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ORIGINAL PAPER

Alien parakeets as a potential threat to the common noctule *Nyctalus noctula*

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Abstract

The ring-necked parakeet *Psittacula krameri* (Aves: Psittaciformes) is a widely distributed species of Asian and African origin, which occurs with over 40 alien populations in the rest of the world. Most established populations of this species are showing a clear trend of territorial expansion and numerical growth. Recent reviews highlighted that one of the main impacts by alien ring-necked parakeets is the competition with threatened bat species using trunk cavities as roosts. In Italy, the only known reproductive population of *Nyctalus* bats (Mammalia: Chiroptera) occurs in an urban area in the central part of the country, surrounded by increasing and expanding populations of ring-necked parakeets. In this work, we updated the population status of both ring-necked and Alexandrine parakeets and breeding noctule bats in the region. Then, we ran a species distribution model using Maxent software to analyze the environmental suitability of the region for the ring-necked parakeet and a connectivity model using Circuitscape software to predict the possibility of its expansion in the area occupied by breeding noctule bats. We recorded a high number of individual parakeets and breeding colonies, together with a remarkable noctule population decline, from about 400 to about 120 individuals, in the last 20 years, possibly due to urban green management practices. Although some ring-necked parakeets have already been observed in the study area, there is no evidence of reproduction in the surroundings of the noctule colony. However, our model showed a high environmental suitability for the ring-necked parakeet in the area occupied by breeding noctules. As well, the connectivity model showed the potential for a direct flow of individuals from the main urban centers to the area used by noctule bats. The arrival of alien parakeets to the area occupied by the bat breeding colony should be tightly monitored by surveying the suitable areas for this bird, as well as the identified ecological corridors. Early detection of new invasions, together with a sustainable urban green management practice, may prevent the extinction of the southernmost breeding colony of the common noctule.

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Keywords Biological invasions · Interspecific competition · *Nyctalus noctula* · *Psittacula krameri* · Threatened species · Urban ecosystems

Introduction

Alien species represent one of the most important causes of the global biodiversity crisis, being responsible for several extinctions, native species outcompeting, and ecosystem alteration (Wonham 2006; Cassey et al. 2015; Mazza and Tricarico 2016; Gerlach et al. 2020). Particularly, the number of alien species in Europe has shown an exponential increase in the last 50 years (i.e., + 76% since the 1990s: Mack et al. 2000; Abellan et al. 2016), mostly due to increased legal and illegal trade (Cassey et al. 2015; Benedict et al. 2007). In this context, the pet trade has been considered responsible for the introduction of many alien species throughout the world, including parrots and parakeets (Lever 1994, 2005; Menchetti and Mori 2014; Mazzamuto et al. 2021). The efficiency of invasive species control strategies using connectivity models has been proven for several species (e.g. opossums, rats and mammalian carnivores: Glen et al. 2013; Perry et al. 2017).

About 100 Psittaciformes species are commonly traded and over 60 species have shown naturalized breeding populations outside their native range (Cassey et al. 2004; Menchetti and Mori 2014). Eleven Psittaciformes species have been reported as breeding alien species in Europe (Lever 2005; Mori et al. 2013). Amongst those, four are also currently present as breeding alien species in Italy: the ring-necked parakeet *Psittacula krameri*, the Alexandrine parakeet *Psittacula eupatria*, the monk parakeet *Myiopsitta monachus* and the turquoise-fronted amazon *Amazona aestiva* (Mori et al. 2013, 2017a; Ancillotto et al. 2015; Baccetti et al. 2021; Giuntini et al. 2021). Particularly, the ring-necked parakeet and the monk parakeet are the most widespread both in Europe and in Italy (Parau et al. 2016), with most ecological impacts on native biodiversity and ecosystems exerted by the former (Menchetti and Mori 2014; White et al. 2019; Mori and Menchetti 2021). Where introduced, the ring-necked parakeet is considered responsible for competition with native European hole-nesting birds, e.g. the nuthatch *Sitta europaea*, the hoopoe *Upupa epops,* the common swift *Apus apus*, and the scops owl *Otus scops* (Strubbe et al. 2010; Orchan et al. 2012; Yosef et al. 2016; Mori et al. 2017b; Grandi et al. 2018), crop damage (Mentil et al. 2018; Viviano and Mori 2021), disease transmission (Mazza et al. 2014; Sa et al. 2014) and, at high population density, noise pollution (Mori et al. 2020). The main impact is the competition with threatened bat species using tree holes as roost sites, including noctule bat *Nyctalus* spp. and other species (Gebhardt 1996; Haarsma and van der Graaf 2013; Hernandez-Brito et al. 2014, 2018; Menchetti et al. 2014; Viviano and Mori 2021). In Sevilla (Spain), the number of parakeet nests exponentially increased in 14 years and at the same time the number of trees occupied by the threatened greater noctule *Nyctalus lasiopterus* declined of about 80% (Hernandez-Brito et al. 2014, 2018). Parakeets occupied most of the trunk cavities previously occupied by noctules, sometimes showing aggressive interference resulting in noctule site-displacement and death (Hernandez-Brito et al. 2014, 2018). In general, parakeets are highly appreciated for their bright plumage by the general public (Carneiro 2017; Crowley et al. 2019; Luna et al. 2019; Mori et al. 2020), thus hindering most control or eradication programs (but see Brichetti and Fracasso 2006; SIF 2017; Saavedra and Medina 2020). Therefore, early detection of new invasions and rapid intervention should be the most recommended strategy to prevent or limit the impact by fast-expanding populations of ring-necked parakeets (Genovesi and Shine 2004;

Vall-Llosera et al. 2016). In Italy, most populations of introduced ring-necked parakeets are expanding in numbers and extent of occurrence (Fraticelli and Molajoli 2002; Fraticelli 2014; Grandi et al. 2018; Mori et al. 2020; Ciprari et al. 2022). Evidence of interactions between parrots and cavity-roosting bats are mostly anecdotal and from areas at the early stages of invasions (e.g. Menchetti et al. 2014; Viviano and Mori 2021), thus requiring targeted and more specific monitoring schemes to be fully assessed. Three species of noctules (i.e. bats from the genus *Nyctalus*) are present in Italy, namely *N. noctula*, *N. lasiopterus* and *N. leisleri* (Loy et al. 2019), where their presence ranges from widespread (*N. noctula* and *N. leisleri*; Ancillotto and Russo 2015; Ducci et al. 2019) to extremely scattered (*N. lasiopterus*; Agnelli et al. 2018; Maenurm et al. 2022). However, the only established population of this genus known to form nurseries on the Italian territory (but see Maenurm et al. 2022) is located in the city of Cervia (province of Ravenna, Emilia Romagna region, Central Italy), where about 300–500 N. *noctula,* i.e. the common noctule, use plane-trees *Platanus* sp. located in urban alleys in the year 2000 (Scaravelli and Guidi 2001; Zaccaroni et al. 2008). Within the same region, three species of introduced parakeets have been recorded so far: the monk parakeet, which could now be locally extinct (Ferri and Villani 1995; Mori et al. 2013; Viviano and Mori 2021), the Alexandrine parakeet, occurring in the city of Reggio Emilia since 2011 (Viviano and Mori 2021), and the ring-necked parakeet, occurring in at least three cities and showing dramatically increasing demographic trends (Parau et al. 2016; Chessa 2020; Viviano and Mori 2021). Although some individuals have been detected in the surroundings of the town with the noctule bat colony, no evidence of reproduction by the ring-necked parakeet is available from this area (cf. Figure S1 in Supplementary Material 1), yet future competition scenarios are likely to occur (Fig. 1).

Species distribution models have been widely used to conduct prediction of parakeet invasion risk and effects, and the integration of species distribution models with further tools in the decision-making process and landscape metrics have been reported as a potential strategy to provide a better understanding on parakeet establishment and invasion steps (Ferrer-Paris and Sànchez-Mercado 2021). Thus, in our work, we aimed at: (i) assessing the status of ring-necked parakeet population at a regional scale, in terms of number of individuals and distribution; (ii) assessing the status of the reproductive population of noctules in terms of numbers of roosts and individuals, and (iii) predicting whether and where expanding populations of ring-necked parakeets may reach the colony of this threatened bat species. Given the long-ranging spatial behaviour of the ring-necked parakeet, as well

Fig. 1 Left: Noctule bat (*Nyctalus noctula*) emerging from its roost in a cavity on a senescent *Platanus* tree in Cervia, Italy (photo by Francesco Grazioli); right: female ring-necked parakeet (*Psittacula krameri*) at the entrance of its nest, in a cavity of a *Platanus* tree (photo by Leonardo Ancillotto)

as its explosive demography in the invaded ranges (Strubbe and Matthysen 2011), we predict that parakeet populations in the region may potentially reach the area currently occupied by noctule bats by exploiting potential corridors of suitable habitat, if present.

Materials and methods

Parakeet population counts

We collected and analyzed all parakeet records uploaded on two of the most used citizen-science online platforms, i.e., iNaturalist: www.inaturalist.org and Ornitho.it: www.ornitho.it, recording species, date and coordinates of each record (Supplementary Material 2). We only used records validated by experts on both online platforms; non-validated ones (N = 7) were checked by the authors and considered as reliable (i.e., they included photos). We avoided taking data from GBIF (https://www.gbif.org/), which includes all validated observations from iNaturalist but also data from other sources such as museum or atlas records, which cannot be directly verified. Similarly, data from eBird (https://ebird.org/home) from this area were only a known subset of those uploaded on ornitho. The ring-necked parakeet usually lives and roosts in flocks (Brichetto and Fracasso 2006; Carneiro 2017). For field validation, we selected all records uploaded in the last 5 years showing parakeets at their nocturnal roosts or perched on branches (N = 32 records from 16 sites, all from “ornitho”). Each location was thus visited by the first author (SG) and systematic counts were conducted following Luna et al. (2016). In detail, we gathered systematic counts of all birds settling at each identified roost at night. Roosts were surveyed once a week in July and August 2021. Each count started 30 min before the sunset and was conducted from a location with a complete view of the roost area. We finished our bird counts five minutes after the last parakeet came to the roost (Luna et al. 2016). We counted all the individual parakeets arriving at roosts by recording them minute by minute. Individuals moving among trees were not counted to avoid double counts, and the number of individuals leaving the roost was subtracted from the total (Luna et al. 2016).

Noctule population counts

Numbers of reproductive common noctules in Cervia (province of Ravenna, Emilia Romagna region, Adriatic coast of Central-Northern Italy, 44.261° N—12.347° E, 0–6 m above sea level) were assessed through direct counts in July 2021. *Nyctalus noctula* may perform frequent roost switching during summer (Ruczyński et al. 2010), and—as a migratory species (Petit and Mayer 2000)—these bats leave Northern Italy at the end of the reproductive season (August–September). As such, we concentrated bat sampling along a short time window, i.e., 2–3 consecutive days in mid-summer (July). Common noctules are known to widely use the treed alleys in the urban area of Cervia (Scaravelli and Guidi 2001; Zaccaroni et al. 2008), so we searched for occupied roosts by walking at dusk along all treed streets and alleys in Cervia (ca. 4.8 km in total), assessing tree species and recording exact location (with a Garmin Dakota GPS, accuracy: 3 m) of each tree where the presence of bats was unequivocally evident. We repeated the same methods used for previous surveys to assess population status and to compare previous data to ours. Presence of bats was assessed by hearing the loud social calls emitted by adult and juvenile noctules before emergence (Furmankiewicz et al. 2011), as well as by spotting urine and droppings from tree cavities (Haffner 1995); species id was also confirmed by using a handheld bat detector (EchoMeterTouch, Wildlife Acoustics), yet no other bat species is known to use trees as roost in the area (Scaravelli et al. 2001). At each located roost, colony size was determined as the numbers of individuals counted at dusk emergence, i.e., exiting from the roost. We recorded all individuals coming out from tree holes at sunset and we counted them systematically, between 30 min before and 1 h after sunset; by counting emerging bats in mid-July, we excluded juvenile bats from colony size assessment, since young bats were presumably still unable to fly. This operation required the simultaneous presence of two skilled operators at each roost. The presence of other species of bats inside the roosts can be excluded as the common noctule does not form heterospecific reproductive colonies (Mayer et al. 2002; Gebhard and Bogdanowicz 2004; Csorba and Hutson 2016). Results of bat counts were compared with previous count data available in the scientific literature for the same colony (Scaravelli and Guidi 2001) and other unpublished data collected in the same way, to determine the local bat population trend.

Species distribution and connectivity models

We assessed the environmental suitability of the Emilia Romagna region for ring-necked parakeets by building a species distribution model with the software MaxEnt, version 3.4.4 (Phillips et al. 2004; Elith et al. 2006). In particular, we used occurrence points of breeding populations collected in 2018–2021 (Supplementary Material 2) to have the most reliable information on the current situation. Our dataset of presence points (Supplementary Material 2) was reduced by keeping only one occurrence per 1 × 1 km grid cell, for a total of 167 occurrences.

Before selecting the final set of variables, we considered 18 candidate environmental predictors: five land cover variables, eight climatic, four topographic, and population density. All variables were projected to the WGS84 UTM32N reference system (reference system of the land cover map of the region) and rasterized at a resolution of 1 × 1 km. Land cover variables were derived from a shapefile of the land cover of the Emilia Romagna region, obtained from the "Emilia Romagna region geoportal" (https://geoportale.regione.emilia-romagna.it/; ground resolution, 7 m; accessed on 22.10.2021). Given the large number of categories in the original land cover classification (N = 88), we reclassified the map in five more general categories, important for the ecology of the species: cultivated areas, forests, green urban areas, shrublands, urban areas (see Table S1 in Supplementary Material 1 for the reclassification table). After reclassification, for each variable we calculated the percentage cover within each 1 × 1 km resolution cell.

Climatic variables were taken from the project CHELSA, version 2.1 (Climatologies at High resolution for the Earth's Land Surface Areas: Karger et al. 2017), where raster files are available as geoTIFF, with a global extent and relevant to the 1981–2010 interval (i.e. the most recent 30-years period among those available). We considered eight climatic variables, mean annual temperature (bio1), temperature seasonality (bio4), mean maximum daily temperature of the hottest month (bio5), mean daily minimum temperature of the coldest month (bio6), total annual rainfall (bio12), total rainfall of the wettest month (bio13), total rainfall of the driest month (bio14), and seasonality of rainfall (bio15), following ecological features of the species (e.g. Juniper and Parr 1998; Ancillotto et al. 2015; Table 1).

Topographic variables were: altitude, aspect (expressed as northness), slope, and roughness and were derived from a digital elevation model of Italy retrieved from the

Table 1 Variables used to model environmental suitability for the ring-necked parakeet in the Emilia Romagna region

Variable	Definition	Original resolution	Source
Mean annual temperature	Annual mean of daily mean temperatures (°C)	30 arcoseconds	CHELSA v. 2.1
Temperature seasonality	Standard deviation of mean monthly temperatures (°C)	30 arcoseconds	CHELSA v. 2.1
Total annual precipitation	Total precipitations in a year (kg m^{-2})	30 arcoseconds	CHELSA v. 2.1
Cultivated	Percentage of soil covered with farmlands	7 m	Emilia Romagna region geoportal
Forests	Percentage of soil covered with woodlands	7 m	Emilia Romagna region geoportal
Green urban areas	Percentage of soil covered with urban green areas	7 m	Emilia Romagna region geoportal
Shrublands	Percentage of soil covered with shrublands	7 m	Emilia Romagna region geoportal
Urban	Percentage of soil covered with human settlements	7 m	Emilia Romagna region geoportal
Aspect	Average northness of the cell	20 m	Italian national geoportal

Italian national geoportal (http://www.pcn.minambiente.it/mattm/). Population density was derived from the HYDE database (Goldewijk et al. 2011) selecting the map of year 2017.

To avoid considering highly correlated predictors, we calculated the Pearson correlation coefficient among all the pairwise combinations of variables (Table S2 in Appendix 1). Amongst variables with a correlation coefficient > |0,7|, we chose to keep the most important ones from an ecological point of view (Juniper and Parr 1998), while trying to remove as few as possible (i.e. eliminating those inter-correlated with more than one variable). The final set of variables included three climatic, five land cover, and one topographic variable (Table 1). For each variable included in the model we plotted the marginal response curve to show the relationship between the variable and predicted suitability. All the maps were prepared in R, version 4.0.5 (R Core Team 2021), through the package *raster* v. 3.4-10 (Hijmans et al. 2015).

The Maxent model was using "linear", "quadratic", and "hinge" features. This feature selection was based on the richness of our dataset, which allowed us to estimate complex relationships (Elith et al. 2011). To select the best regularization multiplier, we build eight models with increasing values of this parameter, from one to eight, selecting the "raw" output of maxent to calculate the AICc value (corrected Akaike Information Criterion) for these eight models. The model with a regularization multiplier of four showed the lowest AICc value and so we used four as the value to run our model with "cloclog" output (Warren and Seifert 2011; Ficetola et al. 2020). A total of 10,000 background points were sampled from the study area and were used as points of the study area where the presence of the species was not detected. Background points were selected from the entire Emilia Romagna region and was justified by the relatively limited extension of the study area and by a fairly homogeneous distribution of observations on online platforms (Figure S2 in Supplementary Material 1). To consider possible bias in the distribution of occurrence records, backgrounds were sampled according to a bias file. We produced a map of density of roads across the 1 km cells, and used this map as a measure of accessibility of the study area (Figure S3 in Supplementary Material 1; cf. Ramellini et al. 2019). Roads were obtained from the Geofabrik OpenStreetMap server (www.geofabrik.de).

We randomly divided the presence dataset into ten groups and ran ten different models where each of the five groups was used four times for training and once for testing the model (Merow et al. 2013). Model performance was assessed through AUC (Area Under the receiver operating characteristic Curve), calculated as the average value obtained across the five models (Narkhede 2018). For each variable, we also considered the permutation importance (hereafter, p.i.), a measure of how much a variable influences the environmental suitability calculated by the model; it corresponds to the AUC lowering measure when the value of the variable is left to chance (Phillips 2005).

To evaluate the connectivity in the Emilia-Romagna region, we built a connectivity model using (Shah and McRae 2008), which applies the theory of electrical circuit theory in the ecological field to model habitat connectivity. This software requires three types of input: a conductance (inverse of resistance) map, a map with the points of input of current (called "sources"), and a map with the points of arrival of current ("ground points"). As a conductance map we used the suitability map obtained through Maxent modelling, and rescaled it between 0 and 1000 (instead of between 0 and 1), to reduce calculation time. To predict the possible spread of this species across the study area, we followed Falaschi et al. (2018), and selected all the cells containing occurrence points of the ring-necked parakeet as sources, whereas cells constituting the perimeter of the study area (Emilia Romagna region) were selected as grounds. Circuitscape was run in advanced mode from R, through a custom-made function (McRae et al. 2016). This function was created because, in the advanced mode of Circuitscape, the current flows from sources (+) to grounds (−), and it is prevented from moving between two sources, leading to a possible repulsive effect of current around source points. The custom-made function available in Falaschi et al. (2018) runs Circuitscape separately for each source point and then calculates the final current map by summing all the maps obtained by selecting one source at time. In this way, it was possible to try to predict the spread of alien parakeets in all possible directions in our study area (Cowley et al. 2015; Falaschi et al. 2018).

Results

Parakeet population count

We collected a total of 944 citizen-science records of parakeets from Emilia Romagna, 243 from Reggio Emilia (RE), 57 from Ferrara (FE) and 644 from the Bologna (BO) province (Supplementary Material 2). Number of records between 2010 and 2021 increased on online platforms (Fig. 2).

We identified a total of 43 different areas where to count parakeets, including urban parks, public and private gardens, cemeteries and some alleys with suitable vegetation for roosting in all the cities where ring-necked parakeet were observed as breeding species, i.e. Ferrara, Reggio Emilia, and Bologna (Supplementary Material 1). In 2021, we counted 13 individual ring-necked parakeets in a single roost in Ferrara (Parco Giorgio Bassani), 482 in Bologna (31 roosts in several alleys in the city as well as in Budrio, Granarolo nell'Emilia, Castenaso, Casalecchio di Reno, Ozzano nell'Emilia and San Lazzaro di Savena), and 78 in three roosts in Reggio Emilia.

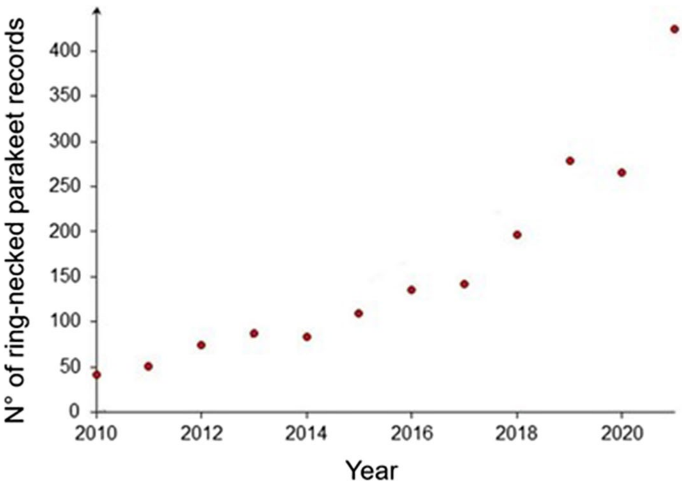

Fig. 2 Trends in number of ring-necked parakeet records on online platforms (iNaturalist.org; Ornitho.it) between 2010 and 2021

Noctule population count

The count of common noctules in 14–16 July 2021 was conducted on five alleys in Cervia, for a total of 4.8 km and about 310 *Platanus* sp. trees. We identified 5 roosts, all located in rot cavities on senescent *Platanus* sp. trees, containing on average (±SD) 28.8±26.5 bats each (range 11–75), totalling 144 adults (Fig. 3).

Suitability and connectivity models

The environmental suitability model for the ring-necked parakeet showed good performance, with AUC test=0.947±0.02 (mean±SD: Fig. 4). The connectivity map showed flows mostly directed to the “Via Emilia” road, up to the eastern coastline (Fig. 4). To the north, the flow reaches the north-eastern borders (Fig. 4). The variable providing the greatest contribution was temperature seasonality (p.i.=54.7), followed by mean annual temperature (p.i.=18.3), and total annual rainfall (p.i.=12.9: Table 2). As temperature seasonality increased, an increase in environmental suitability was observed, reaching a peak at intermediate values; the same was observed for the average temperature, and the peak was reached approximately at 15 °C (Fig. 5). On the contrary, when total rainfall increased, suitability showed a reduction, and the peak corresponds to rather low values, i.e. at about 620 kg/m^2 (Fig. 5). Accordingly, portions with the highest levels of suitability within the region seem to follow the “Via Emilia” road, and consequently the main human settlements (Fig. 5). The highest values are reached in the urban and suburban area of Bologna. Shrublands and green urban areas showed positive relationships with suitability but a very low permutation importance (PI<1).

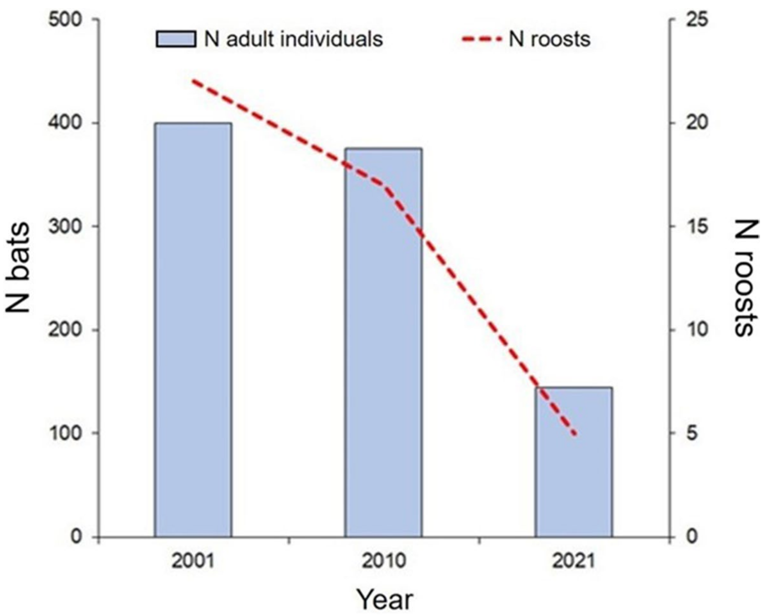

Fig. 3 Trends in numbers of known roosts and observed individuals of common noctules (*Nyctalus noctula*) in Cervia (Italy), between 2001 and 2021

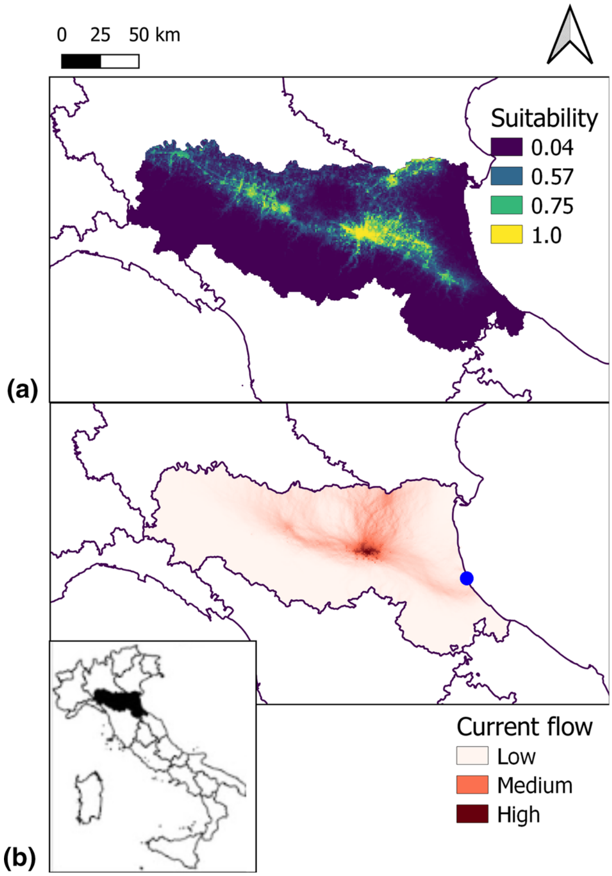

Fig. 4 **a** Map of environmental suitability for the ring-necked parakeet in Emilia Romagna region. The lowest eligibility value in the legend corresponds to the minimum training presence (i.e. the value below which no attendance record was found); the second value corresponds to the 10th percentile training presence (i.e. the value above which 90% of occurrences are placed). **b** Connectivity map for the ring-necked parakeet in the Emilia Romagna region. In red the current flow; points of origin (sources) are represented by records of the ring-necked parakeet; arrival points (grounds) correspond to the border of the Emilia Romagna region. The blue dot indicates the location of the reproductive area of common noctules (*Nyctalus noctula*). Total occurrences used for the construction of the model were 167, one for each cell occupied by the species

Table 2 Permutation importance values for all considered variables

Variable	Permutation importance
Temperature seasonality "bio4"	54.7
Mean annual temperature "bio1"	18.3
Total annual precipitation "bio12"	12.9
Forests	6.2
Cultivated	5.2
Urban	2.1
Green urban areas	0.3
Aspect	0.2
Shrublands	0.1

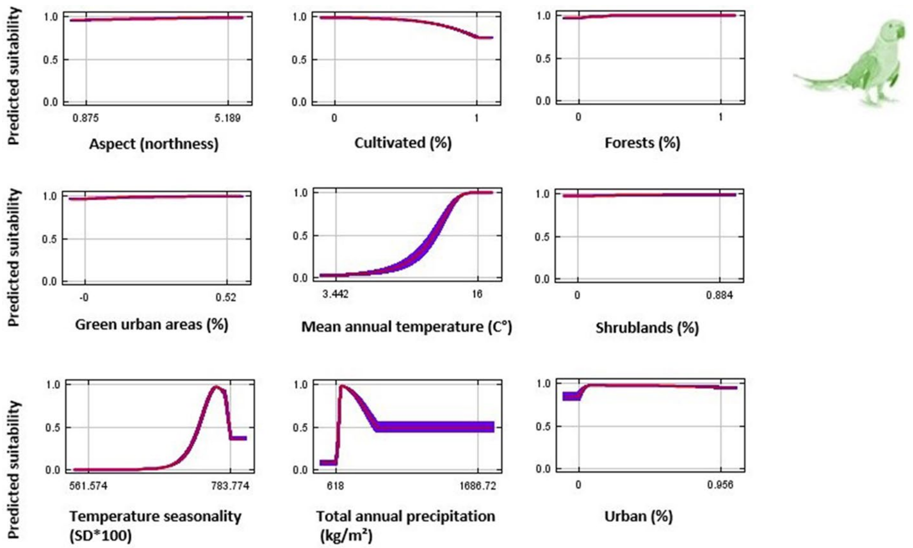

Fig. 5 Response curves showing the effect of each considered variable on the environmental suitability of the ring-necked parakeet. Purple, mean of the five computed models through the cross-validation method; blue, ± 1 standard deviations

Discussion

Parakeet and noctule population counts

In our work, we provide a robust workflow to assess the potential threat by alien ring-necked parakeets to bats at a regional scale, by combining in-field population assessments and modeling approaches. Parakeets are suitable species for citizen-science monitoring due to their bright color and loud calls (Ancillotto et al. 2015; Vall-Llosera et al. 2016; Per 2017). Therefore, given the high citizen-science record coverage in Emilia Romagna (cf. Figure S2 in Supplementary Material 1), citizen-science records provided an exhaustive picture of the species' occurrence within the study area. The increasing numbers of records per year, paired by an increase in the occupied area, also suggest a genuine population growth, as other citizen-based case studies evidenced (Ciprari et al. 2022). Conversely, the population of *N. noctula* breeding in Cervia showed an opposite trend, with a remarkable decrease in the number of roosts (− 77%) and adult individuals (− 52%) in 10 years, even before the arrival of parakeets in this area. This is in line with the decrease in the number of detected roosts, counted with our same methods in 2001 and 2010 (22 in 2001, 17 in 2010, 5 in 2021: cfr. Scaravelli and Guidi 2001). Whether this drop in numbers of bats in the area represents a genuine demographic response, or a changed used of the area by the bats is yet to ascertained, yet surveys in the surrounding areas of Cervia did not succeed in finding alternative roosts (authors, pers. obs.); moreover, roost counts represent a standard technique to assess bats' population trends (Van der Meij et al. 2015; Ancillotto et al. 2021). Following the management of the urban green areas conducted by the municipality of Cervia since 2003–2005, several old plane trees have been replaced with *Celtis australis* and forms of plane tree known as "Platanor Vallis Clausa", a cultivar selected for its resistance to the "colored cancer of the plane tree", a disease caused by *Ceratocystis fimbriata* (Andrivon 2014; Tsopelas et al. 2017). This fungus is responsible for the formation of cavities where noctule bats and parakeets breed (Tsopelas et al. 2017). Plane trees appear to be the most common tree species used by noctules in the study area. To create nurseries, noctules need natural or artificial cavities, e.g., in trees (Haarsma and van der Graaf 2013). Therefore, replacing senescent or dead adult trees with juvenile plants (as well as different varieties and/or different species) may significantly deplete roost availability to *N. noctula*. The continuous use over time (at least 20–25 years) of the plane tree within the urban area of Cervia by noctules suggests evidence for an actual, yet local, decline of the species. Thus, the potential arrival and settlement of ring-necked parakeets could accelerate its local extinction (Haarsma and Van Der Graaf 2013; Menchetti et al. 2014; Hernández-Brito et al. 2018).

Suitability and connectivity models of alien parakeets

A large portion of the Emilia Romagna region was found to be suitable for colonization from alien parakeets, in particular along the main urban centers, through the "Via Emilia" road. This is not surprising, as in line with the preference for urban areas by this parakeet species in its introduced range (Strubbe et al. 2015). This habitat type may help the settlement of the species and the maintenance of viable populations, thanks to a pre-adaptation of the ring-necked parakeet to share its habitat with humans, also observed in the native range in India (Strubbe et al. 2015). Furthermore, urban and suburban areas are particularly suitable for the settlement of the ring-necked parakeet because of the high abundance of available nesting sites (e.g. large trees of advanced age and, prone to the formation of cavities, but also buildings), often kept inside city parks to their aesthetic value (Strubbe et al. 2015; Grandi et al. 2018). As well, higher temperatures in urban areas with respect to the countryside may have helped the establishment of this subtropical and tropical parakeet (cf. Ancillotto et al. 2015). Furthermore, in urban areas, parakeets are fed by humans, which increases the suitability of these areas (Clergeau and Vergnes 2011).

To conclude, in urban parks, the ring-necked parakeet is a stronger competitor with respect to native bird species (e.g., Passeriformes and Columbiformes) in shared feeding areas (Peck et al. 2014). Moreover, the bat colony is located only 15 km away from highly suitable areas for parakeet establishment. This is particularly worrying if we take into consideration sightings of first groups of ring-necked parakeets in the province of Ravenna (i.e. where the breeding colony of noctule bats occurs, Supplementary Material 1). These records, although no breeding event has been observed yet, may be due to local accidental releases or, most likely, to the dispersal of some individuals from breeding colonies (particularly those in the Bologna area, i.e., the most abundant in Emilia Romagna), which may soon bring to the establishment of new populations (as the one in Ferrara). Thus, although the connectivity map may represent an underestimation of the actual landscape conductance, as being based on environmental suitability for the ring-necked parakeet and not on its ability to move, it is still of fundamental importance to determine areas where to concentrate efforts for an early detection of new invasions. Accordingly, these models have been used to study how native bird species may thrive in unsuitable habitats, e.g. urban and anthropized areas (Grafius et al. 2017; Estrada-Carmona et al. 2019).

An education campaign is necessary before any project of eradication or control of the ring-necked parakeet, as parakeet removal projects have been hindered several times in Europe due to violent protests by citizens (Crowley et al. 2019; Saavedra and Medina 2020). In any case, it is also worth evaluating direct protection measures towards the noctule bats, if the colonization of Cervia by the ring-necked parakeet could not be prevented. Hernández-Brito et al. (2018) suggest—following the numerical reduction of the giant noctule that occurred in Seville due to the parakeet—the provision of artificial shelters, such as bat-boxes, in order to avoid the disappearance of the population. Although the same expedient can probably also be implemented in Cervia, it is only an emergency measure to minimise an extremely critical situation, which may not be successful (Rueegger 2016). Actually, noctules slowly learn to use the bat-boxes (Rueegger 2016), in contrast to the generally rapid time of numerical and range expansion of the ring-necked parakeet. However, even if a potential noctule movement to another area would occur, the local extinction of this urban bat colony would be dramatic from a conservation point of view. In fact, the time required to find a new location of the breeding bat population would probably be long; an unmarked/unknown colony is inevitably unprotected and consequently vulnerable to any type of anthropogenic and non-anthropogenic threat.

The use of connectivity models for conservation purposes, e.g., to predict the movement of an animal species, has become frequently used in recent years (Chetkiewicz et al. 2006; McRae et al. 2016), although it has been used only rarely to predict the spread of an alien species (Falaschi et al. 2018; Cowley et al. 2015). Some issues still need to be addressed, such as the use of landscape permeability derived from habitat suitability. For instance, migrating individuals can move through an unsuitable landscape matrix, hence using habitat suitability as a proxy for landscape permeability can result in underestimating potential movements of species. For this reason, our estimates of connectivity can be considered as a lower estimate of the potential spread of alien parakeets. On the other hand, suitability represents an objective measure of the species preferences and allows the use of expert-based values when detailed information of movement ecology of the species is not available. Here we showed how species distribution models and connectivity models can be used to assess the potential spread of an alien species, in cases where native species of conservation concern are potentially threatened by the range expansion of an invasive organism.

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