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Population Size, Non-Breeding Fraction, and Productivity in a Large Urban Population of Burrowing Parrots (*Cyanoliseus patagonus*)

Daiana N. Lera [1], Natalia Cozzani [1,*], José L. Tella [2] and Sergio Zalba [1]

[1] GEKKO, Grupo de Estudios en Conservación y Manejo, Departamento de Biología, Bioquímica y Farmacia, Universidad Nacional del Sur, San Juan 670, Bahía Blanca B8000CPB, Buenos Aires, Argentina; daiana.lera@conicet.gov.ar (D.N.L.)
[2] Estación Biológica de Doñana (EBD-CSIC), Américo Vespucio 26, 41092 Sevilla, Spain; tella@ebd.csic.es
* Correspondence: ncozzani@uns.edu.ar

Abstract: Psittaciformes are one of the bird orders with the highest number of threatened species and the most marked declining population trends. At present, the lack of information on the population size, reproductive fraction, and productivity of most parrot populations makes it difficult to design effective conservation actions. In this study, we monitored a population of Burrowing Parrots (*Cyanoliseus patagonus*) breeding in urbanized habitats in the southwest of Buenos Aires province, Argentina. Every December and February from 2018 to 2023, we counted the individuals arriving at a single communal roost, located in the main park of Bahía Blanca city, which gathers all the parrots breeding in 18–22 colonies within a radius of 20 km. Censuses were conducted before (December) and immediately after the incorporation of juveniles into the flocks (February). Breeding pairs were also counted annually in the colonies, and the average annual productivity and the proportion of juveniles were estimated from surveys in pre-roosting and feeding areas in February. The non-breeding fraction approached half of the population with no statistically significant differences among years (range: 37–53%), and the breeding population showed little annual variation, with a minimum of 1363 and a maximum of 1612 breeding pairs. The proportion of juveniles in the flocks and the estimated productivity showed larger variations among breeding seasons. Our results add insight to the scarce information available on the breeding-to-non-breeding-population ratios in parrots, and birds in general, and show key breeding parameters for a species that is thriving well in urban habitats.

Keywords: coloniality; floaters; population dynamics; Psittacidae; quarries; ravines; reproduction; urbanization

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1. Introduction

The order Psittaciformes contains approximately 400 species, 56% of which are in global decline and 28% of which are listed as threatened by the IUCN [1,2]. Habitat loss, degradation and fragmentation, and wildlife trade are considered the main anthropogenic threats to this group of birds [3]. Despite this situation, there is still a lack of information on the population size and productivity for most parrot species [4,5], as well as on the non-breeding fraction of their populations [6–8], which are key to understanding the relationship between the reproductive ecology of a species and its ability to persist in the long term, and to identify and manage the forces that compromise its persistence.

The abundance of "floaters", i.e., individuals that are able to breed but do not do so, may respond to different factors, ranging from the restriction of mates or nesting sites, to the "decision" of individuals to avoid breeding in sites that reduce their fitness [9,10]. Floaters may buffer the risk of population extinction, although their interaction with breeding pairs could also interfere with their reproductive success [11]. Adequate knowledge of the changes in the proportion of floaters and their causes is also key for designing effective conservation policies [10,12,13].

The Burrowing Parrot (*Cyanoliseus patagonus*) is a Neotropical psittacine found in Argentina and Chile [14,15], and occasionally reaching Uruguay [16]. Its populations have declined since the early 19th century as a result of the loss and degradation of natural environments, its persecution for mistakenly being considering an agricultural pest, and the pet trade [17–19]. The Burrowing Parrot is one of the few primary cavity nesters in its order, and it generally requires limestone or sandstone cliffs to excavate its nests, forming colonies of variable sizes, mostly along river banks and seasides [18,20]. Like other riparian bird species, it is limited by the availability of nesting substrates [21,22], but it is able to take advantage of constructions and anthropogenic environments for breeding [23]. In particular, artificial ravines and quarries associated with public works give access to additional nesting sites, especially in areas with limited natural cliffs [20].

Although several studies have been carried out on the abundance and reproductive biology of Burrowing Parrots [24–27], little is still known about the productivity of the species, especially in urban environments [28]. Moreover, although the presence of non-breeding individuals has been recorded in breeding areas [18], there is limited information on the reproductive fraction and the abundance and importance of floaters for this species [29]. In fact, to our knowledge, the breeding-to-non-breeding-population ratios have been only estimated among psittacines for two macaw species [6–8] , in spite of a wide consensus about its theoretical and applied importance [11,12,29,30].

Given the continuous process of loss and transformation of natural environments and the advance of human-dominated habitats, including urban and peri-urban environments, it is of particular interest to assess the breeding population structure and reproductive performance of the Burrowing Parrot in urban areas and how it could contribute to the conservation of the species. In this study, we present estimates of the abundance, non-breeding fraction, and productivity of a Burrowing Parrot population inhabiting a highly modified landscape in the southwest of Buenos Aires province, Argentina, over four breeding seasons.

2. Materials and Methods

2.1. Nesting Sites and Abundance of Breeding Pairs

This study comprised the colonies of Burrowing Parrot located in the city of Bahía Blanca, Argentina (38°43′0′′ S, 62°16′0′′ O), and in the surrounding rural areas within a radius of 20 km [31]. All the individuals breeding in this large area congregate daily over the years in a single urban communal roost [20,25] (Figure 1a). Colonies were defined as well-delimited nesting sites, such as quarries and slopes along main routes and country roads. These sites greatly varied in suitable nesting surface, accessibility to predators, and human disturbances [31]. In a few instances, quarries offered several artificial cliffs occupied by Burrowing Parrots within a range of 400 m but, after [32], these reproductive cores were considered as single colonies given that all individuals reacted together against human or predator intruders. Therefore, although breeding birds from different colonies may share foraging grounds and communal roosts, the particularities of each nesting site may strongly affect breeding success and colony dynamics [33] and thus justify this functional definition of a colony from a reproductive point of view.

We conducted 79 censuses of breeding pairs in four breeding seasons, which extend from September to February: 18 in 2018–2019, 22 in 2019–2020, 21 in 2021–2022, and 18 in 2022–2023. These censuses were carried out during the incubation and parental care periods (October and November), because the monitoring of nesting sites at the beginning of the season (September) can lead to the erroneous assignment of breeding pairs, considering that floaters may search for burrows but ultimately fail to breed [34].

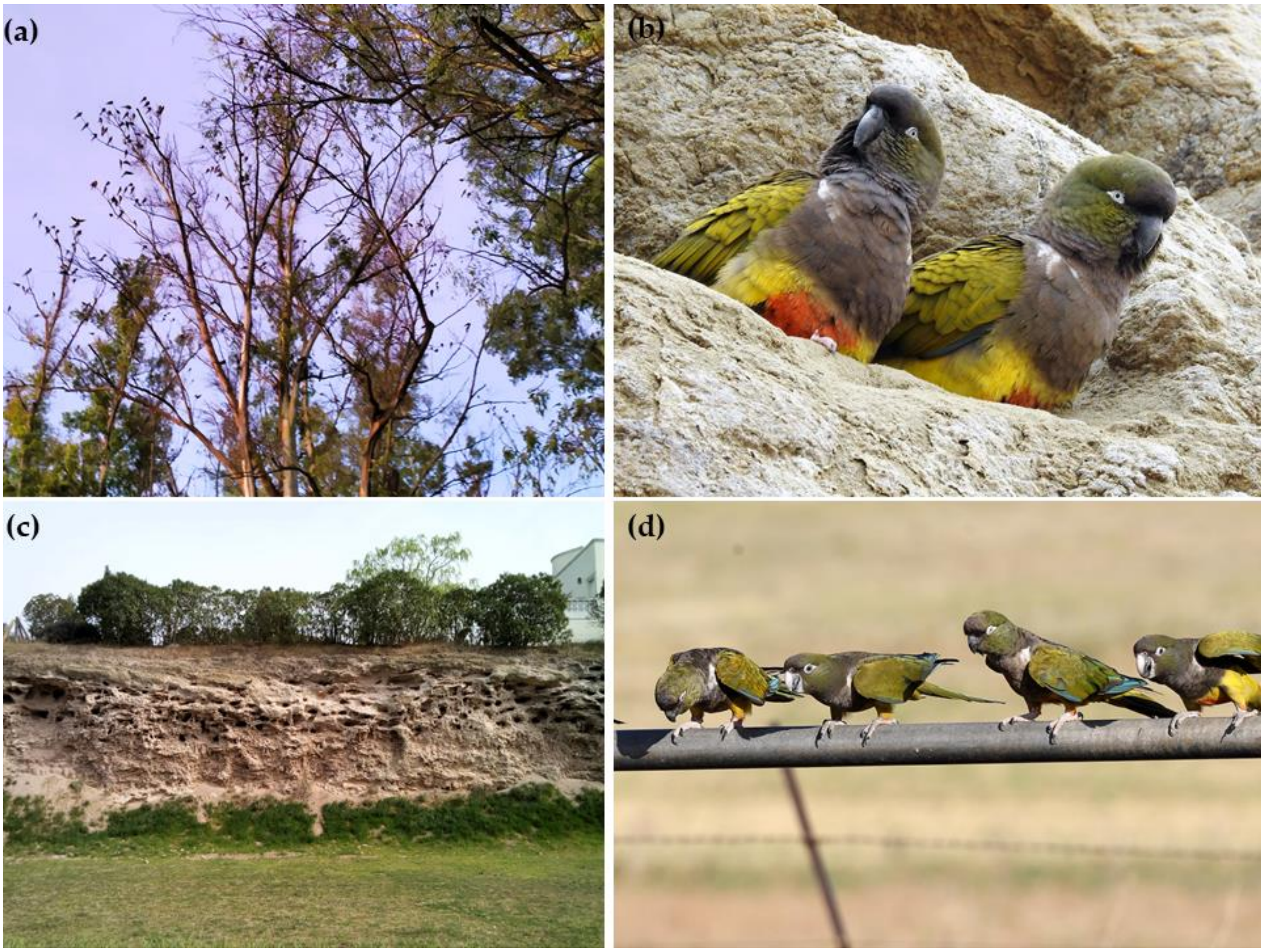

Figure 1. (**a**) Burrowing Parrots roosting in eucalyptus trees on the urban communal roost in Bahía Blanca. Photograph: Daiana Lera. (**b**) Breeding pair of Burrowing Parrots in the entrance of their nest cavity. Photograph: Carlos Soulier. (**c**) Urban ravine with burrow nests of Burrowing Parrots in the city of Bahia Blanca. Photograph: Daiana Lera. (**d**) Phenotypic differences between adult and juvenile stages of the species, with dark bills in the former and ivory-colored bills in the latter. Photograph: José L. Tella.

We recorded the number of burrows in which adults were observed entering and/or exiting, or perched at the entrance for extended periods of time (more than 15 min; Figure 1b). Each section of a ravine with breeding activity was censused for 40 min (Figure 1c). The number of active burrows was counted every ten minutes (four times per census). The counts were carried out between 7:00 a.m. and 1:00 p.m., this being the time range of greatest activity detected in pilot tests. Individuals that entered the nest repeatedly and those whose close proximity to the burrow and permanence in the place exceeded 15 min were considered as breeders. Food provision events between the members of a pair in proximity of a burrow were also taken into account to identify active nests. The maximum number of active nests recorded was used as the colony size for the analyses. A one-way analysis of variance test was performed to detect possible interannual variations in the number of breeding pairs.

2.2. Non-Breeding Fraction and Total Population Size

To estimate the percentage of the non-breeding population, data on the total number of breeding pairs in the whole study area were combined with censuses carried out during the same periods in the communal roost, located in an urban park in the city, where the whole population congregates every night [20,25,28]. Roost counts were conducted in December, when the well-developed chicks are still in the nest while their parents gather into the roost every night, as we observed during our surveys. Six censuses were completed: one in 2018, one in 2019, two in 2021, and two in 2022. Since nestlings were still in their nests, the individuals counted in the roost censuses corresponded to the total number of adults, breeders, and non-breeders (i.e., total population size) present in the study area each year. The non-breeding fraction was then calculated by subtracting from the total population size the estimated number of breeding adults resulting from the censuses of colonies. A contingency table [35] was used to evaluate possible differences in the reproductive fraction between the studied seasons.

The roost censuses were carried out with the collaboration of volunteers who worked in groups distributed at six fixed points located at distances ranging between 300 and 1200 m around the communal roost. Each group of two or three observers was positioned at a fixed point and covered a transect relatively perpendicular to the flight directions of parrots arriving to the roost, so that, altogether, they completed a closed observation polygon surrounding the roost. During each survey, which lasted between 45 and 60 min before sunset until after evening twilight, the number of parrots flying towards the communal roost was recorded in consecutive 15 min time slots. The groups of observers communicated with each other and stopped the tasks after about 15 min had passed without any observations, which tended to vary between surveys, resulting in differences in duration. Rainy and windy days were avoided to minimize weather conditions that could reduce visibility and/or interfere with parrot arrival times.

2.3. Proportion of Juveniles and Average Annual Productivity

Counts at the communal roost were repeated each February in order to estimate the number of juveniles joining the population at the end of the breeding season (one census in 2019, one in 2020, two censuses in 2022, and two in 2023). To estimate the proportion of juveniles, 61 surveys were conducted during February of each breeding season, 8 in February 2019, 17 in 2020, 21 in 2022, and 15 in 2023. In 2019, the counts were carried out in feeding areas and in pre-roosting areas (urban spaces where concentrations of individuals were recorded minutes before flying to the communal roost), while in February 2020, 2022, and 2023, they were only concentrated in pre-roosting areas. Only groups of 20 or more parrots were considered. The individuals were observed with binoculars or telescopes at distances of 10 to 50 m. Juveniles were easily identified at distance by the ivory-white color of their bills in contrast to the dark gray of the adults (Figure 1d), and by the dark iris of the eyes of juveniles, in contrast to the almost white iris of adults, differences that disappears after a few months.

The proportion of juveniles with respect to the total number of parrots was calculated for each survey. A one-way analysis of variance was performed to evaluate possible variations in the proportion of juveniles between years. Significant differences were compared using Scheffé's test [35]. Finally, the annual productivity was calculated as the average number of juveniles per breeding pair. For this, the number of juveniles in each breeding season was estimated as the product of the total estimated population size in February (after the effective incorporation of juveniles) multiplied by the proportion of juveniles estimated in the corresponding surveys, and then divided by the total number of breeding pairs.

3. Results

3.1. Nesting Sites and Abundance of Breeding Pairs

Twenty-three colonies of Burrowing Parrots were recorded and monitored throughout this study, with all of them located in substrates of anthropic origin, corresponding to roadsides and quarries (Table 1). Four additional small colonies were found on natural substrates, with all of them arranged on stretches of ravines next to watercourses, and mostly located on private land. However, they were excluded from the analysis given the difficulty of accessing these sites for accurately counting the breeding pairs, also considering their minor contribution to the breeding population (estimated as less than 40 pairs per year in total).

Table 1. Colonies of Burrowing Parrot detected in the city of Bahía Blanca, Argentina, and the surrounding rural area within a radius of 20 km in four reproductive seasons. The number of breeding pairs counted per colony and per year, and the anthropic substrate on which each colony was established are reported.

Colony N°	Breeding Pairs 2018–2019	2019–2020	2021–2022	2022–2023	Substrate
1	41	85	25	72	Quarry
2	130	125	112	72	Roadside
3	8	3	3	3	Quarry
4	5	No parrots	No parrots	No parrots	Quarry
5	84	103	59	73	Quarry
6	5	11	17	9	Roadside
7	16	16	10	6	Roadside
8	10	13	36	39	Quarry
9	12	28	No census	No census	Quarry
10	33	57	18	68	Quarry
11	163	166	240	242	Quarry
12	19	31	13	No census	Quarry
13	69	56	47	38	Quarry
14	75	111	123	129	Quarry
15	645	554	498	367	Quarry
16	29	59	65	54	Quarry
17	19	68	43	41	Quarry
18	No parrots	16	17	8	Quarry
19	No census	11	7	No census	Quarry
20	Did not exist	49	59	81	Roadside
21	Did not exist	35	147	131	Roadside
22	Unknown	15	No census	No census	Roadside
23	No parrots	No census	6	No census	Quarry

The number of sites surveyed each year varied depending on the accessibility to the properties where they were located, and because of the availability of new sites that were colonized by the species (Table 1). Colony size ranged from 3 to 645 breeding pairs. The maximum total number of breeding pairs (1612) was recorded during the 2019–2020 season, distributed among 22 colonies, while the minimum (1363 pairs breeding in 18 colonies) was recorded in 2018–2019 (Table 2). Apart from this, the mean values of the number of pairs per colony showed no significant differences between years (F = 0.003; p = 0.99).

Table 2. Maximum number of individuals counted at the communal roost in December (pre-fledgling population size), number of breeding pairs, non-breeding population fraction (%), and colonies surveyed in an area of 20 km radius around the city each year.

Season	Pre-Fledgling Population Size	Breeding Pairs	Non-Breeding Fraction (%)	Number of Colonies
2018–2019	5802	1363	53.02	18
2019–2020	5110	1612	36.91	22
2021–2022	5845	1545	47.37	21
2022–2023	5095	1433	43.75	18

3.2. Population Size and Non-Breeding Fraction

The maximum annual number of parrots counted at the communal roost ranged from 5095 in December 2022 to 5802 in the same month of 2018, with a mean of 5448 (Table 2). The mean number of breeding pairs was 1488. The non-breeding fraction ranged from a minimum of 36.91% in December 2019 to a maximum of 53.02% in December 2018, and did not vary significantly along the four breeding seasons ($X^2 = 7.815$; df = 3; $p = 0.8$).

3.3. Proportion of Juveniles and Mean Annual Productivity

The mean number of individuals counted in the surveys used to estimate the proportion of juveniles at the end of the breeding season was 90.88 ± 50.67 (n = 61). The number of juveniles, in turn, was 21.08 ± 15.26. The proportion of juveniles ranged from 0.15 ± 0.11 (approximately one juvenile for every six adults) in February 2019 to a maximum of 0.32 ± 0.10 (approximately one juvenile for every two adults) in February 2023. The proportion of juveniles varied significantly between the years studied ($F = 8.33$; $p < 0.0001$), with significantly higher values in February 2023 with respect to those calculated for the same month in 2019 ($p = 0.0002$), in 2020 ($p = 0.02$), and in 2022 ($p = 0.04$). The minimum productivity corresponded to the 2021/2022 season and was 1.16 ± 0.46 juveniles per breeding pair, while the peak in productivity was estimated for the 2022/23 season, with 2.27 ± 0.68 juveniles per breeding pair (Table 3).

Table 3. Maximum number of individuals counted at the communal roost in February (post-fledgling population size), estimated number and proportion of juveniles, and productivity per pair in four breeding seasons (±SD). Values in brackets indicate number of surveys.

Season	Post-Fledgling Population Size	Number of Juveniles	Proportion of Juveniles	Productivity (Juveniles/Breeding Pair)
2018–2019	12,693	1873 ± 1354	0.15 ± 0.11 (8)	1.37 ± 0.99
2019–2020	12,972	2824 ± 1031	0.22 ± 0.08 (17)	1.8 ± 0.64
2021–2022	7739	1786 ± 715	0.23 ± 0.09 (21)	1.16 ± 0.46
2022–2023	10,024	3247 ± 988	0.32 ± 0.10 (15)	2.27 ± 0.68

4. Discussion

The results of this study show that the use of anthropic nesting substrates, together with the ability of the Burrowing Parrot to colonize urban environments [36], has allowed the area surveyed to host a large breeding population, perhaps one of the largest populations known to date, after the Condor and La Lobería in the province of Río Negro [14]. Although historical data are not available, this breeding population is likely to have been much smaller due to nest site limitations before human activities in the area allowed the species to occupy quarries [20]. This opportunistic use of artificial ravines as nesting substrates has been cited for birds from different groups and in different regions of the world (e.g., *Merops apiaster* [37], and *Riparia riparia* [38]); however, we are not aware of similar reports for other species of psittacines, at least not with the disproportionate intensity of use carried out by the Burrowing Parrot in our study area.

The assessment of population size is key for conservation planning, but estimating the number of breeding individuals is particularly challenging for species for which accurate population biology information is not available. In the case of parrots, their gregarious behavior decreases in the breeding season, when breeding pairs may be much more associated with their sparser nesting sites and thus are less detectable [39,40]. However, our studied population congregates repeatedly over the seasons and years in a single urban communal roost [25], and breeds colonially year after year in urban and rural anthropic substrates [20], thus facilitating monitoring of both the breeding and total population sizes. Nonetheless, it is worth noting that our results reflect reasonable estimations rather than accurate population censuses. On the one hand, although counts of individuals at roosts are suitable for estimating population sizes of communal roosting parrots that concentrate in well-known localities [39,40], single counts such as those performed here do not allow for identifying uncertainty in population size estimates related to detection errors [41,42]. Despite these limitations, roost counts allow for estimating a reasonable lower bound for total population sizes [43] and their inter-annual changes (e.g., [42,44]). On the other hand, our censuses of breeding pairs, ranging from 1363 to 1612 pairs across years, slightly underestimated the actual breeding population sizes since a few pairs breeding in natural nesting substrates could not be accurately surveyed.

However, with the precaution imposed by the abovementioned methodological constraints, our results suggest little inter-annual variations in breeding population sizes and total population sizes during the chick-earing period (December). However, total population sizes notably increased, even doubled in some years, when fledglings were incorporated into the roosting flocks (February). This increase is explained by the arrival of immigrant adults, probably non-breeders, from distant areas, with the number of immigrants increasing along autumn and winter [25]. In the case this migration process, revealed by our intensive monitoring of the roost [25], would be ignored, the simple calculation of the number of parrots censused in February minus those censused in December would lead to a much-overestimated, unreliable number of fledglings. Taking all this information into account, the estimated fraction of breeding birds, approaching 50% of the local population size, did not statistically change over the years, and resembled the calculations made by [28], who obtained a value of 54% in December 2013 for the same population.

The percentage of breeding individuals of Burrowing Parrots was high compared to the lower values (ca., 20%) reported for Red-fronted macaws *Ara rubrogenys* and Lear's macaws *Anodorhynchus leari*, whose world populations are dominated by non-breeding individuals [6–8]. These differences between species could be related to their life histories, particularly to the greater longevity and delayed maturity in macaws, which could be especially relevant in short-term studies [45,46], and could logically lead to smaller breeding fractions [47]. Therefore, it is important to study the longevity and age of first breeding of the species in the wild, but also the length of the post-reproductive life (senescence), which also greatly varies among species as indicated by data from captive parrots [46] and may contribute to the non-breeding fraction of the populations. There is a marked scarcity of information on breeding-to-non-breeding ratios for psittacines and birds in general [12,48]. Therefore, it is necessary to expand knowledge on the reproductive biology of species with different life history traits, including the estimation of non-breeding population fractions, considering its particular importance for monitoring vulnerability and designing conservation actions [49].

In addition to the potential effects of life history traits, the relatively high percentages of breeding individuals found for Burrowing Parrots could also be associated with their ability to excavate their own nests and its flexibility to colonize new sites suitable for nesting. These facts could give an advantage over other parrot species that nest in secondary cavities, thus depending not only on pre-existing hollows but also on their specific characteristics, such as the width of the entrance, the depth of the cavity, and the height from the ground [50–53].

On the other hand, the relatively constant number of breeding pairs detected between seasons may indicate that although artificial ravines provide additional nesting sites for the species, the region may be saturated with breeding pairs [31].

The estimation of the proportion of juveniles by means of surveys conducted just after each breeding season can allow for obtaining an indirect measure of productivity when the breeding population size is known and juveniles are phenotypically distinct from adults [6]. In the case of Burrowing Parrots, the juveniles are easily identified at distance by the ivory-white coloration of their bills, which reduces possible calculation errors. The highest productivity in our study corresponded to 2023, preceded by much lower values in the three previous years, and always below the values previously estimated for the species at El Cóndor, where the mean number of juveniles fledged per breeding pair was 3.0 ± 0.2 [26]. The decreases in juvenile production coincide with regional drought events that are frequent in southwestern Buenos Aires [54]. This scarcity of precipitation is commonly associated with the meteorological phenomenon of La Niña, cited as responsible for reductions in the survival of fledglings on the natural cliffs of northeastern Patagonia, Argentina [26,55] and mass mortality events of individuals in 2020–2021 [56]. It should be noted that the productivity values in our study are slightly overestimated because a few small colonies breeding in natural substrates were not included in the analyses. Moreover, the productivity of materials could have also been affected by the extractive activity in certain quarries, which resulted in the destruction of some nests, and by the extraction of chicks by illegal collectors. Although professional nest poaching for the international pet trade ceased with the European ban in wild-bird trade in 2005 [20], we have direct and indirect records of nest poaching, such as the presence of hooks in the ravines.

Our results add valuable insights to the scarce information available on the breeding-to-non-breeding-population ratios in parrots and show key breeding parameters for a species that seems to be thriving well in urban habitats. The ability of the Burrowing Parrot to reproduce on artificial substrates in urban and suburban environments provides a new perspective for the conservation and management of its populations.

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