Rivista Italiana di Ornitologia - Research in Ornithology, 92 (2): 7-20, 2022 *DOI: 10.4081/rio.2022.564*

Analysis of the Rook (*Corvus frugilegus*) wintering population in the Friuli Venezia Giulia region (Italy) using maximum entropy models

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Abstract - This research analyzed the wintering population of rooks (*Corvus frugilegus*) in the Friuli Venezia Giulia region (Italy) from 2010 to 2020. The goal was to determine the population size, trend, and distribution over the decade by assessing census data and evaluating the study area's environmental suitability. It was important to identify the relationship between the region's environmental characteristics and the presence of the species by developing territory suitability models, processed using the maximum entropy algorithms and MaxEnt (maximum entropy) software. It was possible to determine the combinations of the factors potentially influencing habitat attendance, to develop environmental suitability maps, and to identify the area with the greater probability of the presence of the species, as well as those areas with potential suitability. Data for the presence of wintering rooks were derived from annual censuses, carried out by direct observation along pre-established transects in the Friuli Venezia Giulia region. Based on the census data, that total number of rooks in Friuli Venezia Giulia across the 10-year period had a maximum peak recorded in 2015 (1543) and a minimum in 2019 (853). The distribution of the species was concentrated in the central-southern areas of the region, with greater turnout in the areas characterized by agricultural land use, while the mountainous areas, located in the southern part of the region, were excluded. The environmental suitability models developed with MaxEnt on a regional scale demonstrated excellent predictive capacity, validating the species' ecological needs. Although the rook is not an endangered species, its range has been drastically reduced in Italy, at least in the last century, and MaxEnt could be used in the future as a management tool in order to outline conservation actions for the species, especially for its habitats.

Keywords: presence data, ecological distribution models, environmental suitability models, MaxEnt.

Riassunto - Analisi della popolazione svernante del corvo (*Corvus frugilegus*) nella regione Friuli Venezia Giulia (Italia) utilizzando modelli di massima entropia.

Questa ricerca ha analizzato la popolazione svernante di Corvo comune (*Corvus frugilegus*) nella Regione Friuli Venezia Giulia (Italia) dal 2010 al 2020. L'obiettivo è stato quello di determinare la consistenza, la tendenza e la distribuzione della popolazione nel decennio attraverso i dati del censimento e valutando lo studio di idoneità ambientale del territorio. È stato importante individuare la relazione tra le caratteristiche ambientali della regione e la presenza della specie sviluppando modelli di idoneità del territorio, elaborati utilizzando gli algoritmi di massima entropia e il software MaxEnt (massima entropia). È stato possibile determinare le combinazioni di fattori potenzialmente influenzanti la frequentazione dell'habitat, sviluppare mappe di idoneità ambientale e identificare l'area con maggiore probabilità di presenza della specie, nonché quelle aree con potenziale idoneità. I dati di presenza del Corvo comune svernante sono stati ricavati da censimenti annuali, condotti mediante osservazione diretta lungo transetti prestabiliti nella Regione Friuli Venezia Giulia. Dai dati del censimento, il numero totale di corvi in Friuli Venezia Giulia nell'arco temporale di 10 anni ha avuto un picco massimo registrato nel 2015 (1543) e un minimo nel 2019 (853). La distribuzione della specie si è concentrata nelle aree centro-meridionali della regione, con maggiore affluenza nelle aree caratterizzate da un uso del suolo di tipo agricolo, mentre sono state escluse le aree montane, collocate nella parte meridionale della regione. I modelli di idoneità ambientale elaborati con MaxEnt a scala regionale hanno dimostrato un'eccellente capacità predittiva, validando le esigenze ecologiche della specie. Pur non essendo il corvo una specie in via di estinzione, in Italia il suo areale è stato drasticamente ridotto, almeno nell'ultimo secolo, e MaxEnt potrebbe essere utilizzato in futuro come strumento gestionale per delineare azioni di conservazione sia per la specie sia per gli habitat.

Parole chiave: dati di presenza, modelli ecologici di distribuzione, modelli di idoneità ambientale, MaxEnt.

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Received for publication: 22 July 2021
Accepted for publication: 10 June 2022
Online publication: 15 December 2022

INTRODUCTION

The rook (*Corvus frugilegus*) is a regular migrant to Italy for wintering and occasional nesting (Fracasso *et al*., 2009; Brichetti & Fracasso, 2011). At the end of the 1800s, this species wintered in most of the lowland areas in Italy, as well as in Sicily and Sardinia (Giglioli, 1889). However, by the mid-1900s, its distribution had become very fragmented, undergoing a significant contraction of the original range from south to north, greatly decreasing across the islands and the flat coastal areas of the Tyrrhenian Sea and disappearing from the southern regions altogether (Caterini, 1955). From the mid-1980s, the wintering area of this species was located only in the central and western Po River Valley and in the northern Adriatic regions, completely disappearing from Sardinia and Sicily (Bogliani, 1985). The main causes of the decline of

Corvus frugilegus in Italy are attributable to various factors, such as the expansion of intensive agriculture with the consequent transformations of the traditional agricultural landscape, the decrease in food availability caused by the plowing of corn stubble after harvesting, the increase in temperature due to climate change, which may have induced the animals to overwinter north of the Alps, and the reclamation of wetlands that took place in the early decades of the 20th century.

In other European countries, often locally, a decrease in the species has also been documented in the last century, for example, in Poland (Chmielewski *et al*., 2019; BirdLife International, 2017; Chodkiewicz *et al*., 2018; Kitowski, 2011; Orłowski & Czapulak, 2007; Biaduń & Wojciak, 2005; Mazgajski *et al*., 2005, 2008), Germany (Krüger *et al*., 2020; Unger & Bauer, 2001), Croatia (Mikuška *et al*., 2015), Serbia (Tucakov *et al*., 2010), Bosnia and Herzegovina (Birdlife International, 2015), England (Brenchley, 2009), Wales (Little, 2001), Scotland (Skilling & Smith, 1993), Holland (Feijen, 1976), Latvia (Hagemeijer & Blair, 1997), Spain (Ena, 1984), Sweden (Malmberg, 1973), Hungary (Kalotas, 1985), and the Transbaykala region in Russia and China (Madge & Burn, 1994), mostly due to the actions of man and the shortening of migratory routes that has occurred as a result of climate change. Recently, Spiess & Keller (2020) provided an update of the dynamics of breeding populations in Europe. The picture that emerges is of an increase between 1980 and 2000 and of a slight decrease thereafter.

Relatively localized monitoring programs represent a priority in trying to understand the population size and species distribution and the possible causes of the decline that, based on the literature, has occurred along the Italian peninsula. Determining the population trend over time can help to elucidate the population state of conservation and can also provide information on the environment in which the population lives. Understanding the environmental suitability, in relation to the needs of one or more species, can highlight the potential for expansion of these species or the possible causes of their decline, allowing establishing program management or conservation measures and verifying their efficacy.

Carrying out censuses through direct observation (visual estimation) is important for estimating the size of the wintering population of rooks and describing the species distribution, as well as understanding the link between the species and the environment.

The Friuli Venezia Giulia region is one of the few areas in Italy that still hosts a consistent wintering population of this species. In addition to population size assessment, trend, and distribution in Friuli Venezia Giulia in the decade 2010-2020, this study aimed to identify a relationship between the environmental characteristics and the presence of the target species through territorial suitability models developed with maximum entropy algorithms using MaxEnt (maximum entropy) software (Phillips *et al*., 2006; Phillips & Dudík, 2008). Recently, this methodology was used several times to carry out ecological studies of birds (Tellini *et al*., 2008; Campedelli *et al*., 2009; Cutini *et al*., 2009; Campedelli *et al*., 2011; Borgo & Mattedi, 2012; Campedelli *et al*., 2012; De Luca *et al*., 2017; Campedelli *et al*., 2018), resulting in a particularly efficient tool for management and conservation purposes. The software allowed identifying areas with the presence of the species with higher probability, as well as potentially suitable areas, determining the combination of factors potentially influencing the attendance habitat, and processing environmental suitability maps. This was possible by using the annual rook census dataset created by the Ornithological Studies and Ecological Research of the Friuli Venezia Giulia Association (A.ST.O.R.E FVG), provided by the Ornitho.it platform.

Although, globally, the rook is not an endangered species, its range has significantly reduced in Italy in the last century. MaxEnt could be used for future analyses as a management tool to outline conservation actions for the species and its habitats. Future developments about the assessment of the distribution of rooks should include research concerning climate change at the European level in order to establish how much global warming may have affected the species distribution in Italy.

MATERIALS AND METHODS

Study area

The Friuli Venezia Giulia region is located in northeastern Italy and covers an area of 7845 km². The region is morphologically divided into four zones: Alpine and prealpine, hilly, flat, and coastal. Mountainous areas represent 43% of the entire surface and occupy the northern part. The hilly area represents 19% of the region, located in the south of the mountainous zone and along the central part of the border with Slovenia. The flat zone is located in the central-southern area of the region and represents 38% of the territory, consisting of high lowlands located further north and low lowlands further south. The northern mountainous area and the upper part of the lowlands, the less fertile area, are scarcely cultivated. Crops are mainly found in the flat area, predominantly comprising corn, rye, sugar beets, tobacco, and fruit (apples and pears). Vineyards are also widespread, scattered everywhere in the hilly and flat areas. The rook (*Corvus frugilegus*), although not very abundant, is present during the winter in the lower plain of Friuli Venezia Giulia, in several places in the provinces of Udine and Pordenone. Otherwise, it is sporadically observed in Gorizia Province, but is practically unknown in Trieste Province.

Dataset Field data collection

As part of the Rook Project, the Ornithological Studies and Ecological Research of the Friuli Venezia Giulia Association (A.ST.O.R.E. FVG) proposed monitoring the *Corvus frugilegus* wintering population in Friuli Venezia Giulia, starting from 2010. Every year, several surveyors carry out a species census throughout the region, using fixed and pre-established transects. Monitoring is carried out in the morning, following an unchanged car transect. There were 14 transects in total in the studied decade (Fig 1).

The surveyors record and note, on their special survey sheets, the rook specimens encountered in their transect through direct observation (visual estimate) using GPS, binoculars, telescopes and digital cameras. The censuses

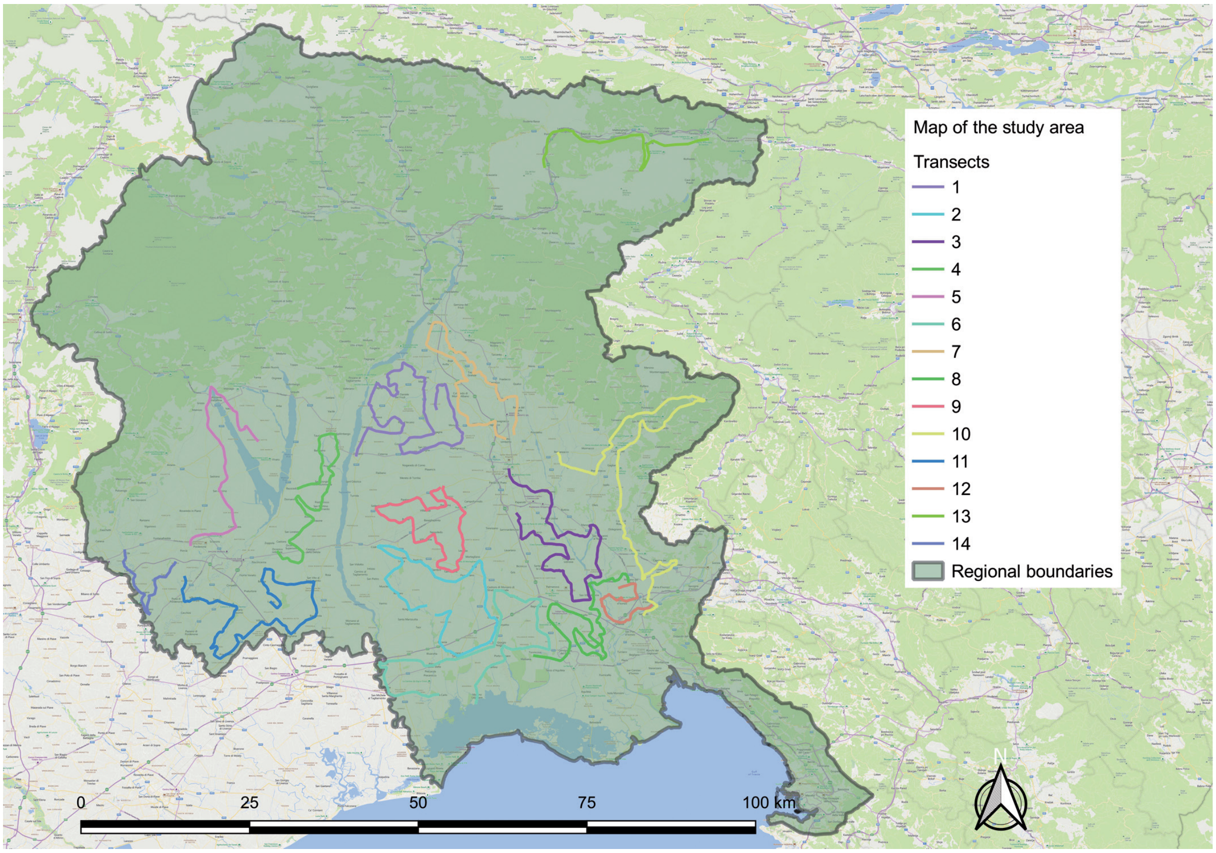

Fig. 1 - Map of the study area and transects. / Mappa dell'area di studio e dei transetti.

involve 118 of the total of 215 municipalities in the region. The Alpine area is excluded from the survey protocol, as it is not part of the species' frequented habitat during wintering. On the contrary, the lowland area is highly suitable for this species. Considering the species' biological cycle, migratory and wintering in Italian territory, with maximum peaks in presence between the end of January and the end of February, the annual census is carried out over the first weekend of February. This period is considered the most suitable because it presents the lowest risk of underestimation due to the failure of observing rooks still arriving from migration and not definitively established in the territory. Likewise, there is certainty around the species not having already left for the return migration to the breeding quarters.

Datasets preparation for analyses Selection of predictors

The survey sheets, containing all of the information regarding the geolocalized observations of the species for every single transect during the 10 years of sampling, were imported in an Excel file. The data of the presence of the species for each year were imported into QGis (Bucaresti 3.12 version). Species monitoring was carried out using a grid of 1 × 1 km, and data preparation and analysis also followed this survey scale; therefore, each parameter was calculated as a raster with a 1 × 1 km grid. The parameters for the space analysis were land use, distance from buildings, distance from roads, and altimetry. For land use, the dataset use was the Corine Land Cover (CLC) of 2012 (EEA, 2012) and 2018 (EEA, 2018), in order to investigate possible differences in the space use by the species related to potential land use changes. First of all, it was necessary to reclassify the uses related to species ecology and to standardize the information related to CLC2012 and CLC2018. For this, some codes of use were reclassified, aggregating some (those assumed to be less relevant for species ecology) and leaving the others as they were (level III; those considered to most influence species distribution). The original codes were retained for the agricultural areas, because, based on the literature and direct observations, rooks use areas rich in arable land (especially corn), ploughed fields, mowing meadows, tree rows (walnut trees especially), poplar groves, vineyards, and orchards during the migratory/winter period (Bogliani, 1985; Groppali, 1994; Grattini, 2005; Brichetti & Fracasso, 2011). On the contrary, the species has never been observed to frequent forests or wetlands of various types (Fornasari *et al*., 1992), which is why all land uses related to wetlands were merged into a single code, while wooded areas, shrubs, and open areas with little vegetation were reclassified to a lower and less detailed level. Through the observations made during the censuses and literature (Brichetti & Fracasso, 2011), it was found that the rook is also present in urban green areas, gardens, home gardens, and even sports fields, so the original codes related to urban green areas and sports fields were retained (Tab. 1).

Tab. 1 - Descriptions and codes of CLC classes. / Descrizioni e codici delle classi del Corine Land Cover.

Class	Code	Level	Abbreviation
Artificial areas	1	I	Urban
Green urban areas	141	II	Green urban areas
Sport and leisure facilities	142	III	Sport and facilities
Non-irrigated arable land	211	III	Agricultural
Vineyards	221	III	Vineyards
Fruit tree and berry plantations	222	III	Orchards
Pastures	231	III	Pastures
Complex cultivation patterns	242	III	Complex cultivation patterns
Land principally occupied by agriculture	243	III	Land occupied by agriculture
Forest and semi-natural areas	31	II	Forest
Shrubs and/or herbaceous vegetation associations	32	II	Shrubs and/or herbaceous assoc.
Open spaces with little or no vegetation	33	II	Open spaces
Wetlands	4	I	Wetlands

Working in 1 × 1 km mesh results in a loss of information regarding uses, as in a 1 × 1 km cell, there may be a use code number (for a very fragmented territory) that fails to represent the real land use mosaic. To fix this, each land use percentage was calculated, creating a raster for each reclassified use code to ensure that the percentage was used for each cell.

It is not uncommon to find rooks in urban environments, especially in large contingents and big cities, benefiting from searching for food of anthropogenic origin; in nearby human settlements, the rook regularly exploits domestic leftovers, mangers, and rubbish dumps as food sources, being an opportunistic species (Brichetti & Fracasso, 2011). It was therefore decided to verify if the presence of buildings, closely related to food discovery, could in any way influence the spatial distribution of the species. A regional territory distance gradient from the buildings for each 1 × 1 km cell was developed. There are no references among the potential impacts of the road network for this species; however, it was interesting to investigate the distance of survey cells from the streets, under the hypothesis that this may be a factor influencing the rook's space use. Therefore, a distance gradient from the road network was elaborated for the consequent impact on species distribution.

Between 1986 and 1992, the rook was common in the Piemonte and Val d'Aosta regions, especially at altitudes between 100 and 200 m a.s.l., with rare occurrences at higher altitudes up to 1650-2000 m a.s.l. in the Provinces of Torino and Cuneo (Cucco *et al*., 1996). In the Lombardy region, the species was more widespread between 100 and 200 m a.s.l. in arable land and lowland meadows, with frequent observations up to 400 m a.s.l. and occasional or localized observations up to 1000 m a.s.l. In Trento Province, around the 2000s, the presence of the species was limited to altitudes below 500 m a.s.l., with rare observations of single rooks with other corvids at altitudes just above 1500 m a.s.l. (Pedrini *et al*., 2005). In the Veneto region, all observations in the studied period occurred at an altitude between 0 and 200 m a.s.l., with a single observation in Belluno Province at 1277 m a.s.l. in January 2011 (Sgorlon & Stival, 2015). Therefore, for altitude and its possible influence on the species' space use, altitude was obtained using a digital elevation model (DEM).

MaxEnt software Data analysis

To process the environmental suitability for the target species, MaxEnt (maximum entropy) version 3.4 was used.

Exploiting the maximum entropy principle, MaxEnt allows the construction of species distribution modeling, starting from presence-only or incomplete data, as well as from environmental information for the total study area, maximizing the model's predictive power (Phillips *et al*., 2004, 2006; Phillips & Dudik, 2008).

MaxEnt allows comparing the environmental information associated with the species presence (sample points) to the background locations throughout the study area (background points), returning a habitat suitability distribution (probability of presence) for the target species and the percent contribution of each environmental variable (Phillips *et al*., 2006; Raes & ter Steege, 2007).

The results obtained with MaxEnt are less influenced by inhomogeneous sampling, often frequent for large-scale studies, making it very useful for identifying the most significant conservation areas of interest (Tsoar *et al*., 2007). Another benefit of this software is the chance of using data collected on a large scale with inhomogeneous census methods or for rare or cryptic species (Campedelli *et al*., 2012). This model, exclusively formulated by presence-only data, unlike other predictive models, removes the error resulting from presence/absence data analysis, which often leads to a wrong environmental parameter assessment that affects a species distribution (Moilanen, 2002; Gu & Swihart, 2004). It is known that absence is, except in some cases, difficult to verify, especially with rare or cryptic species and species with elusive behavior.

MaxEnt requires input from two information categories, which the software then processes, giving as output an environmental suitability model for the species in the study area: georeferenced presence data for the target species (samples points); covariates that characterize the study area background sites (background samples) (Elith *et al*., 2006; Raes & ter Steege, 2007; Phillips & Dudik, 2008; Merow *et al*., 2013). The data relating to the parameters that can influence the potential species distribution must be in raster format. Each raster carries information concerning the parameter to be investigated within the chosen cell resolution. The software assigns a probability for each investigated area pixel, with results ranging from 0 (min) to 100 (max), returning a habitat suitability map that indicates the probability gradient for the potential distribution of the target species (Phillips *et al*., 2006). Pixels with values close to 100 are those where the probability is highest, while cells with values close to 0 are those with less probability within the study area (Phillips *et al*., 2006).

To evaluate the model's efficiency, the value of the area under the receiver operating characteristic (ROC) curve was used, known as AUC and typically used to estimate the predictive accuracy of distributional models derived from species presence/absence data (Lobo *et al*., 2008). The AUC scores can range from 0 (model with no predictive ability) to 1 (model that exactly predicts the presence of the species) and indicates a model's quality. For animal species distribution, 0.75 is the limit value for efficacy acceptability (Lobo *et al*., 2008).

The software also returns results showing the percent contribution for each variable within a model, calculated by considering the average value of the other variables and the permutation value. The permutation value shows the model performance decrease by removing a particular variable; if the decrease in performance is high, it means that the variable is important in explaining the model. High percent contribution and permutation values show that the variable is important, while low values mean that it has a marginal effect (Iacobelli, 2017).

The software provides response curves for each model, which show the change in prediction as each variable changes, preserving all others at an average value. These curves help to elucidate the type and shape of the relationship between each environmental component and species presence. From these curves, it is possible to draw useful conclusions about the meaning of the existing relationships and the ecological coherence of the relationships themselves (Iacobelli, 2017). The jackknife test, i.e., jackknife repeated replication (JRR), is a method for resampling variables, which recalculates the estimates by excluding one observation and assessing the gain in terms of model performance. With this test, the software calculates several models, and for each one, every variable is excluded, creating a model with the residual variables. In this study, different levels of analysis were carried out, processing as many ecological model rook distributions (EMRDs) according to the sample points and background points specified in Table 2.

Tab. 2 - Ecological Model Rook Distribution (EMRD). / Modello ecologico di distribuzione dei corvi (EMRD).

Model	Sample points	Parameters - Background points			
EMRD_01	Rook census dataset 2010-2020	CLC 2012	DEM	Distance from buildings	Distance from road network
EMRD_02	Rook census dataset 2010-2020	CLC 2018	DEM	Distance from buildings	Distance from road network
EMRD_03	Rook census dataset 2010-2012	CLC 2012	-	Distance from buildings	Distance from road network
EMRD_03_01	Rook census dataset 2010	CLC 2012	-	Distance from buildings	Distance from road network
EMRD_03_02	Rook census dataset 2011	CLC 2012	-	Distance from buildings	Distance from road network
EMRD_03_03	Rook census dataset 2012	CLC 2012	-	Distance from buildings	Distance from road network
EMRD_04	Rook census dataset 2016-2018	CLC 2018	-	Distance from buildings	Distance from road network
EMRD_04_01	Rook census dataset 2016	CLC 2018	-	Distance from buildings	Distance from road network
EMRD_04_02	Rook census dataset 2017	CLC 2018	-	Distance from buildings	Distance from road network
EMRD_04_03	Rook census dataset 2018	CLC 2018	-	Distance from buildings	Distance from road network

The first analyses concerned the overall presence data in 2010-2020 (EMRD_01 and EMRD_02), while the subsequent processing was carried out using the presence data of the species, starting from the three years before the preparation of the respective Corine Land Cover, in order to analyze possible variation in the distribution based on land use changes. For these models, it was considered appropriate to analyze the data both in their entirety (EMRD_03 and EMRD_04) and divided by year to evaluate possible annual variation in the species' spatial behavior for the territory under examination.

As regards the first analyzes (EMRD_01 and EMRD_02), the census data were analyzed in their entirety, from 2010 to 2020, considering all the potential influencing variables: DEM, distance from buildings, distance from roads, land use 2012 (EMRD_01), land use 2018 (EMRD_02).

Subsequent analyzes excluded the DEM variable. EMRD_03 was developed for 2010-2012 with the variables land use 2012, distance from buildings, and distance from roads.

Models EMRD_03_01, EMRD_03_02, EMRD_03_03 used the same variables as EMRD_03 but analyzed the census dataset of 2010 (EMRD_03_01), of 2011 (EMRD_03_02), and 2012 (EMRD_03_03).

Model EMRD_04 was developed for 2016-2018 with the variables land use 2018, distance from buildings, and distance from roads.

Models EMRD_04_01, EMRD_04_02, EMRD_04_03 used the same variables as EMRD_04 but analyzed the 2016 (EMRD_04_01), 2017 (EMRD_04_02), and 2018 (EMRD_04_03) dataset census.

RESULTS

Trend and size

The number of rooks sighted from 2010 to 2020 was 12,013, with a maximum peak in the contact recorded in 2015 (1543) and a minimum in 2019 (853). The authors suppose that lower peaks could be due to either years of lower reproductive success, years without a particularly cold winter, or both concomitant factors (Fig. 2).

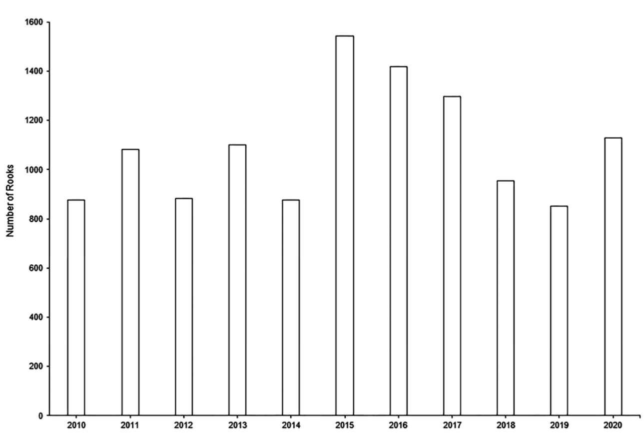

Fig. 2 - Number of wintering rooks in Friuli Venezia Giulia in each year from 2010 to 2020 and population trend over the decade. / Numero di esemplari di corvo comune svernanti in Friuli Venezia Giulia nei singoli annidal 2010 al 2020 e tendenza della popolazione nel decennio.

Regarding climatic variations, some populations may use wintering quarters closer to breeding quarters, thus avoiding a longer and unnecessary migration (Mazgajski *et al*., 2008). It has already been hypothesized that global warming could have shortened the migratory routes of the wintering populations in Italy (Bogliani, 1985). Likewise, studies on the recapture of ringed specimens suggest that some of the existing populations in Europe have two different wintering areas, preferring the secondary wintering area, which is closer to the nesting area, during mild winters (Unger & Bauer, 2001; Busse, 1969). This could explain the reduction in the range that occurred in the Italian territory during the last century.

Distribution and concentration areas

A heatmap (Fig. 3) was obtained using the QGIS Heatmap plugin, creating a density raster from a vector layer of monitoring points. Based on the ecological needs and high motility of the species, the map was developed with a 5 km range.

This map could also represent the species' highest fidelity areas across the 2010-2020 period. It can be deduced that the areas with the greatest turnout were, for Udine Province, those near the cities of Palmanova, San Vito al Torre, and Codroipo, while for Pordenone Province, they were those near San Giovanni di Casarsa, Fiume Veneto, and San Vito al Tagliamento.

Points of presence distribution of the species in the central-southern areas of the region were also observed, characterized by agricultural land uses (codes 211, 221, 222, 242, and 243). Mountainous areas were excluded. The region's northernmost point where sightings occurred was Cividale del Friuli (UD), while the highest point was recorded in San Quirino municipality (PN).

MaxEnt models

EMRD_01 and EMRD_02

Table 3 shows the results of the ROC curves and AUC values for the EMRD_01 and EMRD_02 models. The AUC values were, respectively, 0.956 and 0.957, considered very good based on the models' predictive ability.

From the habitat suitability maps (Fig. 4), higher suitability for the species was observed in the model developed using the 2018 Corine Land Cover. This may be because the rook exhibits a strong fidelity to breeding sites and, at least in part, to wintering sites. This would explain why, although the models consider some areas to be suitable, the species has never actually been sighted there.

Tab. 3 - AUC values for EMRD_01 and EMRD_02 models. / Valori di AUC per i modelli EMRD_01 e EMRD_02.

EMRD	AUC (mean)
EMRD_01	0.956
EMRD_02	0.957

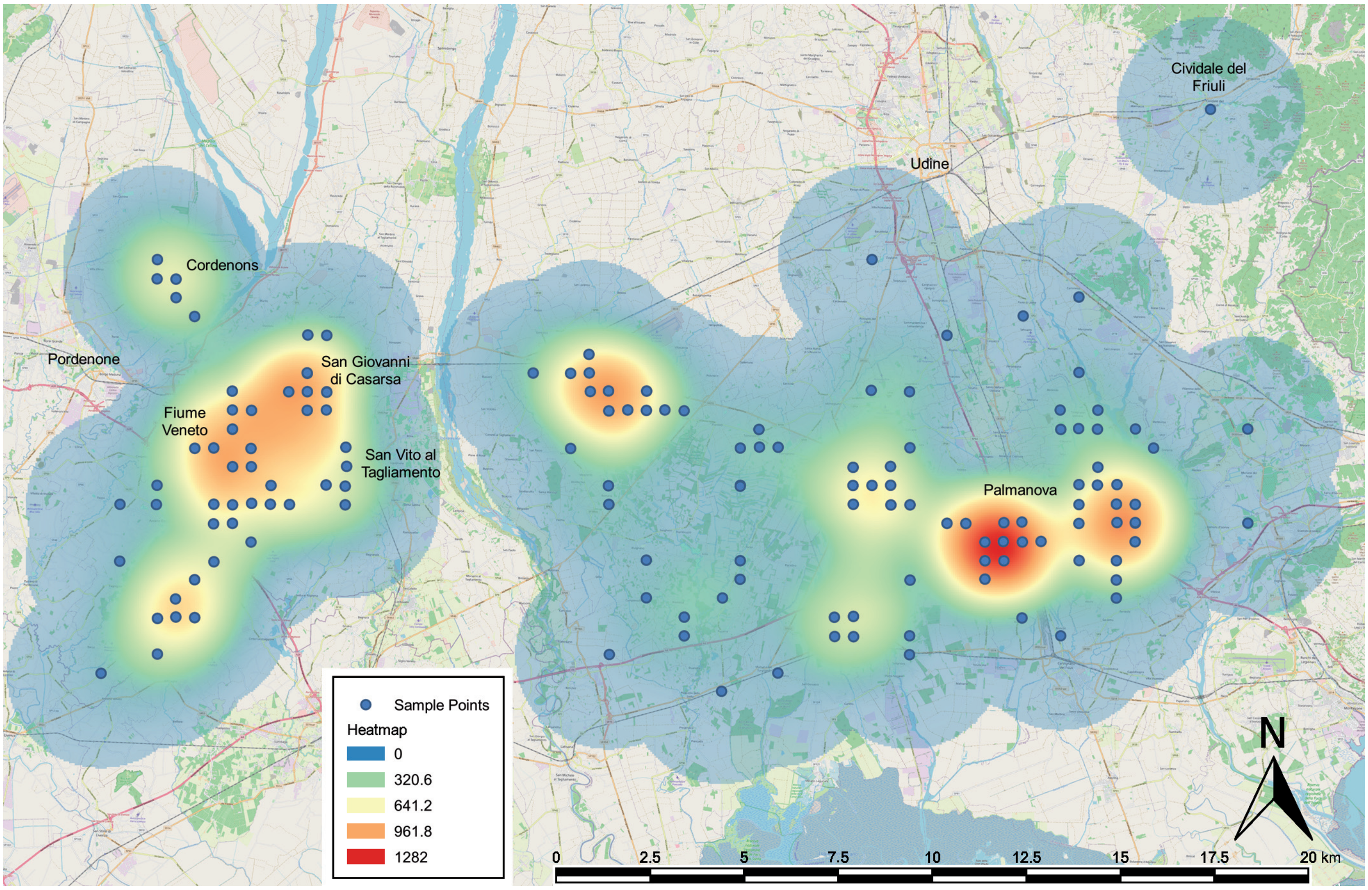

Fig. 3 - Rook heatmap in the Friuli Venezia Giulia region across the decade from 2010 to 2020. In red are highlighted the areas with higher concentration, while in light yellow and light blue are those with lower attendance. / Mappa di calore dei corvi nella regione Friuli Venezia Giulia nel decennio 2010-2020. In rosso sono evidenziate le aree con maggiore concentrazione, mentre in giallo chiaro e azzurro quelle con minore presenza.

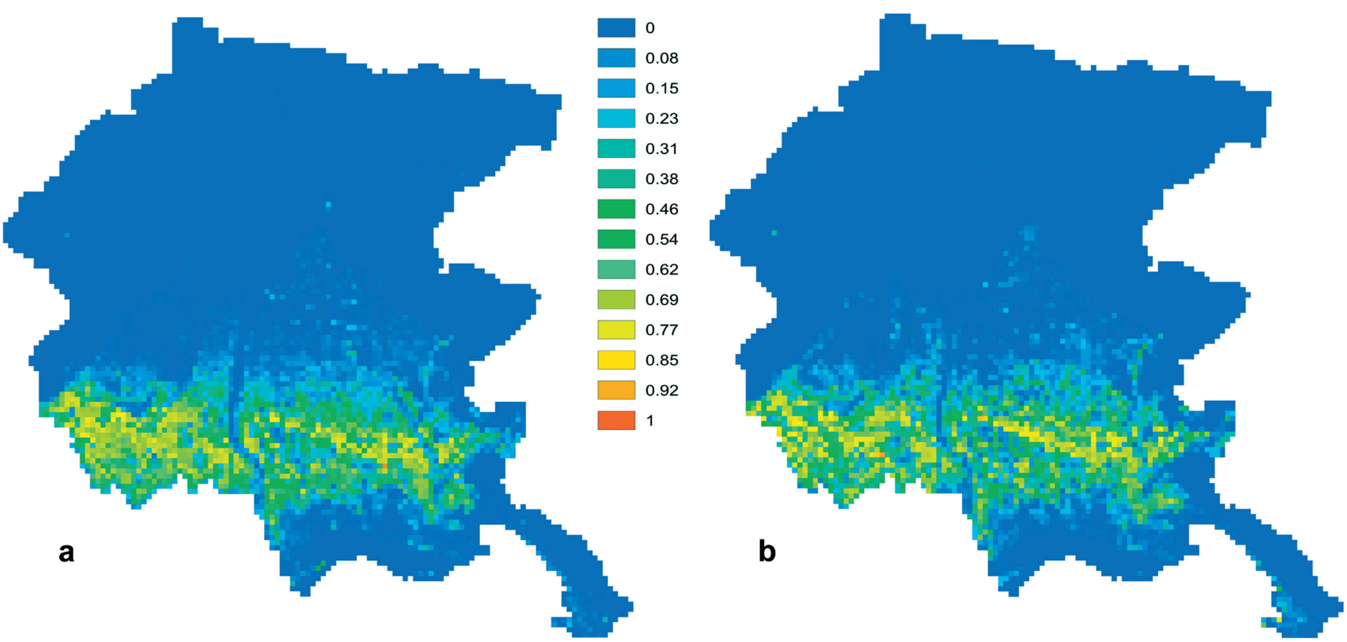

Fig. 4 - Habitat suitability maps for the target species for EMRD_01 and EMRD_02. Areas with intermediate suitability are highlighted in green, those with maximum suitability for potential distribution in red and orange, and those with no suitability are shown in light blue. / Mappe di idoneità degli habitat per le specie target per EMRD_01 e EMRD_02. Le aree con idoneità intermedia sono evidenziate in verde, quelle con idoneità massima per la distribuzione potenziale in rosso e arancione, mentre quelle senza idoneità sono indicate in azzurro.

The results in Table 4 show that for both models, the variables that most contribute to defining the potential presence of the species are the DEM, agricultural use (code 211), forest use (code 31), and urban use (code 1). The high permutation value for the DEM, compared to the other variables, indicates its importance in explaining the models.

The response curves (Fig. 5 a,b) for the urban use (code 1) show that both models indicated a higher probability of species occurrence between 0% and 20% of the urban matrix, which then decreased as code 1 urban use increased, suggesting that the species takes moderate advantage of cities.

For the agricultural use curves (code 211), the species occurrence probability increased as the percentage of agricultural areas increased, confirming the importance of this land cover type for the species (Fig. 5 c,d).

On the contrary, rooks do not appear to prefer wooded areas (code 31), showing a probability of occurrence that decreased as the forest percentage increased, confirming the species' preference for open spaces (Fig. 6 a,b).

Regarding altitude, a higher probability of presence was observed for low altitudes, which then nullified at altitudes higher than 250 m a.s.l. (Fig. 6 d,c), confirming the species' ecology.

Tab. 4 - The percent contribution for each variable and the permutation importance for the EMRD_01 and EMRD_02 models. / Il contributo percentuale di ciascuna variabile e l'importanza della permutazione per i modelli EMRD_01 e EMRD_02.

	Variable	Percent contribution (%)	Permutation importance
EMRD_01	DEM	36.3	51.7
	Agricultural use 2012	30.3	7.3
	Forest use 2012	16.9	18.7
	Urban use 2012	4.3	3.3
EMRD_02	DEM	29.8	62.5
	Agricultural use 2018	25.7	8.4
	Forest use 2018	22.4	8.7
	Urban use 2018	7.8	3.6

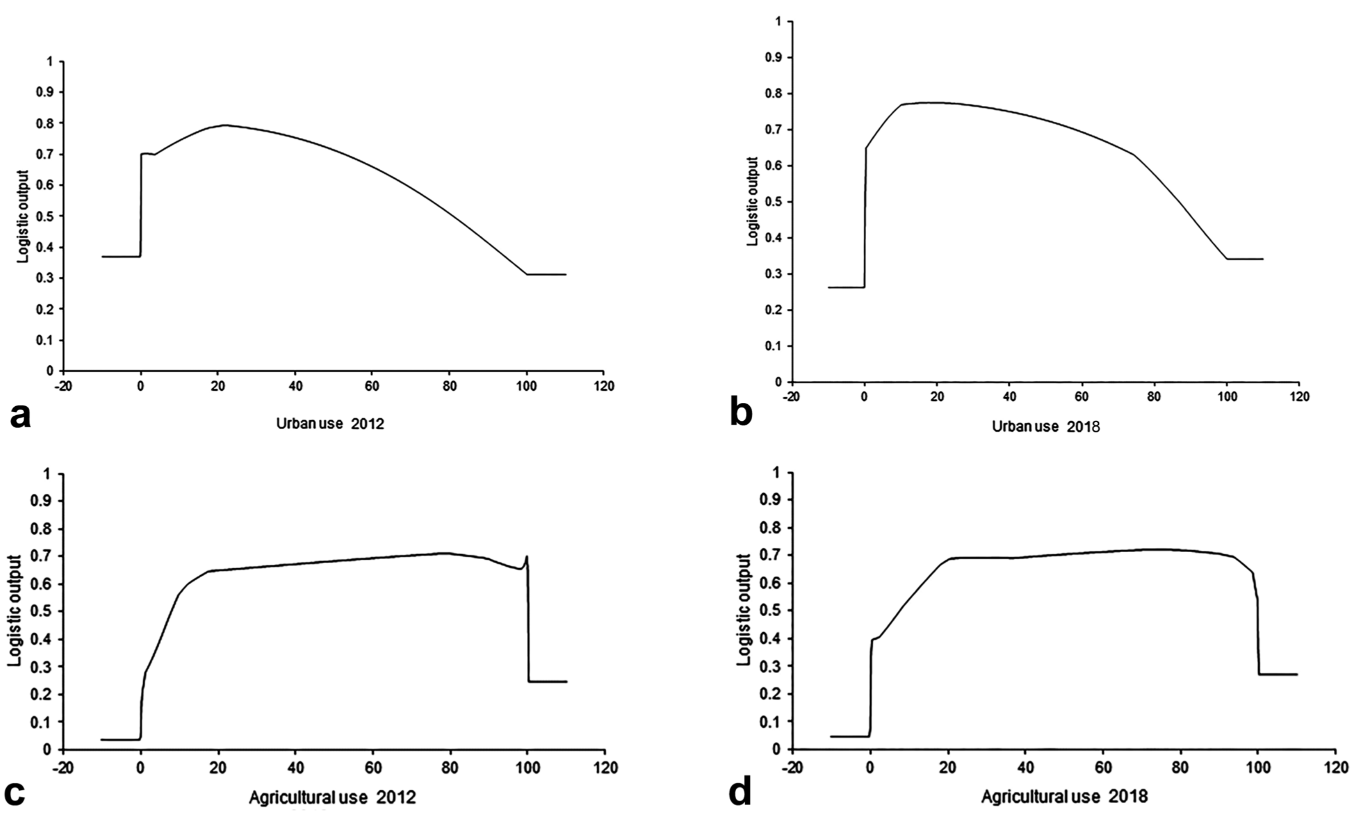

Fig. 5 - Response curves for the urban use (code1) (a,b) and the agricultural use (code 211) (d,c) variables for the EMRD_01 and EMRD_02 models. / Curve di risposta per le variabili uso urbano (codice1) (a,b) e uso agricolo (codice 211) (d,c) per i modelli EMRD_01 e EMRD_02.

As shown by the jackknife test (Fig. 7), the DEM can be considered the most important variable for model efficacy, while urban green areas (code 141), athletic fields and sports facilities (code 142), vineyards (code 221), orchards (code 222), and wetlands (code 4) are not relevant.

Concerning the altitude, the authors assume that this parameter can lead to over-information in the analysis since it can affect the land use by human activities. It is much more probable that agricultural land uses are found at lower altitudes, while forest uses are found in the mountainous part of the territory under consideration. For

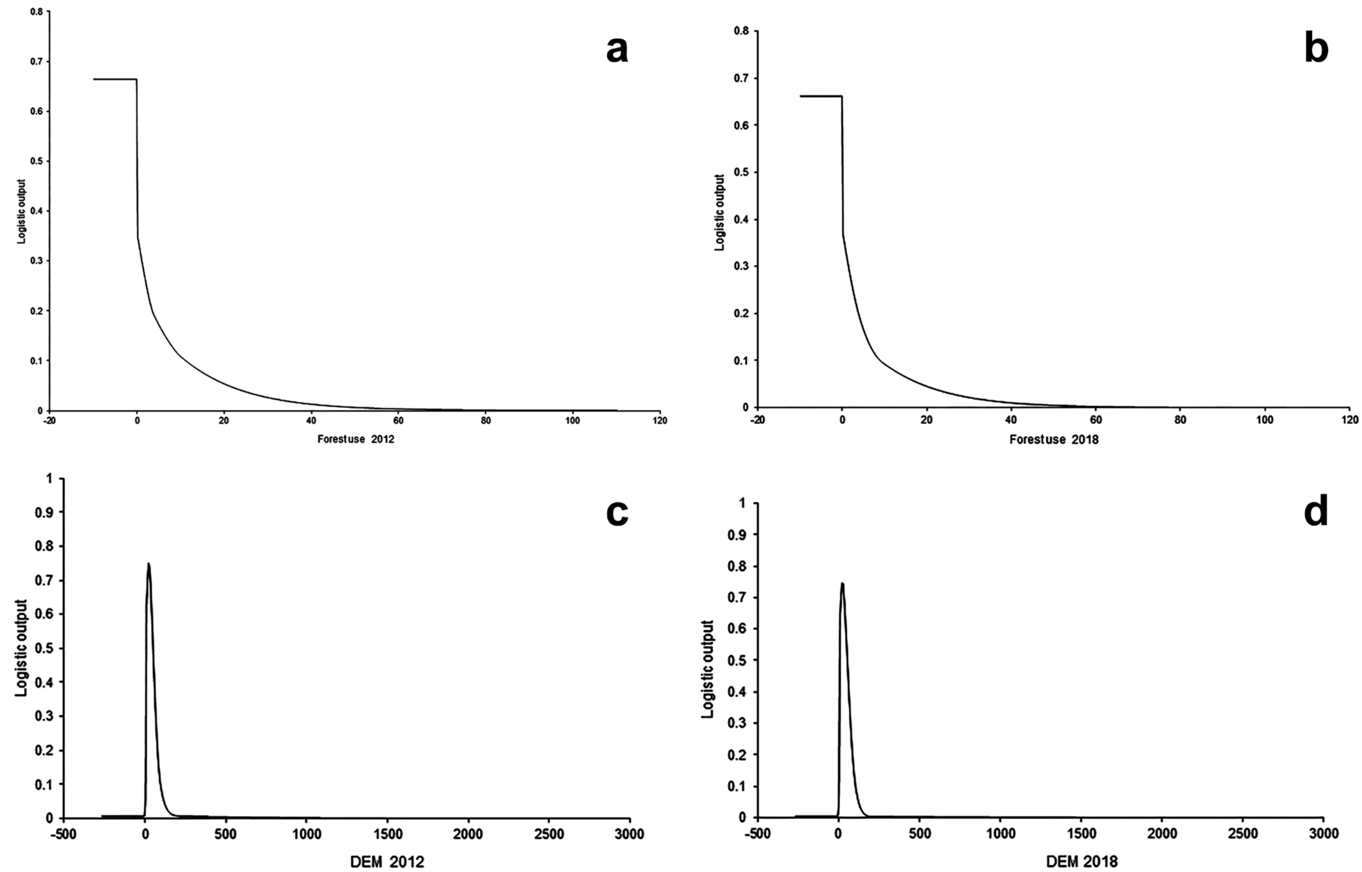

Fig. 6 - Response curves for the forest use (code31) (a,b) and the digital elevation model (DEM) (d,c) variables for the EMRD_01 and EMRD_02 models. / Curve di risposta per le variabili uso forestale (codice31) (a,b) e modello digitale di elevazione (DEM) (d,c) per i modelli EMRD_01 e EMRD_02.

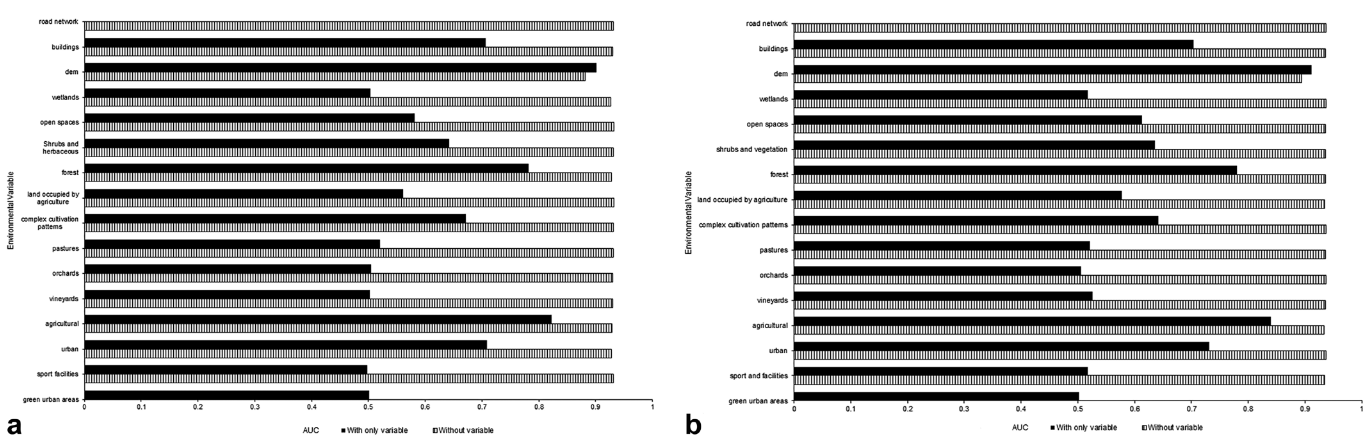

Fig. 7 - Jackknife test (i.e., jackknife repeated replication (JRR)) applied to EMRD_01 and EMRD_02. Blue Black shows the AUC values recorded for the models considering a single variable (on the ordinate), while green grayscale histograms show the AUC values for the models considering the entire variable set, excluding that on the ordinate. / Test Jackknife (cioè jackknife repeated replication (JRR)) applicato a EMRD_01 e EMRD_02. Il blu nero mostra i valori di AUC registrati per i modelli che considerano una singola variabile (sull'ordinata), mentre gli istogrammi in scala di grigi verdi mostrano i valori di AUC per i modelli che considerano l'intero set di variabili, esclusa quella sull'ordinata.

these considerations, subsequent models were developed without this parameter.

EMRD_03 and EMRD_04

The AUC values for EMRD_03 and EMRD_04 decreased slightly compared to those for EMRD_01 and EMRD_02 (Tab. 5). The AUC values derived from each year's presence data during the three years of 2010-2012 (ranging from 0.929 to 0.960) and 2016-2018 (from 0.938 to 0.950) can likewise be considered good.

In the suitability maps (Fig. 8), there was nearly identical suitability for the species in the EMRD_03 and EMRD_04 models, although slightly more homogeneous and widespread in the south-central part of the region in the EMRD_04 model, processed using the 2016-2018 census dataset and the 2018 CLC. For both models, the areas of high and low plains seem suitable, in contrast to the EMRD_01 and EMRD_02 models, where the areas with intermediate and high vocation are limited to the southern lowlands.

Tab. 5 - AUC values for EMRD_03 e EMRD_04. / Valori di AUC per EMRD_03 e EMRD_04.

Model	Sample points	AUC
EMRD_03	2010-2012	0.935
EMRD_03_1	2010	0.960
EMRD_03_2	2011	0.942
EMRD_03_3	2012	0.929
EMRD_04	2016-2018	0.938
EMRD_04_1	2016	0.950
EMRD_04_2	2017	0.950
EMRD_04_3	2018	0.938

Processing the above models, Table 6 shows that the variables with the highest contribution to the models' efficacy are the agricultural use (code 211), forest use (code 31), and urban use (code 1). The presence data test results for each year confirmed that the variables most influencing the models' performances are the same. Regarding the permutation index, we note the high value of code 31 forest use compared to the other variables. This shows the importance, in ecological terms, of the absence of wooded areas for the species, being the rook's distribution conditioned by the presence of open areas.

The response curves (Fig. 9 a,b) for the urban use (code 1) show a higher species probability of presence between 0% and 20% (EMRD_03) and between 0% and 30% (EMRD_04) of the urban matrix. In both models, as the urban matrix increased, the species probability of presence decreased.

For the agricultural use curves (code 211), the species probability of presence increased as the percentage of agricultural areas increased in both models. The upward trend of the marginal curve confirms the importance of this land cover for the species (Fig. 9 c,d).

Rooks do not appear to prefer wooded areas, resulting in a decrease the probability of presence as forest cover increases (Fig. 9 e,f).

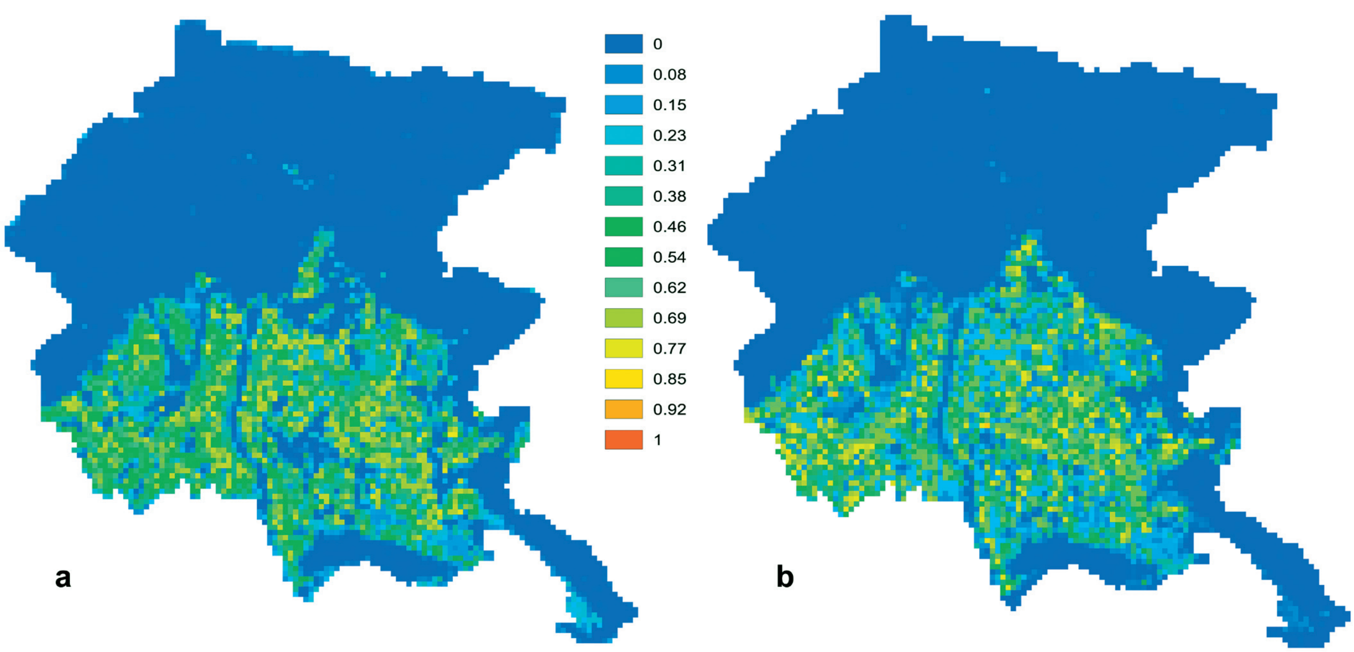

Fig. 8 - Habitat suitability maps for the target species for EMRD_03 and EMRD_04. Areas with intermediate suitability are highlighted in green, those with maximum suitability for potential distribution in red and orange, and those with no suitability are shown in light blue. / Mappe di idoneità degli habitat per le specie target per EMRD_03 e EMRD_04. Le aree con idoneità intermedia sono evidenziate in verde, quelle con idoneità massima per la distribuzione potenziale in rosso e arancione, mentre quelle senza idoneità sono indicate in azzurro.

Tab. 6 - The percent contribution for each variable and the permutation importance for the EMRD_03 and EMRD_04 models. / Il contributo percentuale per ogni variabile e l'importanza della permutazione per i modelli EMRD_03 e EMRD_04.

	Variable	**Percent contribution (%)**	**Permutation importance**
EMRD_03	Agricultural use 2012	39.2	11.6
	Forest use 2012	31.3	55
	Urban use 2012	6.5	4.5
EMRD_04	Agricultural use 2018	45.4	16.6
	Forest use 2018	27.3	43.2
	Urban use 2018	8.8	6.4

The jackknife tests (Fig. 10) showed that the variable agricultural land use (code 211) is the most important for the performance of both models, followed by forest use (code 31) and urban use (code 1) for EMRD_03 and forest use (code 31) for EMRD_04. Urban green areas (code 141), playgrounds and sports and leisure facilities (code 142), vineyards (code 221), orchards (code 222), and wetlands (code 4) were not relevant.

DISCUSSION AND CONCLUSIONS

In Italy, the rook has not been a very well-studied species, especially in the last decade. Therefore, implementing monitoring systems at the regional scale is important to identify the possible causes of the decline of the species, which, based on the literature, has occurred in the Italian peninsula. Analysis of the presence data obtained from the censuses carried out by the A.ST.O.R.E. FVG in the decade from 2010 to 2020 represents a turning point in determining the trend, size, distribution, and concentration of this species in the Friuli Venezia Giulia region. The elaborations carried out with the MaxEnt software allowed us to identify the environmental variables most influencing the target species' distribution. The total number of specimens surveyed was 12,013, with a maximum peak of contact recorded in 2015 (1543) and a minimum in 2019 (853). The nonlinear population trend is probably attributable to global warming and population contraction.

The regions' northernmost point where sightings occurred was Cividale del Friuli (UD), while the highest point was recorded in the San Quirino municipality (PN). From the point of presence distribution, it was observed that the central-southern areas of the region, characterized mainly by agricultural land uses, are the most used areas. The concentration analysis showed that the most remarkable turnout areas were, for Udine Province, those near Palmanova, San Vito al Torre, and Codroipo, while for Pordenone Province, they were those near San Giovanni di Casarsa, Fiume Veneto, and San Vito al Tagliamento. These also represent the highest fidelity areas.

Models EMRD_01, EMRD_02, EMRD_03, and EMRD_04, with high predictive power values, showed that the most important variables in defining environmental suitability for the species were the DEM, agricultural land use, and urban land use. Concerning the variable altimetry, the authors assume that it can affect the land use by human activities because it is much more probable that agricultural land uses are found at lower altitudes, while forest uses are found in the mountainous part of the territory under consideration. For this reason, subsequent analyses were conducted without considering the DEM variable, and still confirmed how the other variables strongly condition the models' performances regarding the species ecological distribution. The distance from the road network turned out to be, for all the models, an irrelevant parameter for the environmental suitability of the species.

The lack of availability of a land use information layer of greater detail at the regional scale than Corine Land Cover (minimum mappable unit of 25 ha) did not allow investigating the frequentation of cornfields, which seems to be the most important trophic resource for the rook during the winter season in Italy. Future surveys could investigate this ecological peculiarity, as well as walnut plantation attendance.

The suitability maps developed for all models showed that the potentially suitable areas for the species are larger than the actual distribution areas. This may confirm that the rook exhibits a strong fidelity to breeding sites and, at least in part, to wintering sites. The land use changes that have occurred over the years, which was hypothesized to be a factor influencing the species' wintering population size, was relatively small and insufficient to affect a change in space use by the species over the decade.

This research highlighted some aspects of the rook's ecology in Friuli Venezia Giulia, a rather large and environmentally diverse study area, showing that the species benefits from intermediate anthropogenic disturbance. Therefore, it is the combination of several factors that determines the environmental suitability for the species in the regional territory. The species seems to prefer environments between agricultural and urban land use, which allow exploiting environments characterized by a higher trophic availability, confirming the adaptability and the opportunistic tendency. The absence of forests is also a key factor in its distribution: the models' environmental unsuitability for the species where land use is predominantly forested, validating its preferences for open places. Environmental suitability models developed with MaxEnt at the regional scale validated the ecological needs of the species.

Although the rook is not an endangered species, in Italy, its range has been drastically reduced, at least in the last century, and MaxEnt could be used for future analysis as a management tool to outline conservation actions for the species, especially for its habitats. According to a cross-analysis of the species' ecology and its population dynamics in the study area, future research regarding assessment of the rook's distribution should include surveys on climate change at the European level to determine how the influence of global warming may have affected the species distribution not only in Friuli Venezia Giulia, but also in Italy.

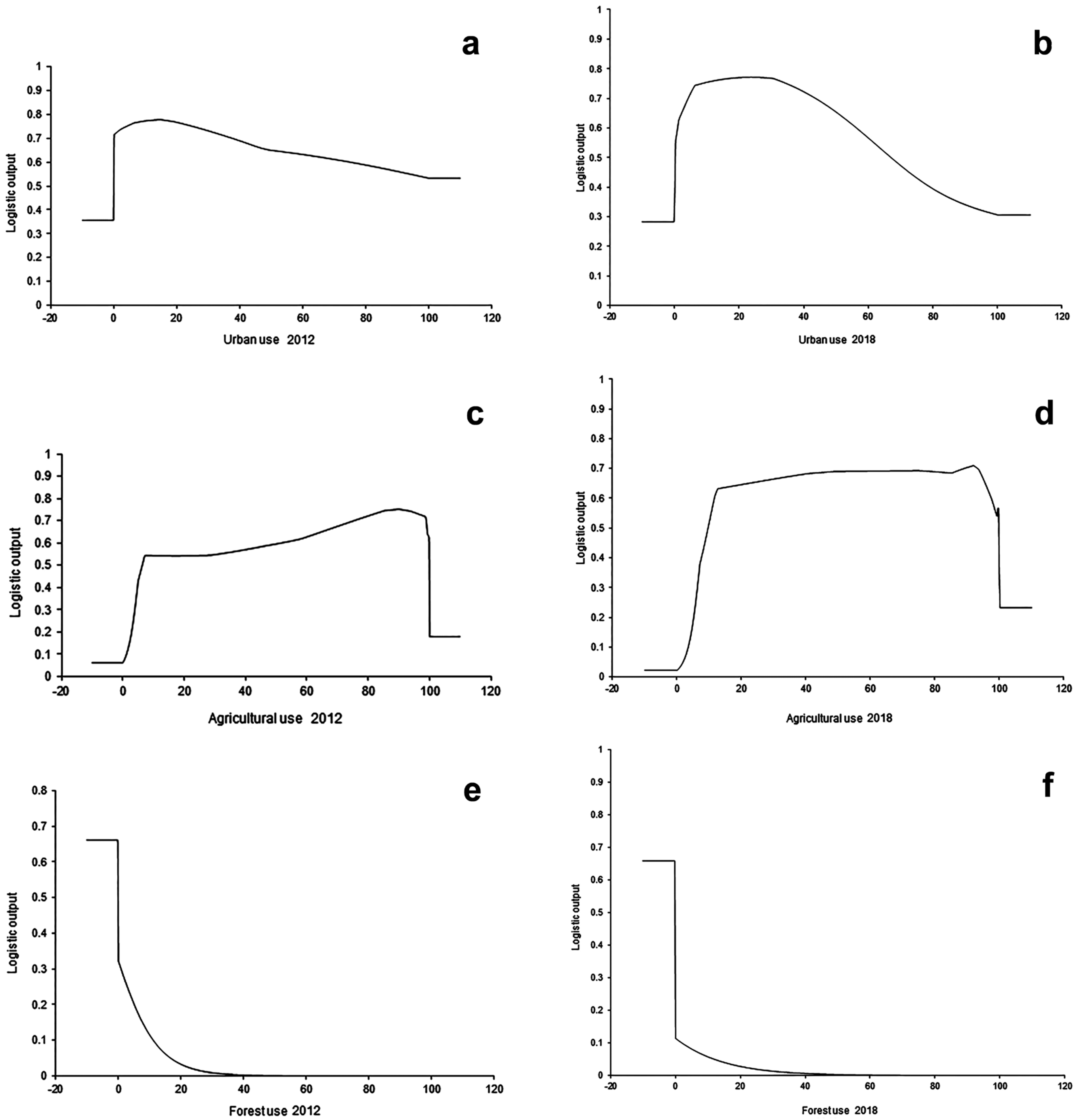

Fig. 9 - Response curves for the urban use (code1) (a,b), agricultural use (c,d), and forest use (code 31) (e,f) variables for the EMRD_03 and EMRD_04 models. / Curve di risposta per le variabili uso urbano (codice1) (a,b), uso agricolo (c,d) e uso forestale (codice 31) (e,f) per i modelli EMRD_03 e EMRD_04.

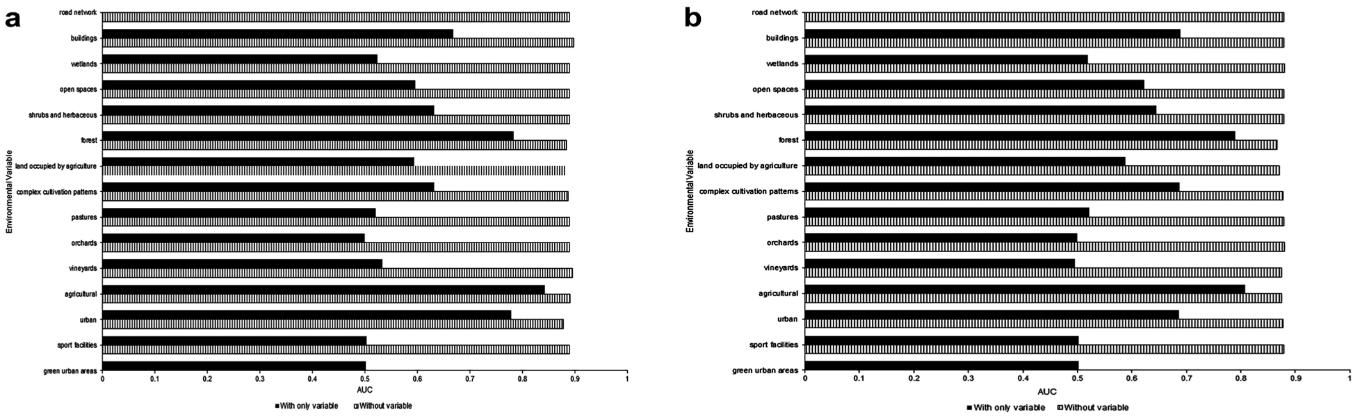

Fig. 10 - Jackknife test (JRR) applied to EMRD_03 and EMRD_04 without the DEM. / Test Jackknife (JRR) applicato a EMRD_03 e EMRD_04 senza DEM.

Acknowledgements

All people mentioned below, have significantly contributed to census of Rooks in the decade 2010-2020: Baradel G., Bearzatto C., Benfatto M., Benedetto P., Bertoli A., Bozzo G., Carbone N., Castellani R., Castenetto D., Cester D., Comuzzo C., Consonni F., Dentesani B., Ermacora E., Fantin F., Finotello P., Grion M., Grion P., Giraldi M., Guzzon C., Haipel G., Maiorano I., Malagola G., Marcolin F., Marcone A., Marcorin I., Mauro L., Perco N., Peressin R., Piani E., Pisa P., Rosso M., Sava S., Scridel D., Skodler M., Simonitti V., Stanic D., Taiariol P.L., Toller M., Trani C., Tremolada M., Turchet S., Valentinuz F., Valvassori C., Vasca P., Venneri C., Viviani M., Zonta P., Zorzenon T.

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