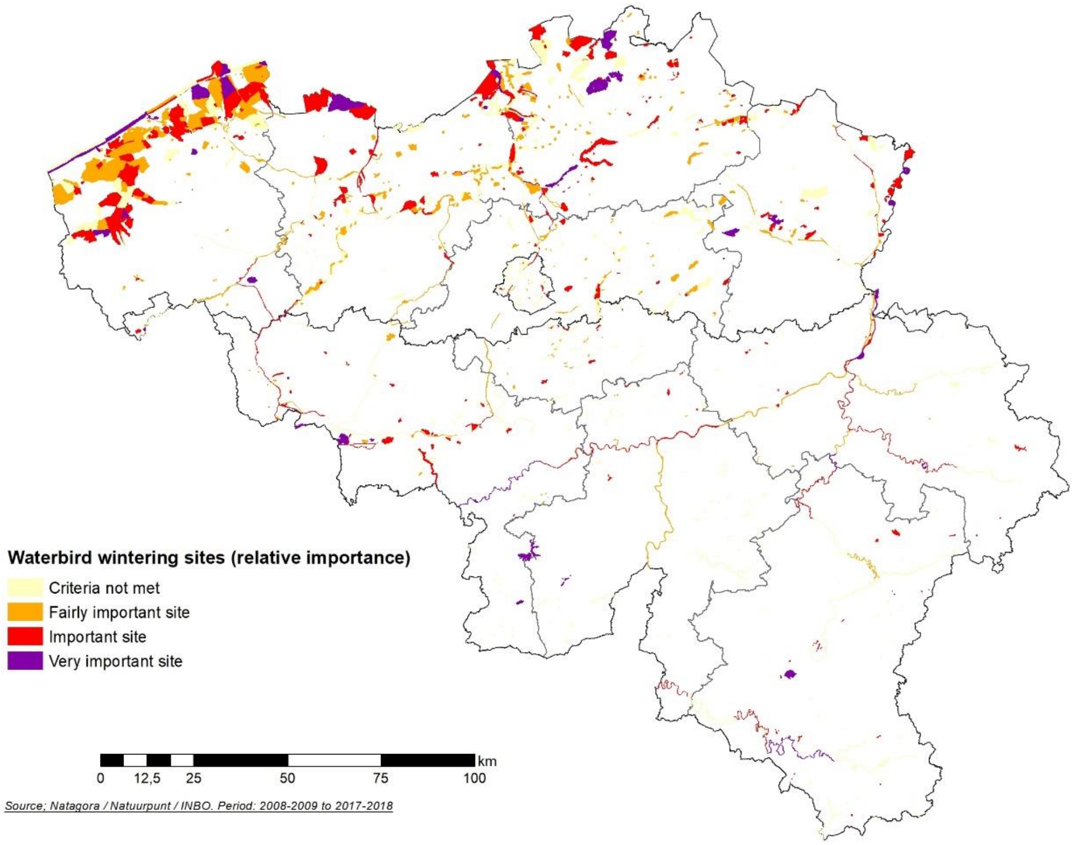

Figure 1: Layer of important sites for wintering waterbirds. See Table 2 for an explanation of the criteria and the rest of the text for how these criteria were calculated based on the 2008-2009 / 2017-2018 counts.

3.3. Roosts of sensitive species

Outside the breeding season, many bird species congregate in large numbers (up to millions of individuals for some species) at specific customary locations to spend the night; these locations are called 'communal night roosts'. Various ethological explanations have been proposed for this spectacular behaviour, namely suggestions that this is a way of keeping them safe from predator attacks, ensuring temperature regulation, and facilitating the exchange of information. In terms of power-line collision risks, these roost locations are significant because they entail daily movements of flocks between the roost and the feeding grounds. Moreover, collision risks may be greater for roosting birds than for colonial breeding birds because the former are migrants that are not necessarily familiar with the local environment.

In this report, data used for assessing roost locations come primarily from www.observations.be and www.waarnemingen.be (data came from selecting 'roost' from the dropdown list in the 'Activity' field). These data have been supplemented with data from organised coordinated counts of Great Cormorants, Eurasian Curlew, Great White Egret and gulls (INBO and Aves data).

Table 3 details the criteria and thresholds used to define the relative importance of roost locations.

Table 3: Criteria applied to define the importance of waterbird roosting sites at regional level.

Importance for waterbirds	Criterion/threshold
Fairly important site	Fewer than 100 individuals regularly counted
Important site	Between 100 and 1,000 individuals regularly counted
Very important site	More than 1,000 individuals or at least 2% of the regional population regularly counted

The map of the selected roosts is shown in Figure 2. Communal night roosts were located and identified for the following waterbird species: gulls (all species of *Larus sp.*), the Great Cormorant, the Eurasian Curlew, the Great White Egret and the Goosander. Geese roosts were excluded from the roost map because we considered geese in a different way, using foraging places instead (see section 3.7).

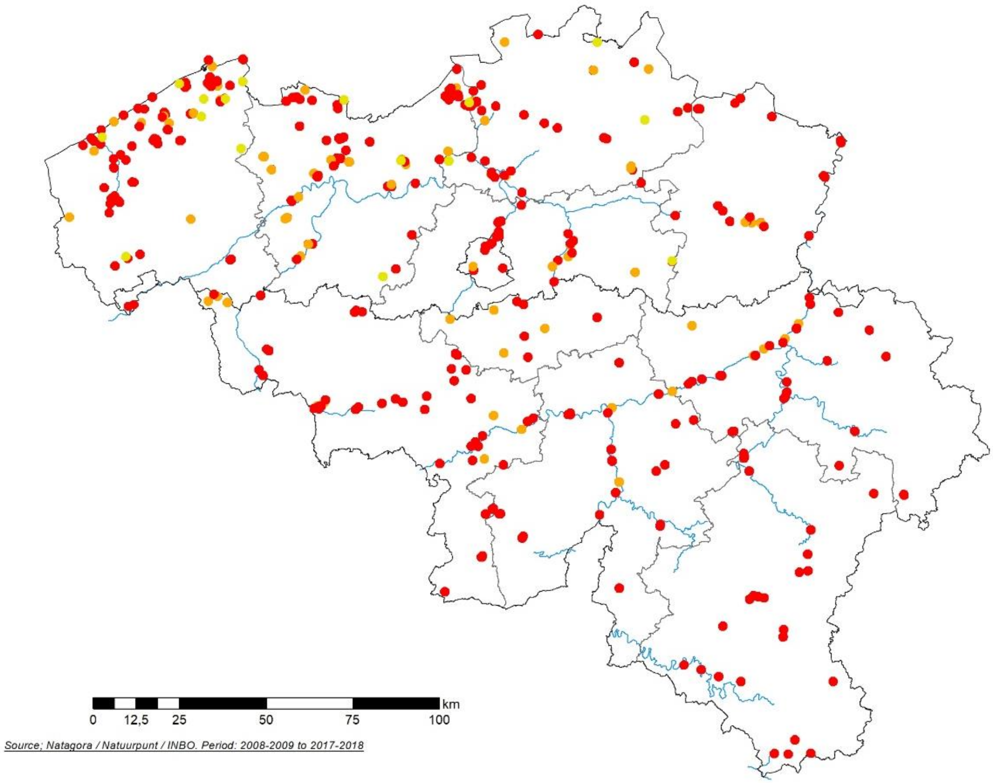

Figure 2: Locations of roosts identified for several sensitive species (see text for a list). "Very important roosts" are in red, "important" in orange, "fairly important" in yellow.

3.4. Breeding colonies of sensitive species

Many species of birds tend to nest in colonies: nests are not built across a wide area where a pair finds all the resources needed for breeding, but instead, nests of several or multiple pairs, sometimes even running into the thousands, are constructed close to each other, with adult birds having to travel outside the colony to find food and other resources. These regular flight trips and the large number of birds sometimes involved mean that colonial birds from sensitive species are particularly at risk of collisions with power lines.

For this update, colonial bird data were selected from the www.observations.be / www.waarnemingen.be dataset for the period 2010-2019 (see Table 4 for the species list). Colonies were selected based on 'important colony sites' being sites where 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 colony sites' being sites where more than 100 breeding pairs are regularly recorded or which have at least 2% (or > 10 breeding pairs) of the regional breeding population.

Table 4: List of colonial species breeding in Belgium with their relative collision risk with high-voltage power lines.

English name	Scientific name	Included in the 2019 risk map	Sensitivity to collisions	Conservation relevance
Great Cormorant	*Phalacrocorax carbo*	yes	high	low
Grey Heron	*Ardea cinerea*	yes	high	low
Eurasian Spoonbill	*Platalea leucorodia*	yes	high	high
Mediterranean Gull	*Larus melanocephalus*	yes	high	high
Black-headed Gull	*Larus ridibundus*	yes	high	high
Common Gull	*Larus canus*	yes	high	high
Lesser Black-backed Gull	*Larus fuscus*	yes	high	low
Herring Gull	*Larus argentatus*	yes	high	low
Sandwich Tern	*Sterna sandvicensis*	yes	high	high
Common Tern	*Sterna hirundo*	yes	high	high
Little Tern	*Sterna albifrons*	yes	high	high
Sand Martin	*Riparia riparia*	no	low	high
Rook	*Corvus frugilegus*	no	low	low

Figure 3 shows all known important colonies of all species that are sensitive to collisions according to Table 4. In the south-east of the country, only Grey Heron colonies are regularly found, while west of the River Meuse there is more diversity in the colonies. There is a very important hotspot around the port of Zeebrugge (especially involving tern colonies).

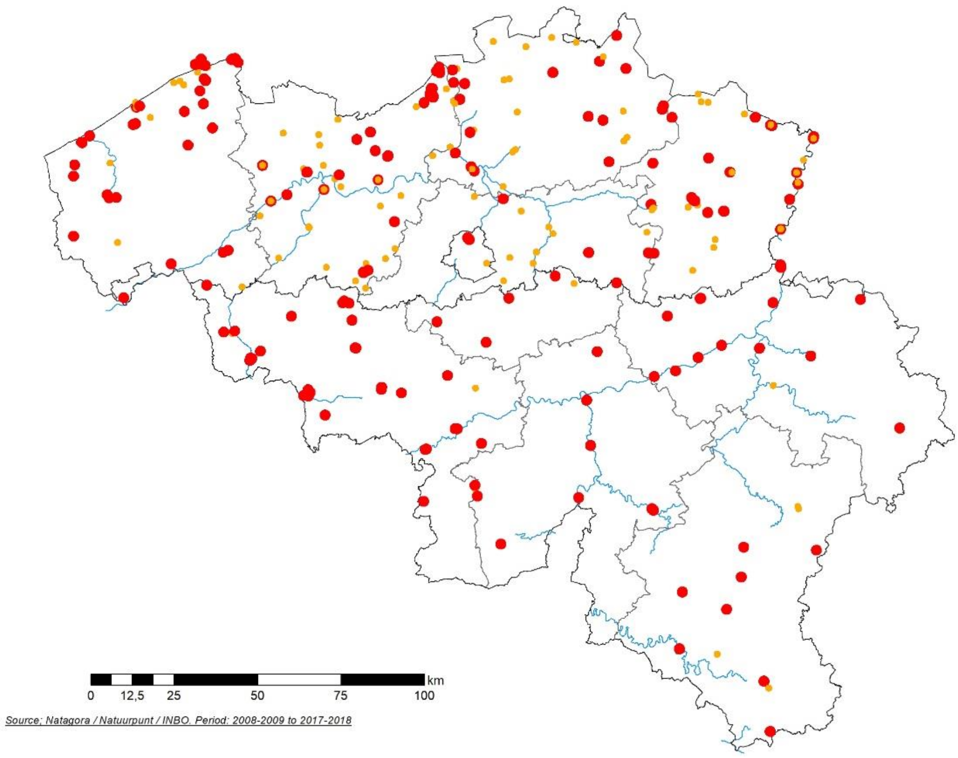

Figure 3: Layer map of colonies of sensitive breeding bird species in Belgium for the period 2010-2019. Red dots are "Very important sites", orange are "Important sites".

3.5. Widespread sensitive bird species

Among the species sensitive to collision, some are not linked to well-defined sites or areas. Although some of these bird species are not abundant, they do have a rather widespread population in Belgium, present in variable densities in a range of habitats. Some species occupy large territories or have an extensive home range, meaning that they can be found on a widespread basis. This is typically the case for some forest birds (woodpeckers) or farmland birds (the Turtle Dove). For these species, which are sensitive to collision, a site-based sensitivity-mapping approach is inappropriate, given that it is often impossible to pinpoint specific sites where addressing the power-line issue would be critical for the species. Therefore, we explored the use of occurrence probability maps as a more effective approach to sensitivity mapping. These high-resolution (1-km²) maps show the relative probability of species' occurrence across the whole country, at. From these maps, we were able to select areas of occurrence for widespread species, thereby adding a layer to the collision risk with power lines. High-resolution occurrence mapping is generally possible through distribution modelling, using known observations of a species and statistical relationships between these data and environmental descriptors to predict the distribution (or abundance) of the species over a whole study area (FRANKLIN, 2009). Distribution modelling must be used rather than actual observational data or actual counted birds as it is generally impossible to obtain a picture of the presence/absence of every species at a very fine-grained resolution (like a 1-km² square) for the entire country.

The spatial model-building procedure is explained in detail in (DEROUAUX *ET AL.*, 2012). In a nutshell, we used observational data for the target species, extracted from www.observations.be/www.waarnemingen.be during the period 2012-2019. All data were plotted on a grid of 1x1-km squares covering Belgium. To model the distribution of the species considered, 20 variables relating to the environment in every square were calculated. These variables describe land use (deduced 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). The modelling method is MaxEnt, a presence-only technique that is now widely used in distribution work (PHILLIPS *ET AL.*, 2006). 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 focus species (ranging from 0 to 1) for every 1x1-km square in the model's grid. The probability of occurrence can be related to the 'habitat suitability' of the square for the species. A bootstrap procedure, leaving out of the training set 30% of all the presence data, is used to validate the model. 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).

Among the species identified as being sensitive to power-line collisions, the following breeding birds were mapped using this modelling procedure: The Grey Partridge, the European Turtle Dove, the Green Woodpecker, the Black Woodpecker and the Middle Spotted Woodpecker. Unlike the 2012 version of the maps, the Northern Lapwing was not modelled here, as we chose to map this species elsewhere in the risk map (as a resting plover group).

The impact of the presence of a widespread sensitive species on the risk score is relatively low (four points for all sensitive species deemed 'present' in a given square – see below), which is consistent with the moderate risk of collisions for these widespread species, which are generally found in pairs or very small groups. The species distribution (and therefore the risk distribution) has changed quite considerably for some 'common' species between the two periods under consideration (see also (DEROUAUX & PAQUET, 2018b)). The Turtle Dove, which is largely declining in Europe, has recently been classified as 'vulnerable' on the global Red List of Threatened Species and is now the subject of an EU Species Action Plan (FISHER *ET AL.*, 2018). As we can see in Figure 4, the Turtle Dove is still present in some parts of Belgium, but has disappeared from most of the central part of the country. Under the pressure of intensive agriculture, the Grey Partridge is also on the wane , while its range is contracting towards the north-west (Figure 5). On the other hand, sensitive species like the Middle-Spotted Woodpeckers are expanding their range to the north (Figure 6). This Birds Directive Annex I species is now present in most of Belgium's mature deciduous forests.

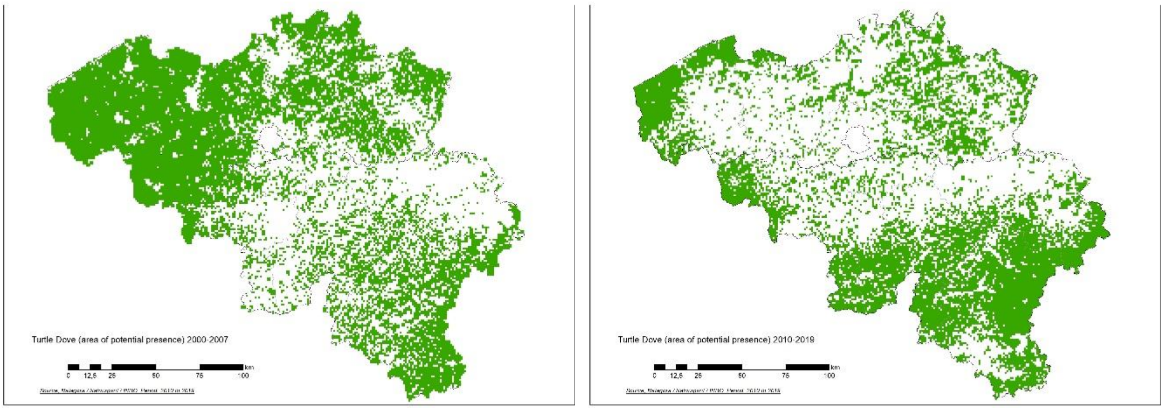

Figure 4: Modelled map for the presence of the Turtle Dove in Belgium (green denotes where the model predicts the species to be present (see the text)). On the left: the period 2000-2007, used in the first version of the risk map. On the right: the period 2010-2019.

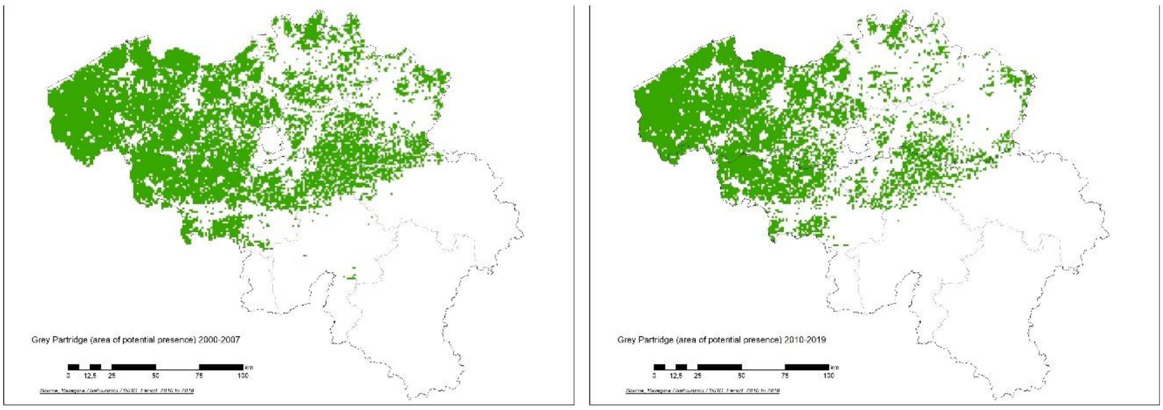

Figure 5: Modelled map for the presence of the Grey Partridge in Belgium (green denotes where the model predicts the species to be present (see the text)). On the left: the period 2000-2007, used in the first version of the risk map. On the right: the period 2010-2019.

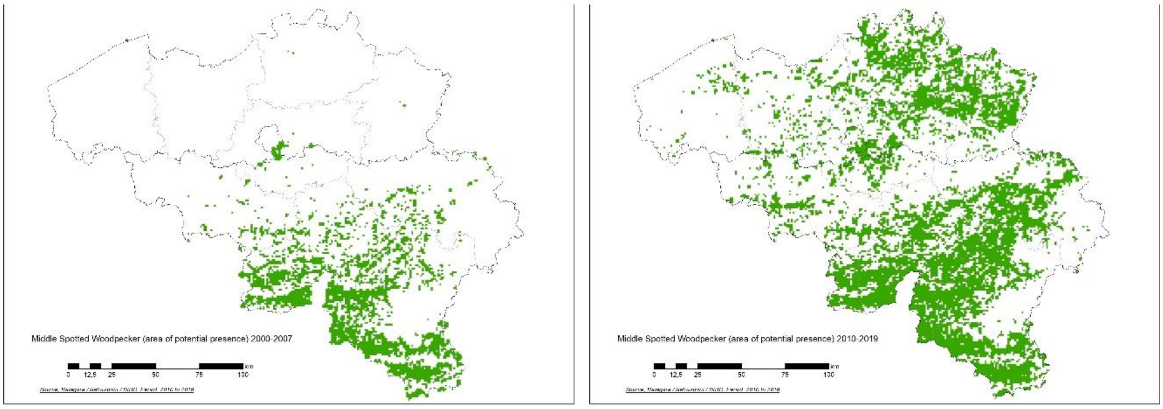

Figure 6: Modelled map for the presence of the Middle-Spotted Woodpecker in Belgium (green denotes where the model predicts the species to be present (see the text)). On the left: the period 2000-2007, used in the first version of the risk map. On the right: the period 2010-2019.

A new bird species that has been added to the sensitivity-mapping exercise which did not form part of it in 2012 is the Woodcock (*Scolopax rusticola*). In 2017, the high frequency of woodcocks among reported casualties prompted us to identify the 'black lines' for high collision risk for this species (DEROUAUX & PAQUET, 2017). We included the model built at that time in the new comprehensive map (Figure 7).

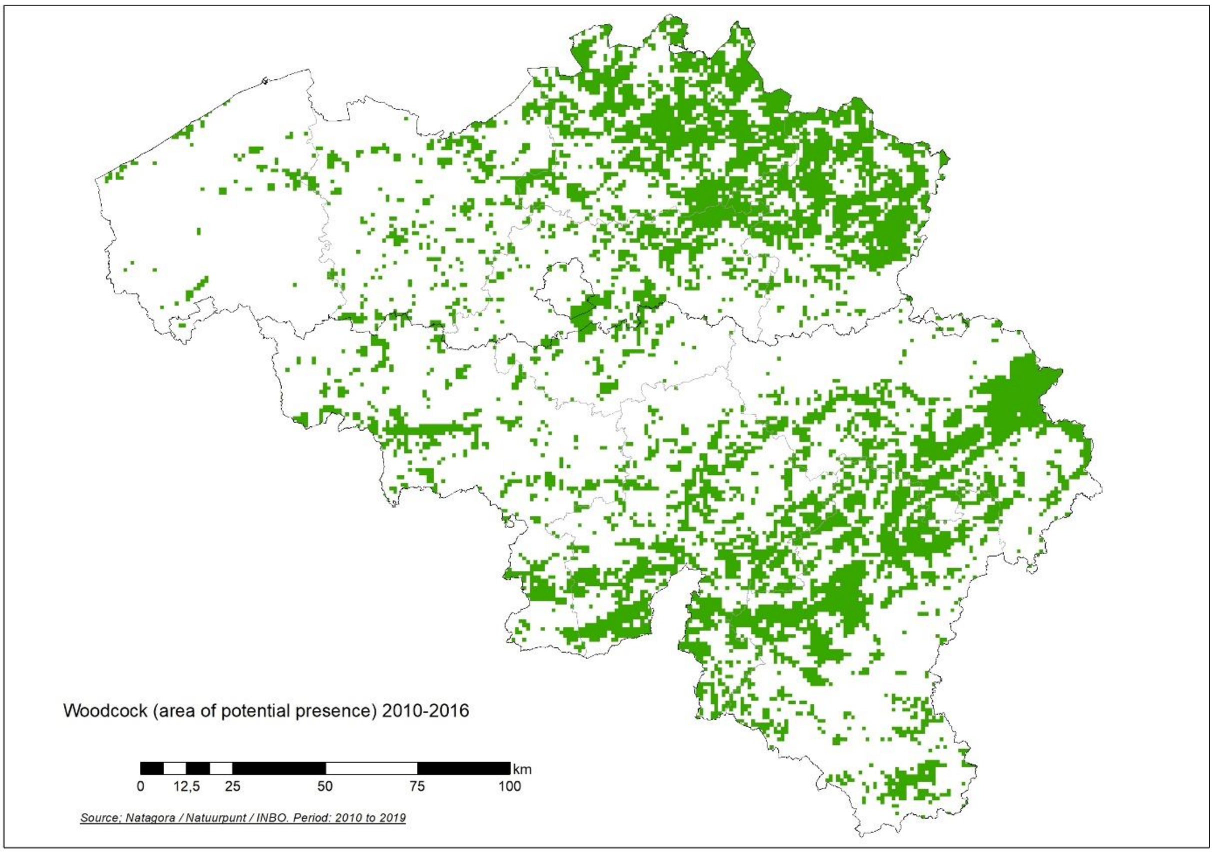

Figure 7: Modelled map for the presence of the Woodcock in Belgium (green denotes where the model predicts the species to be present (see the text)). Period 2010-2016.

3.6. Plover and Northern Lapwing staging areas

Two Birds Directive Annex I species of waterbirds, the Eurasian Dotterel (*Charadrius morinellus*) and the Golden Plover (*Pluvialis apricaria*) are both recognised as being sensitive to collisions and of conservation relevance (see Annex I). Their main staging areas are not well covered by the 'waterbird sites' layer, because these species mostly use terrestrial habitats (farmland) for foraging and resting. Dotterels are usually seen in very open cropland habitats during migration. Formerly thought to be a very rare bird in Belgium, it appeared during the 1990s to be a regular post-nuptial migrant staging in some farmland areas in central Belgium, sometimes in relatively large groups (ROUSSEAU-PIOT, 1995). The golden plover is an abundant migrating and wintering bird in meadows and open land, mostly in the western part of the country, close to the coast, and sometimes also more inland. The use of intensive agricultural habitats is not anecdotal for this species, as open fields can be a favourable staging habitat (LINDSTRÖM *ET AL.*, 2010). Additionally, in the present version of the map we decided to include the Northern Lapwing (*Vanellus vanellus*), targeting the areas where it can be present in large groups, instead of focusing on its breeding territories as we did in the previous version.

To identify the most critical areas for these three species, we used a spatial modelling approach similar to the one used for the widespread breeding species, but based on observation data extracted from the www.observations.be/www.waarnemingen.be database for the period 2012-2019. From this dataset, we selected the locations of resting groups of at least 100 Golden Plovers, resting groups of at least 50 Northern Lapwings or any groups of resting Dotterels (records of flying birds were excluded in favour of a focus on staging areas). For each species, only one observation per year inside a given 1x1-km square was retained (this was to avoid a group of Dotterels that stayed in the same place for a long time and so was recorded in some cases by dozens of 'birders', creating a bias in the modelling procedure). Starting with this dataset, we proceeded as already set out for breeding birds.

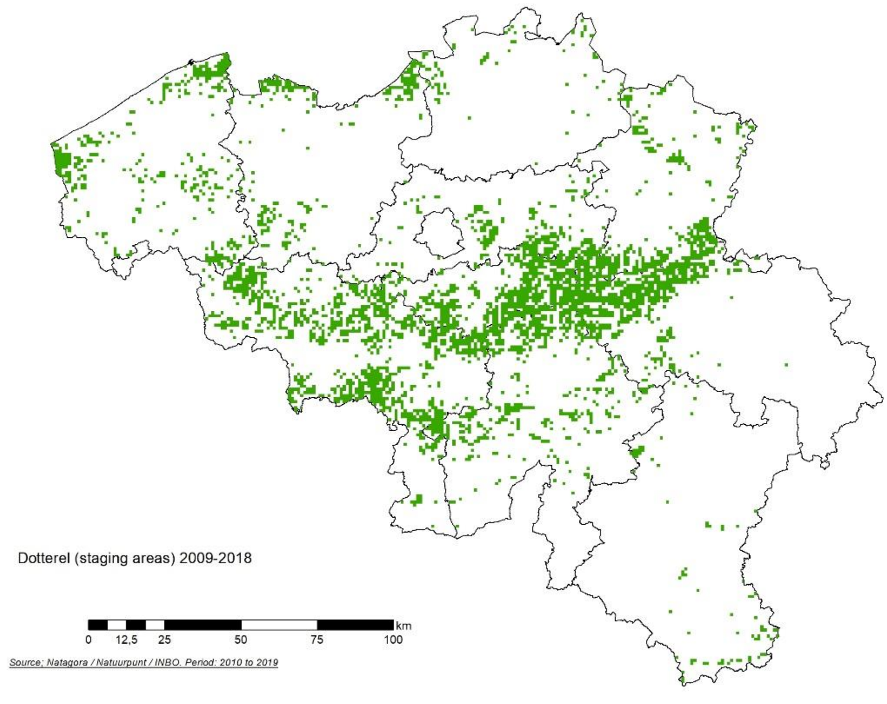

Figure 8: Staging areas of the Dotterel in Belgium based on the modelling of occurrence records.

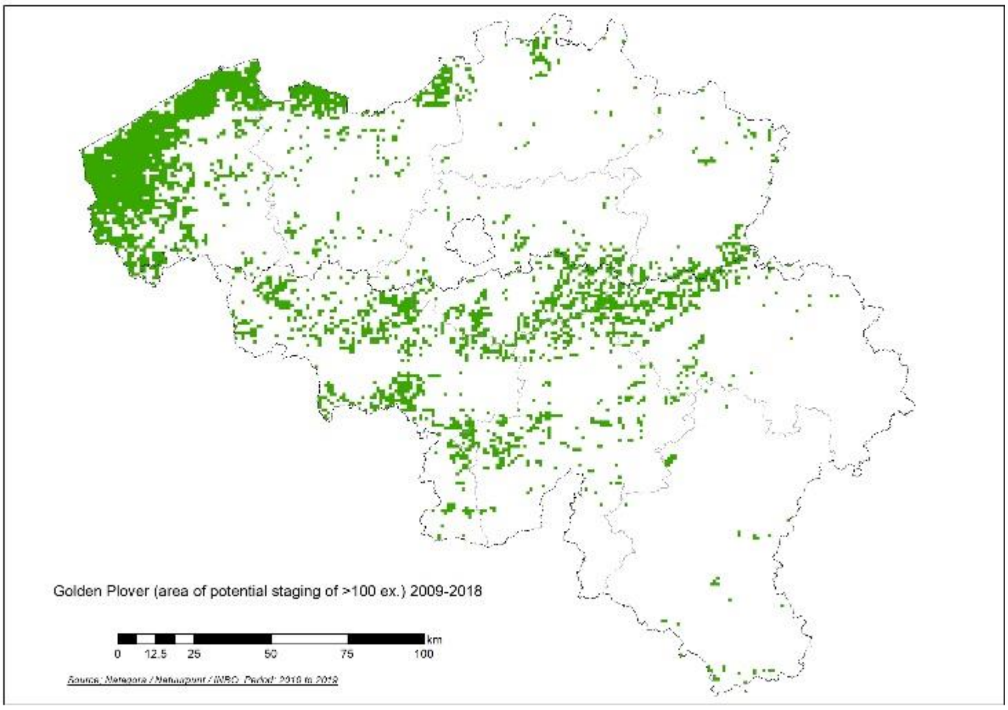

Figure 9: Staging areas of the Golden Plover in Belgium based on the modelling of occurrence records (groups of more than 100 individuals).

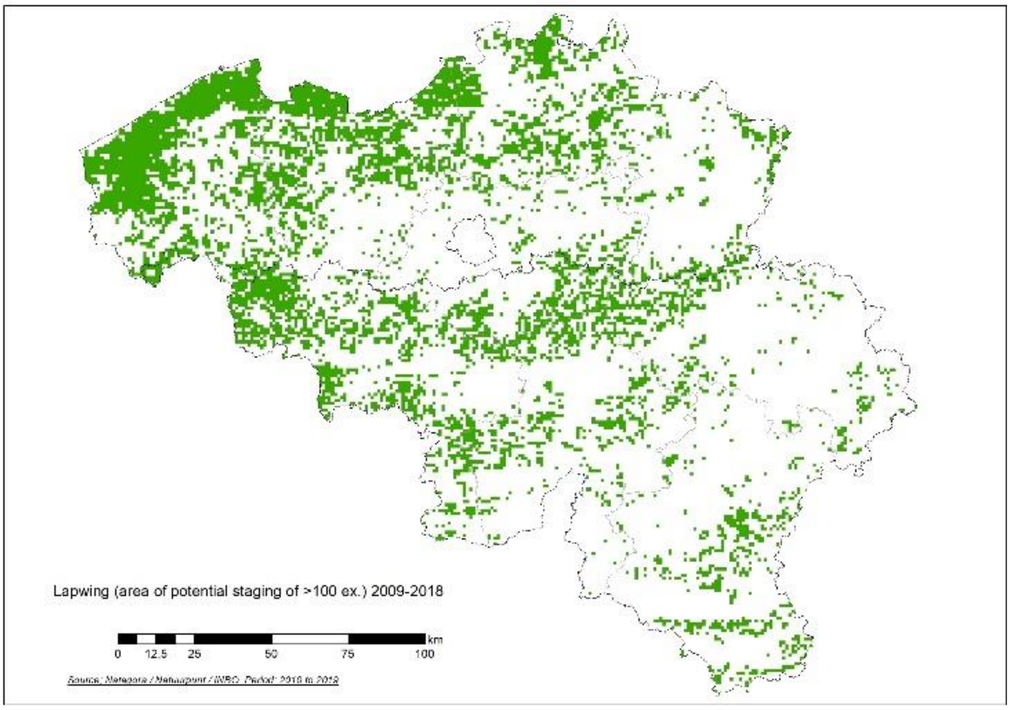

Figure 10: Staging areas of Northern Lapwings in Belgium based on the modelling of occurrence records (groups of more than 50 individuals).

The Dotterel mainly uses open field areas in the central part of Belgium (Figure 8) and is relatively less present in the polders region than the Golden Plover (Figure 9). The most widespread is the Northern Lapwing, also using some grassland areas in the south of the country.

3.7. Foraging areas for geese

These layers are a new feature not included in the previous map. Arctic-breeding geese are waterbirds that winter in very large numbers in Belgium, with these of international importance for three species in particular: White-Fronted Goose (*Anser albifrons*), with an estimated wintering population of between 47,000 and 76,000 individuals in winter (making it the second most abundant wintering waterbird in Belgium, after the Mallard (*Anas platyrhynchos*)), the Pink-footed Goose (*Anser brachyrynchus*), with 23,000 to 28,000 individuals, and the Greylag Goose (*Anser anser*), with 13,000 to 27,000 individuals (ONKELINX & DEVOS, 2019). Geese are mostly present in the polder areas, where they benefit from large-scale nature restoration projects and also intensive agriculture. This also explains why they are often in the air, commuting between roost locations (mostly quiet grassland) and foraging areas (cropland).

The same spatial modelling technique as explained in sections 3.5 and 3.6 was used. Records of groups of at least 50 individuals of the three most numerous geese species were used as a basis for the modelling procedure. The records were extracted from the www.observations.be/www.waarnemingen.be database for the period 2017-2019. Only this recent period was used because some changes in habits have recently been described, at least for Pink-Footed Geese, because of the deployment of new resources in cropland areas, such as in the Zandstreek, south of the traditional polders used by the flocks of geese (KUIJKEN, 2019). These new habits may result in large-scale movements and increase collision risks.

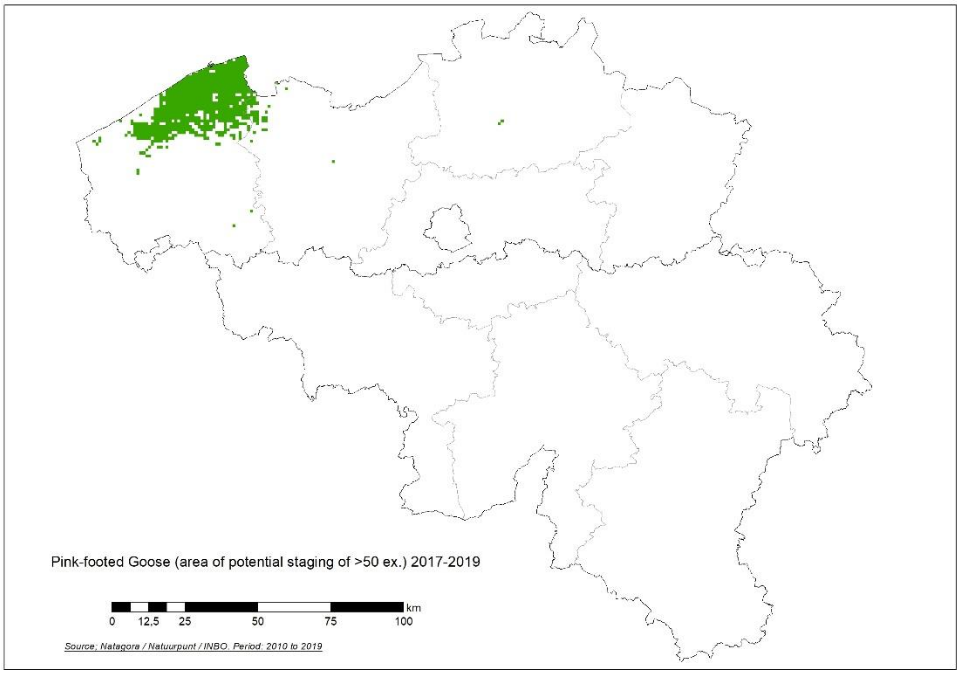

Figure 11: Staging areas of the Pink-footed Goose in Belgium based on the modelling of occurrence records (groups of more than 50 individuals).

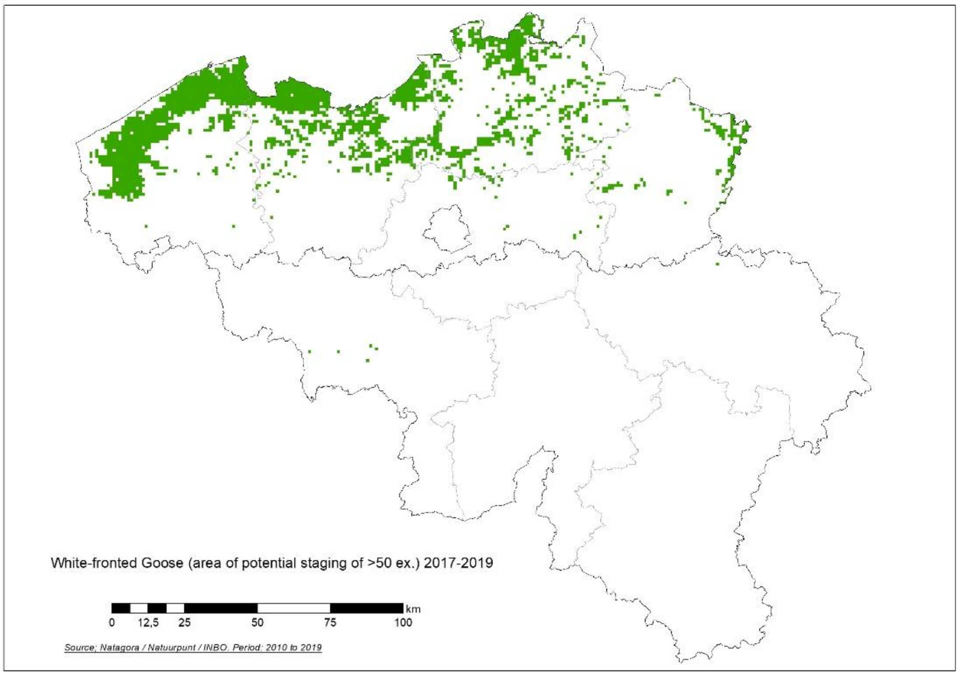

Figure 12: Staging areas of the White-fronted Goose in Belgium based on the modelling of occurrence records (groups of more than 50 individuals).

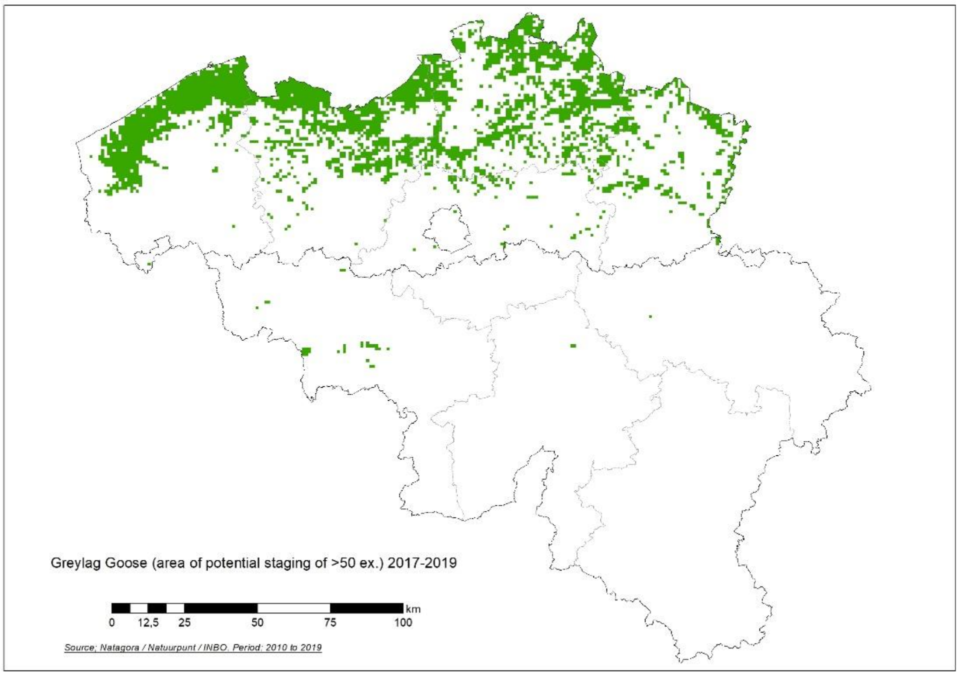

Figure 13: Staging areas of the Greylag Goose in Belgium, based on the modelling of occurrence records (groups of more than 50 individuals).

As Figure 11, Figure 12 and Figure 13 show, geese are almost exclusively present in Flanders, the most localised being the Pink-Footed, while the two other species are much more widespread.

3.8. Rare breeding birds

The list of species identified as being sensitive to collision with power lines includes several rare breeding bird species, of which very small populations are often concentrated at well-known sites. For some species all nest locations are even monitored from year to year. Most of these species have a special legal status (i.e. they are listed in Annex I of the Birds Directive and so are subject to particular measures) or are cited in the regional Red Lists of Threatened Species (see Table 5). Identifying dangerous power lines is particularly important for these species, as their populations are generally under a lot of pressure from other factors already. However, a few of these species (e.g. the Eagle Owl (*Bubo bubo*)) are now quite widespread in some areas. Minimising collision risks is important though as such species are still vulnerable to additional mortality. Two new species have been considered in the present update: the Pygmy Owl (*Glaucidium passerinum*) (a recent addition to Belgian avifauna and an Annex I species (SORBI, 2013)) and the Common Snipe (*Gallinago gallinago*).

Table 5: The legal and biological status of the rare breeding species that are listed as sensitive to collisions with power lines and are breeding in Belgium. The Red List status is taken from the latest versions of the assessment in Flanders (DEVOS ET AL., 2016) and in Wallonia (PAQUET & JACOB, 2010). Population estimates (period: 2013-2018) and short-term trends (the past 12 years) are drawn from the Birds Directive Article 12 reporting (INBO and Natagora, unpublished results). Asterisked species are considered of intermediate sensitivity to collisions in Annex I but are examined in the rare breeding bird map because of their high conservation value and potential sensitivity to additional mortality.

Species		Annex I	Red List (Flanders)	Red List (Wallonia)	Population estimate (BE)	Short-term trend (BE)
Hazel Grouse	*Bonasa bonasia*	X	-	Critically Endangered	0-5 hens	Probably extinct – not taken into account in this new version
Black Grouse	*Tetrao tetrix*	X	Extinct	Critically Endangered	2-5 hens	Decreasing but recently support programme underway
Great Bittern*	*Botaurus stellaris*	X	Critically Endangered	Critically Endangered	20-31 males	Increasing
Little Bittern*	*Ixobrychus minutus*	X	Endangered	Critically Endangered	31-60 pairs	Increasing
Black Stork	*Ciconia nigra*	X	-	Vulnerable	100-150 pairs	Increasing
White Stork	*Ciconia ciconia*	X	-	-	14-48 pairs and some feral populations around zoological parks	Increasing
Red Kite*	*Milvus milvus*	X	-	Vulnerable	360-420 pairs	Increasing

Marsh Harrier*	*Circus aeruginosus*	X	Endangered	Endangered	110-180 pairs	Increasing
Hen Harrier*	*Circus cyaneus*	X	-	Endangered	1-5 pairs	Stable
Montagu's Harrier*	*Circus pygargus*	X	Critically Endangered	Endangered	1-8 pairs	Stable
Peregrine Falcon*	*Falco peregrinus*	X	Endangered	Vulnerable	200-270 pairs	Increasing
Spotted Crake	*Porzana porzana*	X	Critically Endangered	-	20-77 pairs	Fluctuating
Corn Crake	*Crex crex*	X	Critically Endangered	Critically Endangered	1-10 males	Decreasing
Kentish Plover	*Charadrius alexandrinus*	X	Critically Endangered	-	2-6 pairs	Decreasing
Pied Avocet	*Recurvirostra avocetta*	X	Vulnerable	Vulnerable	400-450 pairs	Increasing
Common Snipe	*Gallinago gallinago*		Critically Endangered	Critically Endangered	20-37 pairs	Increasing
Eurasian Eagle Owl	*Bubo bubo*	X	-	Vulnerable	80-140 pairs	Increasing
Pygmy Owl	*Glaucidium passerinum*	X	-	-	1-6 pairs	First breeding in 2012, increasing
Tengmalm's Owl	*Aegolius funereus*	X	-	Vulnerable	1-40 pairs	Fluctuating
European Nightjar	*Caprimulgus europaeus*	X	Near-Threatened	Endangered	620-1,020 males	Increasing (but decreasing in Wallonia)
Eurasian Wryneck	*Jynx torquilla*		Critically Endangered	Endangered	66-101 pairs	Increasing
Grey-headed Woodpecker	*Picus canus*	X	-	Endangered	4-14 males	Decreasing (probably extinct as a regular breeder)

In the 2012 version of the collision risk map, the critical areas for these species have been mapped using two different approaches. For most species, a site-based approach was adopted: the layer was created by identifying specific sites (i.e. Natura 2000 sites) where the breeding population or the core breeding population is located. The second approach, adopted for a few rare breeding species at risk of collisions, was to use the detailed information about breeding territory locations and combine that with an estimation of flight range from the nest during the breeding season. In this version of the collision risk map, breeding records of these rare species were extracted from the www.observations.be/www.waarnemingen.be database and were used to locate more acutely sensitive areas. We used the season and/or activity mentioned by observers (such as 'occupied nest' or 'occupied territory') to select only potential breeding records. Then a buffer of 1-2 km was created around each specific location, based on the approximate flying range of the relevant species, and the 1x1-km square that intersects with the buffer was subsequently selected for this species.

The results, in terms of the number of sensitive rare breeding bird species present in each 1-km² square, are given in Figure 14. Some regions rich in rare species emerge: the polders, Entre-Sambre-et-Meuse, Hautes-Fagnes, the Kempen region and some river valleys, but, all in all, rare breeding birds show a scattered pattern, as some species recently expanded their breeding range, such as the Peregrine (now present all over Brussels), and the Black Stork in the forest landscape of the south of Belgium.

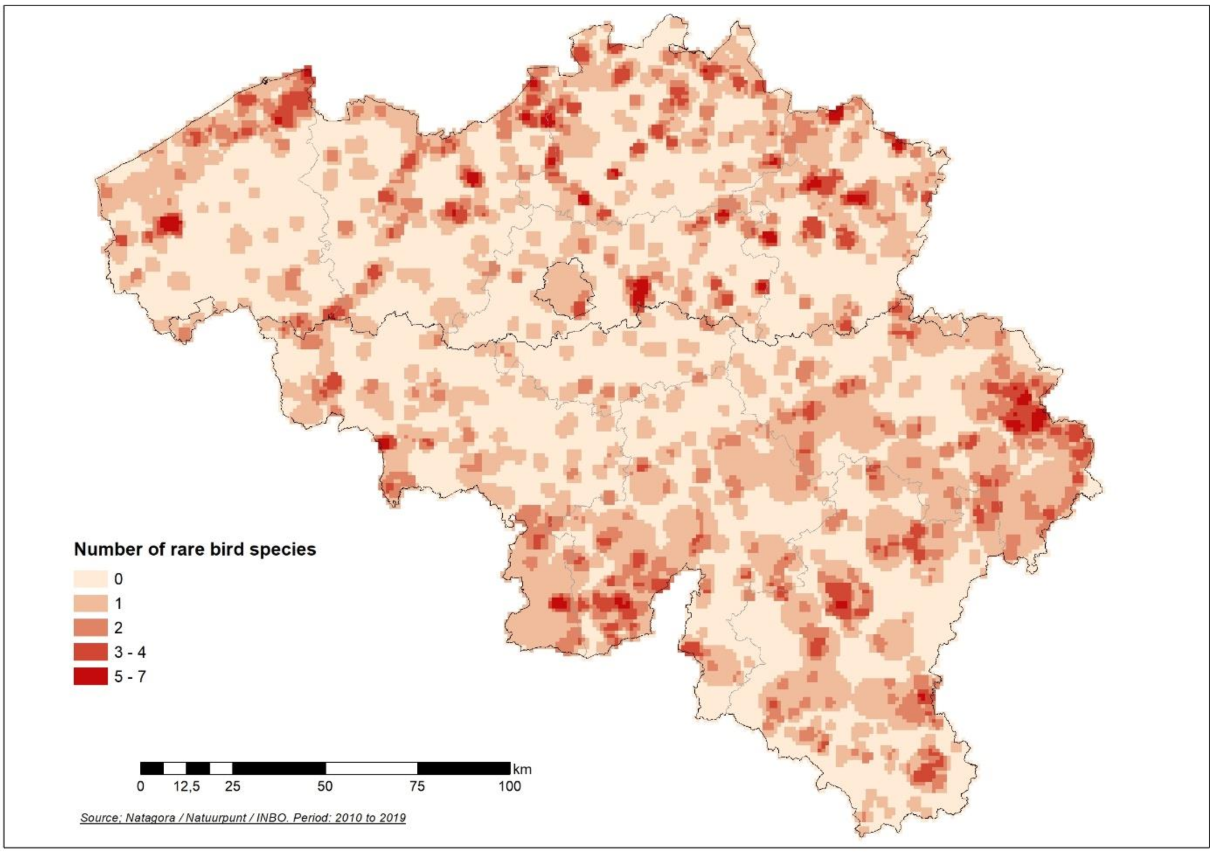

Figure 14: Squares with sensitive rare breeding species, with an indication of the number of rare breeding species for each square.

3.9. Migrants in large numbers

Mapping specific corridors for seasonal bird migration is especially difficult in a low-lying country. While in mountainous areas or regions with special coastal geography, clear migrant funnels can be observed, Belgium lacks such geographical bottlenecks. As a result, millions of migrant birds cross the country over a wide area each year. This results in the collision risk being diluted across the whole of Belgium, even allowing for minor concentration effects for certain species in some areas. In windmill risk atlases for the Netherlands (AARTS & BRUINZEEL, 2009) and Flanders (EVERAERT *ET AL.*, 2011), migration corridors have been tentatively defined, mainly on the basis of expert judgements and visual counts of active migrants by amateur birdwatchers entering their counts on the website www.trektellen.org (TROOST & BOELE, 2019).

Recently, air-force and meteorological radars have been used to survey bird migration flocks. This by-product of radar surveillance is seen as an excellent opportunity to study various aspects of bird migration, including mapping collision risks with human infrastructures (BAUER *ET AL.*, 2019). In Belgium, many observations are recorded by military radars, but this information still needs to be analysed systematically to define migration corridors (S. Sorbi – Belgian Air Force, personal communication). Preliminary analysis and regular observations tend to confirm migration over a wide area rather than in narrow corridors, reflecting the situation in the Netherlands (AARTS & BRUINZEEL, 2009).

To consider migration risks in our update, we started from the rough corridors used in the previous version of the map (Figure 15). For Flanders, this map was based on migration corridors already defined for wind-farm sensitivity mapping (EVERAERT *ET AL.*, 2011), with a focus on migrant waterbirds (especially coastal migration) and an eastern corridor (along the Grensmaas) reflecting the migration of the Common Crane (*Grus grus*) and one of the most abundant migrant birds, the Wood Pigeon (*Columba palumbus*). There are three corridors defined for Wallonia. The first follows the Meuse valley and is a key migration corridor for the Wood Pigeon. The second follows the northern ridge of the Ardennes (Calestienne) and is also used that species. A third, broader corridor is a major route for cranes.

As regards the Common Crane, we recently conducted an in-depth analysis of the collision risk for this charismatic migrant bird (DEROUAUX & PAQUET, 2018a). This specific analysis was prompted by a strong recent increase in numbers for this Annex I species and various collision-related casualties it has suffered, especially during a fog event on 16 November 2018 when seven cranes were found dead or wounded in the south of the country (although it should be mentioned here that only one collided with a high-voltage power line). After plotting the density of migrant cranes in 5x5-km squares, we concluded that the migration corridor has remained unchanged despite the substantial increase in the total population and so we see no reason to modify the corridor shown in Figure 15.

It is important to stress the fact that these corridors are defined at macro-scale and that meso- and micro-scales (i.e. the main local migration axes through a given landscape) are not shown here.

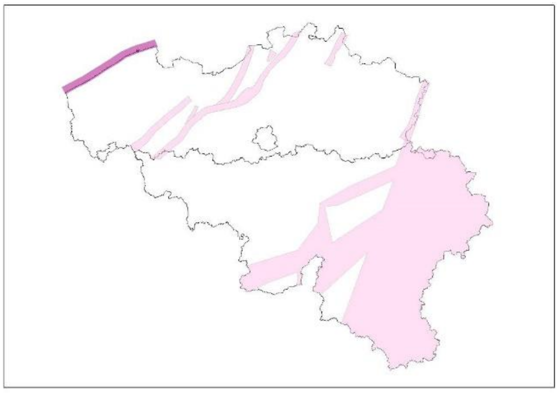

Figure 15: Proposed migration corridor map for Belgium. In violet, the major corridor of the migrants following the coastline and in pink, major inland migration corridors defined by Everaert et al. *(2011) and this publication.*

4. Combining the bird distribution layers into the risk map

'Sensitivity mapping' seeks to establish maps plotting the impact of additional constraints and, through the use of appropriate map resolutions, to identify high- to low-risk areas with a view to guiding decisions to build infrastructure that could be harmful for sensitive species. This is a powerful planning tool when a decision has to be made at regional level as to where to build potentially harmful infrastructure (e.g. power lines and other energy infrastructure) (EUROPEAN COMMISSION, 2018). Regarding power lines, collision risk maps can be used to:

- identify and rank, within the existing high-voltage power grid, the line segments that pose a high risk of causing additional mortality to birds, in order to take mitigating measures, like installing deterring devices in the most suitable order;
- create a high-resolution picture of the 'risk landscape' right across Belgium so that we can work out the best approach to maximise risk avoidance if new lines need to be built.

For both of these aims, we need to combine the various 'bird layers' detailed in section 3 in a way that allows us to assess the risk associated with any location in Belgium or any existing line section.

In practice, to combine the bird layers, in the 2012 study a risk score table was designed (

Table 6). The scoring system was mainly based on expert judgement (DEROUAUX *ET AL.*, 2012). A panel of experts was asked to define a risk score system, with a view to 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. In this study, the same scoring system was used because we see no pressing reason to change it. Field assessments in recent years both from Natuurpunt and Natagora tended to confirm the relevance of the 2012 version of the risk maps. However, as set out in section 3, we have added some new layers, and so the scoring system has been updated accordingly with some additions. We also decided to withdraw one of the risks included in the earlier maps, namely the 'daily corridors' (flight movements between roosts and foraging sites for some species) for two reasons: (1) this information was only available for Flanders (EVERAERT *ET AL.*, 2011); and (2) other layers such as roost locations or modelling of the foraging areas for geese already factor this risk into the maps.

As explained above, we hypothesised that the most detrimental power-line effects would be close to very 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 efforts, 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. All these considerations are reflected in the scoring system shown in

Table 6.

The bird layers and the score system were combined adopting the following procedure. We used a regular 31,472-km² grid covering Belgium – in fact, the same 1x1-km grid as when calculating the bird distribution models in section 3. The highest possible score for a given layer intersecting each square was taken for that square and added together for all layers. For the score depending on the distance to waterbird sites, the distance from the centroïd of the square to the nearest important site was considered. Therefore, each 1x1-km² square received a final score made up of 17 sub-scores corresponding to all the possible bird layers. This means that we can know for any given square what type of risk (waterbird colony, number of rare bird species, migration corridors, etc.) is associated with the final risk score. 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 (a square in the Doel polders, in the new habitat included in the compensation for the expansion of Antwerp harbour). In a future work, we will assess the difference between the present version and the previous risk maps, to check whether the observed differences are due to changes in methodology (taking into account new species, leaving out others, etc.) or changes in bird distribution.

The scoring system when applied to our final spatial map allowed us to draw up a map for collision risk with power lines for Belgium, presented in Figure 16.

Table 6: Priority scoring system for the spatial units in the final map.

	Distance from the considered area				
Bird layer considered	**Inside**	**Less than 1 km**	**Between 1 and 3 km**	**Between 3 and 5 km**	**Over 5 km**
Waterbird roost	If very important, 25; if important, 20	14	9	4	0
Waterbird colony	If very important, 25; if important, 20	14	9	4	0
Important waterbird site	If very important, 30; important, 25; if fairly important, 20	14	9	4	0
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 a power line pylon is inside, 12 for a 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 is predicted to be present by the spatial models				
Geese foraging area	5 points in the areas of occurrence defined by the spatial models				

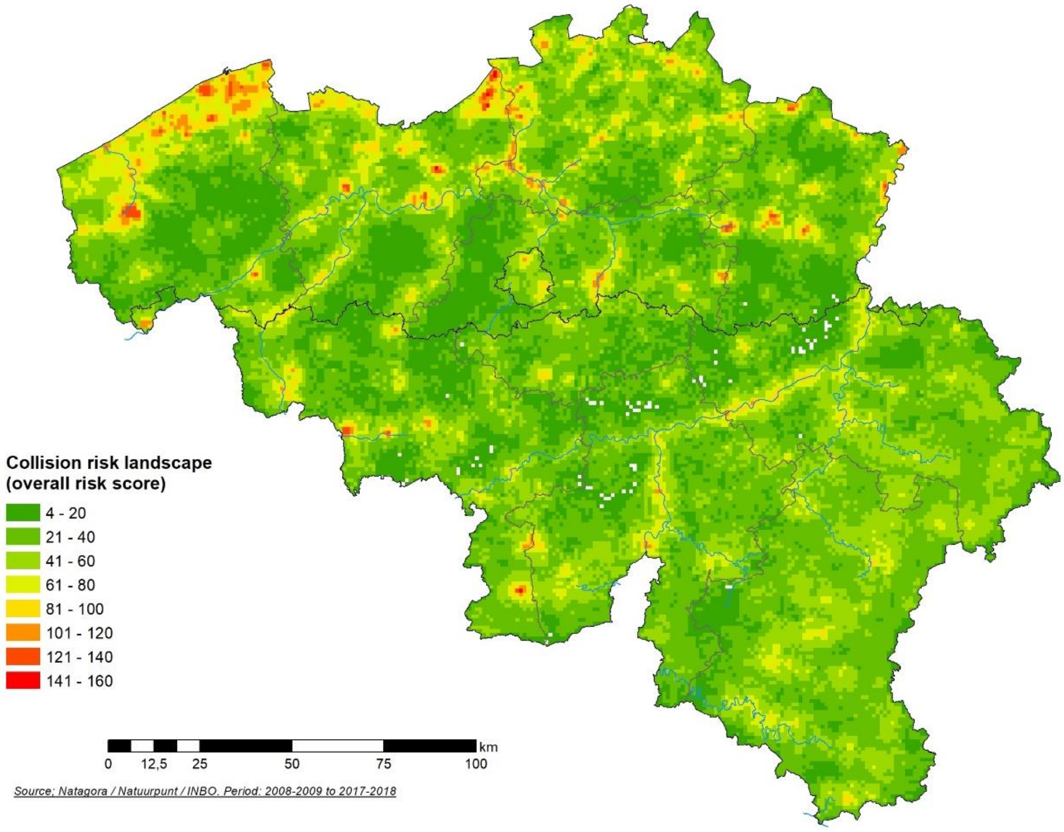

Figure 16: The final collision risk landscape for Belgium, showing a gradient of bird collision risk, should a power line been built in any location.

A visual analysis of this map leads to the following tentative general conclusions:

- The polders area, especially the eastern part of the coast and the Yser valley in the west and the area around Antwerp, are the most critical areas.
- All over the country, major river valleys (including manmade waterways) are focal areas.
- Other wetlands and lake or pond systems (like the Vijvergebied Midden-Limburg, a lakeland area near Hasselt, or the main wetlands in Wallonia (the Haine valley and the Barrages de l'Eau d'Heure (a series of dams in a lakeland area in the south-west of Belgium)) are also risky areas.
- There is a more diffuse risk to the south of the Sambre and Meuse river valley (Ardennes, Lorraine, etc.) and in the Kempen, because of the presence of more high conservation value habitats with some rare bird species.

Finally, power-line sections (the linear segment of lines between two pylons) were combined with the 'landscape' risk score to classify the existing sections based on their relative risk. The final map of the risk score is given in Figure 17. The most dangerous line segment in the present assessment is predicted to be the line crossing the Noordelijk Eiland nature reserve, run by the Flemish Agency for Nature and Forests (ANB), with a score of 133. For the 2012 version of the map, the intersection with the landscape risk map involved the pylons themselves, meaning that the line sections could now sometimes be in more dangerous areas than where the supporting pylons of the same line sections were located. We believe that our assessment is more accurate now.

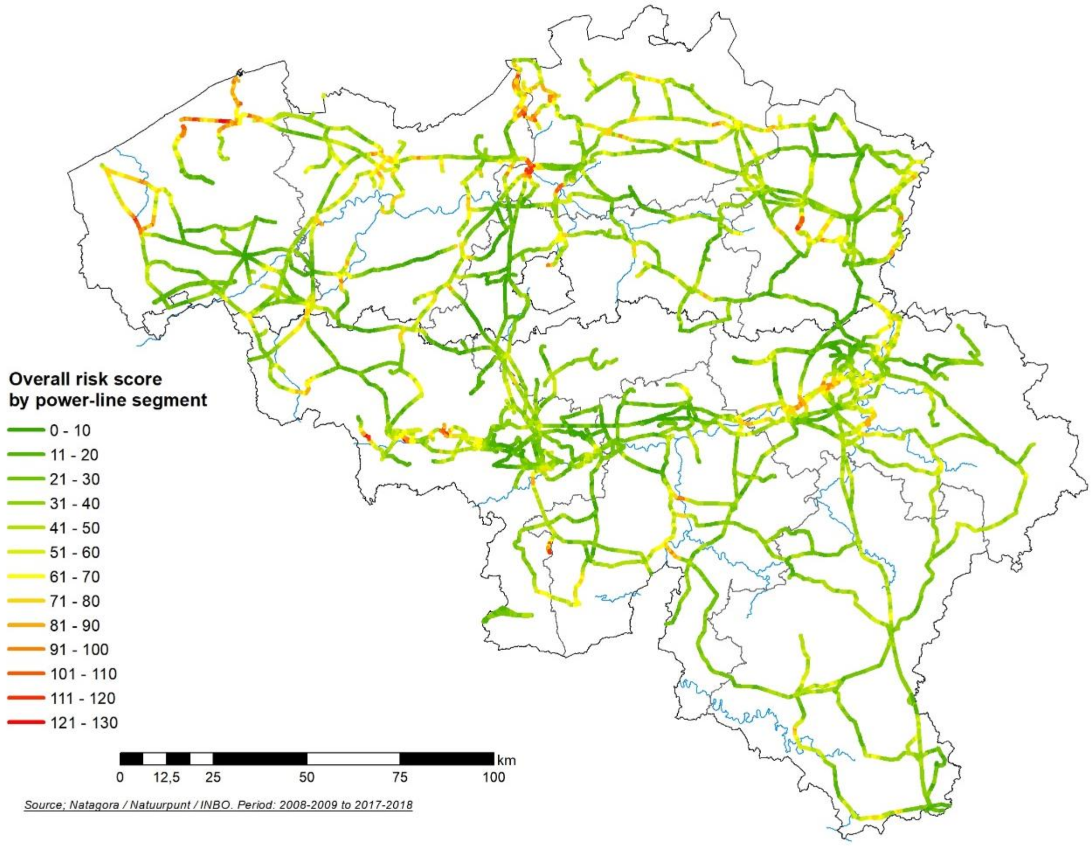

Figure 17: Map of the current Elia grid of power lines (including sections owned by other parties but managed by Elia). Sections are colour-coded based on their collision risk scores. Most of the high-priority lines are close to waterbird sites, with a higher risk clearly existing in the polders area and the Yser valley and the lower Scheldt valley, and in Wallonia around the Harchies marshes and the lower Meuse valley.

Most of the lines run through medium- or low-risk score areas (Figure 18). Looking at the grid as a whole, 5.8% of the total length has a score above 80. The relevant proportions are above average in the provinces of West Flanders (15.8%), Antwerp (10.2%), and East Flanders (9.6%). The Brussels-Capital Region has only a few line sections in total, but the power line entering the region from the north involves a high collision risk, and so the proportion of dangerous lines is also above average (15.2%).

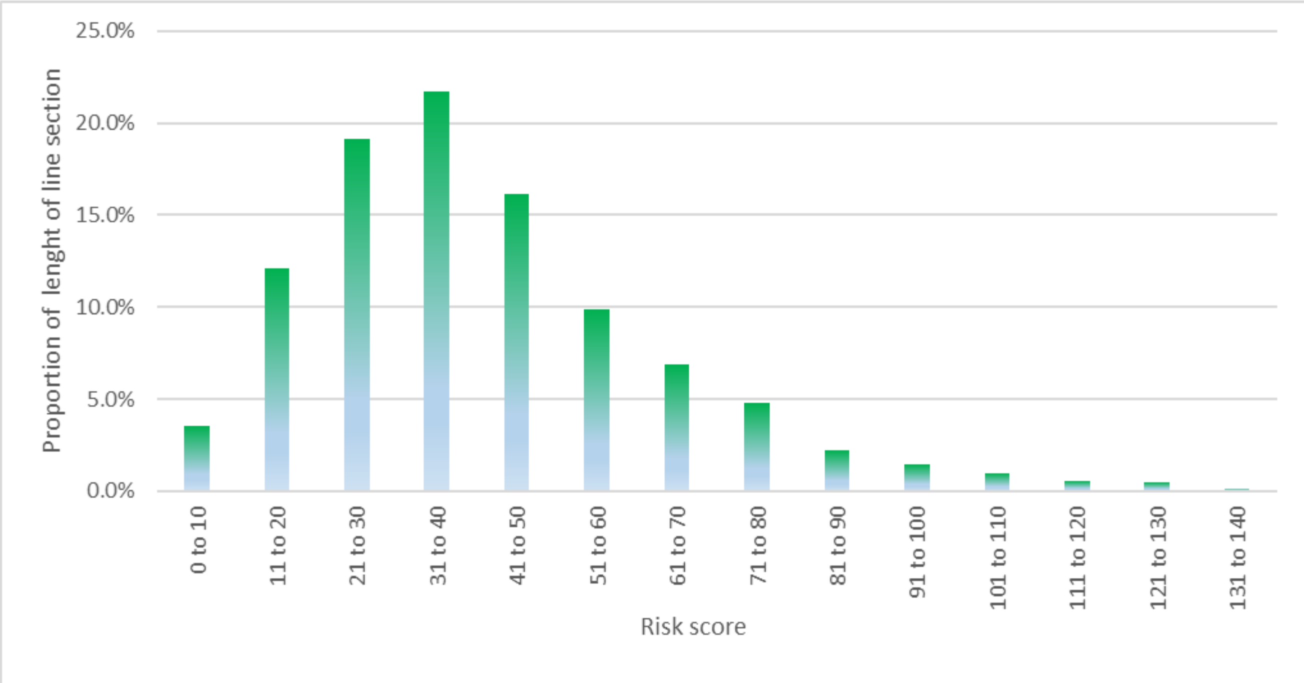

Figure 18: Frequency distribution of grouped risk scores for the total length of overhead line sections (for the whole of Belgium).

5. Conclusion and next steps

This study combined recent bird data accumulated from various sources to produce a comprehensive reassessment of, and map, the risk of bird collisions with power lines across Belgium. This was only possible thanks to the continuous field work of thousands of volunteer birdwatchers and ornithologists, coordinated by several institutions across the country's three regions. New data or data with more accurately pinpointed locations allowed for new bird layers to be included. Some new knowledge about bird collisions with power lines was also take into account in this update.

Detailed analysis will now be carried out with a view to comparing the findings with the 2012 version of the map and then assessing the changes and evaluating whether the observed changes are mostly due to changes in bird distribution (e.g. geese in the polders area) or modifications in the risk assessment procedure. Another angle that could be taken is to try to relate the observed casualties (especially for sections where structured monitoring has been carried out) to the risk scores, and see whether a general relationship could be established between the number of victims and the risk score. In the meantime, this new version of the map can already be used to re-establish a priority list for risk attenuation. Potentially, the risk landscape could be used to compare trajectories of new proposed power lines. However, as the maps given here are only theoretical and represent an initial assessment based on the best available data and knowledge, an environmental impact assessment (EIA) will of course always be needed for any new lines.

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