

# Dietary plasticity in an invasive species and implications for management: the case of the monk parakeet in a Mediterranean city

J. L. Postigo, J. Carrillo–Ortiz, J. Domènech, X. Tomàs, L. Arroyo, J. C. Senar

Postigo, J. L., Carrillo–Ortiz, J., Domènech, J., Tomàs, X., Arroyo, L., Senar, J. C., 2021. Dietary plasticity in an invasive species and implications for management: the case of the monk parakeet in a Mediterranean city. *Animal Biodiversity and Conservation*, 44.2: 185–194, Doi: <https://doi.org/10.32800/abc.2021.44.0185>

## Abstract

*Dietary plasticity in an invasive species and implications for management: the case of the monk parakeet in a Mediterranean city.* Behavioural flexibility may play a relevant role during invasion of a new habitat. A typical example of behavioural flexibility favouring invasion success refers to changes in foraging behaviour. Here we provide data on changes in the foraging strategies of monk parakeets *Myiopsitta monachus* over a period of 17 years (2001–2017) in Barcelona city. During this time, consumption of food on the ground increased by more than 25% and the consumption of anthropogenic food increased by 8%. Detailed information about the food consumed is provided. Feeding on the ground and consumption of low plants allow parakeets to reach not only anthropogenic food but also crops, thereby increasing the risk of crop damage as the invasion evolves. Early detection of damage to crops is crucial in order to prevent further harm, and makes the precautionary principle highly relevant.

Key words: Behavioural shift, Diet, Crop damage, Spillover, Longitudinal study

## Resumen

*La plasticidad en la dieta de una especie invasora y las implicaciones para su gestión. El caso de la cotorra argentina en una ciudad mediterránea.* La flexibilidad del comportamiento puede ser un factor determinante en la invasión de un nuevo hábitat. Uno de los ejemplos más típicos de flexibilidad del comportamiento que favorece la invasión son los cambios en las estrategias de alimentación. En el presente estudio proporcionamos información sobre los cambios producidos en la estrategia alimentaria de la cotorra argentina (*Myiopsitta monachus*) durante 17 años (2001–2017) en la ciudad de Barcelona. A lo largo de este período, el consumo de comida en el suelo y el consumo de alimentos de origen humano aumentaron, respectivamente, más del 25% y el 8%. Se proporciona una descripción detallada de los alimentos consumidos. Alimentarse en el suelo y en vegetación baja pone al alcance de las cotorras comida de origen humano, pero también les da acceso a los cultivos, lo que aumenta el riesgo de que en los estados avanzados de la invasión, puedan ocasionar daños a la agricultura. La detección temprana de los primeros daños que se produzcan en los cultivos es fundamental para prevenir mayores daños en el futuro y hace que el principio de precaución sea especialmente relevante.

Palabras clave: Cambio de comportamiento, Dieta, Daño a cultivos, Derrame, Estudio longitudinal

Received: 3 V 21; Conditional acceptance: 14 VI 21; Final acceptance: 30 XI 21

José–Luis Postigo, Diversity and Conservation Research Team, Department of Animal Biology, Universidad de Málaga, Biogeography, Campus de Teatinos s/n., 29071 Málaga, Spain.– J. L. Postigo, José Carrillo–Ortiz, Jordi Domènech, Xavier Tomàs, Lluïsa Arroyo, Juan Carlos Senar, Museu de Ciències Naturals de Barcelona, Barcelona, Spain.

Corresponding author: José–Luis Postigo. E–mail: [joseluispostigosanchez@gmail.com](mailto:joseluispostigosanchez@gmail.com)

ORCID ID: Jose–Luis Postigo: 0000-0002-1754-0025; Juan Carlos Senar: 0000-0001-9955-3892



## Introduction

Invasive alien species are a major driver of recent extinctions (Bellard et al., 2016). Several species of birds have shown to be successful invaders (Kark et al., 2009), with one of the most successful being parrots (Menchetti and Mori, 2014). The monk parakeet *Myiopsitta monachus* Bodaert is native to parts of South America but it has become one of the most successful species of introduced parrots worldwide. The species can currently be found in many countries in Europe, in North, Central, and South America, and in Israel, among others (Briceño et al., 2019; Hobson et al., 2017; Postigo et al., 2017, 2019; Pruett-Jones et al., 2007).

Knowledge of the behaviour of invasive species is critical for their management (Berger-Tal and Saltz, 2016; Weis and Sol, 2016). The process through which organisms explore and adopt to new food sources is known as behavioural plasticity. Behavioural flexibility may play a relevant role during a new habitat invasion and contribute to the likelihood of an alien species establishing a naturalized population (Martin and Fitzgerald, 2005). In the introduced habitat, some species may deploy a foraging behaviour that is distinctive from that in their native habitat, possibly explaining their higher invasion success (Pintor and Sih, 2009). The monk parakeet frequently feeds on the ground both in its native range (Aramburu, 1997; Bucher and Aramburu, 2014; Pezzoni et al., 2009) and in the invasive range (Borray-Escalante et al., 2020; Di Santo et al., 2013; South and Pruett-Jones, 2000), but interestingly, it rarely does so in the early stages of the invasion (Freeland, 1973; Santos and Sol, 1995; Shields, 1974). This change in foraging strategy (not feeding on the ground) can be considered behavioural flexibility. The new behaviour could be learnt from other species exploiting anthropogenic food, such as pigeons *Columba livia* Gmelin (Wright et al., 2010). It could also be the result of habituation to humans, or to a mix of the two possibilities. Feeding on anthropogenic food requires habituation to humans since in many Mediterranean urban environments people traditionally feed birds in the streets and squares, throwing them bread or seeds, in contrast with the use of bird feeders. Feeding on grass also requires habituation to humans as urban grass is more exposed, requiring the birds to be closer to humans than when perching on trees. As an adaptation to new environments, habituation may play an important role in facilitating invasion success and crop damage. However, to the best of our knowledge, the time required to perform this behavioural change has not been quantified previously. Using longitudinal data on feeding behaviour of the monk parakeet over a 17-year period in Barcelona city, we documented and quantified this change. Barcelona is home to one of the largest populations of monk parakeets in Europe, a population that has quintupled in size since the study began, increasing from 1,441 in 2001 to 7,100 individuals in 2017 (Borray-Escalante et al., 2020; Domènech et al., 2003). Understanding the behavioural flexibility of monk parakeets can help predict potential impact and allow the design of tailored management strategies (Wright et al., 2010).

## Material and methods

The study was carried out in the north east of Spain in the city of Barcelona. Barcelona belongs to the Mediterranean biogeographical region (Council Directive 92/43/EEC) and it is characterized by warm dry summers and mild humid winters (Yaalon, 1997). Between 2001 and 2017 we collected information about the feeding events of monk parakeets in the city. The sampling unit was the feeding event. Therefore, independently of the size of the group of monk parakeets feeding, each observation of a group was recorded as one feeding event. Data were collected by walking around the transects of monk parakeets established during various studies of the species in the city (Carrillo-Ortiz, 2009; Domènech et al., 2003; Molina et al., 2016; Rodríguez-Pastor et al., 2012). The walks were conducted during the hours of maximum activity, from 8 a.m. to 2 p.m., and complemented with non-systematic observations collected by staff at the Natural History Museum of Barcelona or through contributions by local birdwatchers (table 1s in supplementary material). Data recorded were date, type of food: tree or shrub (for every plant except grass), grass, anthropogenic food (i.e. human food and seeds fed to the parakeets in the streets), or other (i.e. sand or gravel). In the case of plant food, we recorded the part of the plant eaten (leaves, fruits, flowers, seeds or sprouts) and also the genus or species when possible (fig. 1s in supplementary material). The species of food were classified as native or alien.

We tested for variation in the seasonal use of different food sources using contingency tables and applying Pearson's Chi-Square test ( $\chi^2$ ). To test the seasonal variation in the use of biological structures we also applied Pearson's Chi-Square test. To test for a potential feeding behavioural variation, we divided the data into two groups; group 1 from 2001–2009 and group 2 from 2010–2017, with 2,255 and 2,062 observations, respectively. This division provided a balanced number of observations between the two periods, compensating for the difference in the number of samples between years. We then compared the observations of ground feeding versus perched feeding groups, and the use of anthropogenic food versus natural food. In both cases, we applied a crosstabs analysis using Pearson's Chi-Square test. Statistical analyses were conducted using the R software v.4.0.2 (R Core Team, 2020)

## Results

We recorded 4,317 feeding events, of which 3,064 (71%) corresponded to urban vegetation. Of these, 2,552 (83%) were identified at least to the genus level. These plants were distributed in 36 genera from 22 families (table 1). Alien species made up 53% of the genus/species consumed by parakeets. The most highly consumed family was poaceae (mainly grass), with 1,744 feeding events recorded (40% of the total observations). Other natural sources of food were sand or gravel, with 11 observations (0.25%).

Table 1. Family and species or category of food types consumed by monk parakeets in Barcelona (2001–2017), with the number of samples (N) and the percentage of the total number of observations (%): NA, not applicable.

Tabla 1. Tipo, familia y especies o categoría de los alimentos consumidos por la cotorra argentina en Barcelona (2001–2017), con el número de muestras (N) y el porcentaje respecto de las observaciones totales (%): Na, no aplicable.

Origin/Family	Species/group	N	%
Urban vegetation			
Arecaceae	<i>Phoenix dactylifera</i> , <i>Chamaerops humilis</i> , <i>Palm</i> sp.	150	3.47
Asteraceae	<i>Helianthus annuus</i>	15	0.35
Betulaceae	<i>Betula</i> sp.	1	0.02
Bignoniaceae	<i>Catalpa speciosa</i>	1	0.02
Casuarinaceae	<i>Casuarina</i> sp.	3	0.07
Cupressaceae	<i>Cupressus sempervirens</i> , <i>Juniperus</i> sp.	60	1.39
Fabaceae	<i>Acacia dealbata</i> , <i>Arachis hypogaea</i> , <i>Cercis siliquastrum</i> , <i>Mimosa</i> sp., <i>Parkinsonia aculeata</i> , <i>Robinia pseudoacacia</i> , <i>Sophora japonica</i> , <i>Tipuana tipu</i>	74	1.71
Fagaceae	<i>Quercus ilex</i>	10	0.23
Magnoliaceae	<i>Magnolia glandiflora</i>	2	0.05
Malvaceae	<i>Brachychiton</i> sp., <i>Tilia</i> sp.	21	0.49
Meliaceae	<i>Melia azedarach</i>	6	0.14
Moraceae	<i>Ficus</i> sp.	3	0.07
Myrtaceae	<i>Eucaliptus</i> sp.	1	0.02
Oleaceae	<i>Olea europaea</i> , <i>Ligustrum japonicum</i>	7	0.16
Phytolaccaceae	<i>Phytolacca</i> sp.	5	0.12
Pinaceae	<i>Pinus</i> sp., <i>Abies</i> sp.	5	0.12
Platanaceae	<i>Platanus hispanica</i>	41	0.95
Poaceae	<i>Grass</i> sp.	1,696	39.29
Rosaceae	<i>Eriobotrya japonica</i> , <i>Malus domestica</i> , <i>Prunus persica</i> , <i>Prunus</i> sp.	18	0.42
Salicaceae	<i>Populus</i> sp.	372	8.62
Tamaricaceae	<i>Tamarix</i> sp.	1	0.02
Ulmaceae	<i>Celtis australis</i> , <i>Ulmus</i> sp.	53	1.23
No id.	No id.	472	10.93
Natural			
NA	Sand, stones	11	0.25
Anthropogenic			
NA	Cookies, hot dog, legumes, unidentified plants	54	1.25
NA	Bread	1,187	27.50
Poaceae	<i>Oryza sativa</i> , <i>Triticum aestivum</i> , <i>Phalaris canariensis</i>	48	1.11
Total		4,317	100

Anthropogenic food was consumed in 1,289 events (30%). The primary anthropogenic food source was the bread thrown by the public to urban birds in squares and public gardens (92% of anthropogenic food), followed by seeds such as corn and sunflower seeds, fruit, and hot dogs (8%).

The main food type consumed throughout the study was blades of grass (39%), which is plentiful

in numerous parks and avenues in Barcelona. This was followed by anthropogenic food (30%) and then by food provided in trees and shrubs (30%). Sixteen plant families accounted for less than 1% of each of the feeding events (table 1).

We observed a marked seasonal shift in the diet of the monk parakeet based on the type of food consumed. Grass was the most widely used food source

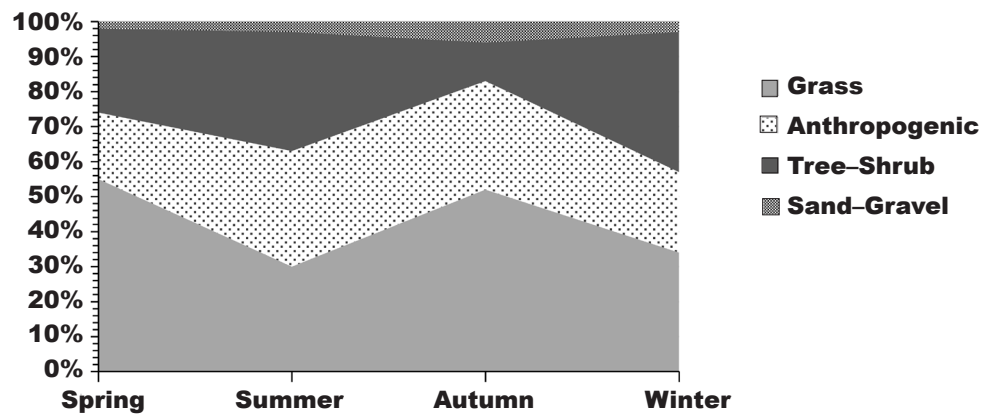


Fig. 1. Seasonal variation in food sources used by monk parakeets in Barcelona (2001–2017).

*Fig. 1. Variación estacional de las fuentes de alimentación utilizadas por la cotorra argentina en Barcelona (2001–2017).*

in spring and autumn (55% and 52% respectively). In summer, the three main sources of food (trees–shrubs, anthropogenic food, and grass) were almost equally represented, 34%, 33% and 30%, respectively. In winter, the main source of food was that provided by trees and shrubs (40%). All food source types were used in all seasons (fig. 1). Seasonal differences were significant ( $\chi^2_9 = 353.00$ ,  $p < 0.001$ ) (fig. 1s in supplementary material).

We analyzed the seasonal variation in the use of different plant parts. Leaves were the main biological structure consumed across seasons (56%), followed by fruits (17%), seeds (9%), sprouts, and flowers (8% each). Leaves (including grass) were also the most regularly consumed structure in every season (range: 45% in winter–78% in autumn). The num-

ber of biological structures consumed each season varied from three in autumn to five in spring and winter. These seasonal variations were significantly different ( $\chi^2_{12} = 1373.60$ ,  $p < 0.001$ ) (fig. 2).

We analyzed the difference between 'ground feeding' (anthropogenic food and grass) and 'perched feeding' (leaves –excluding grass–, seeds, fruits and sprouts) during the two periods described (2001–2009 versus 2010–2017) to determine whether the feeding behaviour changed over time. 'Ground feeding' increased by 26% in the second period ( $\chi^2_1 = 335.26$ ,  $p < 0.001$ ) (fig. 3). We also checked the variation in the use of food of natural origin versus the anthropogenic food during the two periods. Our findings showed that the anthropogenic food increased by 8% ( $\chi^2_1 = 26.436$ ,  $p < 0.001$ ) (fig. 3).

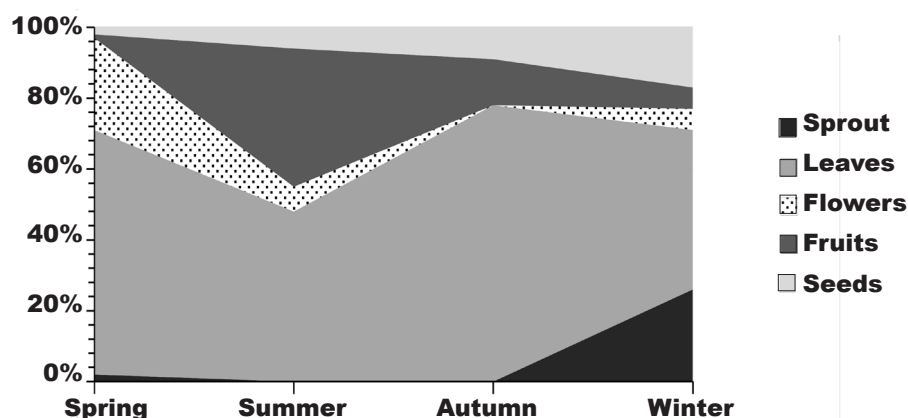


Fig. 2. Seasonal variation of the biological structures consumed by monk parakeets in Barcelona (2001–2017).

*Fig. 2. Variación estacional de las estructuras biológicas consumidas por la cotorra argentina en Barcelona (2001–2017).*

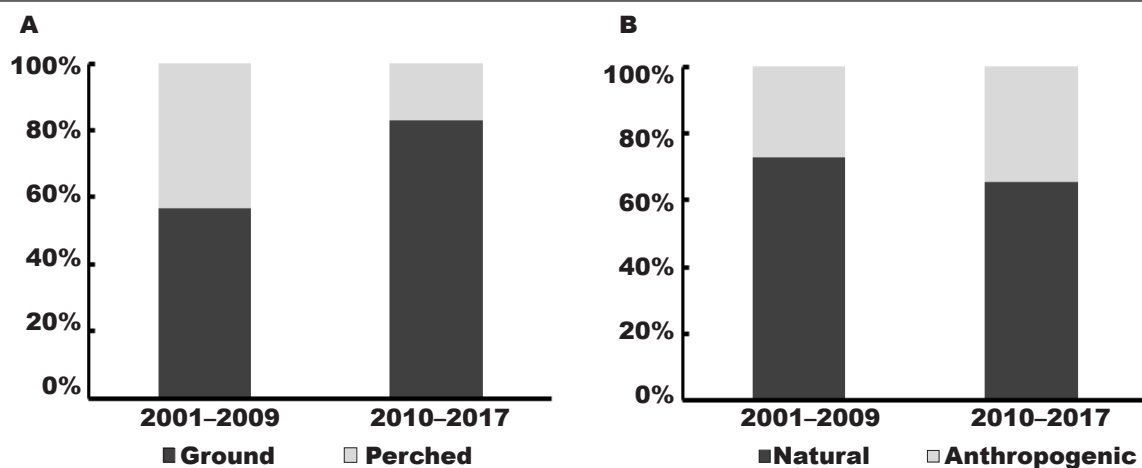


Fig. 3. Changes in the foraging behaviour of monk parakeets in Barcelona between 2001–2009 and 2010–2017: A, ground feeding versus perched feeding (in trees and shrubs); B, use of anthropogenic food versus natural food sources.

*Fig. 3. Cambios en el comportamiento de alimentación de la cotorra argentina en Barcelona entre los períodos de 2001–2009 y 2010–2017: A, alimentación en el suelo con respecto a la alimentación en los árboles y arbustos; B, consumo de comida de origen humano con respecto a la comida de origen natural.*

## Discussion

### Diet variation

Our results are consistent with most previous studies concerning the diet of monk parakeets. Most former studies, however, had short sampling periods (table 2). Here we observed that the most common food source of the parakeets in Barcelona throughout the year was the family poaceae (grass sp.), followed by anthropogenic food, mainly bread. As bread is made of wheat, which also belongs to the poaceae family, poaceae represented 65% of the total observations. Various studies of monk parakeet diet in their native range found the poaceae or asteraceae families were the first or second choice of monk parakeets (table 2). Nevertheless, in our study, the asteraceae family represented less than 1% of the diet, probably due to the low availability of this family of plants in the study area. Anthropogenic food was the second choice in our study, representing 29% of the observations. In the invasive range, anthropogenic food is one of the most commonly consumed foods in most studies (table 2). In previous studies, anthropogenic food was a main factor affecting the distribution of monk parakeets in Barcelona (Rodríguez–Pastor et al., 2012). Consumption of sand and gravel was anecdotal in this study (0.3%), and no capture of invertebrates was detected, although they were found to represent up to 28% of the diet of nestlings in the native range (Aramburú and Corbalán, 2000). Invertebrates are likely underrated in this study due to the difficulty in determining whether a monk parakeet apparently eating grass on the ground is actually capturing invertebrates. The dominant fa-

milies of food in the diet of the monk parakeet across studies and the extended use of the anthropogenic food when available depict a diet pattern (table 2) that is consistent with the suggestion of Di Santo et al. (2013) that the consumption of food by monk parakeet is independent of its availability. However, this is not the case in Chicago (Hyman and Pruett–Jones, 1995). We therefore consider that the monk parakeet has an opportunistically selective feeding behaviour.

The seasonal variation in the diet of the monk parakeet in Barcelona appears to be more homogeneous than that in other studies carried out (Aramburú, 1997; South and Pruett–Jones, 2000). In Barcelona all four types of food are included each season. Between three and five of five biological structures are present in the diet each season. Using stable isotopes in Barcelona, Borray–Escalante et al. (2020) found that the most commonly used food by monk parakeets in summer in Barcelona was anthropogenic food and grass (42% and 27%, respectively). The order of preference of food sources was identical in both studies and the proportion each one represented in the diet was reasonably close to the respective 33% and 30% they represent in summer in this study, considering the isotope study measures assimilation during the moult season and this study measures frequency of the feeding events. It is also possible that the anthropogenic food could be more used in the area where the monk parakeets were trapped for the isotopes study, in relation to the whole city sampled in this study, but Borray–Escalante et al. (2020) ruled out the possibility that the isotopic study overrepresented anthropogenic food respective to other sources. One particularity of the seasonal diet pattern in Barcelona is that anthropogenic food and



grass combined represent between 57% and 83% of the diet each season. In contrast, in colder areas of the USA, monk parakeets were found to feed exclusively on bird seeds in winter. In its native range, on the other hand, during the austral winter, up to 70% of their food is crops, and in the austral summer, monk parakeets living in the country feed solely on wild plants (Aramburu, 1997; South and Pruett-Jones, 2000). The homogeneous diet of these parakeets in Barcelona throughout the seasons is probably due to the typically mild winters in the Mediterranean basin and the large number of alien plant species cultivated in gardens and parks, species that provide food to monk parakeets throughout the whole year. In effect, most of the taxa (species/genus, 52.8%) consumed by monk parakeets in Barcelona are not native. Consequently, this food provided by humans, directly or indirectly, can increase the breeding success and survival of monk parakeets (Chamberlain et al., 2009). The monk parakeet population of Barcelona experiences some of the highest reproductive indexes known for the species, with more breeding attempts per season and higher hatching success than anywhere else, including in its native range (Senar et al., 2019). This finding is supported by the fact that the population growth and spread rates in Mediterranean regions are higher than those in Atlantic regions (Postigo et al., 2019).

#### Behavioural shift

Behavioural plasticity has been related to higher invasive success (Sol et al., 2013). South and Pruett-Jones (2000) described how monk parakeets in Chicago developed a foraging innovation by starting to use bird feeders in backyard gardens in winter. Here, we document and quantify how ground feeding of these parakeets increased by 26% and the use of anthropogenic food increased by 8% during the 17 years of our study. Such a behavioural shift greatly increases the food sources available to monk parakeets, allowing them to access grass and anthropogenic food. Such food is available throughout the year and virtually un-

limited, as grass is a fast growing plant and because the public, providing more food as the population of parakeets grows provides more and more food (Borray-Escalante et al., 2020). Besides, this behavioural shift to ground feeding can supply parakeets with a third important source food, that is, low crops such as tomatoes, wheat, corn, and sunflowers, which may be common in suburban areas. Such crops, their third food source, are typically abundant during a particular season, and parakeets can learn to exploit them as they do in their native range (Aramburu, 1997). In its original range, the monk parakeet is considered one of the main bird pest species causing damage to crops in several countries in South America (Bruggers et al., 1998; Bucher, 2021; Spreyer and Bucher, 1998). In its invasive range (e.g. U.S., Belgium, or U.K.), monk parakeets are often not considered a threat to agriculture because they mainly occupy urban areas where the damage to crops is less extensive (Muñoz and Real, 2006; South and Pruett-Jones, 2000; Tayleur, 2010; Weiserbs, 2010). In Spain and Italy, however, monk parakeets cause relevant damage in crops at the outskirts of the cities of Barcelona and Rome (Battisti, 2019; Senar et al., 2016). This damage occurs when the parakeets leave the city to feed on the crops on the outskirts of the city, causing damage especially to low plants, such as tomatoes.

The reason why a widespread invasive species like the monk parakeet causes crop damage only in a few locations after decades of presence could be that the population of monk parakeets occurring near crops must be relatively large, as predicted by Bucher (1992) for the native population. According to our results, we hypothesize here a plausible relation between the availability of anthropogenic food in cities and the potential crop damage in their surroundings.

The results of this study suggest the monk parakeet population in the city of Barcelona may be subsidized by anthropogenic food resources, which could also contribute to the population increasing five-fold in 17 years in a disturbed area, and to the species being considered an 'abundant vertebrate' according to Goodrich and

Table 2. Bibliographic review of the feeding studies of monk parakeets: A, distribution area (N, native; I, Invasive); C/S, country/state (ARG, Argentine; PE, Pennsylvania; NJ, New Jersey; CH, Chicago; ITA, Italy; FL, Florida; SPA, Spain); M, methodology (Sc, stomach content; Cs, cafeteria study; OQI, Observational/qualitative; O/Qn, observational/quantitative; Fe, feeding events; Cc, crop contents; Is, Isotopos study; Ol, observational longitudinal study; BWR, Boreal winter resource; FG, feed on the ground; Cp/c, crops present/consumed; N, sample size; FB, feeding behaviour shift (Y, yes; N, no; Bf, use of birdfeeders; Ua, use of anthropogenic food; Fg, feeding on the ground). (Y, yes; NA, not applicable; N, no; \* Austral summer).

Tabla 2. Revisión bibliográfica de los estudios de alimentación de la cotorra argentina: A, área de distribución (N, autóctona; I, invasora); C/S, país/estado (ARG, Argentina; PE, Pensilvania; NJ, Nueva Jersey; CH, Chicago; ITA, Italia; FL, Florida; SPA, España); M, metodología (Sc, contenido estomacal; Cs, estudio en una cafetería; OQI, observacional/cualitativo; O/Qn, observacional/cuantitativo; Fe, eventos de alimentación; Cc, contenido de cultivos; Is, estudio con isótopos; Ol, estudio observacional longitudinal; BWR, recurso de invierno boreal; FG, alimentarse en el suelo; Cp/c, cultivos presentes/consumidos; N, tamaño de muestra; FB, cambio de comportamiento de alimentación (Y, sí; N, no; Bf, consumo de comida en comederos para aves; Ua, consumo de comida de origen humano; Fg, alimentación en el suelo). (Y, sí; N, no; NA, no aplicable; \* verano austral).

A	C/S	M	Preferred family/group	Study period	BWR	FG	Cp/c	Characteristics	N	FB	Reference
N	ARG	Sc	Poaceae	I–III* (14 months)	Cultivated plants	Y	Y/Y	Post-mortem analysis	166 indiv. 4 colonies	N	Aramburu (1997)
N	ARG	Cs	Asteraceae > Poaceae	VIII–XII*	NA	NA	Y/NA	Wild MP captured for the study	5 indiv. 5 tests	N	Aramburu and Bucher (1999)
N	ARG	Cs	Asteraceae > Poaceae (wild origin)	XII*	NA	NA	NA/N	Poaceae underestimated	11 indiv. nestlings 21 samples	N	Aramburu and Corbalán (2000)
N	ARG	Sc	Poaceae > Asteraceae	XII*	NA	Y	NA/NA	Nestlings diet study	32 indiv. 3 colonies	N	Pezzoni et al. (2009)
I	PE	O/QI	Corn, native fruit, seeds and bread year around. Native fruit in summer	IX–VIII	Apples and pears	Y	N/N	First couple in the area, shy of feeders, feed on patio decks.	5 indiv.	Y	Freeland (1973) (Bf)
I	NJ	O/Qn	Ulmaceae > Cupressaceae > Pinaceae	III–IV (14 days)	Bird feeders	N	N/N	Arrived in winter, left in spring	2 indiv.	N	Shields (1974)
I	CH	Fe	Bird seeds > Rosaceae > Poaceae (in winter)	VII–VI	Bird seeds	Y	N/NA	Grass no available observations	1,426 feeding	Y	South and Pruet–Jones (2000) (Bf)
I	ITA	Fe	Asteraceae > Poaceae > ...	VII–IX	NA	Y	N/N	Availability: Poaceae > Asteraceae.	558 feeding observations	N	Di Santo et al (2013)
I	FL	Cc	Asteraceae	Summer	NA	NA	N/N	Food subsidized by human activities sunflower > millet	26 indiv. nestlings	Y	Avery and Shields (2018) (Bf)
I	SPA	Is	Anthropogenic food > Poaceae (herbaceous)	IX–VIII	NA	Y	N/N	Measures assimilation during moult season	72 indiv.	Y	Borray–Escalante et al. (2020) (Ua)
I	SPA	OI	Poaceae > anthropogenic food (17 years)	I–XII	Grass and anthropogenic	Y	N/N	Test the evolution of the feeding behaviour	4,317 feeding observations	Y	This study (↑Fg)

Buskirk (1995). Consequently, they are susceptible to produce damage to other species outside the disturbed areas by what we could term 'spillover crop-damage' if they eventually leave the city in large numbers to feed on crops in the surroundings, in a process equivalent to 'spillover predation' (Boarman, 2003). This seems to be the process occurring in Barcelona and Rome with monk parakeets (Battisti, 2019; Senar et al., 2016), and also with rose-ringed parakeets *Psittacula krameri* Scopoli around the city of Lihue in Hawaii (Avery and Shiels, 2018). All three of these populations of monk parakeets and rose-ringed parakeets are among the largest in their country/state (Avery and Shiels, 2018; Postigo et al., 2019). Moreover, the spread of monk parakeet assisted by white storks recently, in rural areas has been described (Hernández-Brito et al., 2020). The potential consequences of this association are unknown, but could potentially increase the spreading capacity of monk parakeets and consequently increase the crops exposed to damage.

#### Implications for management

As the monk parakeet population in Barcelona continues to increase and expand, as its behavioural shift allows it to access virtually unlimited food sources (grass and anthropogenic food), and as locally relevant crop damage have been quantified, we strongly recommend population management should be considered to avoid crop-damage by spillover increasing even further in the future. This recommendation becomes even more important considering the population keeps growing and expanding. Limiting access to food sources can reduce the growth rate of urban bird populations (Haag-Wackernagel, 1995; Senar et al., 2017), but given the growth rate of the population of monk parakeets and the fact that their main food sources in Barcelona are grass and anthropogenic food, it seems unlikely that the population size will decrease without extractive methods (Conroy and Senar, 2009; Dawson Pell et al., 2021; Senar et al., 2021). Although culling parakeets has been carried out successfully in the past (Esteban, 2016; Senar et al., 2021) and would be legal given the monk parakeet was declared an Invasive Alien Species in Spain in 2011 (Real Decreto 1628/2011), control plans in various cities have been cancelled given the opposition from animal right activists who consider the species charismatic and are against any lethal method of removal (Hernández-Brito et al., 2018). Nevertheless, we stress that social considerations should not prevent relevant governmental bodies from pursuing efforts to control the species. Recently, a management plan in the Canary Islands (Spain) successfully eradicated a small number of rose-ringed parakeet from La Palma island by combining trapping and shooting with social collaboration (Saavedra and Medina, 2020). We recommend, therefore, a multidisciplinary approach, combining various methods to remove the parakeets, and building as much social learning and trust as possible by promoting effective communication and education of the public (Crowley et al., 2019; Perry and Perry, 2008; Senar et al., 2021; Shackleton et al., 2019). If our hypothesis is correct, all the populations of monk parakeets in the

Mediterranean region, independently of their present size, are susceptible to produce crop damage in the future, when they reach the appropriate size, given that they are all growing exponentially (Postigo et al., 2019). In consequence, we strongly recommend managing all the populations of monk parakeets in the Mediterranean region, independently of their size, so as to prevent future damage to crops. In addition, further efforts to identify the limiting factors affecting the monk parakeet populations in the Mediterranean region and early detection of emerging crop damage by monk parakeets in new areas are essential to prevent potential massive damage and the need for costly control measures. In our opinion, this is a fine example of where the precautionary principle could be applied (Edelaar and Tella, 2012; Kumschick Brunel et al., 2001).

#### Acknowledgements

The fieldwork for this study was supported by research project CGL-2020 PID2020-114907GB-C21 awarded to JCS from the Ministry of Economics and Enterprise, Spanish Research Council, Spain. Thanks to Parcs i Jardins of Barcelona City Council for facilitating work in Barcelona parks. Thanks also to Alba Ortega-Segalerva, Jordi Domènech, Danielle Mazzoni, Helena Navalpotro, Monica Navarro and all the volunteers for field assistance.

#### References

- Aramburu, R. M., 1997. Ecología alimentaria de la cotorra (*Myiopsitta monachus monachus*) en la provincia de Buenos Aires, Argentina (Aves Psittacidae). *Physis*, 53: 29–32.
- Aramburu, R. M., Bucher, E. H., 1999. Food preferences in the Monk Parakeet *Myiopsitta monachus* (Aves: Psittacidae) in captivity. *Ecología Austral: Preferencias alimentarias de la cotorra Myiopsitta monachus* (Aves: Psittacidae) en cautividad. *Ecología Austral*, 9: 11–14.
- Aramburú, R., Corbalán, V., 2000. Dieta de pichones de Cotorra *Myiopsitta monachus monachus* (Aves: Psittacidae) en una población silvestre. *Ornitología Neotropical*, 11: 241–245.
- Avery, M. L., Shiels, A. B., 2018. Monk and Rose-Ringed Parakeets. In: *Ecology and management of terrestrial vertebrate invasive species in the United States*: 333–357 (W. C. Pitt, J. C., Beasley, G. W. Witmer, Eds.). CRC Press Taylor and Francis Group, Boca Raton.
- Battisti, C., 2019. Impact of monk parakeet *Myiopsitta monachus* on commercial orchards: evidence on persimmon *Diospyros kaki* fruits (Rome, central Italy). *Alula*, 26: 139–142.
- Bellard, C., Cassey, P., Blackburn, T. M., 2016. Alien species as a driver of recent extinctions. *Biology letters*, 12(2): 20150623.
- Berger-Tal, O., Saltz, D., 2016. *Conservation Behavior*. Cambridge University Press Cambridge.
- Boarman, W. I., 2003. Managing a subsidized preda-



- tor population: reducing common raven predation on desert tortoises. *Environmental management*, 32(2): 205–217.
- Borray–Escalante, N. A., Mazzoni, D., Ortega–Segalera, A., Arroyo, L., Morera–Pujol, V., González–Solís, J., Senar, J. C., 2020. Diet assessments as a tool to control invasive species: comparison between Monk and Rose–ringed parakeets with stable isotope. *Journal of Urban Ecology*, 6(1): 731.
- Briceño, C., Sandoval–Rodríguez, A., Yévenes, K., Larraechea, M., Morgado, A., Chappuzeau, C., Muñoz, V., Dufflocq, P., Olivares, F., 2019. Interactions between Invasive Monk Parakeets (*Myiopsitta monachus*) and Other Bird Species during Nesting Seasons in Santiago, Chile. *Animals : an open access journal from MDPI*, 9(11): 923.
- Bruggers, R. L., Rodriguez, E., Zaccagnini, M. E., 1998. Planning for bird pest problem resolution: a case study. *International Biodeterioration and Biodegradation*, 42(2–3): 173–184.
- Bucher, E. H., 1992. Neotropical parrots as agricultural pests. In: *New world parrots in crisis*: 201–219 (S. R. Beissinger, N. F. R. Snyder, Ed.). Smithsonian Institution Press, Washington D.C., London.
- 2021. Management of human–parrot conflicts: the South American experience. In: *Naturalized parrots of the world: distribution, ecology, and impacts of the world's most colorful colonizers*: 123–132 (S. Pruett–Jones, Ed.). Princeton University Press, Princeton.
- Bucher, E. H., Aramburú, R. M., 2014. Land–use changes and monk parakeet expansion in the Pampas grasslands of Argentina. *Journal of Biogeography*, 41(6): 1160–1170.
- Carrillo–Ortiz, J. G., 2009. Dinámica de poblaciones de la cotorra de pecho gris (*Myiopsitta monachus*) en la ciudad de Barcelona. PhD thesis, University of Barcelona.
- Chamberlain, D. E., Cannon, A. R., Toms, M. P., Leech, D. I., Hatchwell, B. J., Gaston, K. J., 2009. Avian productivity in urban landscapes: a review and meta–analysis. *Ibis*, 151(1): 1–18.
- 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. *Environmental and Ecological Statistics*, 3: 491–510.
- Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Council of Europe, Strasbourg, France.
- Crowley, S. L., Hinchliffe, S., McDonald, R. A., 2019. The parakeet protectors: understanding opposition to introduced species management. *Journal of Environmental Management*, 229: 120–132.
- Dawson Pell, F. S. E., Senar, J. C., Franks, D. W., Hatchwell, B. J., 2021. Fine–scale genetic structure reflects limited and coordinated dispersal in the colonial monk parakeet *Myiopsitta monachus*. *Molecular Ecology*, 30(6): 1531–1544.
- Di Santo, M., Vognoli, L., Battisti, C., Bologna, M. A., 2013. Feeding activity and space use of a naturalized popul. *Revue d'Écologie*, 68: 275–282.
- Domènech, J., Carrillo–Ortiz, J., Senar, J. C., 2003. Population size of the Monk Parakeet *Myiopsitta monachus* in Catalonia. *Revista Catalana d'Omitologia*, 20: 1–9.
- Edelaar, P., Tella, J. L., 2012. Managing non–native species: don't wait until their impacts are proven. *The Ibis*, 154(3): 635–637, Doi: [10.1111/j.1474-919X.2012.01250.x](https://doi.org/10.1111/j.1474-919X.2012.01250.x).
- Esteban, A., 2016. *Control de la especie cotorra argentina (Myiopsitta monachus) en Zaragoza: Periodo 2006–2016*. Ayuntamiento de Zaragoza. Available online at <https://www.zaragoza.es/contenidos/medioambiente/InformeCotorraArgentina.pdf> [Accessed 20 February 2019].
- Faus, J., 2008. Valoració dels mètodes d'estimació de l'abundància de la Cotorreta de pit gris (*Myiopsitta monachus*) en medis urbans. Final Degree Project, University Autònoma de Barcelona, Bellaterra.
- Faus, J., Ortega, A., Arroyo, L., Senar, J. C., 2010. *Determinació de l'àrea de deambulació de la cotorra de pit gris a la ciutat de Barcelona*. Museu de Ciències Naturals de Barcelona, unpublished report.
- Freeland, D. B., 1973. Some food preferences and aggressive behavior by Monk Parakeets. *Wilson Bulletin*, 85(3): 332–334.
- Goodrich, J. M., Buskirk, S. W., 1995. Control of abundant native vertebrates for conservation of endangered species. *Conservation Biology*, 9(6): 1357–1364.
- Haag–Wackernagel, D., 1995. Regulation of the Street Pigeon in Basel. *Wildlife Society Bulletin*, 23: 256–260.
- Hernández–Brito, D., Blanco, G., Tella, J. L., Carrete, M., 2020. A protective nesting association with native species counteracts biotic resistance for the spread of an invasive parakeet from urban into rural habitats. *Frontiers in Zoology*, 17(1): 1–13.
- Hernández–Brito, D., Carrete, M., Ibáñez, C., Juste, J., Tella, J. L., 2018. Nest–site competition and killing by invasive parakeets cause the decline of a threatened bat population. *Royal Society Open Science*, 5(5): 1–11.
- Hobson, E. A., Smith–Vidaurre, G., Salinas–Melgoza, A., 2017. History of nonnative Monk Parakeets in Mexic. *Plos One*, 12(9): e0184771, Doi: [10.1371/journal.pone.0184771](https://doi.org/10.1371/journal.pone.0184771)
- Hyman, J., Pruett–Jones, S., 1995. Natural history of the Monk Parakeet in Hyde Park, Chicago. *Wilson Bulletin*, 107: 510–517.
- Kark, S., Solarz, W., Chiron, F., Clergeau, P., Shirley, S., 2009. Alien Birds, Amphibians and Reptiles of Europe. In: *Handbook of Alien Species in Europe*, Springer Series in Invasion Ecology, vol 3: 105–118 (DAISIE). Springer, Dordrecht
- Kumschick Brunel, S., Fernández–Galiano, E., Genovesi, P., Heywood, V. H., Kueffer, C., Richardson, D. M., 2001. Invasive alien species: a growing but neglected threat? In: *Late lessons from early warnings: the precautionary principle*: 486–508 (P. Harremoës, D. Gee, M. MacGarvin, A. Stirling, J. Keys, B. Wynne, S. Guedes Vaz, Eds.). European Environment Agency Report, Copenhagen. Available online at: <https://www.eea.europa.eu/publications/late-lessons-2> [Accessed on 18 November 2021].
- Martin, L. B., Fitzgerald, L., 2005. A taste for novelty

- in invading house sparrows, *Passer domesticus*. *Behavioral Ecology*, 16(4): 702–707.
- Menchetti, M., Mori, E., 2014. Worldwide impact of alien parrots (Aves Psittaciformes) on native biodiversity and environment: a review. *Ethology Ecology and Evolution*, 26(2–3): 172–194.
- Molina, B., Postigo, J. L., Román-Muñoz, A., Del Moral, J. C., 2016. *La Cotorra argentina en España: Población reproductora en 2015 y método de censo*. SEO/BirdLife, Madrid.
- 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.
- Perry, D., Perry, G., 2008. Improving interactions between animal rights groups and conservation biologists. *Conservation Biology*, 22(1): 27–35.
- Pezzoni, M., Arambarri, A. M., Aramburú, R., 2009. Dieta de pichones de Cotorra *Myiopsitta m. monachus* (Aves: Psittacidae) en la provincia de Buenos Aires. *FACENA*, 25: 39–43.
- Pintor, L. M., Sih, A., 2009. Differences in growth and foraging behavior of native and introduced populations of an invasive crayfish. *Biological Invasions*, 11(8): 1895–1902.
- Postigo, J. L., Shwartz, A., Strubbe, D., Muñoz, A. R., 2017. Unrelenting spread of the alien monk parakeet *Myiopsitta monachus* in Israel. Is it time to sound the alarm? *Pest Management Science*, 73: 349–353.
- Postigo, J.-L., Strubbe, D., Mori, E., Ancillotto, L., Carneiro, I., Latsoudis, P., Menchetti, M., Pârâu, L. G., Parrott, D., Reino, L., Weiserbs, A., Senar, J. C., 2019. Mediterranean versus Atlantic monk parakeets *Myiopsitta monachus*: towards differentiated management at the European scale. *Pest Management Science*, 75(4): 915–922.
- 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.
- Pujol del Río, J., 2016. Monk parakeet's (*Myiopsitta monachus*) home range behavior in the city of Barcelona. Master Thesis, University Autònoma de Barcelona, Bellaterra.
- R Core Team, 2020. *R: A language and environment for statistical computing* (v.4.0.2). Available online at: <https://www.r-project.org/> [Accessed 1st August 2020].
- Real Decreto 1628/2011, de 14 de noviembre, por el que se regula el listado y catálogo español de especies exóticas invasoras. Boletín Oficial del Estado, Ministerio de Medio Ambiente, y Medio Rural y Marino.
- Rodríguez-Pastor, R., Senar, J. C., Ortega, A., Faus, J., Uribe, F., Montalvo, T., 2012. Distribution patterns of invasive Monk parakeets (*Myiopsitta monachus*) in an urban habitat. *Animal Biodiversity and Conservation*, 35(1): 107–117, Doi: [10.32800/abc.2012.35.0107](https://doi.org/10.32800/abc.2012.35.0107)
- Saavedra, S., Medina, F. M., 2020. Control of invasive ring-necked parakeet (*Psittacula krameri*) in an island Biosphere Reserve (La Palma, Canary Islands): combining methods and social engagement. *Biological Invasions*, 22: 3653–3667, Doi: [10.1007/s10530-020-02351-0](https://doi.org/10.1007/s10530-020-02351-0)
- Santos, D. M., Sol, D., 1995. *Ecología de la cotorra de pit gris a Barcelona: biología de la especie*. Ayuntamiento de Barcelona.
- Senar, J. C., Carrillo-Ortiz, J. G., Ortega-Segalerva, A., Dawson Pell, F. S. E., Pascual, J., Arroyo, L., Mazzoni, D., Montalvo, T., Hatchwell, B. J., 2019. The reproductive capacity of Monk Parakeets *Myiopsitta monachus* is higher in their invasive range. *Bird Study*, 66(1): 136–140.
- Senar, J. C., Conroy, M. J., Montalvo, T., 2021. Decision-making models and management of the Monk parakeet. In: *Naturalized parrots of the world: Distribution, ecology, and impacts of the world's most colorful colonizers*: 102–122 (S. Pruett-Jones, Ed.). Princeton, Princeton University Press.
- Senar, J. C., Domènech, J., Arroyo, L., Torre, I., Gordo, O., 2016. An evaluation of monk parakeet damage to crops in the metropolitan area of Barcelona. *Animal Biodiversity and Conservation*, 39(1): 141–145, Doi: [10.32800/abc.2016.39.0141](https://doi.org/10.32800/abc.2016.39.0141)
- Senar, J. C., Montalvo, T., Pascual, J., Peracho, V., 2017. Reducing the availability of food to control feral pigeons: changes in population size and composition. *Pest Management Science*, 73(2): 313–317.
- Shackleton, R. T., Larson, B. M. H., Novoa, A., Richardson, D. M., Kull, C. A., 2019. The human and social dimensions of invasion science and management. *Journal of Environmental Management*, 229: 1–9.
- Shields, W. M., 1974. Use of native plants by Monk Parakeets in New Jersey. *Wilson Bulletin*, 86(2): 172–173.
- Sol, D., Lapiedra, O., González-Lagos, C., 2013. Behavioural adjustments for a life in the city. *Animal Behaviour*, 85(5): 1101–1112.
- South, J. M., Pruett-Jones, S., 2000. Patterns of flock size, diet, and vigilance of naturalized Monk Parakeets in Hyde Park, Chicag. *The Condor*, 102: 848–854.
- Spreyer, M. F., Bucher, E. H., 1998. Monk Parakeet (*Myiopsitta monachus*). In: *The Birds of North America*: 1–23 (A. Poole, F. Gill, Eds.). The Birds of North America Inc., Philadelphia, PA.
- Taylor, J. R., 2010. A comparison of the establishment, expansion and potential impacts of two introduced parakeets in the United Kingdom. *BOU Proceedings: the impacts of non-native species*: 1–12.
- Weis, J. S., Sol, D. (Eds.), 2016. *Biological Invasions and Animal Behaviour*. Cambridge University Press, Cambridge.
- Weiserbs, A., 2010. Espèces invasives : le cas des Psittacidés en Belgique. Incidences, évaluation des risques et éventail de mesures. *Aves*, 47(1): 21–35.
- Wright, T. F., Eberhard, J. R., Hobson, E. A., Avery, M. L., Russello, M. A., 2010. Behavioral flexibility and species invasions: the adaptive flexibility hypothesis. *Ethology Ecology and Evolution*, 22(4): 393–404, Doi: [10.1080/03949370.2010.505580](https://doi.org/10.1080/03949370.2010.505580)
- Yaalon, D. H., 1997. Soils in the Mediterranean region: what makes them different? *CATENA*, 28(3–4): 157–169, Doi: [10.1016/S0341-8162\(96\)00035-5](https://doi.org/10.1016/S0341-8162(96)00035-5)

**Supplementary material**

Table 1. Number of feeding events per year, and characteristics of the sampling method. The Ciutadella Park study area includes more than 600 ha around the park: 'Study' refers to the main aim of the work undertaken in that period, but that was also used to collect data on the diet of the species in a systematic way; 'Related work' refers to the paper published following the main aim.

*Tabla 1. Número de episodios de alimentación por año y características de la metodología de muestreo. La zona del Parc de la Ciutadella incluye una superficie de más de 600 ha alrededor del parque: "Study" hace referencia al objetivo principal del trabajo realizado en ese período, pero que también se utilizó para recopilar datos sobre la dieta de la especie de forma sistemática; "Related work" se refiere a los artículos publicados en relación con el objetivo principal.*

Year	Events	Surveyed area	Study	Related work
2001	19	Barcelona city	City census	Domènech et al. (2003)
2002	469	Ciutadella Park area	Diet study	
2003	284	Ciutadella Park area	Diet study	Carrillo-Órtiz (2009)
2004	317	Ciutadella Park area	Diet study	Carrillo-Órtiz (2009)
2005	7	Barcelona city	Opportunistic observations	
2006	1	Barcelona city	Opportunistic observations	
2007	22	Barcelona city	Opportunistic observations	
2008	274	Barcelona city	City census	Faus (2008)
2009	861	Ciutadella Park area	Home range study	Faus et al. (2010)
2010	231	Barcelona city	City census	Rodríguez Pastor et al. (2012)
2011	103	Ciutadella Park area	Diet study	
2012	250	Ciutadella Park area	Diet study	
2013	106	Ciutadella Park area	Diet study	
2014	295	Ciutadella Park area	Diet study	
2015	398	Barcelona city	City census	Molina et al. (2016)
2016	659	Ciutadella Park area	Home range study	Pujol del Río (2016)
2017	21	Ciutadella Park area	Opportunistic observations	
Total	4,317			

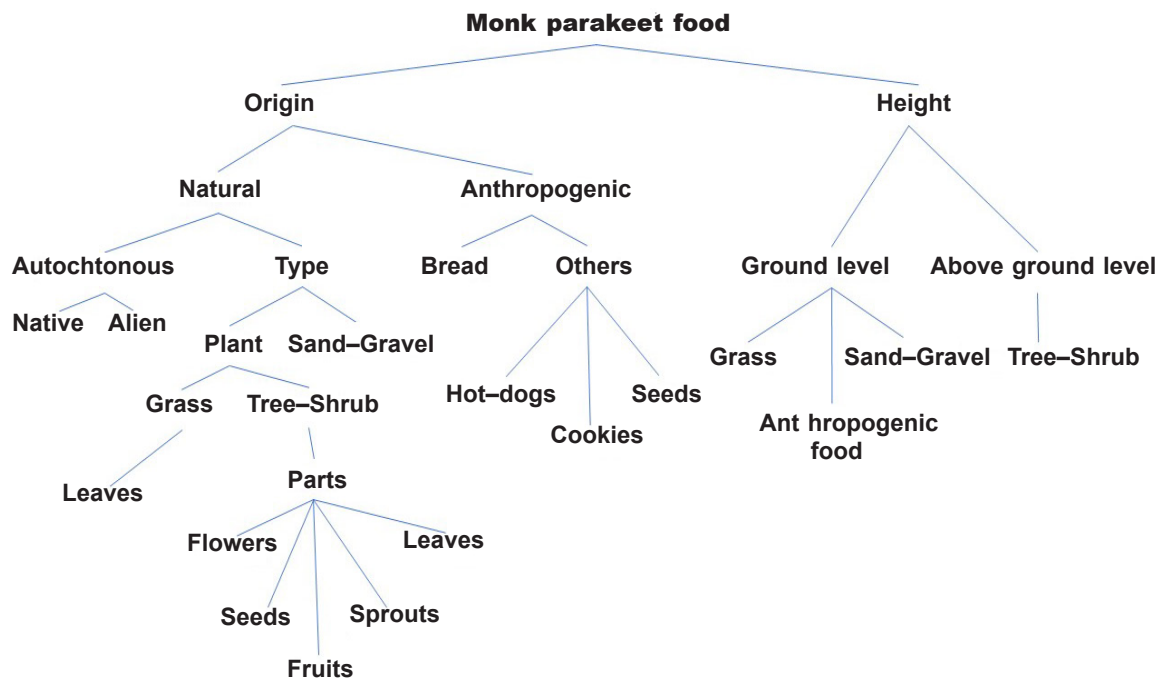


Fig. 1. Classification of the types of food consumed by monk parakeets.

*Fig. 1. Clasificación de los tipos de alimento consumidos por la cotorra argentina.*