How far will they go? Considerations on the potential expansion of the Ring-necked Parakeet (*Psittacula krameri*) and Monk Parakeet (*Myiopsitta monachus*) in Veneto region (Italy) with MaxEnt distribution models

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Abstract

Predictive models of species distribution, including several parakeets, may be very useful for understanding the actual and potential distribution of alien species. The Ring-necked Parakeet and the Monk Parakeet are two alien species found in the Veneto region (north-east Italy) that are well-suited for conducting potential distribution studies to identify suitable areas of occurrence. In this paper, I use the MAXENT algorithm to predict the potential distribution maps of these species in the Veneto region, which finds the probability distribution of maximum entropy that is constrained by the ecological parameters considered. The authors of the Veneto photo-sound atlas kindly provided presence data for the two species. The potential distribution models for the two parakeets performed very well overall (AUC = 0.966 for Ring-necked Parakeet and AUC = 0.987 for Monk Parakeet) and indicated that high suitability areas correspond primarily to areas near known occurrences of the species. Overall, the study found that the presence of the species in provinces other than those with large populations is highly unlikely. The distribution maps produced can aid in the selection of monitoring areas for these two alien species' populations and potential expansion.

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Introduction

Many species of animals and plants have increasingly overcome ecological barriers that have favoured their speciation in recent decades. Anthropogenic activities have distorted all evolutionary processes that have previously resulted in biodiversity enrichment.[1] There has been a shift of organisms outside their original areas of origin since mankind's existence. There are currently over ten thousand alien species in Europe, with 11% having documented negative impacts on ecosystems.[2] As a result, it is necessary to monitor and manage alien species in order to avoid and minimize damage to indigenous biocenoses.[3,4] These species also include several bird species,[5-7] particularly pets such as Psittaciformes,[8] which, once introduced into the environment, can have a relatively negative impact on biodiversity and the ecosystems in which they settle,[8-10] as well as human activities.[11,12] Although alien populations of parrots and parakeets have been shown to remain near the release site,[8,13] these species have enormous invasive potential.[14]

In Veneto, Northeast Italy, nine species of Psittaciformes were reported during the 21st century, of which two with stable populations and with cases of confirmed nesting,[15] *i.e.* Monk Parakeet *Myiopsitta monachus* and Ring-necked Parakeet *Psittacula krameri*.[16] With this work I want to evaluate the possible expansion of these two species in the Veneto territory, trying to predict the diffusion directions and the areas potentially suitable for their presence through the application of species distribution models.[17] This methodology has already been widely used to understand the expansion of some alien species;[8,18] and, for this reason, it has also been used in the present work.

Materials and Methods

Study area and data origin

This work has taken into consideration the entire territory of the Veneto region (north-east Italy), using as a reference file the shapefiles of the Italian regions, which can be downloaded for free from the ISTAT website (https://www.istat.it/).[19]

The presence data collected in the context of the drafting of the photo-sound atlas of the birds of Veneto,[16] kindly granted by the authors, were used to prepare the species distribution models. The data spans approximately ten years, from January 1, 2009 to December 31, 2019. The data for the atlas were extracted from Ornitho.it (an ornithological platform) by project observers and kindly delivered to the atlas authors. As a result, the observations refer to both precise localizations and the centroid of the kilometric square of reference, as well as, in some cases, a locality. The analysis included 145 Ring-necked Parakeet observations and 91 Monk Parakeet observations. Because the sampling effort was most likely not consistent over the course of the 10-year survey, some areas are likely over-represented in the database.

The nine variables used in the modelling were related to climatic conditions (mean annual temperature, temperature seasonality, total annual precipitation, precipitation seasonality, and mean air temperatures of the coldest quarter), landscape characteristics (percentage of urban areas, percentage of forest cover, and distance from rivers), and finally altitude. All variables' raster images have been downloaded/prepared at a resolution of 1 km^2.

The following variables were chosen because they are already widely used in the modelling of species distribution models relating to exotic bird species.[18,20] The climatic data were specifically downloaded from the CHELSA (Climatologies at high resolution for the Earth's surface) dataset, using the average data recorded from 1981 to 2010.[21] In addition to the usual temperature and rainfall data, it was decided to include the minimum winter temperatures because it appears that the species, particularly the Ring-necked Parakeet, but presumably all parakeets, suffer from winter weather mortality.[22-24] The species are linked to the presence of trees for nesting, so a percentage map of forest cover was chosen.[24-26] Because the species appear to adapt well to urban areas, particularly city parks, a percentage map of the degree of urbanization was created.[27] Finally, a raster image relative to the distance from the nearest river was created because it is assumed that the species can use these corridors as expansion routes, as is the case for another exotic species found in Italy, *Leiothrix lutea*.[28]

Species distribution models

The distribution models for the two species under consideration were implemented in the R environment using the 'dismo' package.[29] The MaxEnt algorithm was used to assess the potential distribution of parakeets in particular.[30,31] This model finds the probability distribution of maximum entropy that is constrained by the ecological and climate parameters that have been taken into account in order to estimate the target species probability distribution. In the case of species distribution modelling, these constraints are the values of the pixels where the species has been detected.[30-32] MaxEnt models generate predictions in the form of numbers ranging from 0 to 1, representing the likelihood of occurrence in the study area.[32] K-fold cross-validation (in this study, 5-fold cross-validation) was used to train and test the models. Cross-validation is a statistical technique for determining how well the findings of a statistical study generalize to a different data set.[33]The model output was then computed using the mean of the 5 replicates. The threshold-independent Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) was used to assess prediction quality.[34] Variable contributions were also calculated to evaluate the impact of climatic and landscape variables on Parakeet's modeling performance.

Results

The average AUC for the replicate runs for the *Psittacula krameri* distribution model is 0.966, and the standard deviation is 0.01. Instead, the average AUC for the replicate runs when modeling the *Myiopsitta monachus* distribution is 0.987, with a standard deviation of 0.007. Cross-validation of the model demonstrates high predictive accuracy, which is consistent with other studies that have investigated this validation technique.[35,36] Table 1 and 2 show the variable contributions for the two models. Figure 1 and 2 show the relationship between the environmental variables and suitability; Figure 3 and 4 show the potential distribution maps.

Table 1. Environmental variables and their percentage contribution and permutation importance in the MaxEnt model for predicting occurrence of *Psittacula krameri* in Veneto region.

Variable	Percent contribution	Permutation importance
Urbanization	39.1	5.4
Temperature seasonality	15.4	11.9
Distance from the nearest river	11.9	3.1
Mean annual temperature	10.7	48.4
Precipitation seasonality	9.7	10.2
Altitude	9.7	16
Annual precipitation	3.3	4.9
Forest cover	0.2	0.1
Mean air temperatures of the coldest quarter	0	0

Table 2. Environmental variables and their percentage contribution and permutation importance in the MaxEnt model for predicting occurrence of *Myiopsitta monachus* in Veneto region.

Variable	Percent contribution	Permutation importance
Distance from the nearest river	29.4	18.8
Precipitation seasonality	27.1	22.3
Altitude	24.9	42
Temperature seasonality	7.2	0.8
Urbanization	4.8	0
Annual precipitation	4.7	11.1
Mean annual temperature	1.2	2.5
Forest cover	0.5	0.1
Mean air temperatures of the coldest quarter	0.2	2.4

Discussion

Psittacula krameri

The average AUC for the replicate runs indicates that the model appears to perform well in predicting the distribution of the species under consideration.[34] Observing the map of the species' potential distribution, we can confirm that it appears to find highly suitable areas only in the vicinity of Padua and Verona, or in areas where its presence is already currently stable. Despite this, the predictive model identifies other, albeit limited, areas of the territory that are highly suitable for the presence of the parakeet, particularly in the southern part of the province of Verona and, on occasion, in the central-eastern Paduan area. At the moment, it appears that the province of Belluno is not at risk of colonization, whereas the provinces of Treviso, Venice, Vicenza, and Rovigo have only a few areas that are reasonably suitable. The potential distribution area of the Ring-necked parakeet appears to be primarily influenced by urbanization (Table 1), with a high suitability value at medium-high urbanization percentage values, as evidenced by the variable response curves. This demonstrates the species' adaptability to urban environments.[27,37] The permutation importance[31] indicates that the model appears to be influenced by other variables, most notably the annual average temperature (Table 1). In the regional context, this appears to be much more decisive in hypothesizing areas of presence, particularly with respect to the average temperature of the coldest quarter, and thus to winter temperatures, a factor that may limit the species' naturalization and spread.[38] Ring-necked parakeets prefer tree cavities, which may be scarce in some urban areas, but these birds may also use artificial cavities, such as those found on buildings.[39] This would explain why the percentage of forest cover influences the model to such a small extent, with a suitability value decreasing as the percentage of forest cover increases. It remains to be seen whether the species' expansion will follow the positive trend of the region's Picidae populations,[40] which, due to their ability to create cavities, may favor the presence of additional sites suitable for parakeet reproduction.[23] The climatic variables, on the other hand, show how the species appears to be linked to temperate climates, with rainfall values slightly below the regional average (ARPAV data, https://www.arpa.veneto.it/).[41]

Myiopsitta monachus

In this case, too, the average AUC for the replicate runs indicates that the model appears to perform well in predicting the distribution of the species under consideration.[34] The Monk Parakeet prediction map shows areas of high suitability for the species' presence near two large clusters of presence in the provinces of Treviso and Verona. The situation envisioned above all for the Treviso area is

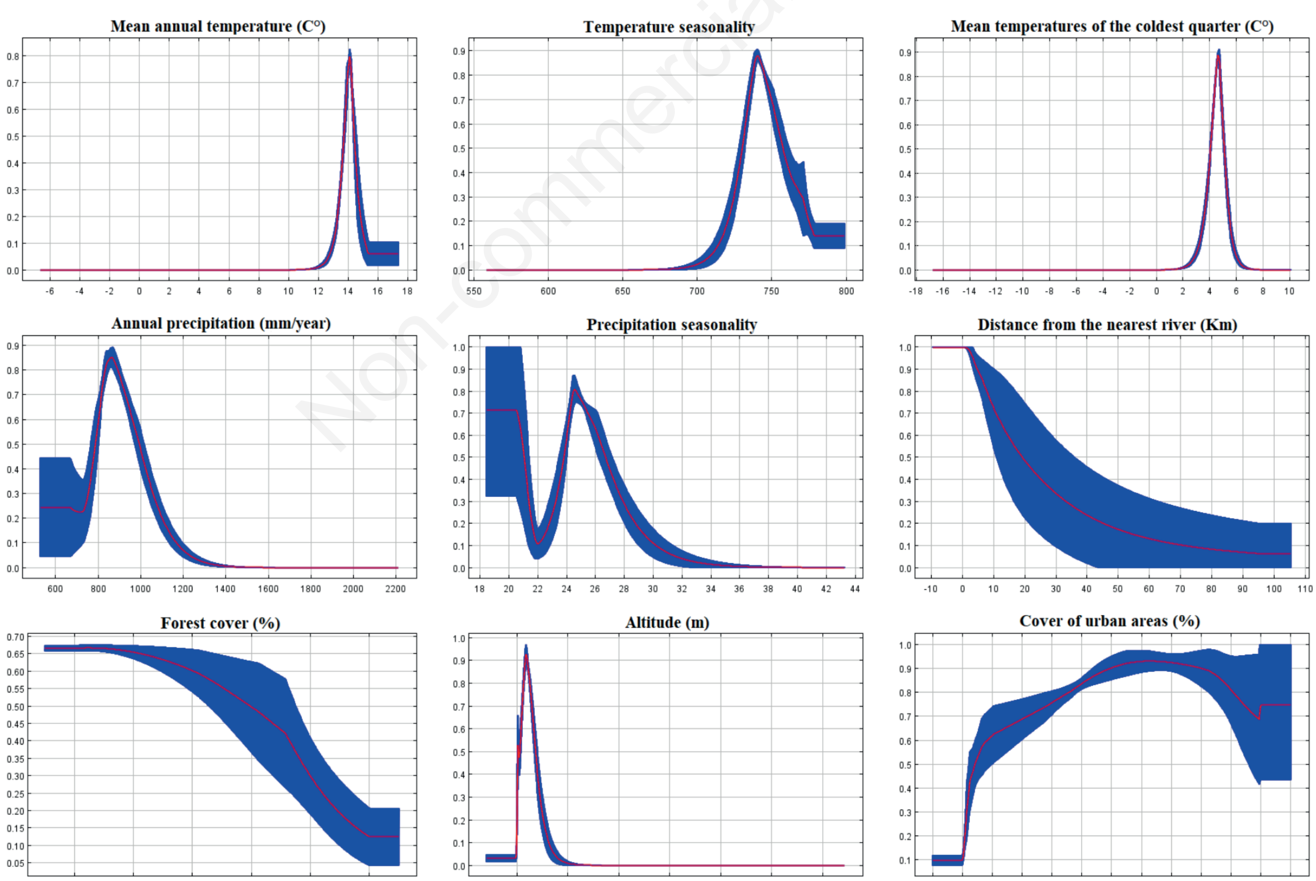

Figure 1. Response curves showing the relationship between the environmental variables and suitability (in the y-axis) for *Psittacula krameri*. For each graph, the blue shades represent the standard deviation computed on the basis of a 5-fold cross validation.

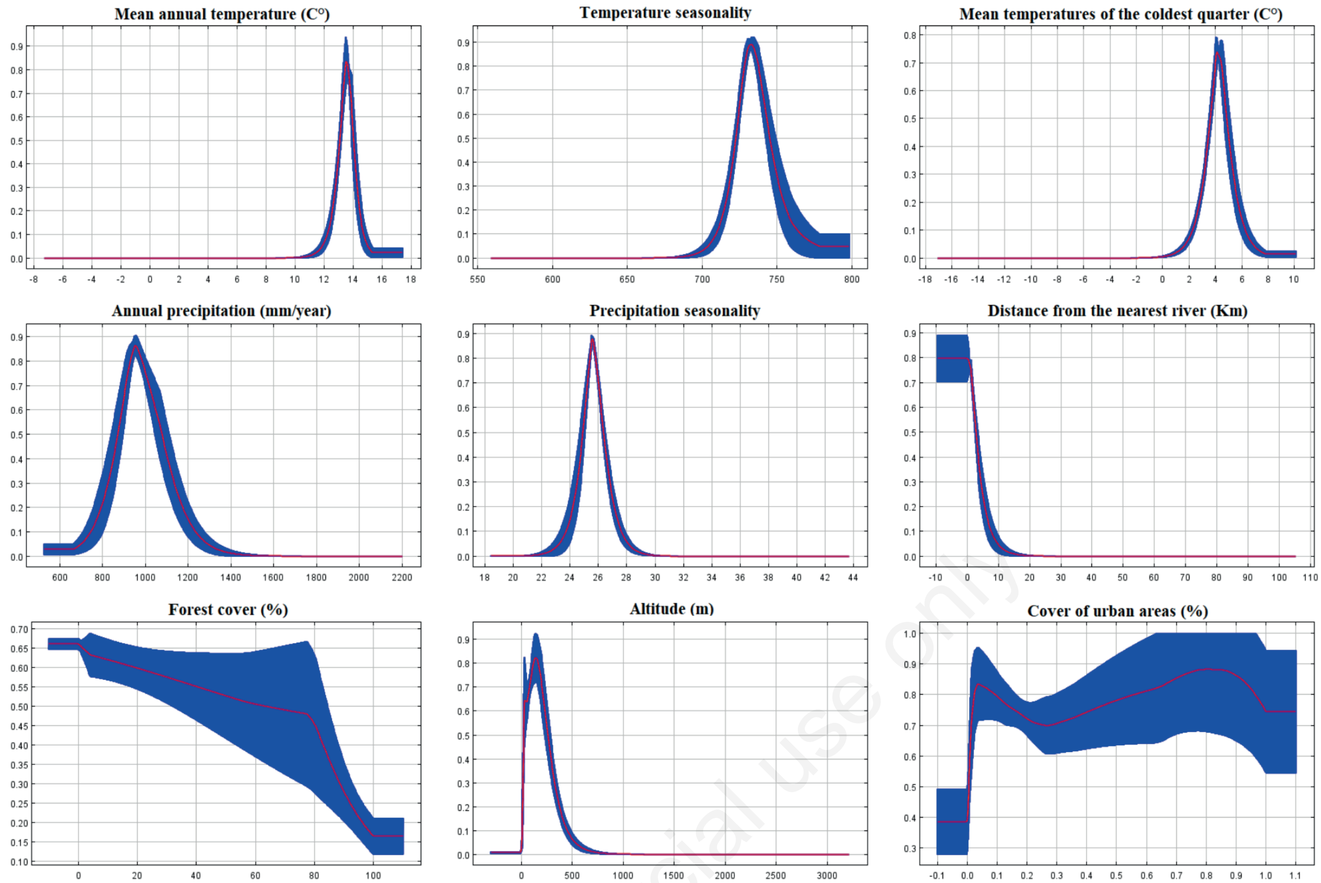

Figure 2. Response curves showing the relationship between the environmental variables and suitability (in the y-axis) for *Myiopsitta monachus*. For each graph, the blue shades represent the standard deviation computed on the basis of a 5-fold cross validation.

intriguing, because a remarkable portion of the province's central-eastern region appears to be highly suitable for the presence of the species; and as such, it merits attention. The provinces of Padua and Vicenza have only a few areas of low suitability, while colonization in the provinces of Venice, Rovigo, and, above all, Belluno appears unlikely at the moment. The distance from the nearest river is the most important environmental variable in explaining the distribution of the Monk Parakeet. This finding may indicate that the species, like other birds,[42] requires ecological corridors such as riparian forests to move between suitable habitats. It should be noted that the output may be influenced by the numerous observations in the Treviso context, as the parakeet population is located precisely near the Piave river. By examining both the percentage contribution and the permutation importance, it is possible to conclude that altitude and precipitation seasonality have a notable impact on the model's output. Observing the response curves in particular, it can be stated that the species' predicted distribution does not appear to extend beyond 500m of altitude, despite the fact that it can reach 1600m above sea level in other contexts.[27] Also, the percentage of forest cover does not appear to have a major influence on the model for this species, and the response curve for this variable appears to indicate a preference for open habitat situations, which is consistent with what is known about this species.[43] In contrast, urbanization, which is important in the output of the model relating to the Ring-necked parakeet, is almost irrelevant in the current model. The response curve appears to predict high suitability values at both low and high urbanization percentages, indicating a strong adaptability to various situations.[44] In terms of climatic variables, there are no major differences between what is observed from the response curves resulting from the Ring-necked parakeet model.

Conclusions

Although these are preliminary and experimental models, the findings of this study allow us to speculate on the possibility of the two analyzed parakeet species colonizing new areas. They can also be used to develop local and regional monitoring and management plans for the species. In fact, alien species should always be monitored in order to properly manage them.[4] Monitoring these species' populations is necessary to prevent them from becoming a conservation emergency;[8] collecting information on their distribution can be the first step in minimizing the potential impact due to their stabilization in new areas.[18] The interpretation of maximum entropy results should be done with caution, especially given the number and quality of variables considered in the model,[31] and further research is required.

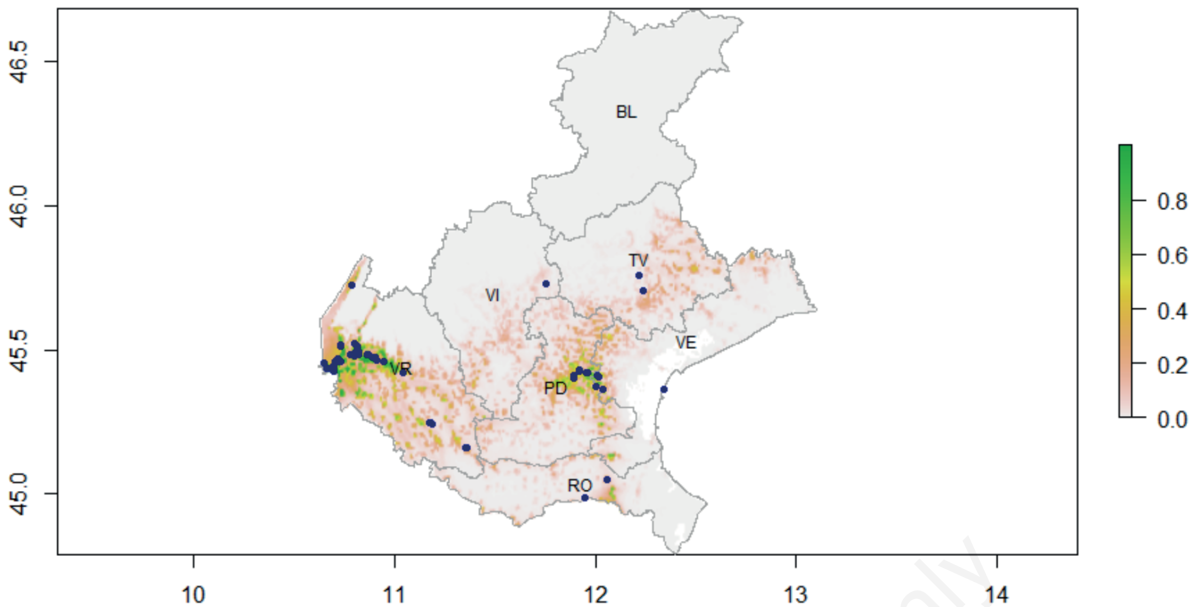

Figure 3. Habitat suitability map for *Psittacula krameri* in the Veneto region. Suitability goes from 0 (unsuitable) to 1 (high suitability). Blue points represent the occurrence points of the species.

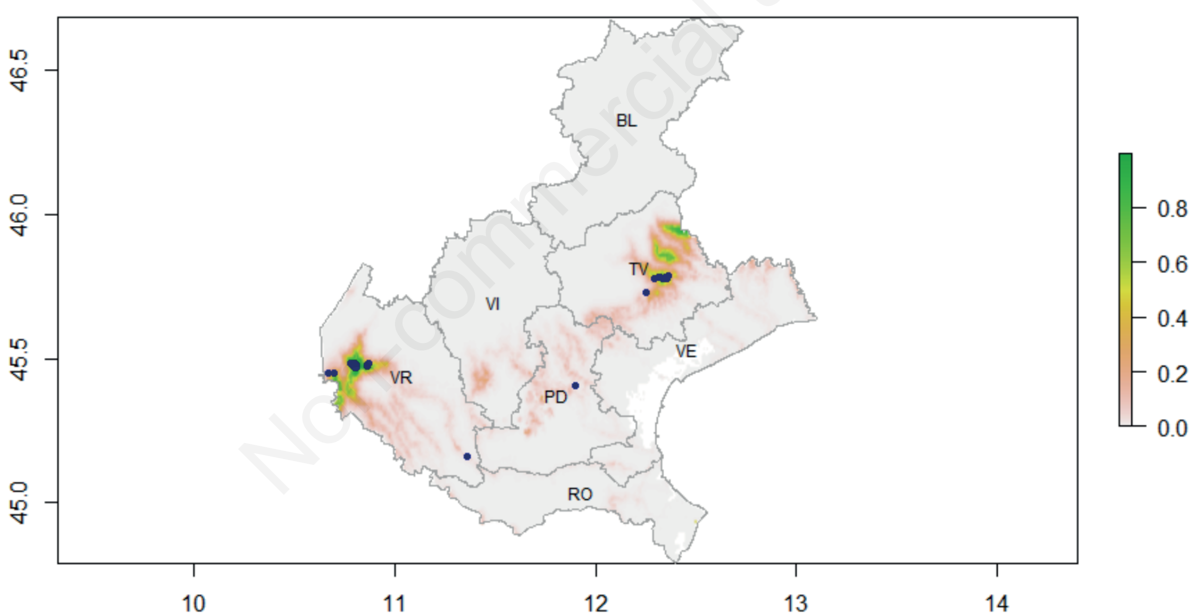

Figure 4. Habitat suitability map for *Myiopsitta monachus* in the Veneto region. Suitability goes from 0 (unsuitable) to 1 (high suitability). Blue points represent the occurrence points of the species.

References

1. Mack R, Simberloff D, Mark Lonsdale W, et al. Biotic invasions: causes, epidemiology, global consequences, and control. Ecol Appl2000;10:689-710.
2. Andaloro F, Blasi C, Capula M, et al. L'impatto delle specie aliene sugli ecosistemi: proposte di gestione.2009. Available from: https://www.mite.gov.it/biblioteca/limpatto-delle-specie-aliene-sugli-ecosistemi-proposte-di-gestione
3. IUCN. IUCN Guidelines for the Prevention of Biodiversity Loss caused by Alien Invasive Species. Approved by the 51st Meeting of the IUCN Council, Gland, Switzerland, February 2000.
4. Genovesi P, Shine C. European strategy on invasive alien species: Convention on the Conservation of European Wildlife

and Habitats (Bern Convention) (No. 18-137) 2004. Council of Europe.
5. Lever C. Naturalized birds of the world. New York, NY:Longman Sci Tech; 1987.
6. Lockwood JL. Using taxonomy to predict success among introduced avifauna: Relative importance of transport and establishment. Conserv Biol 1999;13:560–67.
7. Duncan RP, Blackburn TM, Sol D. The ecology of bird introductions. Annu Rev Ecol Evol Syst 2003;34:71–98.
8. Mori E, Di Febbraro M, Foresta M, et al. Assessment of the current distribution of free-living parrots and parakeets (Aves: Psittaciformes) in Italy: a synthesis of published data and new records. Ital J Zool 2013;80:158-67.
9. Runde DE, Pitt WC, Foster JT. Population ecology and some potential impacts of emerging populations of exotic parrots. Managing Vertebrate Invasive Species 2007;42.
10. Pârâu L, Strubbe D, Mori E, et al. Rose-ringed parakeet populations and numbers in Europe: A complete overview. Open Ornithol J 2016;9:1-13.
11. Dubois PJ. Les oiseux allochtones en France: status et interactions avec les espèces indigènes. Ornithos 2007;14:329–64.
12. Fletcher M, Askew N. Review of the status, ecology and likely future spread of parakeets in England. CSL, York, England 2007.
13. Strubbe D. Invasive ring-necked parakeets *Psittacula krameri* in Europe: Invasion success, habitat selection and impact on native bird species. Ph.D. Dissertation. Faculteit Wetenschappen Departement Biologie, Universiteit Antwerpen, Antwerpen, The Netherlands; 2009.
14. Blackburn TM, Lockwood JL, Cassey. Avian invasions: The ecology and evolution of exotic birds. USA: Oxford University Press; 2009.
15. Bon M, Latella L, Mizzan L, et al. Parrocchetto monaco – *Myiopsitta monachus*. In: “Fauna aliena ed invasiva in Veneto: problemi e proposte di gestione”, Veneto Tendenze 2/2016, Quaderno di documentazione del Consiglio Regionale del Veneto; 2016.
16. Stival E, Sighele M. Atlante foto sonoro degli uccelli del veneto - ed. 2019 v.2. Birding Veneto 2021; Accessed: 4.02.2021. Available from: birdingveneto.eu/atlasven2019
17. Elith J, Leathwick JR. Species distribution models: ecological explanation and prediction across space and time. Annu Rev Ecol Evol Syst 2009;40:677-97.
18. Ramellini S, Simoncini A, Ficetola GF, et al. Modelling the potential spread of the Red-billed Leiothrix *Leiothrixlutea* in Italy. Bird Study 2019;66:550-60.
19. Istituto Nazionale di Statistica. Available from: https://www.istat.it/
20. Di Febbraro M, Mori M. Potential distribution of alien parakeets in Tuscany (Central Italy): a bioclimatic model approach. Ethol Ecol Evol2015;27:116-28.
21. Karger DN, Conrad O, Böhner J, et al. Climatologies at high resolution for the Earth land surface areas. Sci Data 2017;4:170122.
22. Temara K, Arnhem R. Perruches a collier (*Psittacula krameri*) victims desconditions climatiques en region Bruxelloise. Aves 1996;33:128-9.
23. Butler CJ. Population biology of the introduced rose-ringed parakeet *Psittacula krameri* in the UK. PhD Thesis, University of Oxford, Oxford, UK; 2003.
24. Butler CJ. Naturalized parrots in the United Kingdom. Naturalized Parrots of the World: Distribution, Ecology, and Impacts of the World’s Most Colorful Colonizers 2021; 249-59.
25. Spreyer MF, Bucher EH. Monk Parakeet *Myiopsitta monachus*. The Birds of North America, No. 322 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA; 1998.
26. Juniper T, Parr M. Parrots - a guide to the parrots of the world. London, UK: Christopher Helm Publishers Ltd; 2003: p. 584.
27. Strubbe D, Matthysen E. Establishment success of invasive Ring-necked and Monk Parakeets in Europe. J Biogeo 2009;36:2264-78.
28. Ramellini S. L’Usignolo del Giappone *Leiothrix lutea* nel Lazio: Aggiornamento della distribuzione ed annotazioni eco-etologiche. Alula 2017;24:95–108.
29. Hijmans RJ, Phillips S, Leathwick J, et al. Package ‘dismo’. Circles 2015;9.
30. Phillips SJ, Dudik M, Schapire RE. A maximum entropy approach to species distribution modelling. Proceedings of the Twenty-first Century International Conference on Machine Learning, ACM Press, New York; 2004; p. 472-86.
31. Phillips SJ, Anderson RP, Schapire RE. Maximum entropy modelling of species geographic distributions. Ecol Model 2006;190:231-59.
32. Peterson AT, Papes M, Eaton M. Transferability and model evaluation in ecological niche modelling: a comparison of GARP and MAXENT. Ecography2007;30:550-60.
33. Berrar D. Cross-validation. Encycl Bioinforma Comput Biol ABC Bioinforma 2018;3:542–545.
34. Peterson A, Soberón J, Pearson R, et al. Ecological niches and geographic distributions. Princeton University Press; 2011.
35. Araújo MB, New M. Ensemble forecasting of species distributions. Trends Ecol Evol 2007;22:42–7.
36. Hijmans RJ. Cross-validation of species distribution models: removing spatial sorting bias and calibration with a null model. Ecology 2012;93:679–88.
37. Menchetti M, Mori E. Worldwide impact of alien parrots (Aves Psittaciformes) on native biodiversity and environment: a review. Ethol Ecol Evol 2014;26:172-94.
38. Roscoe DE, Stone WB, Petrie L, et al. Exotic psittacines in New York State. New York Fish Game J 1976;23:99-100.
39. Grandi G, Menchetti M, Mori E. Vertical segregation by ring-necked parakeets *Psittacula krameri* in northern Italy. Urban Ecosyst 2018;21:1011-17.
40. Mezzavilla F, Scarton F, Bon M. Gli Uccelli del Veneto. Danilo Zanetti Editore, Montebelluna; 2016: p. 436.
41. Agenzia regionale per la Prevenzione e protezione Ambientale del Veneto. Available from: https://www.arpa.veneto.it/
42. Mendes A. The use of riparian forests as ecological corridors by passerine birds in the South of Portugal, University of Évora, Portugal. Dissertação de doutoramento. Universidade de Évora, Évora; 2016.
43. Campbell TS. The Monk Parakeet, *Myiopsitta monachus*. Institute for Biological Invasions. Invader of the Month; 2000.
44. Khan HA, Beg MA, Khan AA. Breeding habitats of the Ring-necked Parakeet (*Psittacula krameri*) in the cultivations of central Punjab. Pak J Zool 2004;36:133–8.