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Monk Parakeet's (*Myiopsitta monachus*) Ecological Parameters after Five Decades of Invasion in Santiago Metropolis, Chile

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Simple Summary: Monk Parakeets are invasive birds globally. Through the construction of communal nests, they shape urban bird life. Monk Parakeets were introduced in Chile in 1972 and are now widely distributed in urban environments. Through the description of ecological parameters, we aim to assess the state of the Monk Parakeet in Santiago of Chile after 50 years of invasion. We characterized 1458 Monk Parakeets' nests on 546 trees, 91% of which were introduced species. Tasmanian blue gum and black locust were the trees preferred by parakeets for nesting. The average nest height was at 14.2 m with an occupancy rate of 89.7% and associated to nest height. During two reproductive seasons, chambers had an average of 4.5 eggs and 4.2 nestlings. Results and conclusions obtained will help in understanding the ecology of this avian invasion. Other urban metropolises such as Washington DC, Mexico City, Rome, Berlin, Paris, London, Tokyo, Nairobi, Casablanca and City of Singapore also suffer Monk Parakeet invasion. To aid in the understanding of Monk Parakeet invasive biology, we aim to contribute to better informed decisions in invasive synanthropic species management.

Abstract: Monk Parakeets are considered one of the most invasive bird species given its unique capacity among psittacines to build their own communal nests. Originally introduced as pets in houses from where they escaped or were released, they are currently considered invasive in more than 20 countries worldwide. This is the case in Chile, where Monk Parakeets were introduced during the 1970s. Between 2016 and 2019 we searched Monk Parakeets' nests structures in the Santiago metropolis region. We identified 1458 Monk Parakeets' communal nests on 546 trees belonging to 34 tree species. Ninety-one percent of the occupied trees were also introduced. Paraná pine and cedar of Lebanon were the tree species with highest abundance of nests, averaging more than four nests/tree/species, with 23 and 18 maximum number of nests, respectively. Tasmanian blue gum and black locust were selected by parakeets more often than expected, based on availability. From all trees, 24.6% denoted health problems and 47.3% were pruned. The average nest height was 14.2 m and nests were observed mainly in secondary branches (59.3%). The occupancy rate was 89.7% and was associated to nest height and type of branch. During two reproductive seasons we quantified eggs and nestlings in chambers averaging 4.5 and 4.2, respectively. We provide a rough population size estimate and the characteristics of Monk Parakeets nest and tree selectivity, aiming to characterize several decades of a neglected urban invasion to warrant strategies for improved management measures.

Keywords: ecological invasions; ecosystem engineers; invasional meltdown; invasive psittacine; invasive species; reproductive parameters; synanthropic birds; urban ecology

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1. Introduction

The Monk Parakeet (*Myiopsitta monachus*) is one of the most invasive bird species globally [1–6]. Introduced in more than 20 countries, it is the only member of the parrot family able to build its own nest [7,8]. Thus, as they thrive in introduced urban colonies, so they do their nests; these are many-chambered structures that confer refuge and breeding substrate to colonies of many individuals [7,9–13]. Given that nests provide shelter to several species, it has been recently classified as an ecosystem engineer due to its potential to shape the ecology of sympatric species [14,15]. Invasive engineers may represent a conservation menace, as they have the biggest impact: they may modify habitats and even provide novel resources [16]. For Monk Parakeets, in particular, this relates to the allogenic modulation of a reproductive and year-round resource (i.e., nest key design, size and persistence of the physical structure, continual growth and replacement, and increase in abundance and distribution) [14,16]. Monk Parakeets have a higher reproductive capacity in its invasive range [17], successfully colonizing new territories—especially urban environments [18,19].

Native to Argentina, Bolivia, Brazil, Paraguay and Uruguay [20,21], the Monk Parakeet is considered a pest even if it is native [2], affecting crops [2,4,10,22] and expanding towards Patagonia [23]. It is also accused of attacking orchards and being strident [2,24]. In the USA, they frequent bird feeders, ornamental trees [25], and produce electric outages and fires as they damage circuitry in transmission lines [26]. In Spain, the bulk of invasive Monk Parakeets diet is food of human origin [27] and their impacts are focused upon crops and fruits [28].

Fifty years ago, in 1972, citizens released captive Monk Parakeets in the Eastern part of the Santiago metropolis in Chile. Since then, 15,000 Monk Parakeets have been legally imported from Argentina and Uruguay for the pet trade. Although an import ban for this species has been in effect in Chile since 1997, Monk Parakeets have spread throughout central Chile, with breeding groups present in medium and large cities of regions Valparaíso and Metropolitan [4]. During the early 1980s, sightings became more frequent and by 1998 parakeets were easily observed in Eastern Santiago [29]. Recently, other Monk Parakeet colonies have been observed in other Chilean cities [30,31]. Thus far in Chile, as in the USA, Monk Parakeets seem to remain in urban environments [14,32], though some observations in Spain suggest that invasive Monk Parakeet populations would be under expansion pressure to rural environments [33]. This is what is happening in their native range in Argentina [23]. In Chile, the invasion has been overlooked and no management strategy has been implemented by the Environmental Ministry or the Chilean government [34].

Birds are one of the preferred pets [35,36], in particular parrots [37]. This is the reason why Monk Parakeets became so popular in the 1970s, to later become a successful global invasive species through escapes and releases [2,8]. Hence, some people appreciate Monk Parakeets and furthermore, groups of citizen even engaged in protests when invasive Monk Parakeet nests were removed in USA or England [24,38].

In Santiago de Chile, although the majority of citizens recognize them as invasive, interviewees say that Monk Parakeets enrich the city [39]. Further, urban park workers say that during reproductive seasons when nests fall off trees, they take Monk Parakeet nestlings into care [40]. This may represent an occupational risk associated to zoonoses [40,41]. Thus, human attitudes toward Monk Parakeets may be one of the key challenges to their control management [39], where education and outreach is imperative, especially among decision makers, veterinarians and wildlife managers [42].

Although evidence indicate that Monk Parakeets may be tolerant to other species [14,43], agonistic interactions or even occupation of parakeets' nests may result in a risk to native fauna [14]. Ectoparasites have been found dwelling in Monk Parakeets, representing a menace to local bird fauna [34,41]. Furthermore, pathogens that Monk Parakeets may harbour represent a sanitary concern for populated cities, as Monk Parakeets may be potential sources of zoonotic pathogens [41,44]. Therefore, it is important to elucidate parameters associated to the ecology of Monk Parakeet invasion, including nest distribution, abundance and potential preferences.

We hypothesize that nest distribution of this invasive birds is not uniform, responding to urban landscape features. The aim of this study is to describe ecological parameters of Monk Parakeet invasion at a colony level describing tree richness for nests, tree selectivity and some reproductive parameters. These results contribute to understanding a five-decade Monk Parakeet invasion and contribute to Monk Parakeet invasive species management.

2. Materials and Methods

2.1. Study Site

The study was conducted in Santiago (33°27′ S; 70°38′ W), the capital city of Chile in the Metropolitan Region (Figure 1). The region is in the Mediterranean bioclimatic zone of Central Chile, characterized by dry summers and wet winters, with marked inter-annual variability due to El Niño-Southern Oscillation phenomenon [45]. Mean annual temperature is 13.2 °C, and the mean annual precipitation is 531 mm [46]. Santiago has reduced spatial variation of climatic conditions given its location between mountain ranges and reduced altitude variation (<200 m; [47,48]). Temperature and moisture patterns are primarily a function of topography, resulting in a vegetation mosaic of *Acacia caven* shrubland at lower hillslopes, and evergreen sclerophyllous forest, mainly in drainage corridors and southern aspect slopes [46,49]. The Metropolitan Region has 52 municipalities and 40% of the national population, with 7,112,808 inhabitants, making it the highest densely populated region in the country, with an average of 462 people/km^2, and up to 17,435 people/km^2 in the city centre [50]. Santiago is the seventh most densely populated city in Latin America [48,51] and one of the 50 most agglomerated cities in the world [48,52]. This area has experienced a profound landscape transformation since the mid-sixteenth century, mainly due to logging, urban and agriculture expansion, livestock overgrazing, and the introduction of invasive species [46,53]. Further, Santiago city is considered to have quickly grown in a disorganized manner, fuelled by neoliberal policies over the last decades, resulting in urban sprawl with intense environmental degradation and air pollution [54,55]. Currently, 96.3% of the metropolitan human population lives in urban environments [50], in a region acknowledged as one of the world's 25 biodiversity hotspots [56].

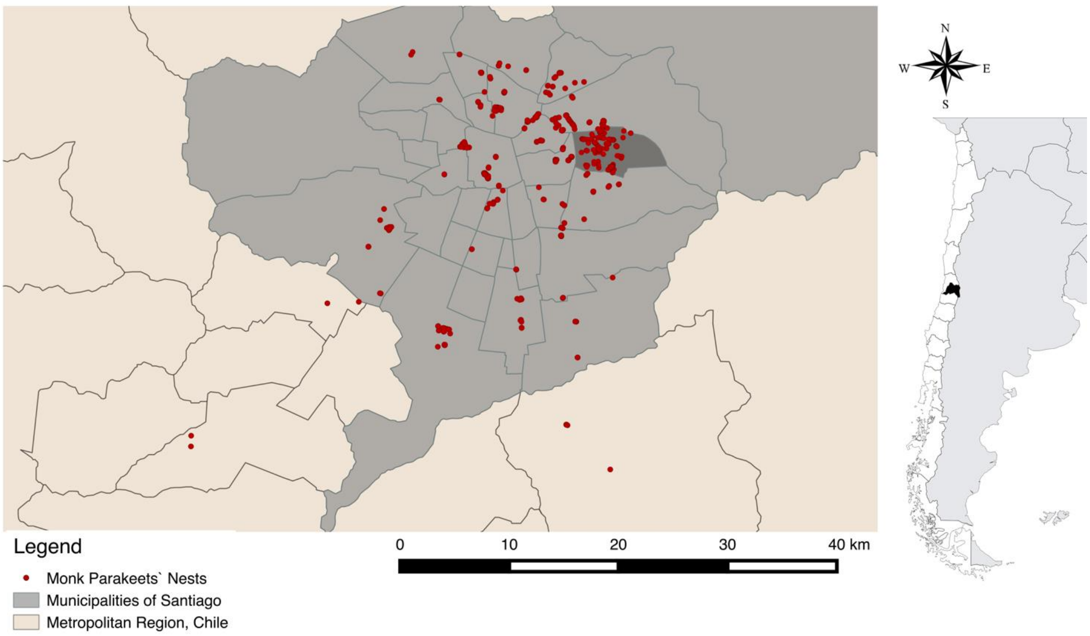

Figure 1. Study area in the Metropolitan Region of Chile (**right** inset). Dark central area is Santiago Metropolis and darker municipality is La Reina. Red dots mark 546 trees with 1458 Monk Parakeet's nests, located in 25 municipalities between 2016 and 2019.

2.2. Study Species

The Monk Parakeet is a medium-size parrot weighing 90 to 120 g [10,20], with adult males being slightly larger (1.5 to 3.5%) and juveniles slightly smaller [25]. The species is highly social [10], with reproductive pairs formed as monogamous couples [57]. Females incubate eggs [21] and members of the colony assist as helpers to rear the young [11].

In addition to their capacity to construct nests, other ecological attributes such as their flexible diet, gregarious behaviour, tolerance to human disturbance and high population growth rates contribute to the invasive success of Monk Parakeets [5,7,23,58,59]. Within urban habitats, it seems that Monk Parakeets tend to be more abundant within parks [60]. Accordingly, we focused our sampling in public trees in streets and parks. In addition, given that parks are administered by municipalities, we expected less urban habitat transformation derived from land-ownership rotation and thus oldest urban trees, which Monk Parakeets would prefer for nesting [61].

2.3. Data Collection

2.3.1. Santiago Metropolis

As a part of a research project [14], Monk Parakeets' nests were intensively but opportunistically searched within the Santiago metropolis in Chile, between the 16th of January of 2017 and the 2nd of May of 2019. Search was systematically organized in pairs of team members, who searched by foot or in vehicles within the urban city. In addition, information on location of nests was obtained directly from municipalities, SAG (National Agriculture and Animal Service), or through citizens that informed Monk Parakeet nest location in a map through a web page for outreach and citizen science (http://www.cotorrainvasora.uchile.cl/contacto.html; accessed on 5 November 2020) [62]. Being the only massive and conspicuous nest that may be found in the city, when a team of searchers saw a nest, several variables were collected including the geographical location of the tree, tree species, tree height, canopy diameter (average of two perpendicular independent projected measures of canopy diameter crossing the center and obtained for each tree in the ground with a measuring tape), trunk diameter at breast height [63], tree health (healthy, unhealthy senescent), tree management (pruned or not pruned), number of nests, nest height, number of chambers by nest, nest location within the tree and nest occupancy. We also assigned three categories to nests sizes [64]; small, medium and large, based upon relative size and number of chambers. Equipment for data collection included the Chilean urban tree field guide (Hoffmann 2010), binoculars (Nikon, Aculon several models, Tokyo, Japan), GPS (Garmin GPSMAP 64, Kansas, USA), clinometers (Suunto PM5/360 PC, Vantaa, Finland), rangefinder The Truth (Bushnell Outdoor Products, Kansas, USA) 50 m measuring tapes, 65 cm tree calipers type 1208 (Silvanus Forstbedarf GmbH, Kirchdorf an der Krems, Austria), a 15 m pole with a digital camera attached (GoPro HERO5, San Mateo, CA, USA) and a drone (Phantom 3 Advanced, DJI Technology Co, Shenzhen, Guangdong, China). These latter two products were used to assess nest occupancy. A nest was considered unoccupied when no signs of occupation were systematically registered in all observations within the calendar year (including reproductive season), in all visits through direct observation with binoculars, and no Parakeet was observed fleeing from nests when approached by a researcher, camera or drone.

Our sampling included access to some of the nests via a 17 m hydraulic lifting crane to access at least one of the nests of a tree to a first chamber inspection using an endoscope. This allowed the project's aims to be fulfilled: to gather data on the number of eggs and parakeets inside, during the reproductive spring seasons. Sampled parakeets were processed at the Avian Pathology Laboratory at the University of Chile, weighted, necropsied, aged and sexed [44]. Most sites were visited more than once; at least a first visit once the nest was discovered and variables collected, and an additional visit during the reproductive seasons.

2.3.2. La Reina Municipality

La Reina Municipality is where the first release of monk parakeets by citizens is reported in Chile [4]. Between October 2016 and June 2017, the locations of nest structures were systematically scrutinized as part of a master thesis covering all avenues, streets, restricted passages and parks of the Municipality [62]. Tree records included public and private locations. In addition, we used the 2014 tree census database collected for La Reina by The Geomatic Laboratory at the Faculty of Forestry Sciences and Nature Conservation at the University of Chile. La Reina has an area of 23.4 km^2 and is located between 608 and 2000 m amsl. The community has a population of 92.787 inhabitants living in 29.801 houses as of 2017 [50].

2.4. Statistical Analyses

2.4.1. Santiago Metropolis

To explore nest size and distribution data, we used continuous and categorical variables in initial exploratory analyses. We used (a) position measures (average, median and percentiles) and dispersion (range, variance and variation coefficients), and (b) graphic analyses (boxplots and pie graphs). For the analyses of distribution and quantitative variables we used the Shapiro–Wilk test (S–W test) for normality. To examine associations among categorical variables we used Pearson's chi-squared and Fisher's exact test, using 5% significance and, when we found differences, we further analysed residuals to assess which categories generated significance. To compare quantitative variables by groups we used the Kruskal–Wallis test (K–W test), and associations between categorical variables were evaluated at a 5% level of significance. All analyses were conducted using Stata 16.0 (StataCorp. 2019. Stata Statistical Software: Release 16. College Station, TX, USA: StataCorp LLC).

2.4.2. La Reina Municipality

To determine Monk Parakeet preference or avoidance of tree species to construct their nests, in conjunction with the chi-square analysis, we calculated simultaneous Bonferroni intervals for each species and evaluated whether nests in certain tree species occur more or less frequently in La Reina Municipality [65,66]. Tree availability was obtained from the aforementioned 2014 tree census database, which included 14,295 public trees within the municipality. We evaluated Monk Parakeet tree selectivity considering a confidence level of 94.38%, given that the original confidence level must be adjusted to the number of categories, in this case 8 tree species with Monk Parakeet nests in La Reina (k = 8). Thus, alpha is divided by two times the number of categories, being the confidence interval (CI) formula:

$$\mathrm{CI}(P_i) = p_i \pm z_{\frac{\alpha}{2k}} \sqrt{\frac{p_i(1-p_i)}{n}}$$

where p_i is the proportion of trees of the i species occupied by parakeets in the sample (observed), P_i the proportion of trees of the i species available (expected) according to the 2014 census [65]. If the proportion of the i tree species (P_i) is within the CI, the tree species is selected according to its availability. If the P_i is below the lower CI value, Monk Parakeets prefer this tree species to the others available. If the P_i is above the upper CI limit, the tree species is avoided.

3. Results

3.1. Trees

Between October 2016 and May 2019, we detected 546 trees and one lamp post which had at least one Monk Parakeet nest in 25 Municipalities from Santiago metropolis, Chile (Figures 1 and 2a). All registered trees were classified regarding species level, identifying a total of 34 species, from which only three were native and 31 were introduced species (Table 1). Eighteen (53%) were deciduous and 16 (47%) perennials. Of these trees, 401

(73.57%) were healthy, 117 (21.47%) had minor health problems, 17 (3.12%) major health problems and 10 (1.83%) were senescent (n = 545). With regard to management, 258 trees (47.34%) were pruned, and 287 (52.66%) were not pruned (n = 545). Average tree height was 20.86 m (min = 6.1 m, max = 50 m, SD = 7.78, n = 542), diameter at breast hight (DBH) 0.67 m (min = 0.4 m, max = 4.09 m, SD = 0.38, n = 531) and canopy diameter of 10.66 m (min = 0.49 m, max = 25.45, SD = 5.17, n = 534).

(**a**) (**b**)

Figure 2. (**a**) The only Monk Parakeet nest found in a lamp post (9 m) in this study, conducted in Santiago metropolis, Chile between 2016 and 2019; (**b**) one of several Monk Parakeet nests constructed on utility poles (12 m) found in 2022 in Temuco City, some 600 km south to Santiago (J. E. Jiménez).

3.2. Nests

During the same period, we detected 1458 Monk Parakeets' nests in the 546 identified trees. Height of nests ranged from 2 to 35 m with a 62.33% spanning between 10 to 20 m and an average height of 14.2 m (min = 2 m, max = 38 m, SD = 5.44, n = 1452). A 73.35% of the recorded nests were built above 10 m being the height of most nests (39.05%) in the >10–15 m range (Figure 3). Nests were mainly observed in secondary branches with 862 nests (59.28%), while 587 (40.37%) were located in principal branches, and four (0.28%) included both of them (n = 1454). Of these nests, 880 (60.98%) were of small size, 441 (30.56%) medium and 122 (8.45%) large (n = 1.443).

Of 1174 nests for which we were able to assess with confidence the activity inside or around the immediate entrance of a nest chamber, we detected a total of 1054 (89.78%) nests occupied by Monk Parakeets and 120 (10.22 %) that had no occupation.

The total number of recorded nest chambers was 2717 (n = 1363 nests), with an average of 1.99 chambers per nest (min = 1, max = 20, SD = 1.76, n = 1363). The variable number of chambers did not have a normal distribution (S–W test; W = 0.76801; p = 0.0001). There were significant differences between determined nest sizes and number of chambers, with an average of 1.36 chambers for small (SD = 0.81, n = 835), 2.49 for medium (SD = 1.56, n = 410) and 4.80 for large (SD = 3.47, 114) nests (Chi-square = 355, 3; p = 0.0001; K–W test).

Table 1. Thirty-four tree species chosen by Monk Parakeets to construct their communal nests in the Santiago metropolis, Chile. The list is organized by frequency of Monk Parakeet nests and includes several tree and nest parameters: tree height, diameter at breast height (DBH) and canopy diameter measured in meters. * Native species.

Tree Species (*Scientific Name*)	N° of Trees with One or More Nests (%)	Mean Tree Height (SD)	Mean DBH (SD)	Mean Tree Canopy Diameter (SD)	Total N° of Nests	Mean N° of Nests/Tree (SD)	Max N° of Nests *Per* Tree
Paraná pine (*Araucaria angustifolia*)	96 (17.58)	17.98 (6.70)	0.56 (0.28)	9.60 (3.47)	399	4.16 (4.22)	23
Cedar of Lebanon (*Cedrus libani*)	90(16.48)	27.31 (7.27)	0.83 (0.44)	16.05 (4.02)	379	4.21 (3.69)	18
Tasmanian bluegum (*Eucalyptus globulus*)	73 (13.37)	23.60 (6.91)	0.57 (0.31)	10.20 (4.42)	172	2.36 (1.87)	12
Black locust (*Robinia pseudoacacia*)	61 (11.17)	17.55 (3.72)	0.74 (0.31)	10.73 (2.35)	89	1.46 (0.91)	5
Chinese windmill palm (*Trachycarpus fortunei*)	51 (9.34)	11.34 (2.70)	0.39 (0.35)	3.16 (1.78)	53	1.04 (0.28)	3
Monterey pine (*Pinus radiata*)	26 (4.76)	26.31 (6.39)	0.60 (0.22)	11.11 (4.76)	72	2.77 (2.21)	9
Bunya pine (*Araucaria bidwillii*)	21 (3.85)	21.83 (3.92)	0.77 (0.53)	9.97 (2.70)	48	2.29 (1.62)	7
American pepper (*Schinus molle*)	17 (3.11)	20.09 (5.98)	0.90 (0.18)	13.94 (3.62)	50	2.94 (1.95)	7
White poplar (*Populus alba*)	16 (2.93)	22.63 (4.54)	0.63 (0.16)	7.45 (8.34)	25	1.56 (0.89)	4
Common ash (*Fraxinus excelsior*)	16 (2.93)	20.03 (4.91)	0.48 (0.24)	9.08 (2.31)	24	1.5 (0.82)	4
Monterey cypress (*Cupressus macrocarpa*)	12 (2.20)	31.58 (10.32)	0.84 (0.27)	16.49 (2.76)	44	3.67 (1.67)	6
Black poplar (*Populus nigra*)	11 (2.01)	21.18 (4.85)	0.67 (0.33)	10.98 (3.35)	17	1.55 (0.69)	3
Canary palm (*Phoenix canariensis*)	11 (2.01)	14.86 (3.59)	0.72 (0.21)	7.63 (1.69)	17	1.55 (1.51)	6
Desert fan palm (*Washingtonia filifera*)	7 (1.28)	16.14 (3.80)	0.71 (0.12)	4.62 (1.68)	8	1.14 (0.38)	2
Oriental plane tree (*Platanus orientalis*)	6 (1.10)	26.83 (3.82)	1.14 (0.25)	14.46 (3.31)	11	1.83 (0.75)	3

Table 1. *Cont.*

Tree Species (*Scientific Name*)	N° of Trees with One or More Nests (%)	Mean Tree Height (SD)	Mean DBH (SD)	Mean Tree Canopy Diameter (SD)	Total N° of Nests	Mean N° of Nests/Tree (SD)	Max N° of Nests *Per* Tree
American elm (*Ulmus americana*)	5 (0.92)	22 (1)	1.16 (0.87)	13.63 (1.41)	11	2.2 (1.3)	4
* Chilean wine palm (*Jubaea chilensis*)	3 (0.55)	13.83 (3.55)	1.00 (0.14)	9.00 (0.46)	3	1 (0)	1
Coast redwood (*Sequoia sempervirens*)	3 (0.55)	26 (1)	0.76 (0.18)	9.33 (2.93)	6	2 (1.1)	3
Box elder (*Acer negundo*)	2 (0.37)	25	0.61 (0.21)	16.30 (8.34)	3	1.5 (0.71)	1
Ceibo (*Erythrina umbrosa*)	2 (0.37)	16.75 (1.77)	0.62 (0.17)	9.85 (0.08)	2	1 (0)	1
Water oak (*Quercus nigra*)	2 (0.37)	24 (2.83)	1.72 (0.18)	15.44 (7.44)	4	2 (0)	2
Weeping willow (*Salix babylonica*)	2 (0.37)	33.5 (7.78)	0.99 (0.11)	19.18 (0.25)	2	1 (0)	1
Queen palm (*Syagrus romanzoffiana*)	2 (0.37)	9.25 (1.06)	0.29 (0.04)	3.59 (2.51)	2	1 (0)	1
Norfolk Island pine (*Araucaria heterophylla*)	1 (0.18)	22	1.02	8.52	1	-	1
Australian blackwood (*Acacia melanoxylon*)	1 (0.18)	13.5	1.00	6.00	1	-	2
Horse chestnut (*Aesculus hippocastanum*)	1 (0.18)	18	2.15	8.25	2	2	2
Atlas cedar (*Cedrus atlantica*)	1 (0.18)	37.5	1.06	22.00	1	-	1
Mediterranean cypress (*Cupressus sempervirens*)	1 (0.18)	16.5	0.89	17.30	1	-	1
Common oak (*Quercus robur*)	1 (0.18)	22	0.99	15.25	2	2	2
Sweet gum (*Liquidambar styraciflua*)	1 (0.18)	18	1.33	9.05	1	-	1
* Chilean acorn (*Cryptocarya alba*)	1 (0.18)	16	0.92	14.40	4	4	4

Table 1. *Cont.*

Tree Species (*Scientific Name*)	**N° of Trees with One or More Nests (%)**	**Mean Tree Height (SD)**	**Mean DBH (SD)**	**Mean Tree Canopy Diameter (SD)**	**Total N° of Nests**	**Mean N° of Nests/Tree (SD)**	**Max N° of Nests *Per* Tree**
* Chilean soapbark tree *(Quillaja saponaria)*	1 (0.18)	16	1.00	5.00	1	-	1
Japanese Pagoda Tree *(Styphnolobium japonicum)*	1 (0.18)	18	0.60	13.70	1	-	1
Cabbage tree *(Cordyline australis)*	1 (0.18)	8	0.14	2.80	2	2	2
TOTAL	546 (100)				1458		

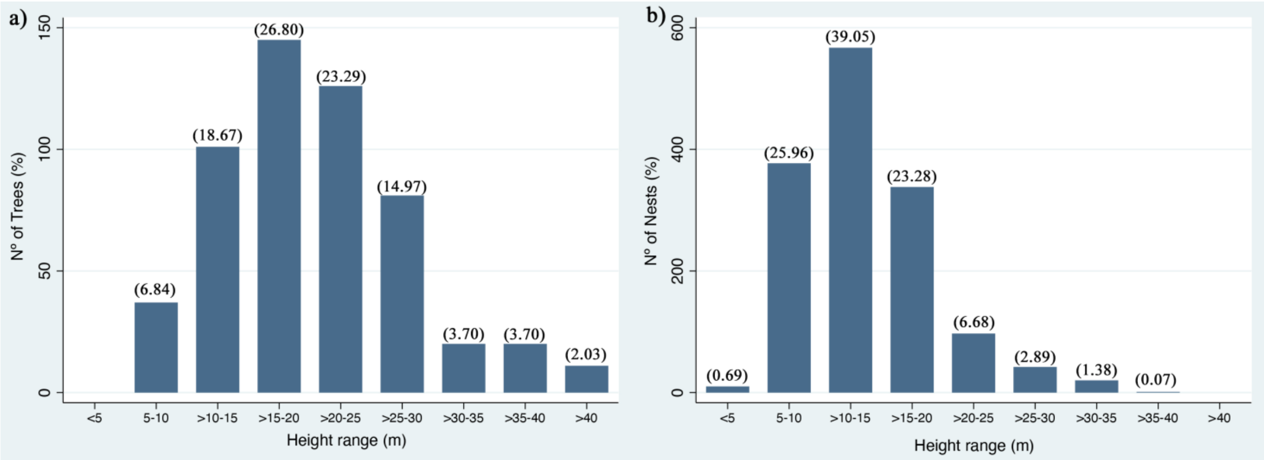

Figure 3. Box plots for height ranges of trees (**a**) and their Monk Parakeet nests (**b**) located between 2016 and 2019 in Santiago, Chile. Percentages shown between parentheses.

We assigned three categories to nest sizes, following [64], but without a standardized comparative point (e.g., transformers). We could check then that our size estimates were consistent, as we found significant differences between our size categories and number of chambers.

3.3. Associations

Associations between variables were explored with bivariate analyses and significate associations are described. There was a significant association between nest size and which branch it was located on. Thus, large and medium nests were positively associated with principal branches, whereas small nests were associated with secondary branches (Chi-square = 42.081; $p < 0.001$; Fisher's exact test).

In regard to Monk Parakeet occupancy, occupied nests were on average higher (14.19 m) than unoccupied nests (13.00 m; Chi-square = 4.807; $p = 0.0281$; K–W test). Also, there was an association between occupancy and type of branch, in which occupied nests were more common on principal branches (Chi-square = 8.271; $p = 0.041$; Fisher's exact test). There were no statistical differences between occupancy and DBH.

3.4. Monk Parakeet Tree Selectivity for Nest Construction

Of the 152 trees found with Monk Parakeet nests in La Reina Municipality, 86 were located in public areas (observed). This was contrasted with La Reina's tree census considering all 6166 public trees higher than 10 m, a height that included a 93.16 % of trees with nests, according to our results (expected). Eight tree species were observed as having nests, as well as being available and represented in the census; these nest observations were not uniform and indicated that Monk Parakeets occupy certain tree species with higher frequency (Chi-square = 141.43; $p < 0.0001$; Chi2-Tests Goodness of Fit). Bonferroni joint confidence intervals showed that the black locust and Tasmanian blue gum tree were the preferred tree species in which Monk Parakeets build their nests in (Table 2). Paraná pine, cedar of Lebanon, Monterey pine, white poplar and American pepper were used by parakeets in proportion to their availability. In contrast, the box elder was a tree species avoided by parakeets for constructing nests.

3.5. Monk Parakeet Breeding Parameters

Although eggs and nestlings were found throughout the whole sampling reproductive period, during 2017 and 2018 eggs were found in Monk Parakeet nests on the very first days of sampling, which were the 2nd of November and 26th of October, respectively. No eggs were found in nests on the last sampling days, which were the 15th and 17th of

December for years 2017 and 2018. On these dates, nestlings were found with estimated ages of 21 and 42 days, respectively.

Table 2. Eight tree species where we found Monk Parakeets nests in La Reina and represented in the municipality's census (available versus observed). Abundance and proportion of trees are compared to confidence intervals to test for Monk Parakeet selectivity. Pi = Proportion of trees of the i species. CI = Confidence interval.

	Available		Observed		Bonferroni CI		
Tree Species	**N° of Trees**	**Expected Pi**	**N° of Trees**	**Expected Pi**	**Lower Limit**	**Upper Limit**	**Selectivity**
Acer negundo	4440	0.72	1	0.01	−0.02	0.04	Avoided
Araucaria angustifolia	1	0.00	3	0.03	−0.01	0.08	According
Cedrus libani	3	0.00	4	0.05	−0.01	0.10	According
Eucalyptus globosus	234	0.04	17	0.20	0.09	0.31	Preferred
Pinus radiata	198	0.03	4	0.05	−0.01	0.10	According
Populus alba	305	0.05	9	0.10	0.02	0.19	According
Robinia pseudoacacia	739	0.12	45	0.52	0.39	0.66	Preferred
Schinus molle	246	0.04	3	0.03	−0.01	0.08	According
Total	6166	1.00	86	1.00			

The average number of eggs per chamber was 4.53 (min = 1, max = 12, SD = 2.08, n = 47) while the average number of nestlings per chamber was 4.29 (min = 1, max = 8, SD = 1.39, n = 173).

4. Discussion

By definition, cities are heavily transformed areas and hotspots of biological invasions, with a set of common invasive species shared in many urban areas around the world [67]. We evaluated ecological parameters of Monk Parakeets after almost 50 years since invasion, a similar length of time to populations in USA and Spain [17,25,38]. To date, one hundred and seventy-one tree species are recognized in urban Santiago, 21 native and 150 exotic [48]. In our study, we identified 34 tree species among the 546 trees where we found at least one parakeet nest. Of these trees, 320 (58.6%) corresponded to only four species: Paraná pine, cedar of Lebanon, Tasmanian blue gum and black locust (Table 1). We found the latter two tree species to be preferred by Monk Parakeets for constructing their nests. Exotic blue gum trees (*Eucalyptus* spp.) were selected by native raptor species to build their nests [68,69]. For Monk parakeets, Tasmanian blue gum is important for nest construction in its native range in Argentina, contributing to their population expansion toward Patagonia [23]. This apparent preference of Monk Parakeets to build their nests in blue gum trees *versus* smaller native trees would relate to blue gum's height and, thus, a higher productivity of reproductive parakeet couples that choose them [11,12,70]. The Tasmanian blue gum tree and other genera such as *Pinus* sp. and *Phoenix* sp. were also chosen by invasive Monk Parakeets to construct their nests in Barcelona, Spain [9]. During the establishment of Monk Parakeets in Barcelona, *Phoenix* sp. seemed to be the preferred genera where parakeets built their nests, shaping their distribution, abundance and therefore expansion [3]. *Phoenix canariensis* was also the most frequent tree used by Monk Parakeets' to nest in Málaga, Spain [71]. *Phoenix* sp. and blue gum tree were the trees that invasive Monk Parakeets chose to build nests in Tel Aviv, Israel [72]. In Rome Italy, 72% of invasive Monk Parakeet nests were constructed in cedars of Lebanon [59]. These four tree species at the top of Table 1 are all introduced; we could only detect Monk Parakeets' nests in native Chilean trees on five opportunities; in the Chilean acorn (*Cryptocarya alba*), Chilean soapbark tree (*Quillaja saponaria*) and Chilean wine palm (*Jubaea chilensis*). Thus, urban trees are indeed a mixture of native and exotic species, and in South American cities exotic trees dominate urban green spaces [73,74]. We demonstrated that Monk Parakeets are selective; preferring or avoiding certain tree species to build their nests. Nesting site selection is critical for many species because it can affect reproductive success, and thus species population size [75,76]. It seems that there are certain attributes that make these trees suitable for nest structures. For instance, we found that Monk Parakeets prefer higher nest structures as the average height of occupied nests was significantly higher than unoccupied nests. This is concordant with an apparent preference of Monk Parakeets for taller trees in their native [11,61,70,77] and introduced distributions [3,59]. Common urban trees have become globally popular for some attributes, such as fast growing rates [78]. In fact, 99% of the trees on which we found one or more parakeet nests in Santiago were exotic. For this reason, it would be important to study further whether this is a case of invasional meltdown, where invasive tree species are contributing to the population success and propagule pressure of Monk Parakeets (*sensu* [79–81]). This potential invasive species' mutualism is particularly important with regard to Monk Parakeets, considered ecosystem engineers because of their unique capacity to build large communal nests structures in Santiago [14]. Furthermore, this synergy could be shaping the distribution of other urban communities, including parasites [34,41,44].

On average, we found 2.67 nests in 546 trees belonging to 34 different species. Five tree species were above average, specially the two at the top of the list in Table 1: Cedar of Lebanon and Paraná pine had 4.21 and 4.16 nests on average, reaching a maximum of 18 and 23 nests in one tree, respectively. Thus, only 186 (34.07%) trees of these two species accounted for 778 (53.36%) of the nests found. This is important for the design and management of urban parks, where these tree species should be avoided to limit the Monk Parakeet demographic expansive success. Furthermore, these characteristics could be considered to be an ecosystem disservice caused by these exotic trees [82–85].

The majority of nests that we found were at the 15 to 20 m height band, the same as what was observed with Monk Parakeet nests in *Eucalyptus* sp. in Argentina [61]. These 26 trees in Argentina were in average higher (29.4 m) and thicker (DBH = 0.69 m) than our records for 73 *Eucalyptus globulus* of 23.6 m and 0.57 m. Volpe et al. (2011) [61] found that Monk Parakeets choose the tallest *Eucalyptus* sp. to build their nests and they suggest selective pruning of tallest and bulkier trees. This is relevant for management capacity and strategies.

The Paraná pine was the tree species where we found the majority of nests, as well as the single tree with more nests (Table 1). The native distribution of this critically endangered tree species overlap with Monk Parakeets native distribution in Rio Grande do Sul and Santa Catarina, Brazil [77,86–89]. Paraná pine has been introduced in Chilean cities [90], though it is not the most abundant urban species in Santiago [91]. Hence, it is possible that Monk Parakeets prefer this species given their evolutionary history. The tropical screech owl (*Megascops choliba*) and the grey-bellied hawk (*Accipiter poliogaster*) have been reported to nest in branches of native Paraná pines in Brazil [92,93]. Endemic tree species, Chilean wine palm and Chilean soap bark tree, have been described to sustain parakeet nests [14], while in this study we also found Chilean acorn. In the case of Chilean soap bark tree, it has also been recently observed as part of the parakeet diet [94].

We identified 1458 nests in 546 trees. At 89.78% occupancy rate we would have 1309 occupied nests. Almost two (1.99) chambers by each nest. If at least one chamber is occupied by one breeding pair (1309 $*$ 4.29 nestlings/chamber), as a conservative estimate, there would be 5616 new Monk Parakeets each reproductive season [33,38]. Correcting for first year survivorship at 61% is then 3426 [11]. Adding two reproductive parents to potential nestlings *per* chamber, the number would triple to 14,658. Considering a 81% adult survivorship [11,95], it may be reduced to 11,873 individuals; this at the end of a reproductive year. Nonetheless, this gross estimate is conservative, not considering nest detectability, other parakeet members such as helpers [11] and second broods, estimated in 56% for Barcelona, Spain [17]. This number is larger than what has been estimated for Monk Parakeet populations in other metropolises. The greater Chicago region in USA estimates some 778 birds after 40 years of invasion [38]. Several cities in Spain suffer Monk Parakeet invasion. In this country, 193,600 Monk Parakeets were imported mainly between

1975 and 2005 [96] and now, their total abundance is estimated in 20,000 individuals [97]. In Seville, the Monk Parakeet population is estimated to be 1487 individuals [33], while in Barcelona it is estimated to be between 5000 and 7000 individuals [27,97,98]. In Madrid, it is estimated to be the largest population, with almost 8200 individuals [97]. In Chile, reported breeding sites have increased from 90 to 1309 in fifteen years [4], and this invasive Monk Parakeet population may be one of the largest. Perhaps similarities on a regional neotropical scale, plus their urban settlement associated to invasive tree species (abundant in urban Santiago), have favoured their rapid expansion.

The size of Monk Parakeet nests is a concern according to public opinion, associated with potential massive detachments that may fall, causing danger. A 47.4% of citizens in Santiago consider that Monk Parakeets represent a threat through the risk of nest detachment [39]. Nonetheless, among 1443 observations the majority of nests that we found were of small size (60.98%) and only 8.45% were large, averaging 4.8 chambers. The total number of recorded nest chambers was 2717 (n = 1363), with an average of 1.99 chambers per nest (min = 1, max = 20, SD = 1.76, n = 1363).

It is worth noting that in our intense Monk Parakeet nest survey in Santiago, we only found one nest on a manufactured structure: a lamp post (Figure 2a). Literature describe Monk Parakeet urban impact specially upon fabricated structures such as lamp posts and buildings in USA where they construct many of their communal nests [25,26,99]. In New Jersey USA, 45% of identified nests were located in manufactured structures, including 37% of nests constructed in utility poles [100]. In Texas, USA, 75% of surveyed nest colonies were located on electric utility structures [99], while in South Florida it was 68% of nests [26]. In their native distribution they also use utility facilities, perhaps less [101]. In Pantanal Brazil, only six nests (5.77%) were found in utility poles [77]. It is possible that the Monk Parakeet nest that we found in a utility structure was constructed by a juvenile, inexperienced pair. It is also possible that there were not many tall trees available in the nearby area, which is related to social and economic status of neighbours [91]. Another possibility is that the greater use of utility structures in USA, transformers in particular, is related to an environmental challenge for a Neotropical species in colder environments, aiming at increasing nest chamber temperature during winter. This is supported by reports of several Monk Parakeet nests constructed on utility structures in Temuco city (J. E. Jiménez pers. comm. Figure 2b), some 600 km south of Santiago, and colder with a mean annual temperature of 12 °C and mean annual precipitation of 1000 mm [102].

Finally, given the importance of some invasive trees for monk parakeets, perhaps this is another example of invasional meltdown [79], where some trees increase the likelihood of Monk Parakeet survival and magnitude of ecological impact [103]. Given that Monk Parakeets are invasive ecosystem engineers in urban environments, the importance of invasive tree species (historically preferred in cities) as substrate for Monk Parakeet nest construction is even higher. Our results provide evidence of Monk Parakeet preference to certain tree species to nest. This information is useful in urban planning. Decision makers should aim to prevent providing optimal nesting resources for invasive Monk Parakeets in cities.

Our results demonstrate a successful Monk Parakeet invasion in Chile with its largest invasive population in the Santiago metropolis. Management challenges are related not only to the biology of this invasive species, but also to urban territorial complexities, as well as the social dimension. We urge the implementation of a national management plan to monitor the Monk Parakeet population systematically, evaluate their impact and coordinate control and/or mitigation strategies, in order to integrate this information and, in the mid-term future, assess the feasibility for their eradication. The only way to achieve this will be through educating and working with the community and local governments with national coordination and funding.

5. Conclusions

We collected Monk Parakeet parameters through observation and nest sampling and describe the ecology of the largest invasive population in Chile, after almost fifty years since its first reported sighting in Santiago. Recording the locations of Monk Parakeet nests and their attributes, we characterize several aspects of this urban invasion. We found that this population nest at 14 m of height, preferring invasive trees: the Tasmanian blue gum and black locust in particular. Thus, this ecosystem engineer sustains the network of nests in particular invasive trees, which are abundant in urban metropolises. We provide a rough population size estimate and characteristics of Monk Parakeet nests and tree selectivity, aiming to contribute to better urban planning, and to understanding the complexities required to address this expanding bird invasion in many cities of the world.

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