Evaluation of the invasion potential of the monk parakeet, *Myiopsitta monachus*, in Natural Protected Areas in Mexico

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Abstract

Evaluation of the invasion potential of the monk parakeet, Myiopsitta monachus*, in natural Protected Areas in Mexico*. The monk parakeet, *Myiopsitta monachus,* is a species of parrot that is native to South America. By 2016 it had become invasive in Mexico and its populations have since increased dramatically, particularly in urban areas. It is currently difficult to predict whether it will expand into non–urban areas of the country. The aim of this work was to assess the risk of invasion of this parakeet into the Natural Protected Areas (NPAs) of Mexico, where interaction with the native parrots is worrisome due to the aggressive nature of this parakeet. Using potential distribution models we evaluated this risk using MaxEnt. We performed a functional analysis of all native parrots of Mexico and *M. monachus* seeking possible competition or displacement of the species. According to the MaxEnt model, the Biosphere Reserve Tehuacán–Cuicatlán is the NPA with the highest risk of such invasion (~42 % of its area presents climatically suitable values ≥ 0.75). The functional trait assessment revealed that the barred parakeet, *Bolborhynchus lineola*, is the species most similar (97 %) to the invasive monk parakeet. It is naturally distributed in the Biosphere Reserve of Tehuacán–Cuicatlán and, from all functional traits considered, differs only in nesting type. This study shows the potential risk that the invasive monk parakeet represents in Mexican NPAs, and emphasizes the need for effective actions in order to avoid further potential invasions and expansions of the species occur across Mexico.

Key words: Monk parakeet, Functional ecology, Invasive species, Parrots

Resumen

Evaluación de la capacidad invasora de la cotorra argentina, Myiopsitta monachus*, en áreas naturales protegidas de México*. La cotorra argentina, *Myiopsitta monachus*, es una especie autóctona de Sudamérica que en 2016 fue declarada invasora en México, donde sus poblaciones han aumentado drásticamente, sobre todo en zonas urbanas. Dada la dificultad de predecir si estas poblaciones se expandirán a las zonas rurales del país, el objetivo de este trabajo fue evaluar el riesgo de que esta cotorra invada las áreas naturales protegidas (ANP) de México, donde preocupa la interacción con los loros autóctonos debido al carácter agresivo de esta ave invasora. Para evaluar este riesgo, se elaboraron modelos de distribución potencial mediante el programa informático MaxEnt y luego se realizó un análisis de similitud usando rasgos funcionales de todos los loros autóctonos de México y de *M. monachus* a fin de determinar la posibilidad de que se produzcan fenómenos de competencia o desplazamiento entre las especies. Según el modelo de MaxEnt, la Reserva de la Biosfera Tehuacán–Cuicatlán es el ANP con mayor riesgo de invasión (~42 % de su superficie presenta valores climáticamente idóneos ≥ 0,75). El análisis de similitud de los rasgos funcionales reveló que el perico barvado, *Bolborhynchus lineola*, es la especie más similar (97 %) a la invasora cotorra argentina, que se distribuye naturalmente en la Reserva de la Biosfera de Tehuacán–Cuicatlán, y que de todos los rasgos funcionales considerados, solo difiere en el tipo de anidación. Este estudio muestra el riesgo que esta especie invasora puede representar en las ANP mexicanas, así como la necesidad de adoptar medidas eficaces para su manejo y control antes de que se pueda expandirse e invadir otras zonas de México en el futuro.

Palabras clave: Cotorra argentina, Ecología funcional, Especies invasoras, Cotorras

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Introduction

Invasive species are one of the most serious threats to biodiversity, and in most cases, such introductions are attributable to humans (Wittenberg and Cock, 2001). Of the 800 animal species that have been recorded as extinct since 1500, the cause can be attributed to such invasions in at least 33 % (Blackburn et al., 2019). In some cases, such invasions also reduce the population of native species and affect their health, either directly or indirectly, through the alteration of the structure and function of the ecosystem (Asner and Vitousek, 2005; Havel et al., 2005; Traveset and Richardson, 2006). The monk parakeet, *Myiopsitta monachus*, is a species whose native distribution is Bolivia, Brazil, Paraguay, Uruguay, and Argentina in South America. Nevertheless, because many people have a fondness for parrots as pets and because Mexican laws since 2008 protect native species, those who want to purchase parrots must turn to non–native species such as the monk parakeet. This bird was first seen living free in Mexico in 1999 (Salgado–Miranda et al., 2016). Since then, its populations have increased dramatically. It is now recorded both in the scientific literature and in citizen science databases. The combination of these two sources of information shows the species has now been reported in 97 cities in Mexico, and it has been observed in seven geographic regions (North Pacific, North, Central Pacific, Central Highlands, Gulf Coast, South, and Yucatán) (Hobson et al., 2017). The importance of the species outside its natural range lies in several aspects. For example, it has caused severe damage to agricultural activities in numerous regions of the world, such as Spain, Israel, the United States, and England, and even in its native environments, such as Uruguay and Argentina (Roll et al., 2008, Conroy and Senar, 2009; Canavelli et al., 2012). In the United States, for example, it has shown to have an affinity to nest on electric utility structures, causing power outages (Tillman et al., 2004; Pruett–Jones et al., 2007). It is also known to be highly aggressive towards other bird species in the areas it has invaded, and it can potentially spread clamidiosis, psittacosis, and Newcastle disease among wild bird communities, with devastating (MacGregor–Fors et al., 2011). It may even affect human health (Temple, 1992). In Mexico, it has mainly been reported nesting in trees such as palms (Tinajero and Rodríguez–Estrella, 2015; Muñoz–Jiménez and Alcantara–Carbajal, 2017), eucalyptus, pine, and araucarias (Ramírez–Albores and Aramburú, 2017), but there are also records reporting nesting in electricity utilities and other human–made constructions (pers. obs.).

The invasion of the monk parakeet is relatively recent in Mexico, and most populations have been recorded in urban environments. It was officially declared invasive in here at the end of 2016 (DOF, 2016). The monk parakeet's behavior towards other species of birds and mammals has been described as hostile (Di Santo et al., 2017). It may aggressively intimidate other birds from approaching food and is known to have killed other avian species (Freeland, 1973; Davis, 1974). Furthermore, it may defend its nests aggressively against other species (Port and Brewer, 2004). Whether it will expand into non–urban areas of Mexico is difficult to predict. Despite the multiple records of its presence in many regions of the country, this possibility has not been evaluated to date. Our aim was to assess whether the areas of potential distribution of the monk parakeet in Mexico overlapped with Natural Protected Areas (NPAs), as in this scenario native species of Mexico would potentially be directly affected by said invasion.

Material and methods

Data collection

Georeferenced monk parakeet records in Mexico were obtained from several sources: the GBIF platform (GBIF, 2020), aVerAves (CONABIO, 2021), and scientific publications (when they were included). Records were curated to avoid duplicates and to ensure correct determination. Subsequently, the current climatic variables for Mexico were downloaded from Worldclim at a scale of 30 seconds (~1 Km^2) (Fick and Hijmans, 2017).

To know the risk category of native species of parrots present in Mexican Natural Protected Areas (NPAs), we consulted the management programs of the NPAs and CONABIO's web page Avesmx, and the NOM–059–SEMARNAT 2019.

Generation of the potential distribution model

Using georeferenced monk parakeet records in Mexico, we generated a potential distribution map using the MaxEnt V.3.4.1 program (Phillips et al., 2020), considered one of the best performing algorithms (Elith et al., 2006). In general, it detects non–random relationships between two data sets: (a) georeferenced records of the presence of the monk parakeet in Mexico, and (b) a set of 'raster' (type coverage of digital data representing the climate variables for Mexican territory). With these data, the modeling was carried out as follows: 75 % of the presence records were used as training points and 25 % as validation points. A convergence threshold of 10–5 with 1,000 iterations was used as the upper limit for each run. To estimate the prediction capacity of each model, the area under the curve (AUC) was analyzed, a graphical output where the discrimination capacity of an absence (specificity) is observed (Phillips and Dudik, 2008). The output format analyzed was the cumulative format (range from 0 to 100, which indicates the suitability of the relative potential presence of the species of each pixel but not a probability of its occurrence (logistic output). A Jackknife test was used (Rohlf and Sokal, 1995) to calculate the relative contribution of each variable to the model, and the results of this evaluation are expressed with a measure known as 'gain'. This information is extremely important to demonstrate the climatic characteristics that should be recorded and that probably determine the potential range of the species. Both analyzes, the AUC, and the Jackknife test were implemented in MaxEnt.

A first model of potential distribution was made using the records and the climatic variables. To eva-

Table 1. Functional and behavioral traits of monk parakeet and psittacid species present in the NPAs of Mexico: D, diet (1, folivore; 2, frugivore; 3, granivore; 4, insectivore; 5, omnivore); F, foraging strategy (1, searcher; 2, catcher; 3, scraper; 4, robber); FS, foraging strata (1, water; 2, ground; 3, understory; 4, crown; 5, air); NT, nesting type (1, colonial; 2, individual); SB, social behavior (1, monospecific flock; 2, mixed flock; 3, congregatory; 4, lonely); MS, migratory status (1, altitudinal migration; 2, local migration; 3, continental migration; 4, resident). (Number in parentheses indicates less frequent trait or behavior).

Tabla 1. Rasgos funcionales y de comportamiento de la cotorra argentina y de las especies de psitácidos presentes en las áreas naturales protegidas de México: D, dieta (1, folívora; 2, frugívora; 3, granívora; 4, insectívora; 5, omnívora); F, estrategia de búsqueda de alimento (1, buscadora; 2, cazadora; 3, raspadora; 4, robadora); FS, estratos de alimentación (1, agua; 2, suelo; 3, sotobosque; 4, dosel; 5, aire); NT, tipo de anidamiento (1, colonial; 2, individual); SB, comportamiento social (1, en bandada monoespecífica; 2, en bandada mixta; 3, congregatorio; 4, solitario); MS, patrón migratorio (1, migración altitudinal; 2, migración local; 3, migración continental; 4, residente). (Los números entre paréntesis indican un rasgo o comportamiento menos frecuente).

	Trait					
Species	D	F	FS	NT	SB	MS
Myiopsitta monachus	(1), 3, (4)	1	2, 4	1	1	4
Amazona autumnalis	2, 3	1	4	2	1	1
Ara militaris	(1), 2, 3	1	(3), 4	2	1	1
Bolborhynchus lineola	(1), 2, 3, (4)	1, (3)	2, 3, 4	2	1	4
Amazona albifrons	(1), 2, 3	1	4	2	1	4
Amazona finschi	5	1, 3	2, 4	2	1	4
Eupsittula canicularis	1, 2, 3	1	4	2	1	4
Forpus cyanopygius	2, 3	1	2, 4	2	1	4
Rhynchopsitta terrisi	3	1	4	1	1	4
Amazona viridigenalis	2, 3	1	4	2	2	4
Eupsittula nana	(1), 2, (3)	1	4	2	2	4
Psittacara holochlora	2, 3	1	4	2	1	4
Pionus senilis	2, 3	1	4	2	1	4
Amazona oratrix	1, 2, 3	1	4	2	3	4
Rhynchopsitta pachyrhyncha	3	1	4	2	1	4

luate the contribution of the environmental variables to the prediction of the species model, the results of two ways that the MaxEnt program uses were analyzed: the estimate of the contribution percentages relative to the model and the results of the Jackknife test. In the case of the Jackknife test, three types of models were created. The first model was built with all the variables but excluding an environmental variable to determine how the excluded variable affected the model. The following model was created using each environmental variable independently to observe how it contributed to the general model. Finally, a model was built using all the variables. Among the models created with the independent environmental variables, we selected those that contributed more to the general model as the most important variables and a new potential distribution model was made with these. Among the models created excluding one of the environmental variables, the most important variable was selected as that which, when excluded, caused a lesser the contribution of the other variables (Plasencia–Vázquez et al., 2014).

The model generated by MaxEnt and the layers of the NPAs of Mexico were superimposed using QGIS. The area (ha) was also estimated, as was the percentage of each one with suitability values within three categories (≥ 0.75–0.84, 0.85–0.90, and ≥ 0.91); the suitability value of 0.75 was considered as a significant probability of presence according to Fitzgibbon et al. (2022), but we built the three categories assuming that suitability values of 0.75, 0.86, and 0.91 do not represent the same probability of presence of the species.

Functional traits

For each parrot species native to Mexico, and also for the monk parakeet, the most informative functional traits were collected according to Howell and Webb (1995), Del Hoyo et al. (1997), López–Ordóñez et al. (2015) and Sahagún–Sánchez and Durán–Fernández (2019) (table 1).

Considering the functional and behavioral traits of the monk parakeet and psittacid species present in the NPAs of Mexico (table 2), we performed a two–way cluster analysis to determine the degree of similarity between the species in terms of their functional traits, and also to know which trait or set of traits produce such similarity. For this analysis we used the PAST program version 4.11 (Hammer et al., 2001).

Results

We obtained a total of 5,611 monk parakeet records for Mexico. Nonetheless, the curation process resulted in 1,721 validated records, without duplicates. The model generated by MaxEnt with the validated records showed that the variables that contributed most to the potential distribution of monk parakeet were the average temperature in the coldest quarter, precipitation in the coldest quarter, seasonality of precipitation, temperature seasonality, and maximum temperature of the warmest month (table 2). The regularized training gain was 1.038. After 500 iterations, the training AUC was 0.885.

The potential distribution model for the Monk Parakeet revealed that seven regions in Mexico are especially important according to the obtained suitability value: the southern coast of the Baja California Peninsula; an area in the northwest of the country, in the state of Sonora, which corresponds with an urban center (Hermosillo); the coastline of the state of Nayarit, Jalisco, and Colima; Central portions of Transversal Neovolcanic Axis; the central region of Mexico, Puebla State and Mixteca region in Oaxaca; a small area in the southern portion of Oaxaca state; and in central portion of Chiapas state, near San Cristobal de las Casas (fig. 1).

Superposition of the layers of NPAs of Mexico shows that four regions had greatest suitability values for the potential presence of the monk parakeet: Tehuacán–Cuicatlán, Marismas Nacionales Nayarit, Sierra Gorda, and Sierra de Manantlán (in order from highest to lowest risk) (table 3), all Biosphere Reserves (BR).

According to the analysis of the potential distribution model, only four Mexican NPAs coincide with the regions with suitability values above 0.75 and these values vary in each of them. For example, 42 % of Tehuacán–Cuicatlán BR presents suitability values ≥ 0.75, that is: the current climatic conditions in this region (specifically average temperature of the coldest quarter, precipitation of the coldest quarter, seasonality of precipitation, temperature seasonality, and maximum temperature

Table 2. Contribution of the most important variables in the potential distribution of the monk parakeet derived from the model using MaxEnt: ATcq, average temperature in de coldest quarter; Pcq, precipitation in the coldest quarter; SP, seasonality of precipitation; TS, temperature seasonality, MTwm, Maximum temperature of the warmest month.

Tabla 2. Contribución de las variables más importantes en la distribución potencial de la cotorra argentina derivadas del modelo elaborado utilizando MaxEnt: ATcq, temperatura media en el trimestre más frío; Pcq, precipitación en el trimestre más frío; SP, estacionalidad de la precipitación; TS, estacionalidad de la temperatura, MTwm, temperatura máxima del mes más cálido.

Variable	Contribution (%)
ATcq	23.7
Pcq	23.6
SP	20
TS	17.9
MTwm	14.9

Table 3. Area and percentage of Natural Protected Areas (NPAs) in Mexico with different suitability values for the potential presence of *Myiopsitta monachus*.

Tabla 3. Superficie, absoluta y en porcentaje, de las áreas naturales protegidas (NPAs) de México con diferentes valores de idoneidad para la presencia potencial de Myiopsitta monachus*.*

NPA	Total area % (ha)	Area with suitability value ≥ 0.91	0.85	0.75	Area with suitability ≥ 0.75 (ha)	% total
Tehuacán–Cuicatlán	490,186.88	26.04	9.51	6.41	205,672.24	41.96
Marismas Nacionales Nayarit	133,854.39	10	13.29	14.01	49,931.21	37.30
Sierra Gorda	383,567.45	0	0	5.92	24,607.12	6.42
Sierra de Manantlán	139,577.13	0	0	2.08	2,902.82	2.08

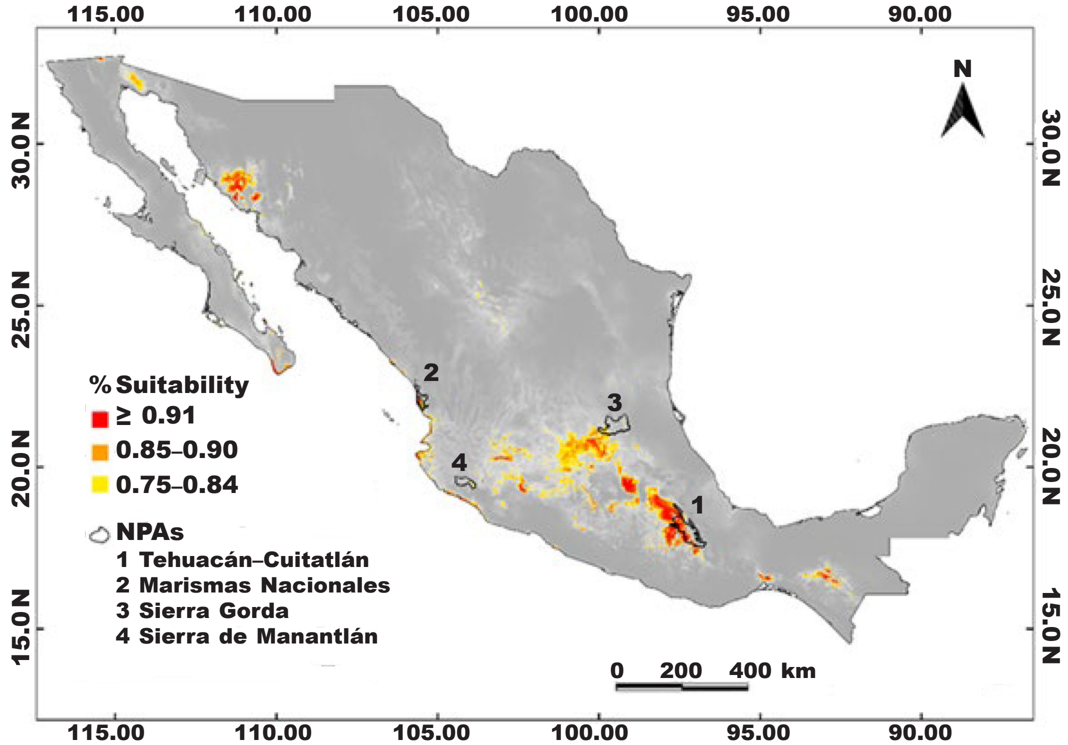

Fig. 1. Potential distribution model for the monk parakeet, generated with MaxEnt and climatic variables. The Natural Protected Areas (NPAs) are Biosphere Reserves (BR).

Fig. 1. Modelo de distribución potencial de la cotorra argentina generado con MaxEnt y variables climáticas. Las áreas naturales protegidas (NPAs) son Reservas de la Biósfera (BR).

of the warmest month), are appropriate for the monk parakeet. Therefore, were it to become established, it would be of high risk. At Sierra de Manantlán, just 2% of the area has suitability values between 0.75 and 0.84 (table 3). In the Tehuacán–Cuicatlán BR, 26% of its surface registered a suitability value for the potential distribution of the species ≥ 0.91, while 9.5% registered a suitability value between 0.85–0.90 and 6.4% with presence suitability between 0.75 and 0.85 (table 3).

In the NPAs with suitability values for the potential distribution of monk parakeet there are 14 species of native parrots, 12 of which are listed in the NOM–059–2019 (table 4). In the Tehuacán–Cuicatlán BR, which is the NPA with the highest suitability value for the species, there are three species of native parrots, and all three are included in NOM–059–2019: one of them (*Ara militaris* military macaw) is in danger of extinction and the other two (*Amazona autumnalis* red–lored parrot and *Bolborhynchus lineola* barred parakeet) are threatened. In Marismas Nacionales, the BR with the second highest suitability values, there are three native species (*Amazona albifrons* white–fronted parrot, *Eupsittula canicularis* orange–fronted parakeet, and *Forpus cyanopygius* Mexican parrotlet) that are under special protection, and another species, the *Amazona finschi* lilac–crowned parrot, is in danger of extinction) NOM–059–2010, NOM–059–2019 (table 4).

Functional trait analysis

The two–way cluster analysis showed that the monk parakeet and the barred parakeet are the two most similar species (97%), but there is also a high similarity between the former and the Mexican parrotlet (94%). Nesting type (individual nesting) is the common difference between these two native species and the monk parakeet (colonial nesting), while *Forpus cyanopygius* also differs in diet type, being frugivorous (fig. 2).

Discussion

Our results show that regions of Mexico that are relevant for the potential distribution model of monk parakeet are important urban and non–urban areas. This finding is in agreement with a description by Sol et al. (1997) who stated that in its native range, this species lives in a great variety of habitats, such as open forests, trees along watercourses, savanna woodlands, dry *Acacia* scrubland, palm groves, farmlands, orchards, and urban parks. This is also in agreement with Neidermyer and Hickey (1977), who stated that in the first known survey of monk parakeets in the United States of America, as a control effort by the Fish and Wildlife Service, 77% of observations were in urban

Table 4. Species of psittacids present in the NPAs that resulted in suitability values ≥ 0.75 for the potential distribution of the monk parakeet: E, in danger of extinction; T, threatened; Pr, special protection; X, not considered under protection (GPC, Mexican governmental protection category).

Tabla 4. Especies de psitácidos presentes en las áreas naturales protegidas (NPAs) que obtuvieron valores de idoneidad ≥ 0,75 para la distribución potencial de la cotorra argentina: E, en peligro de extinción; T, amenazada; Pr, objeto de protección especial; X, no considerada bajo protección (GPC, categoria de protección gubernamental mejicana).

NPAs	Species	Common name	GPC
Tehuacán–Cuicatlán	*Amazona autumnalis*	Red–lored parrot	T
	Ara militaris	Military macaw	E
	Bolborhynchus lineola	Barred parakeet	T
Marismas Nacionales	*Amazona albifrons*	White–fronted parrot	Pr
	Amazona finschi	Lilac–crowned parrot	E
	Eupsittula canicularis	Orange–fronted parakeet	Pr
	Forpus cyanopygius	Mexican parrotlet	Pr
Sierra Gorda	*Rhynchopsitta terrisi*	Maroon–fronted parrot	E
	Amazona autumnalis	Red–lored parrot	T
	Amazona viridigenalis	Red–crowned parrot	E
	Ara militaris	Military macaw	E
	Eupsittula nana	Olive–throated parakeet	Pr
	Psittacara holochlora	Green parakeet	T
	Pionus senilis	White–crowned parrot	T
Sierra de Manantlán	*Amazona finschi*	Lilac–crowned parrot	E
	Amazona oratrix	Yellow–headed parrot	E
	Ara militaris	Military macaw	E
	Eupsittula canicularis	Orange–fronted parakeet	Pr
	Rhynchopsitta pachyrhyncha	Thick–billed parrot	E

and suburban areas. Later, in 2006, Munoz and Real found that human activity explained more than 63 % of the variation in monk parakeet distribution across Spain, and this information was corroborated by Strubbe and Matthysen (2009), who found that successful establishment of monk parakeets across Europe was positively associated with human population density. One might thus think that their presence should not worry us, since in Mexico, although there have been cases of nesting in electrical infrastructures that could represent economic losses (as in the United States), until now they have preferred other types of substrate to construct their nests, such as tall trees. In many cities in central Mexico it has been recorded that wild populations of native parrots could be reproducing and the invasion of monk parakeets may affect them. Furthermore, Sol et al. (1997), assure that in the absence of human control, this species could continue its expansion into urban and non–urban areas, and also into agricultural areas (Muñoz and Real, 2006). In Mexico, it has been reported in sorghum and corn crops in the state of Oaxaca (Pablo–López, 2009), but no economic valuation of its effects has yet been performed. Also importantly, according to the Official Mexican Standard (SEMARNAT, 2019) in various natural protected areas of Mexico several populations of native parrots are in some risk category, so the presence of *M. monachus* could represent further risk for these species. For example, it could be a transmitter of some bacteria as mentioned by Viana et al. (2016), or it could displace native psittacid populations. Such negative effects can extend to other species and other components such as plant cover and availability of nesting sites for other birds.

Even though it is known that variables other than climatic (topographic, vegetation and land cover) condition the occurrence of species and they could be included (Contreras–Medina et al., 2010), in the present work only climatic variables were used. These variables generated a good model on their own, as pointed out by Mota–Vargas et al. (2013). However, it must also be considered that the expansion of monk parakeets may have limitations, such as the height of the vegetation (since they seek high substrates to

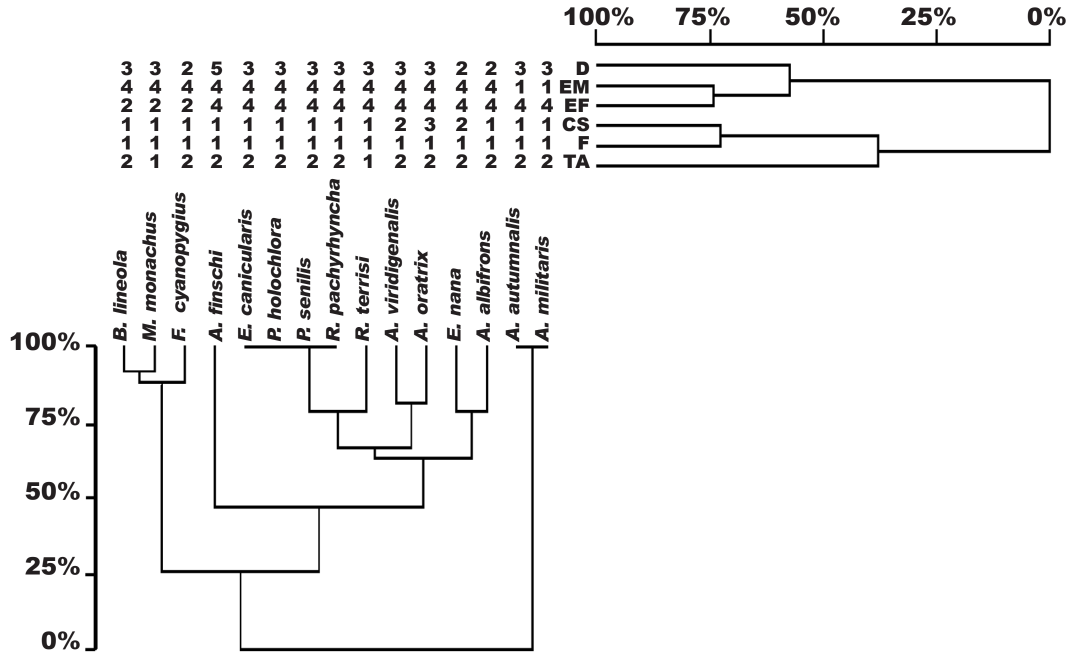

Fig. 2. Two–way cluster analysis according to the functional traits of the native psittacids species present in the NPAs and *M. monachus*: D, diet; F, foraging; FS, foraging strata; NT, nesting type; SB, social behavior; MS, migratory status.

Fig. 2. Clúster de doble entrada según los rasgos funcionales de las especies de psitácidos autóctonos presentes en las áreas naturales protegidas y de M. monachus*: D, dieta; F, búsqueda de alimento; FS, estrato de alimentación; NT, tipo de anidación; SB, conducta social; MS, patrón migratorio.*

nest) and the presence of potential predators, which are scarce in cities.

According to Gill (2007), native parrots stand out among terrestrial birds for making the most of the advantages of social behavior, a phenomenon that occurs in the monk parakeet and the only aspect that, according to our results, makes a difference regarding functional traits with the barred parakeet.

Bonilla–Ruz et al. (2014), pointed out that social behavior and collective nesting in some green macaw populations represent advantages for the species, such as the coordinated formation of flocks and flights, as well as collective detection and defense against nest predators.

In this study, social behavior and collective nesting could represent an advantage for the invasion of monk parakeet to the natural distribution areas of barred parakeet and Mexican parrotlet, causing their displacement due to competition, because it is the opposite case supported by Mason et al. (2005), who stated that a high divergence reflects a high degree of niche differentiation in the species, thereby reducing competition for the most efficient use of resources. According to our findings, however, the divergence between monk parakeet and the two cited species was very low.

According to the structure of the dendrogram derived from the two–way cluster analysis with their functional traits, *Myiopsitta monachus* and *Bolborinchus lineola* are species with a redundant contribution (represented by short or grouped branches), which shows functional overlap (Fonseca and Ganade, 2001; Dalerum et al., 2012; Dalerum, 2013). *Forpus cyanopygius* is located in this same branch of the dendrogram but is a little less similar. From the point of view of functional diversity and ecosystem services this would mean a high potential to buffer the loss of species or environmental disturbances in the ecosystem. Nonetheless, in terms of biological invasions, it could mean that this functional overlap could turn into species displacement or niche hoarding. This latter approach predominates in studies on invasive species and their consequences on biodiversity. However, the monk parakeet can exert a positive influence on other species by facilitating nesting sites (Martella et al., 1985; Hernández–Brito et al., 2021), and therefore assuming the role of ecosystem engineers. This possibility should be considered with caution, nevertheless, because nest availability may occur only when nests have deteriorated and that may be after several clutches. In addition, at least in cities, it is more common for generalist birds to occupy these nests. According to Ricciardi et al. (2021), poor understanding of interspecific interactions in biological invasions reduces our ability to predict and detect impacts on local communities.

Conclusion

This work aimed to contribute to efforts to manage and control invasive populations of the monk parakeet in Mexico. A management program has been developed for the whole country, not only for natural protected areas, but it has not yet been implemented. We hope this study represents an important step towards the development of an effective control strategy and has the potential to become an essential tool for monitoring species movements and management schemes in Biosphere Reserves in Mexico, particularly those around Tehuacán–Cuicatlán and Marismas Nacionales.

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References

Asner, G. P., Vitousek, P. M., 2005. Remote analysis of biological invasion and biogeochemical change. *Proceedings of the National Academy of Sciences of the United States of America,* 102(12): 4383-4386, Doi: 10.1073/pnas.0500823102

Blackburn, T. M., Bellard, C., Ricciardi, A., 2019. Alien versus native species as drivers of recent extinctions. *Frontiers in Ecology and the Environment,* 17(4): 203–207, Doi: 10.1002/fee.2020

Bonilla–Ruz, C., Monterrubio–Rico, T. C., Aviles–Ramos, L. M., Cinta–Magallon, C., 2014. Anidación gregaria y éxito reproductivo en la guacamaya verde (*Ara militaris*) en un bosque tropical costero del Occidente de México. *Ornitología Neotropical,* 25(3): 303–316.

Canavelli, S. B., Aramburú, R. M., Zaccagnini, M. E., 2012. Aspectos a considerar para disminuir los conflictos originados por los daños de la cotorra (*Myiopsitta monachus*) en cultivos agrícolas. *Hornero*, 27(1): 89–101. Available online at: http://www.scielo.org.ar/pdf/hornero/v27n1/v27n1a09.pdf

CONABIO, 2021. aVerAves: Descubre una nueva forma de pajarear. Available online at: https://ebird.org/averaves/home [Accessed on 30 September 2021].

Conroy, M. J., Senar, J. C., 2009. Integration of demographic analyses and decision modeling in support of management of invasive Monk parakeets, an urban and agricultural pest. In: *Modeling demographic processes in marked populations*, 491–510 (D. L. Thompson, E. C. Cooch, M J. Conroy, Eds.). Springer: New York. Available online at: https://link.springer.com/chapter/10.1007%2F978-0-387-78151-8_21

Contreras–Medina, R., Luna–Vega, I., Ríos–Muñoz, C. A., 2010. Distribución de Taxus globosa (Taxaceae) en México: Modelos ecológicos de nicho, efectos del cambio del uso de suelo y conservación. *Revista Chilena de Historia Natural*, 83(3): 421–433, Doi: 10.4067/S0716-078X2010000300009

Dalerum, F., 2013. Phylogenetic and functional diversity in large carnivore assemblages. *Proceedings of the Royal Society B: Biological Sciences*, 280(1760): 20130049, Doi: 10.1098/rspb.2013.0049

Dalerum, F., Cameron, E. Z., Kunkel, K., Somers, M. J., 2012. Interactive effects of species richness and species traits on functional diversity and redundancy. *Theoretical Ecology*, 5: 129–139, Doi: 10.1007/s12080-010-0104-y

Davis, L. R., 1974. The monk parakeet: A potential threat to agriculture. In: *Proceedings of the Vertebrate Pest Conference, vol 6.* University of California. Anaheim, CA, USA: 253–256

Di Santo, M., Battisti, C., Bologna, M. A., 2017. Interspecific interactions in nesting and feeding urban sites among introduced Monk Parakeet (*Myiopsitta monachus*) and syntopic bird species. *Ethology, Ecology and Evolution,* 29(2): 138–148, Doi: https://doi.org/10.1080/03949370.2015.1119761

Del Hoyo, J., Elliott, A., Sargatal, J., 1997 *Handbook of the birds of the world. Volume 4. Sandgrouse to cuckoos*. Lynx Ediciones, Barcelona.

DOF (Diario Oficial de la Federación), 2016. *Acuerdo por el que se determina la lista de las especies exóticas invasoras para México*. Gobierno de México, México D.F.

Elith, J., Graham, C. H., Anderson, R. P., Dudı´k, M., Ferrier, S., Guisan, A., Hijmans, R. J., Huettmann, F., Leathwick, J. R., Lehmann, A., Li, J., Lohmann, L. G., Loiselle, B. A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J. McC., Peterson, A. T., Phillips, S. J., Richardson, K. S., Scachetti–Pereira, R., Schapire, R. E., Soberón, J., Williams, S., Wisz, M. S., Zimmermann, N. E., 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography,* 29(2): 129–151, Doi: 10.1111/j.2006.0906-7590.04596.x

Fick, S. E., Hijmans, R. J., 2017. WorldClim 2: new 1–km spatial resolution climate surfaces for global land areas. *International Journal of Climatology,* 37(12): 4302–4315, Doi: https://doi.org/10.1002/joc.5086

Fitzgibbon, A., Pisut, D., Fleisher, D. 2022. Evaluation of Maximum Entropy (Maxent) Machine Learning Model to Assess Relationships between Climate and Corn Suitability. *Land*, 11(9): 1382, Doi: 10.3390/land11091382

Fonseca, C. R., Ganade, G., 2001. Species functional redundancy, random extinctions and the stability of ecosystems. *Journal of Ecology*, 89(1): 118–125, Doi: 10.1046/j.1365-2745.2001.00528.x

Freeland, D. B., 1973. Some food preferences and aggressive behavior by monk parakeets. The *Wilson Bulletin*, 85(3): 332–334.

GBIF, 2020. *GBIF Occurrence Download*, Accessible online at: https://doi.org/10.15468/dl.m8zylp [Accessed on 16 March 2020]

Gill, F. B., 2007. *Ornithology*. W. H. Freeman and Co, New York.

Havel, J. E., Lee, C. E., Vander Zanden, M. J., 2005. Do reservoirs facilitate invasions into landscapes? *BioScience,* 55(6): 518-525, Doi: 10.1641/0006-3568(2005)055[0518:DRFIIL]2.0.CO;2

Hammer, Ø., Harper, D. A., Ryan, P. D., 2001. Past: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, 4(1). Available online at: http://palaeo-electronica.org/2001_1/past/issue1_01.htm

Hernández–Brito, D., Carrete, M., Blanco, G., Romero–Vidal, P., Senar, J. C., Mori, E., White, T. H., Jr., Luna, Á., Tella, J. L., 2021.The Role of Monk Parakeets as Nest–Site Facilitators in Their Native and Invaded Areas. *Biology,* 10: 683, Doi: 10.3390/biology10070683

Hobson, E. A., Smith–Vidaurre, G., Salinas–Melgoza, A., 2017. History of nonnative Monk Parakeets in Mexico. *Plos One,* 12(9): e0184771, Doi: 10.1371/journal.pone.0184771

Howell, S. N., Webb, S., 1995. *A guide to the birds of Mexico and northern Central America*. Oxford University Press, Oxford.

López–Ordóñez, J. P., Stiles, F. G., Parra Vergara, J. L., 2015. Protocolo para la medición de rasgos funcionales en aves. In: *La Ecología Funcional como Aproximación al Estudio, Manejo y Conservación de la Biodiversidad: Protocolos y Aplicaciones* 81–125 (B. Salgado–Negret, Ed.). Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Bogotá DC, Colombia.

MacGregor–Fors, I. Calderón–Parra, R., Meléndez–Herrada, A., López–López, S., Schondube, J. E., 2011. Pretty, but dangerous! Records of non–native Monk Parakeets (*Myiopsitta monachus*) in Mexico. *Revista Mexicana de Biodiversidad*, 82(3): 1053–1056. Available online at: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1870-34532011000300034&lng=es&nrm=iso [Accessed on 7 December 2022].

Martella, M. B., Navarro, J. L., Bucher, E. H., 1985. Vertebrados asociados a los nidos de la cotorra (*Myiopsitta monachus*) en Córdoba y La Rioja. *Physis,* 43: 49–51.

Mason, N. W. H., Mouillot, D., Lee, W. G., Wilson, B., 2005. Functional richness, functional evenness and functional divergence: the primary components of functional diversity. *Oikos,* 111(1): 112–118, Doi: 10.1111/j.0030-1299.2005.13886.x

Mota–Vargas, C., Rojas–Soto, O. R., Lara, C., Castillo–Guevara, C., Ballesteros–Barrera, C., 2013. Geographic and ecological analysis of the Bearded Wood Partridge Dendrortyx barbatus: some insights on its conservation status. *Bird Conservation International*, 23(3): 371–385, Doi: 10.1017/S0959270912000329

Muñoz, A. R., Real, R., 2006. Assessing the potential range expansion of the exotic Monk Parakeet in Spain. *Diversity and Distributions*, 12(6): 656–665, Doi: 10.1111/j.1472-4642.2006.00272.x

Muñoz–Jiménez, J. L., Alcántara–Carbajal, J. L., 2017. La cotorra argentina (*Myiopsitta monachus*) en el Colegio de Postgraduados: ¿una especie invasiva? *Huitzil, Revista Mexicana de Ornitología,* 18(1): 38–52, Doi: 10.28947/hrmo.2017.18.1.262

Neidemyer, W. J., Hickey, J. J., 1977 The monk parakeet in the United States, 1970–75. *American Birds*, 31(3): 273–278.

Pablo–López, R. E., 2009. Primer registro del perico argentino (*Myiopsitta monachus*) en Oaxaca, México. *Huitzil, Revista Mexicana de Ornitología*, 10(2): 48–51. Available online at: https://www.redalyc.org/articulo.oa?id=75612866002 [Accessed on 7 December 2022].

Phillips, S. J., Dudík, M., 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, 31(2): 161–175, Doi: 10.1111/j.0906-7590.2008.5203.x

Phillips, S. J., Dudík, M., Schapire, R. E., 2020. *Maxent software for modeling species niches and distributions,* Version 3.4.1, https://biodiversityinformatics.amnh.org/open_source/maxent/

Plasencia–Vázquez, A. H., Escalona–Segura, G., Esparza–Olguín, L. G., 2014. Modelación de la distribución geográfica potencial de dos especies de psitácidos neotropicales utilizando variables climáticas y topográficas. *Acta Zoológica Mexicana (n. s.),* 30(3): 471–490, Doi: 10.21829/azm.2014.30372

Port, J. L., Brewer, G. L., 2004. Use of Monk Parakeet (*Myiopsitta monachus*) nests by Speckled Teal (*Anas flavirostris*) in eastern Argentina. *Ornitologia Neotropical*, 15(2): 209–218.

Pruett–Jones, S., Newman, J. R., Newman, C. M., Avery, M. L., Lindsay, J. R., 2007. Population viability analysis of monk parakeets in the United States and examination of alternative management strategies. *Human–Wildlife Conflicts*, 1(1): 35–44, http://www.jstor.org/stable/24875052

Ramírez–Albores, J. E., Aramburú, R. E., 2017. De Suramérica para México, la invasión de la cotorra argentina (*Myopsitta monachus* Boddaert, 1783). *Revista Biodiversidad Neotropical*, 7(2): 86–97. Doi: 10.18636/bioneotropical.v7i1.345

Ricciardi, A., Iacarella, J. C., Aldridge, D. C., Blackburn, T. M., Carlton, J. T., Catford, J. A., Dick, J. T. A., Hulme, P. E., Jeschke, J. M., Liebhold, A. M., Lockwood, J. L., MacIsaac, H. J., Meyerson, L. A., Pyšek, P., Richardson, D. M., Ruiz, J. M., Simberloff, D., Vilà, M., Wardle, D. A., 2021. Four priority areas to advance invasion science in the face of rapid environmental change. *Environmental Reviews*, 29: 119–141, Doi: 10.1139/er-2020-0088

Rohlf, F. J., Sokal, R. R., 1995. *Statistical tables*, 3rd Edition. Macmillan. New York, USA.

Roll, U., Dayan, T., Simberloff, D., 2008. Non–indigenous terrestrial vertebrates in Israel and adjacent areas. *Biological Invasions*, 10: 659–672, Doi: 10.1007/s10530-007-9160-7

Sahagún–Sánchez, F. J., Durán–Fernández, A., 2019. *Los loros de la Reserva de la Biosfera Sierra del Abra Tanchipa*. Incidencia y Gobernanza Ambiental AC, Guadalajara, Jal., México.

Salgado–Miranda, C., Pablo–Medina, J., Sánchez–Jasso, J. M., Soriano–Vargas, E., 2016. Registro altitudinal más alto en México para la cotorra argentina (*Myiopsitta monachus*). *Huitzil, Revista Mexicana de Ornitología,* 17(1): 155–159. Available online at: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1870-74592016000100016&lng=es&nrm=iso [Accesed on 7 December 2022].

SEMARNAT, 2019. Modificación del Anexo Normativo III, Lista de especies en riesgo de la Norma Oficial Mexicana NOM–059–SEMARNAT–2010, Protección ambiental–Especies nativas de México de flora y fauna silvestres–Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio–Lista de especies en riesgo. Publicada el 14 de noviembre de 2019. Diario Oficial de la Federación, https://dof.gob.mx/

Sol, D., Santos, D. M., Feria, E., Clavell, J., 1997. Habitat selection by the Monk Parakeet during colonization of a new area in Spain. *The Condor*, 99(1): 39–46, Doi: 10.2307/1370222

Strubbe, D., Matthysen, E., 2009. Establishment success of invasive ring–necked and Monk parakeets in Europe. *Journal of Biogeography*, 36(12): 2264–2278, Doi: 10.1111/j.1365-2699.2009.02177.x

Temple, S. A., 1992. Exotic birds: A growing problem with no easy solution. *The Auk*, 109(2): 395–397., Doi: 10.2307/4088214

Tillman, E. A., van Doom, A., Avery, M. L., 2001. Bird damage to tropical fruit in south Florida. *Proceedings of the Wildlife Damage Management Conferences,* 13(9): 47–59 (M. C. Brittingham, J. Kays, R. McPeake, Eds.). State College, PA, USA.

Tinajero, R., Rodríguez Estrella, R., 2015. Cotorra argentina (*Myiopsitta monachus*), especie anidando con éxito en el sur de la Península de Baja California. *Acta Zoológica Mexicana (n. s.*), 31(2): 190–197, Doi: 10.21829/azm.2015.312540

Traveset, A., Richardson, D. M., 2006. Biological invasions as disruptors of plant reproductive mutualisms. *Trends Ecology and Evolution,* 21(4): 208–216, Doi: 10.1016/j.tree.2006.01.006

Viana, I. R., Strubbe, D., Zocche, J. J., 2016. Monk parakeet invasion success: a role for nest thermoregulation and bactericidal potential of plant nest material? *Biological Invasions*, 18(5): 1305–1315, Doi: 10.1007/s10530-016-1068-7

Wittenberg, R., Cock, M. J. W., 2001. *Les Especes Envahissantes Exotiques: nn manuel pour une meilleure prévention et de meilleures pratiques de gestion*. CAB Internacional, Wallingford, Oxon, UK.