



Modelling risks posed by wind turbines and power lines to soaring birds: the black stork (*Ciconia nigra*) in Italy as a case study

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Abstract

Recent growth of investments in wind energy and power industries has increased concerns about the associated adverse impacts on wildlife. In particular, flying vertebrates are especially at risk, both directly, through an extra mortality rate due to collision with turbines and electrocution, and indirectly through habitat loss or fragmentation. In this study, we propose a modelling approach that combines species distribution models and data managed in geographic information systems to predict and quantify the effects of wind turbines and power lines on the breeding habitat of a soaring migratory bird, the black stork *Ciconia nigra*, in Italy. The species is recolonizing the country, where it had been driven to extinction in the Middle Age by human persecution. Today, infrastructures such as those considered in our study might in fact hamper this recolonization. Our results show a high probability of presence of the species in several areas in Italy. The most important variables in influencing habitat suitability for *C. nigra* are the mean temperature of May followed by the distance from urban areas, inland wetlands and hydrographic network. Exposure to wind turbine collision and electrocution resulted to be potentially high. In particular, in Northern Italy the main potential risk of mortality for *C. nigra* is posed by power lines, whereas in southern regions the species might be mostly threatened by wind turbines. Our approach makes it possible to detect suitable areas that, although not yet colonized by the species, would imply a high mortality risk should the species colonize them in the future. The tool we provide may therefore prove useful to conservationists and landscape planners in order to mitigate the impact of human infrastructures on this species and encourage a more sustainable planning.

Keywords Ecological niche · Electrocution · Risk map · Spatial analysis · Species distribution models · Wind farms

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Sonia Smeraldo and Luciano Bosso have contributed equally to this work.

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Introduction

The increasing human pressure on ecosystems and the global biodiversity loss highlight that further efforts are necessary to improve the currently available tools to implement biodiversity conservation at different scales (Eaton et al. 2018; Kissling et al. 2018; Morán-Ordóñez et al. 2019). Species distribution models (SDMs) represent an example of effective tools which can be applied to tackle many issues in applied ecology and support conservation planning in several ways (Fois et al. 2018a; Bosso et al. 2018a; Maiorano et al. 2019; Mateo et al. 2019; Bertolino et al. 2020). SDMs are the most widely used correlative models that allow us to understand the relationships between species occurrence and environmental variables, and to identify areas where a given species is likely to occur, in this way defining and quantifying its habitat suitability (Guisan and Thuiller 2005; Rinnhofer et al. 2012; Fois et al. 2018b). This approach may aid conservation decision-making by detecting new areas where the target species presence is unknown, yet likely, and to estimate the potential occurrence of a given species in previously unsurveyed areas (Hernandez et al. 2008). Such models are especially useful for species that are elusive or difficult to observe (Razgour et al. 2016; Mohammadi et al. 2019) and, in particular, for rare and threatened species which are usually a conservation priority (McCune 2016; Proosdij et al. 2016; Bosso et al. 2018b).

The recent growth in environmental awareness and the search for sustainable and renewable energies have led to a fast increase in public and private investments in “green energy” worldwide, with a consequent boost in the development and spread of infrastructures such as power lines and wind farms (Petrescu et al. 2016). However, few studies have assessed systematically the effects of such structures on wildlife at a large scale (May et al. 2019). The application of SDMs to such issues makes it possible to predict the impacts of human activities and infrastructures on animal populations and their habitats, and identify areas of high mortality risk for such species (Hernández-Lambráño et al. 2018; Maiorano et al. 2019; Heuck et al. 2019). In particular, the impacts of wind farms on biodiversity need to be considered because they may affect adversely wildlife, especially flying vertebrates, both directly, by increasing mortality through collision with the turbines or barotrauma, and indirectly, through habitat loss or fragmentation (Arnett and May 2016; Bastos et al. 2016; Beston et al. 2016). Birds and bats are alarmingly vulnerable to wind turbines (Arnett and May 2016) as documented worldwide (Barrios and Rodriguez 2004; Rollan et al. 2010; Thaxter et al. 2017; Martín et al. 2018). In the last decades, scientists have attempted to understand population-level effects of wind farms through field studies, e.g. the impact on species demography (Beston et al. 2016).

Power lines are other infrastructures that may negatively affect wildlife and in particular birds. Electrocutation and collisions with pylon wires are major causes of mortality for birds (Bayle 1999; Janss and Ferrer 2001). Electrocutation is caused by a contact between two conductors or between a conductor and a ground armament; collision means an impact against cables and pylons—in fact, a phenomenon connected to all overhead lines, not just power lines (Bernardino et al. 2018). Mitigation efforts aimed to reduce collision rates have been increasing worldwide (Fox et al. 2006; Kuvlesky et al. 2007; Pearce-Higgins et al. 2009; Busch et al. 2017), especially through the implementation of wire markers (Janss and Ferrer 1998; Barrientos et al. 2012; D’Amico et al. 2019); but, although these mitigation measures can partially reduce species’ mortality, in most cases they cannot eliminate it.

SDMs represent a potentially powerful mitigation approach through the generation of risk maps, i.e. crucial tools to locate sites where wind farm or power line development is too dangerous to wildlife or where an increase in survey efforts is needed to assess the actual likelihood of impact (Hernández-Lambrano et al. 2018; Maiorano et al. 2019; Heuck et al. 2019).

Among bird species, soaring birds, including most raptors, storks and other large birds, are the group of highest concern. Their migratory and long-range movements are largely dependent upon large open areas where wind and thermal upward currents form, in fact the same areas where energy infrastructures are often established. Wind farms and power lines, therefore, often occur along corridors largely used by soaring birds (Katzner et al. 2012; Martín et al. 2018), which leads to high fatality rates (e.g., Barrios and Rodriguez 2004; Smallwood and Thelander 2008; Ferrer et al. 2012).

In this study, we use as a model species a soaring and long-distance migratory bird, the black stork (*Ciconia nigra*), characterized by the largest breeding range among the Ciconiidae, from Portugal to China, with a distinct population in South Africa (del Hoyo et al. 1992). The species requires special conservation measures in Europe because in the last centuries the European population suffered a considerable decrease. *C. nigra* disappeared from most of their western European breeding range due to uncontrolled hunting and excessive forest exploitation (Cramp and Simmons 1977; Bordignon et al. 2006). Since the 1970s, however, the trend has reversed, especially in several countries of Central Europe: the breeding European population currently numbers 9800–13,900 pairs and is classified as of Least Concern (BirdLife International 2017). Only recently did this species recolonize Italy, with a small migratory breeding population mainly concentrated in southern and central regions (Fraissinet et al. 2018). For Italy, no records have been available since the Renaissance (XIV–XVI century A.D.) (Bordignon et al. 2006). The causes that led black storks to extinction in the country are not well known but they are likely a synergy of factors such as intense deforestation and massive hunting—black storks were in fact consumed by people (Caldarella et al. 2018). The species re-established itself in Italy only in 1994, initially in Piedmont and Calabria (Bordignon 1995; Mordente et al. 1998), and in 2018 black storks numbered 20 pairs (Brunelli et al. 2018; Caldarella et al. 2018; Fraissinet et al. 2018). Nevertheless, both the increase in nesting pairs and breeding range expansion have proven much slower than in other recently recolonized countries of Central and Western Europe (Alexandrou et al. 2016; Kalocsa and Tamas 2016; Lorgé 2016; Denis and Brossault 2016; BirdLife International 2017; Caldarella et al. 2018; Fraissinet et al. 2018). From this perspective, we argue that both wind turbines and power lines, which may kill adult individuals during their movements across Italy, might represent a further obstacle hampering the recolonization process that is taking place in the country. In our study, we combined SDMs and Geographic Information System to analyze the potential distribution of the breeding population of *C. nigra* in Italy and evaluate the potential threat posed by such infrastructures in areas suitable for this species through generation of risk maps.

Specifically, we hypothesize that: (a) due to its high environmental heterogeneity, Italy may offer large recolonization areas to a species characterized by a wide global distribution (i.e. possessing a broad ecological niche) such as *C. nigra* (Fontaneto et al. 2006; Alexandrou et al. 2016; Fraissinet et al. 2018); and that (b) given the widespread presence of power lines and wind farms in Italy (Marcantonini and Valero 2017; Terna 2017), many sites suitable for *C. nigra* might turn into ecological traps by increasing mortality risk in potentially attractive habitat.

Materials and methods

Study area and presence records

The study area included the whole Italian territory covering ca. 301,000 km² between latitudes 45° N–36° N and longitudes 6° E–18° E. The study region has a very heterogeneous topography with an elevation ranging between 0 and 4810 m a.s.l.

We obtained the occurrence records for *C. nigra* from experts' personal databases updated to 2017 (unpublished data provided by the Italian Working Group on black stork GLICINE) and from the online platform Global Biodiversity Information Facility (GBIF 2019). The records obtained from experts corresponded to coordinates of *C. nigra*'s nests in Italy. Instead, from the GBIF, we downloaded records not only for Italy but also for the other European countries where the species breeds in order to cover the species' entire environmental and climatic niche (Jiguet and Villarubias 2004; Vlachos et al. 2008) as done in previous studies (Barbet–Massin et al. 2010; Raes 2012; Guisan et al. 2013; Smeraldo et al. 2017). To homogenize the dataset, we only used GBIF records collected: (1) from 1990 to present; and (2) between June and July, when *C. nigra* nests most frequently across its entire European breeding range (Jiguet and Villarubias 2004; Alexandrou et al. 2016). After this first selection, we considered only records with positional values showing at least two decimal digits (0.01 decimal degrees, corresponding to 1.11 km at the equator; Strubbe et al. 2015). In addition, we filtered these data further to remove duplicated records and those with inaccurate coordinates.

Prior to model calculation, we screened all records in ArcGis (version 10.2.2) for spatial autocorrelation using average nearest neighbour analyses to remove spatially correlated data points and guarantee independence (Kwon et al. 2016; Kabir et al. 2017; Bosso et al. 2017a; Mohammadi et al. 2019). Therefore, from the initial occurrence dataset including 280 records, after the filtering procedure, we selected 136 records from which we generated the SDMs (Fig. S1).

Ecogeographical variables

We selected a set of variables potentially useful to predict the European breeding range of *C. nigra*. Climatic variables were obtained from the Worldclim database version 2.0 (Hijmans et al. 2005; <https://www.worldclim.com/current>). Land cover categories were selected according to the species' preferences for foraging or nesting sites (hydrographic network, urban areas, inland wetlands, mixed forest, non-irrigated arable lands and permanently irrigated lands including rice fields) and calculated as the Euclidean distance from the Corine Land Cover 2012 categories (European Environmental Agency: www.eea.europa.eu/data-and-maps/data/clc-2012-raster). The hydrographic network was taken from the Digital Chart of the World (DCW; <https://www.diva-gis.org/gdata>). All predictors were rasterized at a resolution of ca. 1 km with ArcGis (version 10.2.2). To take into account the pairwise correlation between predictors, the final set of variables was subselected considering a Pearson's correlation coefficient $|r| < 0.75$ (e.g. Hernandez et al. 2006; Lobo et al. 2010) and a variance inflation factor ≤ 5 (Zuur et al. 2010). These procedures were carried out in the R environment (R Core Team 2018). Therefore, from the initial set of predictors, we retained only the eight most relevant variables according to the species' ecological requirements during the breeding season: mean temperature and precipitation of

May, Euclidean distance from hydrographic network, Euclidean distance from urban areas, Euclidean distance from inland wetlands, Euclidean distance from mixed forest, Euclidean distance from non-irrigated arable lands and Euclidean distance from permanently irrigated lands including rice fields. The mean temperature and precipitation of May have been chosen among climatic variables as egg hatching mainly occurs in that month (Alexandrou et al. 2016) and because heavy rain and low temperatures in May can negatively affect *C. nigra*'s foraging activity and reproductive success (Bordignon et al. 2006; Tamás 2012). A list of the most relevant variables used to model *C. nigra*'s potential distribution in Europe and further details about their measurement units are given in Table S1.

Species distribution models

To build the models, we used occurrence records located in the entire European breeding range to avoid truncated niche estimations (Barbet-Massin et al. 2010; Raes 2012; Guisan et al. 2013). SDMs were built through an ensemble forecasting approach, as implemented in the R package “*biomod2*” (<https://cran.r-project.org/bin/windows/base/>; Thuiller et al. 2009). We considered the following seven modelling techniques (Thuiller et al. 2009; Jiguet et al. 2010): (1) Maximum Entropy models (MAXENT); (2) Generalized Linear Models (GLM); (3) Generalized Additive Models (GAM); (4) Generalized Boosted Models (GBM); (5) Multivariate Adaptive Regression Spline (MARS); (6) Random Forests (RF), and (7) Artificial Neural Network (ANN; for further details, see Thuiller et al. 2009). In agreement with the modelling approach used for previous studies (Pio et al. 2014; Smeraldo et al. 2018), GLMs and GAMs were calibrated using a binomial distribution and a logistic link function, while GBMs were developed with a maximum number of trees set to 5000 threefold cross-validation procedures to select the optimal numbers of trees to be kept and a value of seven as maximum depth of variable interactions. MARS models were set with a maximum interaction degree equal to 2, while RF models were fitted by growing 750 trees with half the numbers of available predictors sampled for splitting at each node. MAXENT models were fitted with the default settings with a maximum value of 1000 iterations. To avoid model overfitting, we developed MAXENT models applying species-specific settings selected using the “ENMeval” (Muscarella et al. 2014; Fourcade et al. 2018) R package. This approach runs successively several MAXENT models using different combinations of parameters to select the settings that optimize the trade-off between goodness-of-fit and overfitting.

We set ENMeval to test regularization values between 0.5 and 4, with 0.5 steps, as well as the following feature classes: linear, linear + quadratic, hinge, linear + quadratic + hinge, linear + quadratic + hinge + product and linear + quadratic + hinge + product + threshold, which correspond to the default ENMeval settings. We then selected the parameters that scored lower AIC values. Default parameters were used to fit ANN models. Each occurrence dataset was randomly split into a 70% sample, used for the calibration of the model, and the remaining 30%, used to evaluate model performance. Because our dataset contained only occurrence data, a set of 10,000 background points were randomly placed over a region identified by the WWF terrestrial ecoregions (Olson et al. 2001) where records of *C. nigra* occurred (Hirzel et al. 2002; Barve et al. 2011; Barbet-Massin et al. 2012a, b; Smeraldo et al. 2018). Predictive performances of SDMs were assessed by measuring the Area Under the receiver operating characteristic Curve (AUC; Hanley and McNeil 1982) and the True Skill Statistic (TSS; Allouche et al. 2006). These validation methods have been widely used (Breiner et al. 2015; Smeraldo et al. 2018) and offer excellent

performances. The data splitting procedure was repeated 10 times and the evaluation values averaged. We ran a total of 70 SDMs (seven algorithms \times 10 splitting replicates for model evaluation). After excluding models with $AUC < 0.7$, model averaging was performed by weighting the individual model projections by their AUC scores, a method shown to be particularly robust (Marmion et al. 2009). Models were then projected over the study area. The relative importance of variables was also calculated from the ensemble model using the specifically devoted functionality available in the *biomod2* package (Jiguet et al. 2010). The final potential distribution was obtained by averaging the projections from the 10 replicated ensemble models coming from the subsampling procedure (see above). The final map was binarized into presence–absence values with a threshold maximizing sensitivity (the percentage of correctly predicted presence) and specificity (the percentage of correctly predicted absence; Fielding and Bell 1997). This widely used threshold (Algar et al. 2009; Dubuis et al. 2011; Bosso et al. 2018a; Smeraldo et al. 2018) is among the most accurate ones (Liu et al. 2005).

Risk maps

We generated risk maps to assess the impact of wind turbines and power lines on the potential distribution of *C. nigra* in Italy. To do this, we used the binary map of *C. nigra*, clipped for Italy, and the shapefiles of Italian regions, wind turbines and power lines. We downloaded the administrative boundaries of the Italian regions by the Italian National Institute of Statistics (ISTAT) (<https://www.istat.it/ambiente/cartografia>). We obtained the distribution of wind turbines from the following online databases: ATLAEOLICO (<https://atlanteolico.rse-web.it/>), The Wind Power (https://www.thewindpower.net/country_maps_en_7_italy.php), EMODnet (<https://www.emodnet-humanactivities.eu/view-data.php>), Harvard University World Map (https://worldmap.harvard.edu/data/geonode:osm_worldwide_wind_turbines_qb8), ATLAIMPIANTI (https://atla.gse.it/atlaimpianti/proje ct/Atlaimpianti_Internet.html), and Overpass Turbo (<https://overpass-turbo.eu/>). We then screened such data in ArcGis (version 10.2.2) and deleted unreliable, ambiguous or duplicate records, also excluding those whose geographical location was not precisely defined or incorrect, and checking each wind turbine in Google Earth Pro (version 7.3.2). Furthermore, any wind turbine missing from the databases was added manually to the dataset (Fig. S2). We provide the final database of the wind turbines in Italy in the Supplementary Material 2. We acquired geo-referenced linear power lines from Overpass Turbo (<https://overpass-turbo.eu/>) (Fig. S3).

To assess the amount of *C. nigra*'s suitable habitat that fell inside or close to wind turbines and power lines, we used two different methods. Regarding wind turbines, we selected the buffer recommended by Bush et al. (2017). Hence, we created different buffer areas around each turbine with radiuses of 100 m, 500 m, 1000 m, 3000 m, 5000 m and 10,000 m respectively (Figs. S4 and S5). Instead, for the power lines, we chose buffers based on guidelines provided by previous studies carried out in Italy on *C. nigra*'s ecology (e.g. Caldarella et al. 2018; Fraissinet et al. 2018). Such studies indicated that the species' home range in the breeding season is ca. 100 km² and within such range a mortality risk at 300–2000 m from power lines. For our analyses we investigated the highest probability of electrocution/collision to power lines at distances of 100 m, 500 m, and 1000 m from each power line, which we deemed distances posing major threats to this species (Figs. S6 and S7).

Risk maps for *C. nigra* in Italy were obtained by weighted overlay using the spatial analyst tools in ArcGis (version 10.2.2). Weighted overlay is a technique used to apply a common measurement scale of values to diverse and dissimilar inputs to do an integrated analysis (for details, see: <https://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=How%20Weighted%20Overlay%20works>).

Because weighted overlay only uses raster data, all shapefiles employed in this study were converted into raster format. The input raster data for weighted overlay must contain discrete integers or continuous values and these values must be on a common scale. The weighted overlay tool reclassifies raster input values according to a common evaluation scale of suitability or preference, i.e. on the basis of their relative contribution to the central theme (Iqbal and Khan 2014). In this study, all input raster data were reclassified to assign equal intervals of discrete values and then the final maps were reclassified into five risk classes, respectively low, medium–low, medium, medium–high and high (e.g. Bosso et al. 2017b).

Results

Habitat suitability

SDMs showed an excellent level of predictive performance as indicated by the AUC and TSS value respectively of 0.90 ± 0.01 and 0.64 ± 0.03 (mean \pm standard deviation). Sensitivity and specificity values of AUC were respectively $80.15 (\pm 2.04)$ and $84.16 (\pm 5.32)$, while for TSS, our models showed values of $79.41 (\pm 2.04)$ and $84.44 (\pm 5.22)$, respectively.

The mean temperature of May provided the greatest contribution among the environmental variables we considered, followed by the distances from urban areas, inland wetlands and hydrographic network. In particular, *C. nigra* is more likely to occur where mean temperatures of May are of 15–25 °C (Fig. S8) and habitat suitability decreases for increasing distances from inland wetlands, the hydrographic network, mixed forests and non-irrigated arable areas (Fig. S8). The relevant variable's response curve also showed that probability of presence increased with increasing distances from urban areas (Fig. S8).

Ciconia nigra ensemble model showed a high probability of occurrence in several scattered areas of Europe except the northern regions as the United Kingdom and the Scandinavian peninsula (Fig. S9). The outputs of each algorithm used to compose the final ensemble model are provided in the supplementary materials (Figs. S10–S16). In Italy the species occurs in central and southern lowlands (Fig. 1) while a low probability of presence is estimated for the Alpine and Apennine regions (Fig. 1). Suitable habitat amounted to ca. 121,380 km², which corresponds to ca. 40% of the Italian territory. Sardinia (14,118 km²), Sicily (12,268 km²), Lombardy (11,513 km²), Piedmont (10,743 km²) and Apulia (9140 km²) are the regions encompassing the largest potentially suitable surface for *C. nigra* while Liguria (2411 km²), Marche (2348 km²), Molise (1730 km²), Trentino-Alto Adige (1302 km²) and Aosta Valley (49 km²) were those including the smallest amount of it (Table 1).

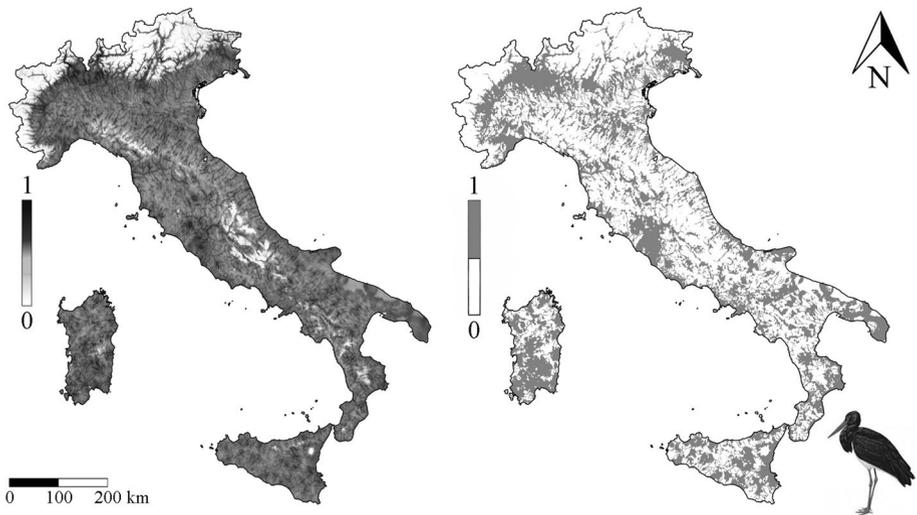


Fig. 1 Species Distribution Models of *Ciconia nigra* in Italy. Left: logistic map; right: binary map. Scales show the probability of presence ranging from 0 to 1

Table 1 Potential surface of the Italian territory suitable to *Ciconia nigra* divided by region according to the biomod2 binarized map

Region	Potential surface by binarized map (km ²)	Regional potential surface by binarized map (%)
Piedmont	10,743	42
Aosta Valley	49	2
Lombardy	11,513	48
Trentino-Alto Adige	1302	10
Veneto	6652	36
Friuli-Venetia Julia	3945	50
Liguria	2411	44
Emilia-Romagna	7559	34
Tuscany	6822	30
Umbria	2882	34
Marche	2348	24
Latium	8431	49
Abruzzi	2668	25
Molise	1730	39
Campania	5859	43
Apulia	9140	47
Basilicata	4077	41
Calabria	6867	46
Sicily	12,268	48
Sardinia	14,118	59

Table 2 Wind turbine impact as predicted using the binarized map of *Ciconia nigra* in Italy

	Buffer (m)					
	100	500	1000	3000	5000	10,000
Surface (km ²)	75	935	2362	10,878	20,491	41,934
Percentage (%)	0.06	0.77	1.95	8.96	16.88	34.55

Circular buffers around each wind turbine were traced adopting radiuses of 100 m, 500 m, 1000 m, 3000 m, 5000 m and 10,000 m, respectively

Table 3 Impact of power lines predicted using the binarized map of *Ciconia nigra* in Italy

	Buffer (m)		
	100	500	1000
Surface (km ²)	6512	27,330	46,530
Percentage (%)	5	22	38

Linear buffers around each power line were traced at distances of: 100 m, 500 m and 1000 m, respectively

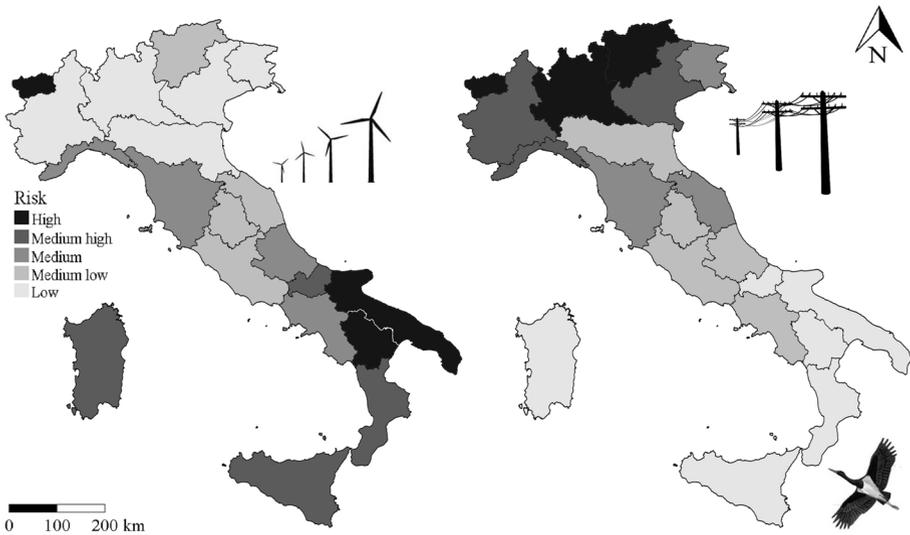


Fig. 2 Risk map for *Ciconia nigra* in Italy taking into account the location of power lines and wind turbines. Left: wind turbine; right: power line

Risk map

The 500 m, 3000 m and 10,000 m buffers we considered around wind turbines for Italy comprise 0.8%, 9% and 34% of suitable habitat, respectively (Table 2). Besides, ca. 38% of suitable surface falls within 1000 m around power lines (Table 3).

The regions where *C. nigra* faces the highest potential risk of interference with wind turbines are Aosta Valley, Basilicata, Apulia, Sicily, Sardinia and Molise, especially considering buffers with a radius of 3000 m to 10,000 m (Table S2). A specific consideration is needed for the Aosta Valley region where the resulting small areas of potentially suitable habitat for *C. nigra* fall almost totally within 5 km and 10 km from wind turbines, which makes the region especially dangerous for this species. Piedmont, Lombardy, Trentino-Alto Adige, Veneto, Friuli-Venetia Julia and Emilia-Romagna are the regions characterized by the lowest potential risk (Fig. 2; Table S2).

For some other regions such as Calabria, Liguria, Campania and Tuscany, despite the high density of wind turbines, we found only a limited portion of suitable habitat falling within the buffers traced around the turbines, which resulted in a medium risk for the species.

Regarding the risk posed by electrocution/collision to power lines, Aosta Valley, Lombardy, Trentino-Alto Adige, Veneto and Liguria were the regions with a percentage of 50–90% of suitable habitat falling into the 1-km buffers around power lines. Sardinia, Basilicata, Apulia, Molise, Sicily and Calabria were the regions at lowest risk (Fig. 2; Table S3).

Discussion

Model performance and habitat preferences

Our SDMs provided a confident delineation of the potential breeding range of *C. nigra* in Europe (Elliot et al. 2020) and in Italy (Fraissinet et al. 2018), as indicated by the very high predictive performances we obtained (Domínguez-Vega et al. 2012; Kabir et al. 2017; Ancillotto et al. 2019). The high reliability of our models derived from the detailed knowledge of the species' seasonal physiological requirements, which is essential to select reliable occurrences and variables representative of a particular phenological pattern (Feng and Papes 2017; Smeraldo et al. 2018). Using the same approach, in a previous study on *C. nigra*, Jiguet et al. (2011) combined winter tracking data and niche-based modelling techniques to predict the species' wintering distribution in Africa. Other studies on different migratory birds used seasonal occurrences to forecast the species' potential breeding or wintering distribution in the current time as well as under future climate change scenarios (Barbet-Massin et al. 2012b; Morganti et al. 2017).

We confirmed the hypothesis that a wide area of Italy is potentially suitable for the species and might be recolonized, in particular the north-western regions, Apulia, Sicily and Sardinia. Nevertheless, the current breeding distribution of *C. nigra* in Italy supports only partly this prediction, as the Italian range of the species since the 1994 recolonization onset has remained confined to a few Italian regions and population growth is much slower than in Hungary, Poland, France, Germany and the Czech Republic (Dzyubenko and Bokotey 2011; Kalocsa and Tamas 2016; Lorgé 2016; Denis and Brossault 2016; Fraissinet et al. 2018). In Denmark, where recolonization was almost contemporary to that of Italy and less forest is available, the breeding population numbers ca. 10 pairs and even a small country such as Luxembourg hosts 4–7 pairs (BirdLife International 2015). In Italy, population increase is mostly restricted to the breeding population in south-central regions, while the north-western population, 20 years after recolonization, has not increased, failing to settle in the central and eastern parts of the subalpine area and Po Valley (Fraissinet et al. 2018).

It is important to clarify that our SDMs' outputs provided, for each Italian region, the amount of potential suitable habitat for the species but by no means population density estimates. In fact, some regions like Basilicata which currently has the highest number of pairs of *C. nigra* (Fraissinet et al. 2018), showed a lower percentage of suitable habitat than did Lombardy, which in fact hosts only one pair. Among Italian central regions, despite the high habitat suitability, only Latium hosts a breeding pair, while Tuscany does none. Noticeably, *C. nigra* does not breed in Sardinia but according to our SDMs the island hosts a wide suitable area. The regular presence of the species in this Italian region in winter is regarded as an attempt to establish a wintering site (Grussu and Floris 2005).

It is important to highlight that SDMs generally show some limitations due to the impossibility to include some factors, not rarely at a small scale (Russo et al. 2015), that might affect the species' presence and that in our case might help explain the scarce recolonization performances observed in Italy (Bordignon et al. 2009; González-Salazar et al. 2013; Wisz et al. 2013; Fraissinet et al. 2018). Our study showed that mean temperature of May represents the main climatic variable limiting the species' distribution. Nesting at exposed sites makes the nests vulnerable to low temperatures, which can affect negatively hatching success (Tobolka et al. 2015), and in turn, potential distribution. We also found that proximity to mixed and deciduous forests, as well as to streams and inland wetlands are important factors influencing habitat preference, in agreement with studies carried out in other regions such as Greece (Vlachos et al. 2008) and Lithuania (Treinys et al. 2009). Jiguet and Villarubias (2004) found that habitat use within core ranges was mostly restricted to mosaics of deciduous forest and open areas and that nesting site location depended on the availability of large trees (Bakaloudis et al. 2005). In Northern Italy, the situation is similar (Fontaneto et al. 2006), while in central and southern Italy breeding pairs nest in large woody areas on hills characterized by steep surfaces such as cliffs and rock jumps (Fontaneto et al. 2006; Fraissinet et al. 2018).

Our findings confirmed *C. nigra*'s preference to forage in natural wetlands and along streams (Jiguet and Villarubias 2004) or at shallow artificial pools surrounded by grasslands (e.g. rice fields) which improve accessibility to food in summer (Alexandrou et al. 2016). In Greece, during the breeding season, *C. nigra* congregates at isolated ponds which constitute the main summer feeding habitat (Alexandrou et al. 2016). In Mediterranean countries, most streams dry out during summer, which confines water to marshy ponds in lowland areas which we found to be highly suitable for the species.

In view of the high availability of suitable habitat that we found, the scarce recolonization performance of *C. nigra* might be due to some factors hindering colonization such as forest fragmentation at a scale that is overlooked by that used for our models (Jiguet and Villarubias 2004). Another small-scale factor which was not possible to consider in our study is food availability that is highly correlated with the nesting density and the breeding success of *C. nigra* (Alexandrou et al. 2016)—in fact, an important factor that might affect habitat suitability. Moreover, wetland degradation and drainage of permanent water courses, likewise difficult to detect in large-scale modeling, also affect populations adversely (Löhmus and Sellis 2001; Czech and Parsons 2002). Pesticides polluting ponds in intensive farmland where the species forages also pose a significant threat (Tucker and Heath 1994) and may substantially degrade the apparently high suitability of a site that might appear when considering land use alone.

Predicting areas of high mortality risk

C. nigra probability of presence decreased in proximity of urban areas, which confirms the fact that unlike white storks (*C. ciconia*), the former species avoids contact with humans and breeds preferentially in undisturbed forest (del Hoyo et al. 1992). Despite avoidance of urbanized areas, we found that exposure to hazardous human infrastructures such as wind turbines and power lines remains high. Concern has been raised about the adverse acute and cumulative effects of wind turbines and power lines on bird populations (Bellebaum et al. 2013; Wang et al. 2015; Bernardino et al. 2018; D'Amico et al. 2019). Casualties may occur especially at infrastructures that are positioned close to or along major landmarks and landscape linear elements (e.g. mountain ranges, coastlines or plains), important for long-distance movements of soaring birds (Rollan et al. 2010; Mulero-Pázmány et al. 2013). *C. nigra* runs the highest risks at migratory bottlenecks which are often also suitable for wind-power production (Martín et al. 2018) such as the top of mountain ranges, windy but also providing a high orographic uplift potential for soaring birds (Katzner et al. 2012). Similarly, infrastructures might indirectly affect the individual behavior of *C. nigra* by disturbing foraging and breeding sites (Barrios and Rodriguez 2004). Studies that compared pre- vs. post-construction phases showed that soaring birds use less the areas where turbines are installed and their populations decrease near wind turbines and power lines due to a functional habitat loss (Barrios and Rodriguez 2004; Pearce-Higgins et al. 2009; Marques et al. 2020).

In our study, the development of a risk map represented the first attempt to quantify the negative effects of wind farms and electrocution/collision to power lines separately on *C. nigra*'s suitable habitat. In Germany, Busch et al. (2017) used the observed distribution of different birds' species, including *C. nigra*, and overlaid them to the areas used for wind energy development. In our case, rather than using the actual observed range, we used the potential range since recolonization is ongoing, so our main aim was to forecast future interferences in order to mitigate or prevent them.

Our work showed different risks in northern vs. southern regions of Italy: in the former, the main risk is posed by power lines, in the latter by wind turbines. This reflects the strong increase in wind turbine numbers in southern regions where two thirds of the Italian *C. nigra* breeding population is found, i.e. Basilicata and Apulia (Fraissinet et al. 2018). Moreover, six documented electrocution cases for *C. nigra* were recorded in northern Italy—Piedmont and Lombardy (Bordignon and Mastroilli 2004)—whereas only one case occurred in the south (Basilicata region) in 2010 (Caldarella et al. 2018).

Implications for conservation

Many countries have adopted measures and guidelines to mitigate bird mortality from wind turbines and power lines (Bright et al. 2008). However, such infrastructures are on this increase and often encroach on areas where their effects on wildlife are still poorly understood (Janss and Ferrer 2001; Marques et al. 2014). Identifying and understanding what factors may influence bird mortality may inform management to mitigate such adverse impacts (Bevanger 1998; Wang et al. 2015).

The model-based methodology we propose represents a valuable tool to support strategic actions for impact mitigation of a range of threats besides those we considered such as e.g. road mortality not only for birds (Hernández-Lambrano et al. 2018; Heuck et al. 2019)

but also for other wildlife, e.g. bats (Roscioni et al. 2014) and other mammals (Maiorano et al. 2019). Our models could be implemented further by including migratory corridors used by the species. In fact, previous studies on different bird species showed that wind turbines and power lines are particularly dangerous when located along migratory routes, especially when birds fly at lower heights near stopover areas (see also Bordignon et al. 2006; Bernardino et al. 2018; Caldarella et al. 2018).

The risk maps we propose may help conservationists and landscape planners to identify the most vulnerable areas where mitigation should be applied to favour *C. nigra*'s recolonization. Besides providing a picture of current potential interferences, our approach also allows predictions about future effects (Bastos et al. 2016; Guisan and Thuiller 2005). Moreover, we identified suitable but not yet colonized areas, where the presence of power lines or turbines might dramatically increase the likelihood of mortality should the species attempt to establish itself there. Such areas correspond to riparian habitats or wetlands where birds spend most of the day flying between breeding/nesting and foraging areas, often around sunset, when light is dim, which increases the risk of collision or electrocution (Garrido and Fernandez-Cruz 2003; Bernardino et al. 2018). Mitigation of wind turbine and power line effects should therefore concentrate in proximity of streams, wetlands, and deciduous or mixed forests which our work confirmed as the main sensitive habitats for *C. nigra*. Moreover, risk maps including all bird species exposed to the same risks of collision and electrocution might also be generated to increase the effectiveness of this approach for mitigation planning.

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References

- Alexandrou O, Bakaloudis DE, Papakosta MA, Vlachos CG (2016) Breeding density, spacing of nest-sites and breeding performance of black storks *Ciconia nigra* in Dadia-Lefkimi-Soufli Forest National Park, north-eastern Greece. *Northwest J Zool* 12:7–13
- Algar AC, Kharouba HM, Young ER, Kerr JT (2009) Predicting the future of species diversity: macroecological theory climate change and direct tests of alternative forecasting methods. *Ecography* 32:22–33
- Allouche O, Tsoar A, Kadmon R (2006) Assessing the accuracy of species distribution models: prevalence kappa and the true skill statistic (TSS). *J Appl Ecol* 43:1223–1232
- Ancillotto L, Mori E, Bosso L, Agnelli P, Russo D (2019) The Balkan long-eared bat (*Plecotus kolombatovici*) occurs in Italy—first confirmed record and potential distribution. *Mamm Biol* 96:61–67. <https://doi.org/10.1016/j.mambio.2019.03.014>
- Arnett EB, May RF (2016) Mitigating wind energy impacts on wildlife: approaches for multiple taxa. *Hum Wildl Interactions* 10:5
- Bakaloudis DE, Vlachos CG, Holloway GJ (2005) Nest spacing and breeding performance in Short-toed Eagle *Circaetus gallicus* in northeast Greece. *Bird Study* 52:330–338
- Barbet-Massin M, Thuiller W, Jiguet F (2010) How much do we overestimate future local extinction rates when restricting the range of occurrence data in climate suitability models? *Ecography* 33:878–886
- Barbet-Massin M, Jiguet F, Albert CH, Thuiller W (2012a) Selecting pseudo-absences for species distribution models: how where and how many? *Methods Ecol Evol* 3:327–338
- Barbet-Massin M, Thuiller W, Jiguet F (2012b) The fate of European breeding birds under climate, land-use and dispersal scenarios. *Glob Chang Biol* 18:881–890
- Barrientos R, Ponce C, Palacín C, Martín CA, Martín B, Alonso JC (2012) Wire marking results in a small but significant reduction in avian mortality at power lines: a BACI designed study. *PLoS ONE* 7(3):e32569

- Barrios L, Rodriguez A (2004) Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines. *J Appl Ecol* 41:72–81
- Barve N, Barve V, Jiménez-Valverde A, Lira-Noriega A, Maher SP, Peterson AT, Villalobos F (2011) The crucial role of the accessible area in ecological niche modeling and species distribution modelling. *Ecol Model* 222:1810–1819
- Bastos R, Pinhaços A, Santos M, Fernandes RF, Vicente JR, Morinha F et al (2016) Evaluating the regional cumulative impact of wind farms on birds: how can spatially explicit dynamic modelling improve impact assessments and monitoring? *J Appl Ecol* 53:1330–1340
- Bayle P (1999) Preventing birds of prey problems at transmission lines in Western Europe. *J Raptor Res* 33:43–48
- Bellebaum J, Korner-Nievergelt F, Dürr T, Mammen U (2013) Wind turbine fatalities approach a level of concern in a raptor population. *J Nat Conserv* 21:394–400
- Bernardino J, Bevanger K, Barrientos R, Dwyer JF, Marques AT, Martins RC, Moreira F (2018) Bird collisions with power lines: state of the art and priority areas for research. *Biol Conserv* 222:1–13
- Bertolino S, Sciandra C, Bosso L, Russo D, Lurz P, Di Febbraro M (2020) Spatially-explicit models as tools for implementing effective management strategies for invasive alien mammals. *Mammal Rev.* <https://doi.org/10.1111/mam.12185>
- Beston JA, Diffendorfer JE, Loss SR, Johnson DH (2016) Prioritizing avian species for their risk of population-level consequences from wind energy development. *PLoS ONE* 11(3):e0150813
- Bevanger K (1998) Biological and conservation aspects of bird mortality caused by electricity power lines: a review. *Biol Conserv* 86:67–76
- BirdLife International (2015) European Red List of Birds. Office for Official Publications of the European Communities, Brussels
- BirdLife International (2017) European birds of conservation concern: populations, trends and national responsibilities. UK BirdLife International, Cambridge
- Bordignon L (1995) Prima nidificazione di *Cicogna nera*, *Ciconia nigra*, in Italia. *Riv Ital Orn* 64:106–116
- Bordignon L, Mastrorilli M (2004) La *Cicogna nera*/*Ciconia nigra* in Lombardia. *Picus* 30:5–18
- Bordignon L, Brunelli M, Visceglia M (2006) La cicogna nera (*Ciconia nigra*) in Italia: tendenze storiche, biologia riproduttiva e fenologia. *Avocetta* 30:15–19
- Bordignon L, Gatti F, Chiozzio G (2009) Tentativo di nidificazione di *Cicogna nera* in Lombardia. *Riv Ital Orn* 79:60–63
- Bosso L, Luchi N, Maresi G, Cristinzio G, Smeraldo S, Russo D (2017a) Predicting current and future disease outbreaks of *Diplodia sapinea* shoot blight in Italy: species distribution models as a tool for forest management planning. *For Ecol Manage* 400:655–664. <https://doi.org/10.1016/j.foreco.2017.06.044>
- Bosso L, De Conno C, Russo D (2017b) Modelling the risk posed by the zebra mussel *Dreissena polymorpha*: Italy as a case study. *Environ Manage* 60:304–313. <https://doi.org/10.1007/s00267-017-0882-8>
- Bosso L, Ancillotto L, Smeraldo S, D'Arco S, Migliozi A, Conti P, Russo D (2018a) Loss of potential bat habitat following a severe wildfire: a model-based rapid assessment. *Int J Wildland Fire* 27:756–769
- Bosso L, Smeraldo S, Rapuzzi P, Sama G, Garonna AP, Russo D (2018b) Nature protection areas of Europe are insufficient to preserve the threatened beetle *Rosalia alpina* (Coleoptera: Cerambycidae): evidence from species distribution models and conservation gap analysis. *Ecol Entomol* 43:192–203. <https://doi.org/10.1111/een.12485>
- Breiner FT, Guisan A, Bergamini A, Nobis MP (2015) Overcoming limitations of modelling rare species by using ensembles of small models. *Methods Ecol Evol* 6:1210–1218
- Bright J, Langston R, Bullman R, Evans R, Gardner S, Pearce-Higgins J (2008) Map of bird sensitivities to wind farms in Scotland: a tool to aid planning and conservation. *Biol Conserv* 141:2342–2356
- Brunelli M, Bordignon L, Caldarella M, Cripezzi E, Fraissinet M, Mallia E, Marrese M, Norante N, Urso S, Visceglia M (2018) Rapporto sulla nidificazione della *Cicogna nera* *Ciconia nigra* in Italia. Anno 2018. *Alula* 25:125–126
- Bush M, Gerlac B, Trautmann S (2017) Overlap between breeding season distribution and wind farms risks: a spatial approach. *Vogelwelt* 137:169–180
- Caldarella M, Bordignon L, Brunelli M, Cripezzi E, Fraissinet M, Mallia E, Marrese M, Norante N, Urso S, Visceglia M (2018) Status della Cicogna nera (*Ciconia nigra*) e linee guida per la conservazione della specie in Italia. Ed. Parco Regionale Gallipoli Cognato Piccole Dolomiti Lucane
- Cramp S, Simmons KEL (1977) The Birds of the Western Palearctic, vol 1. Oxford University Press, Oxford
- Czech HA, Parsons KC (2002) Agricultural wetlands and waterbirds: a review. *Waterbirds* 25:56–65
- D'Amico JM, Martins RC, Álvarez-Martínez JM, Porto M, Barrientos R, Moreira F (2019) Bird collisions with power lines: prioritizing species and areas by estimating potential population-level impacts. *Divers Distrib* 25:975–982

- del Hoyo J, Del Hoyo J, Elliott A, Sargatal J (1992) Handbook of the birds of the world, vol 1. Barcelona: Lynx edicions
- Denis P, Brossault P (2016) Historique de la population nicheuse de *Cigogne noire* en France. *Ornithos Hors-série* 1:61–64
- Domínguez-Vega H, Monroy-Vilchis O, Balderas-Valdivia CJ, Gienger CM, Ariano-Sánchez D (2012) Predicting the potential distribution of the beaded lizard and identification of priority areas for conservation. *J Nat Conserv* 20:247–253
- Dubuis A, Pottier J, Rion V, Pellissier L, Theurillat JP, Guisan A (2011) Predicting spatial patterns of plant species richness: a comparison of direct macroecological and species stacking modelling approaches. *Divers Distrib* 17:1122–1131
- Dzyubenko N, Bokotey A (2011) The present status of the breeding population of the Black Stork (*Ciconia nigra*) in Ukraine. In: Abstract's book of the 8th Conference of the European Ornithologists' Union, pp 27–30
- Eaton S, Ellis C, Genney D, Thompson R, Yahr R, Haydon DT (2018) Adding small species to the big picture: species distribution modelling in an age of landscape scale conservation. *Biol Cons* 217:251–258
- Elliott A, Christie DA, Garcia EFJ, Boesman P (2020) Black Stork (*Ciconia nigra*). In: del Hoyo J, Elliott A, Sargatal J, Christie DA, de Juana E (eds) Handbook of the Birds of the World Alive. Lynx Edicions, Barcelona
- Feng X, Papeş M (2017) Can incomplete knowledge of species' physiology facilitate ecological niche modelling? A case study with virtual species. *Divers Distrib* 23:1157–1168
- Ferrer M, de Lucas M, Janss GF, Casado E, Munoz AR, Bechard MJ, Calabuig CP (2012) Weak relationship between risk assessment studies and recorded mortality in wind farms. *J Appl Ecol* 49:38–46
- Fielding AH, Bell JF (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environ Conserv* 24:38–49
- Fontaneto C, Ferretti G, Bordignon L, Fontaneto D (2006) The black stork *Ciconia nigra* in northern Italy: which environmental features does this species need to nest? *Revue d'écologie (Terre et Vie)* 61:303–308
- Fois M, Bacchetta G, Cuena-Lombrana A, Cogoni D, Pinna MS, Sulis E, Fenu G (2018a) Using extinctions in species distribution models to evaluate and predict threats: a contribution to plant conservation planning on the island of Sardinia. *Env Cons* 45:11–19
- Fois M, Cuena-Lombrana A, Fenu G, Bacchetta G (2018b) Using species distribution models at local scale to guide the search of poorly known species: Review, methodological issues and future directions. *Ecol Model* 385:124–132
- Fourcade Y, Besnard AG, Secondi J (2018) Paintings predict the distribution of species, or the challenge of selecting environmental predictors and evaluation statistics. *Glob Ecol Biogeogr* 27:245–256
- Fox AD, Desholm M, Kahler J, Christensen TK, Petersen IK (2006) Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds. *Ibis* 148:129–144
- Fraissinet M, Bordignon L, Brunelli M, Caldarella M, Cripezzi E, Giustino S, Mallia E, Marrese M, Norante N, Urso S, Visceglia M (2018) Breeding population of Black Stork, *Ciconia nigra*, in Italy between 1994–2016. *Riv Ital Ornit* 88:15–22
- Garrido JR, Fernández-Cruz M (2003) Effects of power lines on a White Stork *Ciconia ciconia* population in central Spain. *Ardeola* 50:191–200
- GBIF.org (2019) GBIF Occurrence Download. <https://doi.org/10.15468/dle7wctr>
- González-Salazar C, Stephens CR, Marquet PA (2013) Comparing the relative contributions of biotic and abiotic factors as mediators of species' distributions. *Ecol Model* 248:57–70
- Grussu M, Floris G (2005) Lo svernamento della Cicogna nera in Sardegna. *Aves Ichnusae* 7:42–53
- Guisan A, Thuiller W (2005) Predicting species distribution: offering more than simple habitat models. *Ecol Lett* 8:993–1009
- Guisan A, Tingley R, Baumgartner JB, Naujokaitis-Lewis I, Sutcliffe PR, Tulloch AI, Martin TG (2013) Predicting species distributions for conservation decisions. *Ecol Lett* 16:1424–1435
- Hanley JA, McNeil BJ (1982) The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology* 143:29–36
- Hernández-Lambrano RE, Sánchez-Agudo JÁ, Carbonell R (2018) Where to start? Development of a spatial tool to prioritise retrofitting of power line poles that are dangerous to raptors. *J Appl Ecol* 55:2685–2697
- Heuck C, Herrmann C, Levers C, Leitão PJ, Krone O, Brandl R, Albrecht J (2019) Wind turbines in high quality habitat cause disproportionate increases in collision mortality of the white-tailed eagle. *Biol Conserv* 236:44–51

- Hernandez PA, Graham CH, Master LL, Albert DL (2006) The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography* 29:773–785
- Hernandez PA, Franke I, Herzog SK, Pacheco V, Paniagua L, Quintana HL et al (2008) Predicting species distributions in poorly-studied landscapes. *Biodiv Conserv* 17:1353–1366
- Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A (2005) Very high resolution interpolated climate surfaces for global land areas. *Int J Climatol* 25:1965–1978
- Hirzel AH, Hausser J, Chessel D, Perrin N (2002) Ecological-niche factor analysis: how to compute habitat-suitability maps without absence data? *Ecology* 83:2027–2036
- Iqbal MF, Khan IA (2014) Spatiotemporal land use land cover change analysis and erosion risk mapping of Azad Jammu and Kashmir, Pakistan. *Egypt J Remote Sens Space Sci* 17:209–229
- Janss GF, Ferrer M (1998) Rate of bird collision with power lines: effects of conductor-marking and static wire-marking (Tasa de Choques por Parte de Aves con Líneas del Tendido Eléctrico: Efecto de Marcadores de Conducción y Marcadores de Estática). *J Field Ornithol* 69:8–17
- Janss GF, Ferrer M (2001) Avian electrocution mortality in relation to pole design and adjacent habitat in Spain. *Bird Conserv Int* 11:3–12
- Jiguet F, Villarubias S (2004) Satellite tracking of breeding black storks *Ciconia nigra*: new incomes for spatial conservation issues. *Biol Conserv* 120:153–160
- Jiguet F, Barbet-Massin M, Henry PY (2010) Predicting potential distributions of two rare allopatric sister species the globally threatened *doliornis* cotingas in the Andes. *J Field Ornithol* 81:325–339
- Jiguet F, Barbet-Massin M, Chevallier D (2011) Predictive distribution models applied to satellite tracks: modelling the western African winter range of European migrant black storks *Ciconia nigra*. *J Ornithol* 152:111–118
- Kabir M, Hameed S, Ali H, Bosso L, Ud Din J, Bischof R, Redpath S, Ali Nawaz M (2017) Habitat suitability and movement corridors of grey wolf (*Canis lupus*) in Northern Pakistan. *PLoS ONE* 12:e0187027. <https://doi.org/10.1371/journal.pone.0187027>
- Kalocsa B, Tamas EA (2016) Statut de population et de conservation de la *Cigogne noire* en Hongrie. *Ornithos Hors-série* 1:38–41
- Katzner TE, Brandes D, Miller T, Lanzone M, Maisonneuve C, Tremblay JA et al (2012) Topography drives migratory flight altitude of golden eagles: implications for on-shore wind energy development. *J Appl Ecol* 49:1178–1186
- Kissling WD, Ahumada JA, Bowser A, Fernandez M, Fernandez N, Garcia EA, Guralnick RP, Isaac NJB, Kelling S, Los W, McRae L, Mihoub JB, Obst M, Santamaria M, Skidmore AK, Williams KJ, Agosti D, Amariles D, Arvanitidis C, Bastin L, De Leo F, Egloff W, Elith J, Hobern D, Martin D, Pereira HM, Pesole G, Peterseil J, Saarenmaa H, Schigel D, Schmeller DS, Segata N, Turak E, Uhlir PF, Wee B, Hardisty AR (2018) Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale. *Biol Rev* 93:600–625
- Kuvlesky WP Jr, Brennan LA, Morrison ML, Boydston KK, Ballard BM, Bryant FC (2007) Wind energy development and wildlife conservation: challenges and opportunities. *J Wildl Manag* 71:2487–2498
- Kwon HS, Kim BJ, Jang GS (2016) Modelling the spatial distribution of wildlife animals using presence and absence data. *Contemp Probl Ecol* 9:515–518
- Liu C, Berry PM, Dawson TP, Pearson RG (2005) Selecting thresholds of occurrence in the prediction of species distributions. *Ecography* 28:385–393
- Lõhmus A, Sellis U (2001) Foraging habitats of the black stork in Estonia. *Hirundo* 14:109–112
- Lobo JM, Jimenez-Valverde A, Hortal J (2010) The uncertain nature of absences and their importance in species distribution modelling. *Ecography* 33:103–114
- Lorgé P (2016) La Cigogne noire au Grand-Duché de Luxembourg. *Ornithos Hors-série* 1:42–43
- Maiorano L, Chiaverini L, Falco M, Ciucci P (2019) Combining multi-state species distribution models, mortality estimates, and landscape connectivity to model potential species distribution for endangered species in human dominated landscapes. *Biol Conserv* 237:19–27
- Marcantonini C, Valero V (2017) Renewable energy and CO2 abatement in Italy. *Energy Policy* 106:600–613
- Marmion M, Parviainen M, Luoto M, Heikkinen RK, Thuiller W (2009) Evaluation of consensus methods in predictive species distribution modelling. *Divers Distrib* 15:59–69
- Marques AT, Batalha H, Rodrigues S, Costa H, Pereira MJR, Fonseca C et al (2014) Understanding bird collisions at wind farms: An updated review on the causes and possible mitigation strategies. *Biol Conserv* 179:40–52
- Marques AT, Santos CD, Hanssen F, Muñoz AR, Onrubia A, Wikelski M, Moreira F, Palmeirim JM, Silva JP (2020) Wind turbines cause functional habitat loss for migratory soaring birds. *J Animal Ecol* 89:93–103

- Martín B, Perez-Bacalu C, Onrubia A, Lucas De, Ferrer M (2018) Impact of wind farms on soaring bird populations at a migratory bottleneck. *Eur J wildlife Res* 64:33
- Mateo RG, Gastón A, Aroca-Fernández MJ, Broennimann O, Guisan A, Saura S, García-Viñas JJ (2019) Hierarchical species distribution models in support of vegetation conservation at the landscape scale. *J Veg Sci* 30:386–396
- May R, Masden EA, Bennet F, Perron M (2019) Considerations for upscaling individual effects of wind energy development towards population-level impacts on wildlife. *J Environ Manag* 230:84–93
- McCune JL (2016) Species distribution models predict rare species occurrences despite significant effects of landscape context. *J Appl Ecol* 53:1871–1879
- Mohammadi S, Ebrahimi E, Shahriari Moghadam M, Bosso L (2019) Modelling current and future potential distributions of two desert jerboas under climate change in Iran. *Ecol Inform* 52:7–13
- Morán-Ordóñez A, Rocas-Díaz JV, Otsu K, Ameztegui A, Coll L, Lefevre F, Reatan J, Brotons L (2019) The use of scenarios and models to evaluate the future of nature values and ecosystem services in Mediterranean forests. *Reg Environ Chang* 19:415–428
- Mordente F, Rocca G, Salerno S, Serroni P (1998) *Cicogne noire, Ciconia nigra*, nidificatrice en Calabre (Italie du Sud). *Alauda* 66:321–323
- Morganti M, Preatoni D, Sarà M (2017) Climate determinants of breeding and wintering ranges of lesser kestrels in Italy and predicted impacts of climate change. *J Avian Biol* 48:1595–1607
- Mulero-Pázmány M, Negro JJ, Ferrer M (2013) A low cost way for assessing bird risk hazards in power lines: fixed-wing small unmanned aircraft systems. *J Unmanned Veh Syst* 2:5–15
- Muscarella R, Galante PJ, Soley-Guardia M, Boria RA, Kass JM, Uriarte M, Anderson RP (2014) ENMeval: An R package for conducting spatially independent evaluations and estimating optimal model complexity for maxent ecological niche models. *Methods Ecol Evol* 5:1198–1205
- Olson DM, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GV, Underwood EC, Loucks CJ (2001) Terrestrial ecoregions of the world: a new map of life on earth: a new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *Bioscience* 51:933–938
- Pearce-Higgins JW, Leigh S, Langston RHW, Bainbridge IP, Bullman R (2009) The distribution of breeding birds around upland wind farms. *J Appl Ecol* 46:1323–1331
- Petrescu RV, Aversa R, Apicella A, Berto F, Li S, Petrescu FI (2016) Ecosphere protection through green energy. *Am J Appl Sci* 13:1027–1032
- Pio DV, Engler R, Linder HP, Monadjem A, Cotterill FP, Taylor PJ, Salamin N (2014) Climate change effects on animal and plant phylogenetic diversity in Southern Africa. *Glob Chang Biol* 20:1538–1549
- Proosdij AS, Sosef MS, Wieringa JJ, Raes N (2016) Minimum required number of specimen records to develop accurate species distribution models. *Ecography* 39:542–552
- R Core Team (2018) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online at <https://www.R-project.org/>
- Raes N (2012) Partial versus full species distribution models. *Nat Conserv* 10:127–138
- Razgour O, Rebelo H, Di Febbraro M, Russo D (2016) Painting maps with bats: species distribution modelling in bat research and conservation. *Hystrix*. <https://doi.org/10.4404/hystrix-27.1-11753>
- Rinnhofer LJ, Roura-Pascual N, Arthofer W, Dejacó T, Thaler-Knoflach B, Wächter GA, Erhard C, Steiner FM, Schlick-Steiner BC (2012) Iterative species distribution modelling and ground validation in endemism research: an Alpine jumping bristletail example. *Biodivers Conserv* 21:2845–2863
- Rollan A, Real J, Bosch R, Tinto A, Hernandez-Matias A (2010) Modelling the risk of collision with power lines in Bonelli's Eagle *Hieraetus fasciatus* and its conservation implications. *Bird Conserv Intern* 20:279–294
- Roscioni F, Rebelo H, Russo D, Carranza ML, Di Febbraro M, Loy A (2014) A modelling approach to infer the effects of wind farms on landscape connectivity for bats. *Landsc Ecol* 29:891–903
- Russo D, Di Febbraro M, Cistrone L, Jones G, Smeraldo S, Garonna AP, Bosso L (2015) Protecting one, protecting both? Scale-dependent ecological differences in two species using dead trees, the rosalia longicorn beetle and the barbastelle bat. *J Zool* 297:165–175
- Smallwood KS, Thelander C (2008) Bird mortality in the altamont pass wind resource area, California. *J Wildlife Manage* 72:215–223
- Smeraldo S, Di Febbraro M, Ćirović D, Bosso L, Trbojević I, Russo D (2017) Species distribution models as a tool to predict range expansion after reintroduction: a case study on Eurasian beavers (*Castor fiber*). *J Nat Conserv* 37:12–20
- Smeraldo S, Di Febbraro M, Bosso L, Flaquer C, Guixé D, Lisón F et al (2018) Ignoring seasonal changes in the ecological niche of non-migratory species may lead to biases in potential distribution models: lessons from bats. *Biodiv Conserv* 27:2425–2441
- Strubbe D, Beauchard O, Matthyssen E (2015) Niche conservatism among non-native vertebrates in Europe and North America. *Ecography* 38:321–329

- Tamás EA (2012) Breeding and migration of the black stork (*Ciconia nigra*), with the special regard to a Central European population and the impact of hydro-meteorological factors and wetland status. Dissertation. University of Debrecen, Hungary
- Terna (2017). <https://www.terna.it/it-it/sistemaelettrico/statisticheprevisioni/datistatistici.aspx>
- Treyns R, Stončius D, Augutis D, Skuja S (2009) Breeding habitat of the black stork *Ciconia nigra* in Lithuania: implications for conservation planning. *Baltic Forestry* 15:33–40
- Thaxter CB, Buchanan GM, Carr J, Butchart SHM, Newbold T, Reen RE, Toggias JA, Foden WB, O'Brien S, Pearce-Higgins JW (2017) Bird and bat species' global vulnerability to collision mortality at wind farms revealed through a trait-based assessment. *Proc R Soc B* 284:1–10
- Thuiller W, Lafourcade B, Engler R, Araújo MB (2009) BIOMOD—a platform for ensemble forecasting of species distributions. *Ecography* 32:369–373
- Tobolka M, Zolnierowicz KM, Reeve NF (2015) The effect of extreme weather events on breeding parameters of the White Stork *Ciconia ciconia*. *Bird Study* 62:377–385
- Tucker GM, Heath MF (1994) *Birds in Europe: their conservation status*. Birdlife International, Cambridge
- Vlachos CG, Bakaloudis DE, Alexandrou OG, Bontzorlos VA, Papakosta MA (2008) Factors affecting the nest site selection of the black stork, *Ciconia nigra* in the Dadia-Lefkimi-Soufli National Park, north-eastern Greece. *Folia Zool* 57:251
- Wisz MS, Pottier J, Kissling WD, Pellissier L, Lenoir J, Damgaard CF et al (2013) The role of biotic interactions in shaping distributions and realised assemblages of species: implications for species distribution modelling. *Biol Rev* 88:15–30
- Wang S, Wang S, Smith P (2015) Ecological impacts of wind farms on birds: questions, hypotheses, and research needs. *Renew Sustain Energy Rev* 44:599–607
- Zuur AF, Ieno EN, Elphick CS (2010) A protocol for data exploration to avoid common statistical problems. *Methods Ecol Evol* 1:3–14

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