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USE OF TREES AS NESTING SUBSTRATE BY THE MONK PARAKEET (*Myiopsitta monachus*) IN AN URBAN PARK IN SANTIAGO, CHILE

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ABSTRACT: Invasive species can have an impact on the ecological, economic, and general well-being of local ecosystems; as such, documenting their establishment in urban environments is relevant for their management. The Monk Parakeet (*Myiopsitta monachus*) uses various tree species as support for its communal nesting structures. The aim of this study was to characterize the occupied trees and to examine the relationship between their structural attributes as well as the number and vertical position of these structures in Parque O'Higgins, Santiago, Chile. Between June 2023 and June 2024, we conducted systematic surveys covering the entire park. For each occupied tree, we recorded its taxonomic category, height, trunk diameter, number of structures and the minimum and maximum positions of the nesting structures. We recorded 69 communal nesting structures in 23 trees. The number of structures was negatively related to trunk diameter, with no association detected with tree height. *Cupressus* sp. held approximately half of the recorded structures, followed by *Cedrus* sp. And *Araucaria* sp., whereas *Eucalyptus* sp. was less represented. These results concur with previous studies conducted in Santiago, which documented a predominant use of exotic trees and similar numbers of structures per tree. Because tree availability was not quantified, the results describe patterns of use without allowing inferences about selection of or preference for particular substrates. This study provides a baseline for future research on substrate availability, occupancy, and breeding dynamics in urban environments.

KEYWORDS: *biological invasions, exotic birds, nesting, Psittacidae, urban ecology*

Invasive species can cause ecological, economic and health impacts, especially in cities, where habitat heterogeneity and resource availability that favor species with high ecological plasticity (McKinney 2006, Gaertner et al. 2017). In Chile, the Monk Parakeet (*Myiopsitta monachus*) establishes itself mainly in urban and peri-urban environments and has been linked to interactions with resident birds, damage to infrastructure and health risks (Briceño et al. 2019, 2022).

In conservation, biological invasions are recognized as a threat that requires prevention, early detection, and monitoring (Ziller et al. 2005, Tala 2016, Programa de las Naciones Unidas para el Desarrollo 2017). This challenge is especially relevant in central Chile, a priority area for biodiversity conservation; however, hotspot status provides a broad prioritization framework and does not replace the local assessment of the effects of an introduced species (Comisión Nacional del Medio Ambiente 2008, Marchese 2015).

The Monk Parakeet is native to southern South America. Its establishment in Chile has been associated with accidental or intentional releases from the pet trade. The first urban records in the Región Metropolitana date from the 1970s and, since then, the species has expanded its distribution in Santiago and other cities in the country (Briceño et al. 2019, 2022). Its breeding in the country has also been included in

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national syntheses of breeding birds (Medrano et al. 2018).

Wildlife responses to urbanization depend on the taxonomic group, species traits, and environmental context; in mammals, for example, no single strategy of urban adaptation has been identified (Santini et al. 2019). Therefore, patterns of establishment and habitat use must be documented for each species and locality.

Unlike most parrots, the Monk Parakeet builds persistent nests with twigs. A structure may contain one or several independent chambers used by different pairs (Eberhard 1998, Hernández-Brito et al. 2021). In the literature, the term 'colony' may refer to the social or spatial group of individuals or nests, but it is not an unambiguous synonym for each physical mass of twigs. Therefore, in this study we called each mass of twigs that were physically separate and visually distinguishable from other structures in the same tree a 'communal nesting structure'.

In Santiago, Briceño et al. (2022) recorded 1458 structures in 546 trees belonging to 34 species and assessed use and selection using information on the available trees. That study demonstrated a marked use of exotic trees but also showed that frequency of use alone is not equivalent to selection. At a local scale, it is still useful to describe how structures are distributed within urban parks and what attributes the occupied trees have, provided that the scope of the inferences matches the sampling design.

Our aim was to characterize the trees occupied by the Monk Parakeet and the vertical distribution of its communal nesting structures in Parque O'Higgins. Specifically, we described the taxonomic composition of the occupied trees, quantified the number of physically separate structures per tree and assessed its association with diameter at breast height and total height. Because unoccupied trees were not inventoried, substrate selection and preference were not assessed.

METHODS

Study area

The study was conducted in Parque O'Higgins, located in the commune of Santiago, Región Metropolitana, Chile (33°28'S, 70°40'W). Parque O'Higgins is a historic metropolitan green area whose layout and transformations have been described by Domínguez (2000). It covers approximately 75 ha and has trees composed of native and exotic ornamental taxa. Santiago has a Mediterranean climate, with rainfall concentrated in the austral winter and a long dry season, according to the 1991-2020 climatological normals (Dirección Meteorológica de Chile 2020). The composition of the trees generates a marked structural heterogeneity potentially relevant to the use of trees by urban birds (Fig. 1).

Survey and observation units

Between June 2023 and June 2024, the authors conducted systematic walking surveys covering the entire park to locate trees with active communal nesting structures. Surveys were conducted between 08:00 and 12:00 h by direct observation and with Bushnell PowerView 2 10 × 50 binoculars. The general design of the surveys and the standardized recording followed wildlife monitoring criteria (De la Maza & Bonacic 2013). The survey aimed to detect visible structures and did not include an inventory of the available trees.

During the study period, we conducted 52 surveys at a weekly frequency. Once identified, the trees used by Monk Parakeets were photographed and georeferenced. In subsequent surveys, the geographic coordinates and photographic records allowed us to recognize previously recorded trees and avoid counting them twice.

A communal nesting structure was defined as a mass of twigs physically separate and visually distinguishable from other masses in the same tree. A tree could hold one or more structures, which were counted separately. A structure was considered active when individuals were observed entering or leaving it, or when the recent addition of plant material was observed. The unit of statistical analysis was the occupied tree, defined as a tree holding at least one active structure.

Identification and recorded variables

Trees were identified *in situ* from visible morphological characters of the bark, foliage and architecture. Records were standardized to the taxonomic level consistently supported by the observations, and the genus level was kept when the species could not be confirmed. The final categories were *Araucaria* sp., *Cedrus* sp., *Cupressus* sp. and *Eucalyptus* sp.; no botanical reference specimens were collected.

For each occupied tree we recorded: i) taxonomic category; ii) number of active, physically separate communal nesting structures; iii) total tree height; iv)

diameter at breast height, measured 1.30 m above the ground with a diameter tape; v) height of the lowest structure; and vi) height of the highest structure.

Total tree height and the minimum and maximum heights of the communal nesting structures were estimated by an adaptation of the stick method, based on the principle of similar triangles (Martin 2022). A 1-m stick was placed vertically next to the trunk and, from an observation point with sufficient visibility, the apparent length of the stick was compared with a ruler to the apparent length of the tree or of the minimum and maximum positions occupied by the structures. The corresponding height was calculated by multiplying the ratio between the apparent length of the tree or of the position assessed and the apparent length of the stick by the known length of the stick (1 m).

To support the main procedure, we used a Vortex Triumph HD 850 laser rangefinder (Vortex Optics, Barneveld, Wisconsin, USA), set to meters, to measure the horizontal distance between the observation point and the trunk and to help select a suitable position for the estimate. The rangefinder did not measure heights directly, and its readings were not used in the proportional calculation. Set to meters, the instrument displays readings with one decimal place, equivalent to displayed increments of 0.1 m. The manufacturer reports a minimum range of 5.5 m and a nominal accuracy of ± 0.46 m up to 91.4 m.

For each tree, we recorded a final estimate of its total height and of the minimum and maximum positions occupied by the communal nesting structures. Because the field sheet did not record the number of repetitions made for each estimate and no independent assessment of the repeatability of the procedure was conducted, no numerical margin of error was assigned to the heights obtained. Although Martin (2022) evaluated the accuracy of the stick method, the error values reported in that study were not applied to these measurements because of differences in observation conditions and procedures.

When a tree held a single structure, the minimum and maximum heights were the same value. To describe the central vertical position, we calculated the midpoint of the interval as: midpoint = (minimum height + maximum height)/2. This value does not represent the mean height of all individual structures.

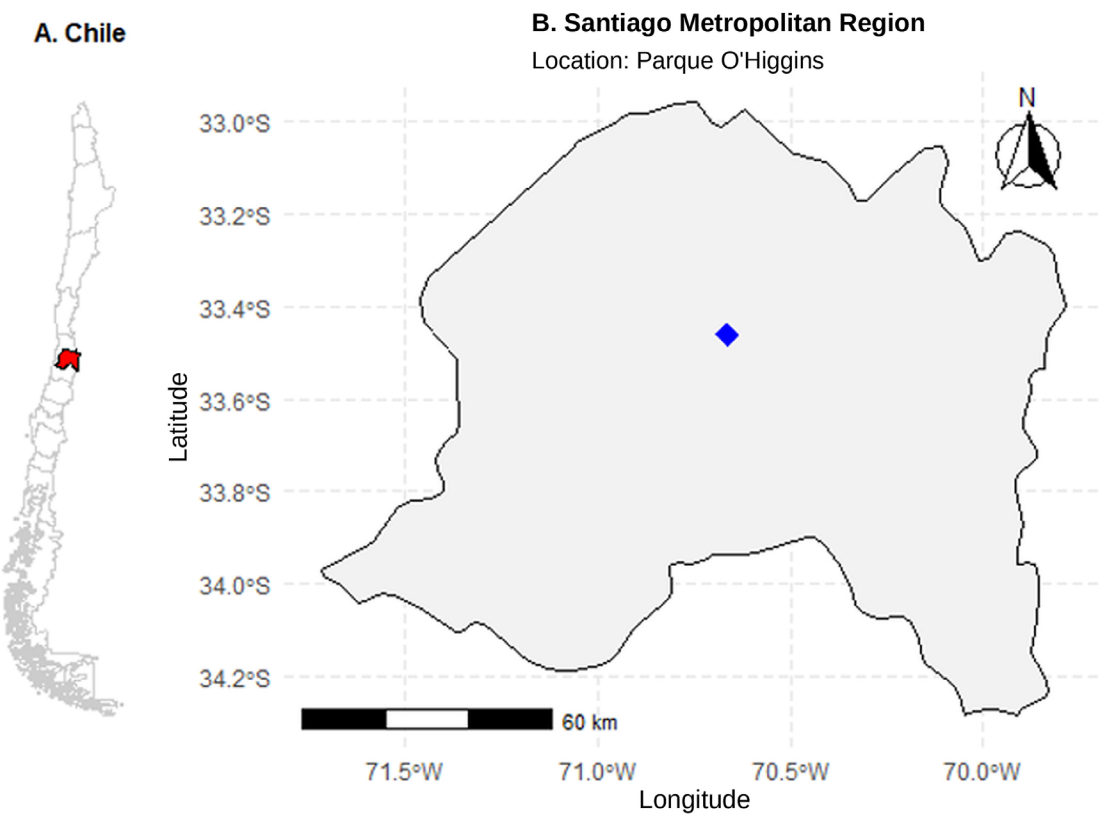


Figure 1. Study area. (A) Location of the Región Metropolitana in Chile. (B) Location of Parque O'Higgins within the Región Metropolitana.

Table 1. Distribution of the trees used and of Monk Parakeet (*Myiopsitta monachus*) communal nesting structures by tree category in Parque O'Higgins, Chile.
[1]SD: standard deviation. No standard deviation is given for *Eucalyptus* sp. because the category was represented by a single tree.

Tree category	Trees, *n*	Trees (%)	Structures, *n*	Structures (%)	Structures per tree, mean ± SD[1]	Median
Araucaria sp.	6	26.1	15	21.7	2.50 ± 1.22	2.50
Cedrus sp.	5	21.7	17	24.6	3.40 ± 1.67	3.00
Cupressus sp.	11	47.8	32	46.4	2.91 ± 2.98	2.00
Eucalyptus sp.	1	4.3	5	7.2	5.00	5.00
Total	23	100.0	69	100.0	3.00 ± 2.30	2.00

Table 2. Descriptive statistics of the trees used and of the vertical distribution of Monk Parakeet (*Myiopsitta monachus*) communal nesting structures in Parque O'Higgins, Chile.
[1]SD: standard deviation.
[2]DBH: diameter at breast height.
[3]In trees with a single communal nesting structure, the minimum and maximum heights were the same value.
[4]The midpoint of the vertical interval was calculated from the minimum and maximum heights recorded in each tree, so it does not represent the mean height of the individual structures.
[5]IQR: interquartile range.

Variable	*n*	Mean ± SD[1]	Median	Range	IQR[5]
Total tree height (m)	23	25.61 ± 4.91	25.00	17-34	9.00
DBH[2] (cm)	23	50.13 ± 24.67	44.00	17-111	29.00
Number of communal nesting structures per tree	23	3.00 ± 2.30	2.00	1-10	3.00
Minimum height of structures[3] (m)	23	14.83 ± 5.41	15.00	8-27	8.50
Maximum height of structures[3] (m)	23	20.52 ± 4.08	20.00	13-27	8.00
Midpoint of the vertical interval[4] (m)	23	17.67 ± 3.79	17.50	12-27	4.25

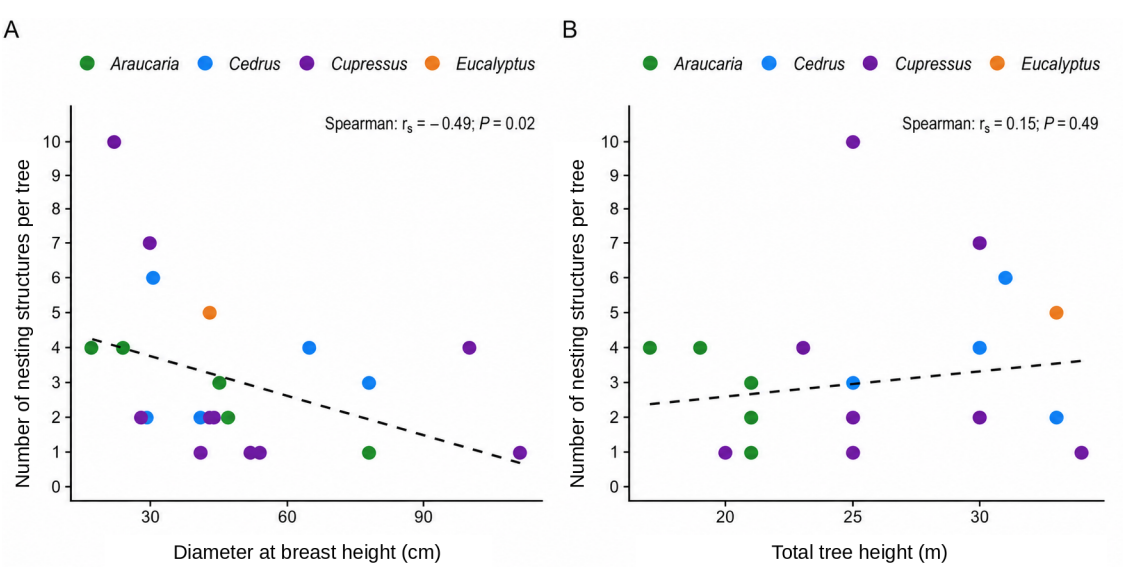


Figure 2. Relationship between the structural characteristics of trees and the number of Monk Parakeet (*Myiopsitta monachus*) communal nesting structures in Parque O'Higgins, Chile. (A) Relationship between diameter at breast height (DBH) and the number of structures per tree. (B) Relationship between total tree height and the number of structures. Colors identify tree categories, and dashed lines represent purely descriptive linear trends. Statistical inference was based on Spearman correlations.

During part of the fieldwork, notes were taken on openings visible from the ground. However, these records were incomplete, were not obtained with a systematic protocol and were aggregated by tree, without reliable assignment to each communal nesting structure. Moreover, an externally observed opening does not confirm the existence or use of an internal chamber. Consequently, these records were excluded from the analyses and were not interpreted as chamber counts.

Statistical analysis

Each occupied tree was considered an independent unit (n = 23). We calculated descriptive statistics for total height, diameter at breast height, number of structures per tree and their vertical positions. Continuous variables were expressed as mean ± standard deviation, median, range and interquartile range.

The association of the number of structures per tree with total height and diameter were assessed with Spearman rank correlation (r_s). Differences between tree categories were explored with the Kruskal-Wallis test. This comparison was interpreted with caution because of the small and unequal group sizes, particularly because *Eucalyptus* sp. was represented by a single tree. Analyses were performed in R 4.3.1 (R Core Team 2023), with α = 0.05. Statistics and probability values are given to two decimal places.

RESULTS

Structures and tree categories

We recorded 69 communal nesting structures in 23 occupied trees. The number of structures per tree ranged from one to ten, with a mean of 3.00 ± 2.30 and a median of 2.00. Sixteen trees held more than one physically separate structure and seven held a singular nesting structure.

The occupied trees belonged to four taxonomic categories. The distribution of trees and communal nesting structures among these categories is shown in Table 1. These frequencies describe only the occupied trees and do not represent selection, because the availability of tree categories in the park was not quantified. The relationship between the number of structures and the structural characteristics of the occupied trees is shown in Fig. 2.

Tree dimensions

The occupied trees had a mean total height of 25.61 ± 4.91 m (range: 17-34 m) and a diameter at breast height of 50.13 ± 24.67 cm (range: 17-111 cm; Table 2).

The number of structures showed a moderate negative correlation with diameter at breast height (r_s = −0.49, p = 0.02, n = 23). Within the set of occupied trees, trees with larger diameters tended to hold fewer physically separate structures (Fig. 2A). No association was detected between total height and the number of structures (r_s = 0.15, p = 0.49, n = 23; Fig. 2B).

The exploratory comparison showed no detectable differences in the number of structures between tree categories (Kruskal-Wallis: H = 3.10, df = 3, p = 0.38; Fig. 3). The size and imbalance of the groups limit this comparison.

Vertical distribution

The minimum and maximum positions recorded spanned 8-27 m above the ground. The midpoint of the vertical intervals was 17.67 ± 3.79 m, with a median of 17.50 m and a range of 12-27 m (Table 2). In trees with multiple structures, the span between the lowest and highest positions ranged between and 17 m (Fig. 4). In trees with a single structure, the interval was zero.

The auxiliary records of visible openings were not chamber counts: they were available only for some of the trees and in aggregated form, so no means or standard deviations per structure were calculated.

DISCUSSION

This study provides a quantitative, tree-scale characterization of Monk Parakeet nesting in Parque O'Higgins. We recorded 69 physically separate communal nesting structures in 23 trees and described their distribution among tree categories, their vertical position and their relationship with the dimensions of the occupied trees. Within this set, the number of structures was negatively associated with trunk diameter, but not with total height, and no differences was detected between the four tree categories. These results do not assess substrate selection, but they do establish a local baseline with which temporal changes and new sectors of the park can be compared.

The spatial relationship between the present study and Briceño et al. (2022) should be interpreted with caution. The maps published by those authors show records in central Santiago, but their resolution and symbol size do not allow us to determine unambiguously whether any of the recorded trees were within the boundaries of Parque O'Higgins or to calculate an

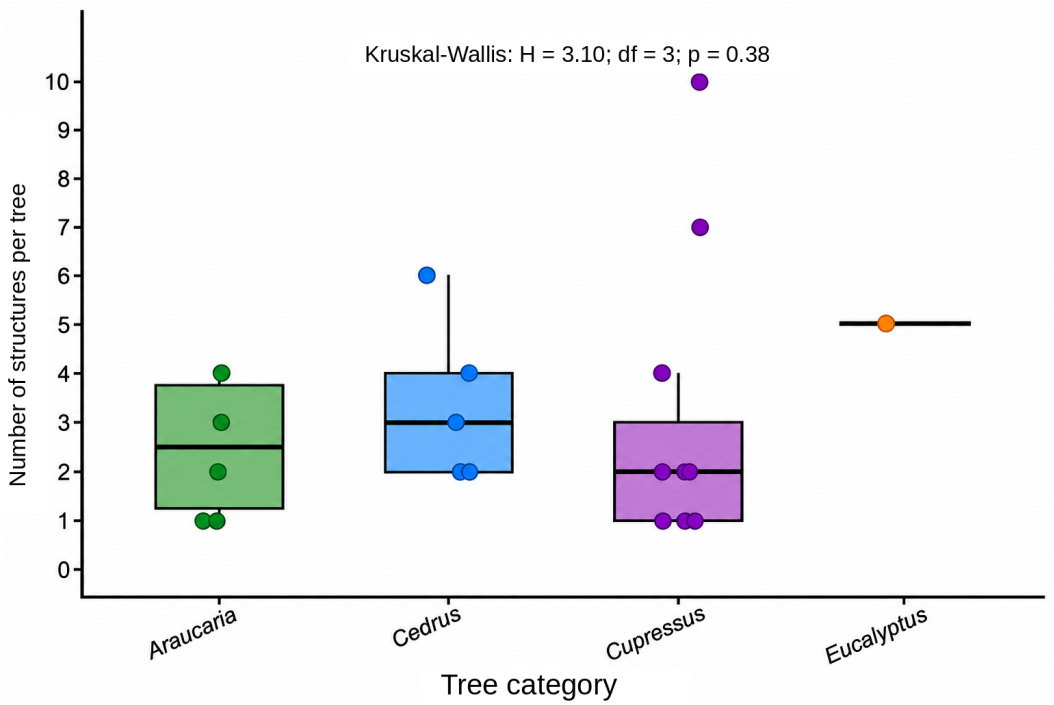


Figure 3. Exploratory comparison of the number of Monk Parakeet (*Myiopsitta monachus*) communal nesting structures per tree between tree categories in Parque O'Higgins, Chile. Boxes represent the interquartile range and median, and points correspond to individual trees. The exploratory comparison showed no detectable differences between categories (Kruskal-Wallis: $H = 3.10$; df = 3; $p = 0.38$). *Eucalyptus* sp. was represented by a single tree, so the results should be interpreted with caution.

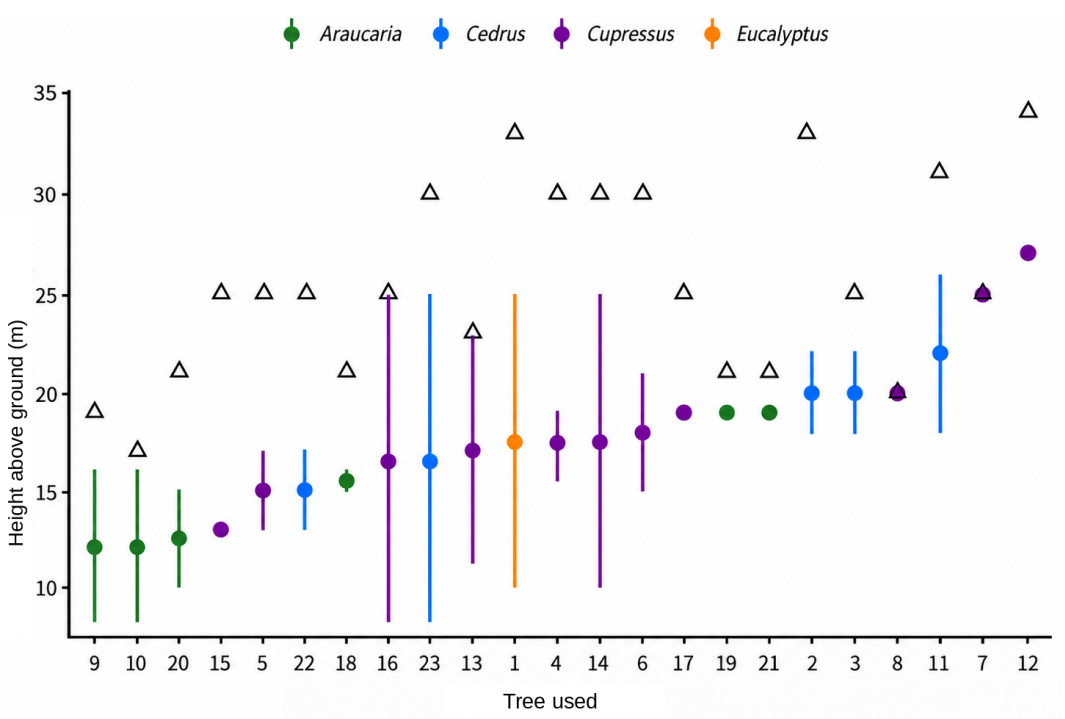


Figure 4. Vertical distribution of Monk Parakeet (*Myiopsitta monachus*) communal nesting structures in the trees used in Parque O'Higgins, Chile. Each colored segment represents the interval between the minimum and maximum heights of the structures recorded in a tree, and the dot indicates the midpoint of the vertical interval. Triangles indicate the total height of each tree. Colors identify tree categories. In trees with a single structure, the interval has zero length and is represented only by a dot.

exact minimum distance from the trees assessed in this study. The individual coordinates of the records of Briceño et al. (2022) are not available in the publication, so a metric spatial comparison between the two datasets was not possible. Consequently, we avoided inferring spatial overlap or identity between the sampled sites based solely on the graphical representation. Nevertheless, both studies belong to the urban matrix of Santiago and allow a descriptive comparison of the recorded patterns. The mean of 3.00 structures per tree observed in Parque O'Higgins was close to the 2.67 reported by Briceño et al. (2022) for 546 trees in Santiago. This numerical similarity does not imply equivalence between the two datasets, since Briceño et al. (2022) covered a larger spatial extent and 34 tree species, whereas the present study was restricted to one park and four taxonomic categories. In addition, those authors reported means above four structures per tree in Paraná pine (*Araucaria angustifolia*) and cedar of Lebanon (*Cedrus libani*), with maximums valueshigher than that recorded in this study. The differences between the two studies could be related to sampling scale, tree composition, local occupancy history or recording criteria; these explanations are hypotheses and were not directly assessed.

The negative association between trunk diameter and the number of communal nesting structures per tree ($r_s = -0.49$; $p = 0.02$) was the primary pattern detected. Its direction might seem counterintuitive, since trees with larger diameters would be expected to offer greater support capacity. However, trunk diameter does not necessarily represent crown architecture, the availability of bifurcations, branch strength or the age of the structures. In urban environments, some large-diameter trees may be individuals subjected to repeated pruning or crown modifications that reduce the available anchoring points, whereas trees of intermediate diameter could retain an architecture more favorable for supporting multiple structures. Nor did we quantify the volume, mass or number of chambers of the structures. Therefore, the observed correlation does not demonstrate a causal effect or a preference for smaller-diameter trees. This interpretation is hypothetical, since crown architecture, pruning history and the biomechanical characteristics of the branches were not assessed. Its value lies in identifying an empirical relationship that can be tested by incorporating attributes of the crown and of the supporting branches.

The lack of a detectable association with total height shows that, among the occupied trees, the tallest trees did not necessarily hold more structures. The positions recorded between 8 and 27 m are consistent with the elevated nesting described in other cities (Burger & Gochfeld 2000, Volpe & Aramburú 2011, Briceño et al. 2022). This interval provides a local reference for future monitoring of the same trees. However, the minimum and maximum measurements do not allow the individual height of the 69 structures to be reconstructed and, because the repeatability of the proportional method was not assessed, the vertical distribution should be interpreted considering the uncertainty inherent in an indirect estimate.

Cupressus sp. was the most represented category among the occupied trees, followed by *Araucaria* sp., *Cedrus* sp. and *Eucalyptus* sp. This composition documents the substrates used in the park during the study period and makes it possible to identify trees and categories that can be prioritized in subsequent monitoring. However, their frequency is not equivalent to selection. Briceño et al. (2022) compared used and available trees in Santiago and documented selection of some species, whereas Volpe & Aramburú (2011) assessed preferences with information on the available trees in an Argentine city. Because the available trees were not inventoried in Parque O'Higgins, the greater representation of a category may reflect both its local availability and its use by the parakeets. Likewise, the absence of detectable differences between categories should not be interpreted as evidence of equivalence, given the small and unequal group sizes.

A limitation of the study is that the number of internal chambers of the communal nesting structures was not quantified. The field notes referred to openings visible from the ground, were incomplete and could not be reliably assigned to each structure. Moreover, an external opening does not confirm the existence of an internal chamber or its use for breeding. Therefore, it was not possible to estimate the internal complexity of the structures or to make quantitative comparisons with studies that explicitly distinguished nests, openings and chambers, such as Aramburú et al. (2023). Direct inspection or the use of appropriate remote methods would allow this variable to be addressed in future studies.

Even with these constraints, the baseline obtained can support focused ecological monitoring. Recording the number of structures per tree, their vertical interval and the dimension of the substrate provides reference points for detecting, in subsequent surveys, the appearance or disappearance of structures and changes in their distribution within the park. This usefulness relates to monitoring and does not in

itself constitute a risk assessment. Nor do the results justify interventions concerning the different tree categories or allow us to state that higher or more numerous structures are more likely to collapse. A management assessment would require combining ecological monitoring with arboricultural inspections, measurements of the size and condition of the structures and records of their proximity to areas of public use. Control decisions also require explicit objectives and evaluation of effectiveness (Canavelli et al. 2012).

Future studies should make an inventory of the available trees, including occupied and unoccupied trees and record attributes of the crown and of the supporting branches. Repeated monitoring of individual trees would allow the persistence and turnover of structures to be assessed, whereas direct inspection or appropriate remote methods would allow their internal complexity to be estimated. With larger samples, this data could be analyzed with multivariate count models and explicit use-availability designs. It would then be possible to assess whether the pattern associated with diameter persists after controlling for other tree characteristics and local availability.

In summary, we quantitatively characterized Monk Parakeet nesting in 23 occupied trees in Parque O'Higgins. The study documented the composition of the substrates used, the vertical distribution of the structures and a negative association between their number and trunk diameter. This relationship does not demonstrate causality or preference, but it is a verifiable pattern. The main contribution is therefore a local, tree-scale baseline and a set of results that allow explicit predictions to be formulated for future studies on the use of urban trees.

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USE OF ARTIFICIAL INTELLIGENCE

No artificial intelligence was used during the research for the collection, generation, modification or analysis of the data, or for obtaining the scientific results. During the preparation and revision of the manuscript, generative artificial intelligence (ChatGPT, OpenAI) was used as a support tool for organizing information, language editing, checking the coherence and consistency of the text, and visual refinement of figures previously prepared by the authors. Artificial intelligence was not used to generate data, determine results, make scientific interpretations autonomously or replace the review of the original sources. The authors verified the sources, analyses, interpretations and final version of the manuscript, and take full responsibility for its content.

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