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Anthropogenic nesting sites and density of Burrowing Parrot (*Cyanoliseus patagonus*) in northern Argentinian Patagonia

Daiana N. Lera[1,2*], Natalia Cozzani[1], José L. Tella[3] and Sergio Zalba[1,2]

Abstract

Background The expansion of human activities and the development of urban centers are among the main driving forces accounting for the transformation and loss of natural environments. At the same time, and especially for some birds, anthropogenic activity provides new habitat resources. This is the case of the Burrowing Parrot (*Cyanoliseus patagonus*), in and around Bahía Blanca, a city of ca. 335,000 inhabitants in northern Argentinian Patagonia, where urban and rural quarries and constructed ravines on roadsides are where most of its reproductive activity occurs.

Methods In this study we monitored anthropogenic nesting sites and estimated the number of breeding pairs from 2018 to 2023 through censuses conducted annually in 23 colonies within a radius of up to 20 km from the communal roost located in the city.

Results Most of the nesting sites (57%), and the breeding pairs (60 to 80%) were in urban environments, and the remaining in rural areas. Ravines along roadsides and quarries represented the substrate that was most frequently used for nesting. Mean nest density was significantly higher in roadside ravines compared to quarries, and, in turn, higher in urban roadsides compared to rural roadsides.

Conclusion Anthropogenic substrates appear as key components for the reproduction of the species, with possible effects on its numbers. The ability of the Burrowing Parrot to reproduce on artificial substrates in the urban environment, and especially the rapid colonization of recently opened sites, represents a new perspective for the conservation and management of its populations.

Keywords Psittacidae, Reproduction, Urban ecology, Conservation

Background

The Burrowing Parrot (*Cyanoliseus patagonus*) is found in Argentina and Chile [20, 26], occasionally reaching Uruguay [4]. The species is currently categorized as "Least Concern" and with a decreasing population trend according to IUCN (2023). In Argentina the species is categorized as "Threatened" [21], while in Chile the subspecies *C. patagonus bloxami* is classified as "Endangered" in the Atacama and Coquimbo Regions, and as "Vulnerable" in the rest of the country [12]. Specialists agree that the Argentine burrowing parrot populations

*Correspondence:
Daiana N. Lera
daiana.lera@conicet.gov.ar
[1] GEKKO, Grupo de Estudios en Conservación y Manejo, Departamento de Biología, Bioquímica y Farmacia, Universidad Nacional del Sur, San Juan 670, CP 8000 Bahía Blanca, Buenos Aires, Argentina
[2] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, Argentina
[3] Estación Biológica de Doñana (EBD-CSIC), Américo Vespucio 26, Seville 41092, Spain

began to decline significantly during the early nineteenth century as a result of the loss and degradation of natural environments, its persecution because it was wrongly considered an agricultural pest, and the wildlife trade [10, 19, 28].

The Burrowing Parrot is one of the few primary cavity excavator among the psittacines and generally requires limestone or sandstone cliffs to build its nests [19]. Like other cavity-nesting bird species it is limited by the availability of nesting substrates [13, 14] and is able to take advantage of constructions and anthropogenic environments for breeding. In particular, quarries and artificial ravines associated with public works give access to additional nesting sites, especially in areas with few natural cliffs [6, 31].

Like many birds of the order Psittaciformes that have managed to adapt and survive in cities [15], this species is able to replicate its wild habits within urban areas. Studies conducted in the southwest of Buenos Aires province, Argentina, show that the Burrowing Parrot has the ability to breed successfully in environments with intense human activity [31].

Bahía Blanca is a city of 335,000 inhabitants located on the Atlantic coast on the northern border of the Argentinian Patagonia. The Burrowing Parrot nests there mainly using artificial ravines and the population congregates every night in a communal roost located in one of the main green spaces of the city [16]. This situation is not exceptional, since the presence and reproduction of the species have been cited for other urban centers of different sizes in its distribution area [27].

In this study we surveyed and monitored anthropogenic nesting sites of the Burrowing Parrot in urban and rural areas of southwestern Buenos Aires province, Argentina, over four breeding seasons, and estimated nest densities for each site and for each environment in 2018, 2019, 2021 and 2022.

Methods

Nesting areas

This study was conducted in Bahía Blanca (38°43′0″ S, 62°16′0″ W) and adjacent rural sectors. Previous surveys conducted in the breeding seasons between 2003 and the 2013 [31] and 2013–2014 [5] were used to identify the sites where Burrowing Parrot breeding activity is concentrated. These data were complemented with quarry records provided by the Mining Department of the Municipality of Bahía Blanca, and with the collaboration of residents of the study area who contributed with information on other possible nesting areas. In addition, Google Earth images were analyzed in search of abandoned quarries and ravines compatible with breeding activity, and trips were made by car along main and country roads.

All sites where the presence of individuals was observed were considered, and each colony was georeferenced. In this study, we defined "colonies" as those well-delimited nesting sites, such as quarries and slopes on main and country roads, where the species was found to breed. We made this identification regardless of the number of active nests at each site, which were never less than three. Sites varied markedly in suitable nesting surface, accessibility to predators and human disturbance. In a few instances, quarries offered several artificial ravines occupied by burrowing parrots within a range of 400 m but, after Brown and Brown [3], these reproductive cores were considered as single colonies given that all individuals reacted together against human or predator intruders. Breeding birds from different colonies may share feeding grounds and community shelters, however, we consider that the particularities of each nesting site can strongly affect reproductive success and colony dynamics [29], which justifies the use of the functional definition of "colony" above-mentioned.

Each colony was assigned to one of two types of environments: urban and rural. Sites with clustered dwellings located at a distance of no more than 1,000 m (mean = 295, 72 m; range = 23,58 m – 764,16 m) were classified as urban, and rural areas were those located at distances greater than 1,000 m (mean = 4851,35 m; range = 1498 m – 14303 m) from the nearest urbanization.

At each nesting site, the surface area of the ravine section(s) occupied by active nests was measured in each season. For this, the most extreme burrows occupied were considered and photographs were taken with a 48 megapixel cellular camera, using a 120 cm long calibration rod divided every ten centimeters, placed at the base of the ravine, for subsequent calculation of the average height of the sector occupied by the nests (Fig. 1a). Each photo was taken at the same height from the front and by the same person to avoid parallax errors. In each ravine, photographs were taken every ten, and in some cases every 20 m, at a time of day that allowed clear observation of the nests and the edges of the ravines. The minimum number of measurements considered to calculate the average height per front was three. Each image was processed with *ImageJ* software [11] and the height values obtained were then averaged. The length, in meters, was obtained from Google Earth, having previously taken the coordinates at the beginning and end of the sector of ravine with the presence of active cavities. For each site and for each season, the area occupied by nests was estimated by multiplying the length of each ravine with nests by the value of its average height.

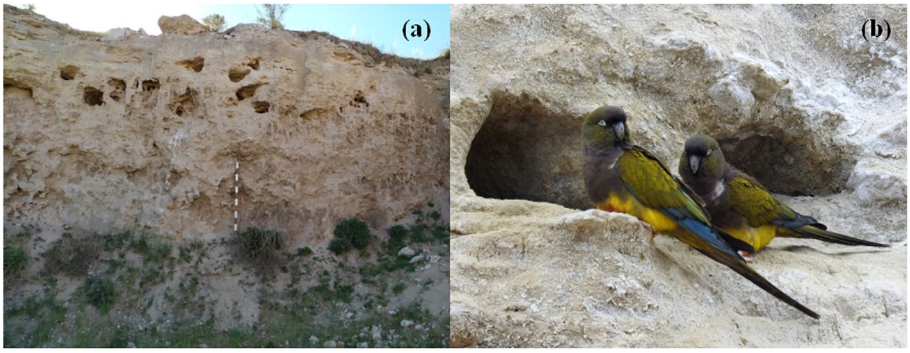

Fig. 1 **a** Front of a ravine with burrows excavated by Burrowing Parrot for nesting, with a 120 cm calibration road resting at its base. Photograph: Daiana Lera. **b** Breeding pair of Burrowing Parrots in the entrance of their nest cavity. Photograph: Carlos Soulier

Density of active nests

Nest density was calculated for each breeding site and each breeding season as the number of active burrows over the area in m^2 of substrate used for nesting. The sampling included 79 censuses of breeding pairs in four breeding seasons: 18 in 2018–2019, 22 in 2019–2020, 21 in 2021–2022 and 18 in 2022–2023, in the total number of colonies detected in this study (23). Active burrows were counted at each section of ravine during 40 min censuses between 7:00 am and 1:00 pm. In order to avoid an overestimation of pairs by counting floaters searching for burrows but ultimately failing to breed [1], surveys were conducted in October and November, when egg laying and parental care takes place, and breeding pairs were identified as those that entered the nest repeatedly and whose proximity to the burrow and permanence in the place exceeded 15 min (Fig. 1b). Food provision events between the members of a pair in the proximity of the burrow were also taken into account to confirm this identification.

Data analysis

All assumptions of the statistical tests were met. Homogeneity of variances was tested using Levene's test. One-way analysis of variance was used to evaluate any possible interannual changes in nest density, and between urban and rural environments. We also searched for differences in nest density between quarries and roadsides, urban quarries vs. rural quarries, active vs. unused quarries, urban roadsides vs. rural roadsides, and for the four study breeding seasons: 2018–2019, 2019–2020, 2021–2022 and 2022–2023, using an unbalanced two-factor ANOVA with interactions.

A one-way analysis of variance was performed to detect possible interannual variations in the number of breeding pairs. Using the same combinations of independent variables described above, unbalanced two-way ANOVA tests with interactions were used to evaluate the effects that the years and the different nesting environments could have on the number of breeding pairs. Significance was set at $p < 0.05$, and Bonferroni-corrected post hoc comparisons were used for significant differences.

Results

Nesting areas

A total of 23 Burrowing Parrot colonies were identified in the surveyed area. The mean distance from the nesting sites to the urban park used as a roost was 14, 5 km (DE = 5,6 km; range = 1, 88 km – 20 km). ca. 50% of the colonies were located less than 10 km from the communal roost and all of them were established on substrates of anthropogenic origin. Fifty-seven percent of the nesting sites were in urban environments, and the rest in rural areas. Only four nesting colonies in natural substrates were detected throughout the study in the surveyed area, all of them arranged on ravines along watercourses, and mostly located on private land. These sites were excluded from the analysis on account of the difficulty of accessing these sites for counting the nesting pairs and estimating the surface area of the stream banks, and also considering their minority contribution to the breeding population (less than 40 pairs per year in total).

Seventy-four percent of the nesting sites studied corresponded to quarries and 26% to slopes on roadsides (Fig. 2). Of the 17 quarries surveyed, 59% were located in urban areas, while 41% were associated with rural environments. Eleven of the 17 quarries in which reproductive activity was detected (65%) were out of use at the time of the surveys, while the rest were in use with machinery for the extraction of aggregates. The percentage of quarries that were active simultaneously with parrot breeding activity ranged from 18.7% in 2018 to 29.4% in 2021. While most quarries remained in the same condition of exploitation throughout the study period, three

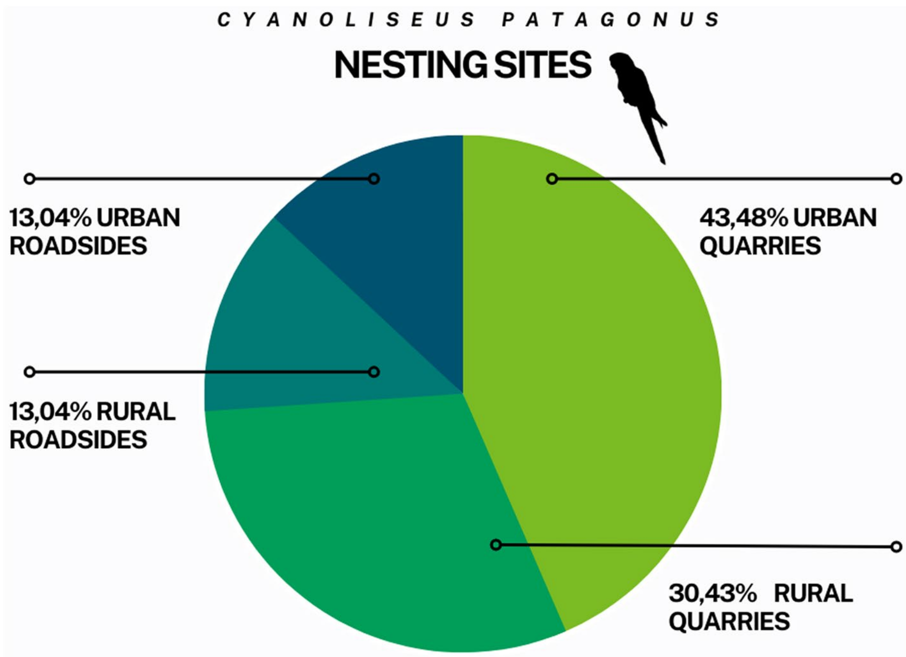

Fig. 2 Burrowing Parrot nesting sites at different anthropogenic substrates in the vicinity of Bahía Blanca, Buenos Aires province, Argentina

of them alternated activity and non-activity between successive years (colonies 5, 14 and 15), and they were considered in the category of active quarries when calculating the percentages above. Of the six colonies located on profiles cut for the construction of roads, three were located in urban areas and three corresponded to rural roadsides. Two of these profiles were opened as part of road construction in 2018 and were colonized the following year (colonies 20 and 21).

The number of sites surveyed each year varied depending on the difficulties in accessing the private properties where they are located and the opening of new sites that were colonized by the species. Despite these restrictions, 14 nesting sites could be visited regularly in each breeding season throughout the study period. In a similar way, the area used for nesting sometimes varied from year to year for the same site due to the opening of new slopes or ravines (Table 1).

Abundance of breeding pairs

Colony size ranged from three to 645 breeding pairs. Between 60% and nearly 80% of the total number of pairs detected each year used urban ravines for nesting, while between 20 and 40% nested in artificial ravines associated with rural environments. The maximum total number of breeding pairs (1612) was recorded during the 2019 season, distributed between 22 nesting sites, but it was only slightly higher than the numbers of pairs registered during the rest of the seasons (8% above the interannual average, Table 2). The mean values of the number of pairs per nesting site showed no significant differences between years ($F=0.003$; $P=0.99$).

Nest density

The minimum density per colony was 0.009 nests/m^2 and the maximum density was 0.17 nests/m^2 (Table 3). The average nest density at all nest sites did not vary significantly between the four seasons ($F=0.603$; $P=0.615$). No differences were found in mean nest density between sites in urban and rural environments, and this homogeneity persisted among years ($F=0.578$; $P=0.631$; Fig. 3).

We found no significant variation in nest density between quarries located in urban vs. rural environments ($F=0.168$; $P=0.918$) or between active and unused quarries ($F=0.641$; $P=0.592$). The mean nest density of the total number of sites, on the other hand, was significantly higher in environments associated with roadsides compared to quarries ($F=4.133$; $P=0.046$; Fig. 4), and, also, higher on urban roadsides compared to rural roadsides ($F=4.981$; $P=0.047$; Fig. 5), both differences were also supported by Bonferroni complementary p-values of $p=0.049$ and $p=0.042$, respectively. Finally, the mean nest density in 2019 for the 14 colonies censused in all seasons did not vary significantly with respect to 2018 ($F=0.808$; $P=0.377$), despite the opening and colonization of two new sites (colonies 20 and 21), and no changes were observed in the following seasons ($F=0.699$; $P=0.557$).

Table 1 Nesting area (m^2) used by the Burrowing Parrot at each of the sites and in each reproductive season in the vicinity of Bahía Blanca, Buenos Aires province, Argentina. For each colony, the location and the substrate are also indicated

Sampling site (N °)	2018	Area (m^2) 2019	2021	2022	Location	Substrate
1	514.57	514.57	514.57	514.57	Urban	Quarries
2	740.13	740.13	740.13	740.13	Urban	Roadsides
3	105	105	105	105	Urban	Quarries
4	276.86	276.86	276.86	276.86	Urban	Quarries
5	677.14	677.14	1364.39	1364.39	Rural	Quarries
6	228.06	228.06	228.06	228.06	Rural	Roadsides
7	240.61	240.61	240.61	240.61	Urban	Roadsides
8	359.21	359.21	359.21	359.21	Rural	Quarries
9	602.45	602.45	No data	No data	Rural	Quarries
10	585.42	468.12	468.12	1093.27	Rural	Quarries
11	3287.50	3287.50	2913.48	2850.58	Rural	Quarries
12	564.16	564.16	564.16	No data	Urban	Quarries
13	1316.35	1316.35	1316.35	1316.35	Urban	Quarries
14	1922.96	3482.58	5259.68	5259.68	Urban	Quarries
15	8146.53	8146.53	7259.21	6177.86	Urban	Quarries
16	1055.16	1055.16	1055.16	1055.16	Urban	Quarries
17	789.04	789.04	789.04	789.04	Urban	Quarries
18	836.20	836.20	836.20	836.20	Urban	Quarries
19	204.10	204.10	204.10	No data	Rural	Quarries
20	Did not exist	665.33	665.33	817.26	Urban	Roadsides
21	Did not exist	1357.59	3937.27	1955.56	Rural	Roadsides
22	178.85	178.85	No data	No data	Rural	Roadsides
23	112	No data	112	No data	Rural	Quarries
Total (m^2)	22.247,43	26.207,61	29.209,00	25.979,86		

Table 2 Number of breeding pairs, nesting sites, total nesting area and average annual nest density during four breeding seasons in the vicinity of Bahía Blanca, Buenos Aires province, Argentina

Year	Number of breeding pairs	Nesting sites	Área (m^2)	Mean nest density
2018	1363	18	22247	0.061
2019	1612	22	26095	0.062
2021	1545	21	29209	0.053
2022	1433	18	25979	0.055

Discussion

Habitat degradation and especially the low availability of nesting areas are cited as the factors that most restrict cliff nesting bird populations [13, 20]. Consequently, the capacity of the burrowing parrot to nest on artificial substrates, including those located in the urban environment, and its ability to occupy new sites as soon as a year after opening, are encouraging for its conservation.

Our census of nesting sites show that between 60% and nearly 80% of the pairs detected each year selected artificial urban ravines for nesting, while rest nest in artificial ravines associated with rural environments. This behavior was described as an innovation for the species [31] and could be due to the displacement of populations to areas where the scarcity of natural substrates acts as a limiting factor for reproductive activity, as is the case in the study area where natural ravines are restricted to certain areas along the few watercourses that traverse it [5]. Thus, quarries and artificial slopes could be key for the presence of the Burrowing Parrot in a region that provides it with other resources, such as communal roosting areas, food resources and water sources. Man-made ravines could offer some advantages, either real or perceived, at the time of nest site selection that should be considered in future studies. These advantages could be associated with characteristics such as height, which at some sites in the study area is greater than that of natural cliffs and with the angle of the cliff, typically vertical in quarries, that could be associated with greater protection against predators. Artificial nesting environments

Table 3 Density of Burrowing Parrot nests (active nests/m^2) for 23 nesting sites and four breeding seasons on anthropogenic nesting substrates in the vicinity of Bahía Blanca, Buenos Aires province, Argentina

		Nest density	(nest/m^2)	
Site (n°)	**2018**	**2019**	**2021**	**2022**
1	0.079	0.165	0.048	0.139
2	0.175	0.168	0.151	0.097
3	0.076	0.028	0.028	0.028
4	0.018	No parrots	No parrots	No parrots
5	0.124	0.152	0.043	0.053
6	0.021	0.048	0.074	0.039
7	0.066	0.066	0.041	0.024
8	0.027	0.036	0.100	0.108
9	0.019	0.046	No census	No census
10	0.056	0.121	0.038	0.062
11	0.049	0.050	0.082	0.084
12	0.033	0.054	0.023	No census
13	0.052	0.042	0.035	0.028
14	0.039	0.031	0.023	0.024
15	0.079	0.068	0.068	0.059
16	0.027	0.055	0.061	0.051
17	0.024	0.086	0.054	0.051
18	No parrots	0.019	0.020	0.009
19	No census	0.053	0.034	No census
20	Did not exist	0.073	0.088	0.099
21	Did not exist	0.025	0.037	0.066
22	Unknown	0.083	No census	No census
23	No parrots	No census	0.053	No census

often also provide larger nesting surfaces which, may allow for the establishment of larger colonies. Although no studies have been carried out on the effect of colony size on the fitness of Burrowing Parrot individuals, the species holds the record as the parrot with the largest colonies in environments where natural ravines are not a limitation [18, 19].

To this could be added an eventual reduction of predation risk depending on the composition and abundance of the predator assemblage in more anthropized environments compared to riparian areas with a greater predominance of native vegetation. However, although cities can function as refuges that minimize predation risk [25], they can also influence the presence of highly efficient and abundant predators depending on geographic and cultural factors [9, 17], although this has not been studied for this particular species.

Terrestrial carnivores such as the Pampas Fox *Pseudalopex gymmnocercus*, the Lesser Grison *Galictis cuja* and reptiles such as the Patagonian Green Runner *Philodryas patagoniensis* and the Black and White Tegu *Salvator merianae* have been observed in the urban and rural ravines of the study area. The latter has only been recorded in one of the natural environments not included in this study. Indeed, species such as *Apus apus* in Spain and *Cyanoliseus patagonus* in Chile build their nests in high ground ravines and avoid cavities close to the ground, possibly as a mechanism to reduce the probability of attacks by terrestrial predators [8, 24].

Of the 23 locations sampled in this study, ten cited as active by Canale 5 were still harboring breeding individuals in 2022 and one site was only occupied by five pairs in 2018, as in 2014 [5]. Our study added 12 new locations over the different sampling years. Four of them (Table 1, sites 1, 6, 9 and 17) may not have been detected previously due to insufficient search effort,one corresponds to a quarry that had just been opened and remained uncolonized in the previous survey [5] (Table 1, colony 5) while the other seven sites (Table 1, sites number 7, 14, 18, 20, 21, 22 and 23) correspond to slopes and quarries opened after 2015. For the particular case of sites 20 and 21, soil movement began around March 2018 and the first observations of parrots using these slopes were recorded in July 2019. The establishment of colonies and the first successful nesting at these sites occurred during the 2019–2020 breeding season, highlighting the rapidity of the species to colonize new nesting sites.

The abundance of breeding pairs calculated during this work was similar to that recorded during 2013 [31], in spite of the opening of new breeding grounds. This finding contrasts with the idea proposed by those authors, who stated that the reproductive population in the area was limited by the availability of appropriate nesting sites. However, it is noteworthy that the new breeding sites added during our study never exceeded 12% in total surface area compared to the interannual average since, in many cases, they were offset by the loss of fronts occupied by colonies due to the extraction of materials in the quarries. Our results thus continue to support the hypothesis that the reproduction of the Burrowing Parrot in the area would remain below the limit imposed by the availability of nesting areas, which is also consistent with the proportion of floaters calculated (Lera et al., 2023 in prep).

The average nest density at the 14 nesting sites visited along the whole study did not vary significantly, although a slight increase in active nests per m2 was detected, from 0.061 in 2018 to 0.080 in 2019. In particular, two of the new sites opened in the study area, corresponding to roadside banks (20 and 21), showed an increase in the number of active nests per m2 from 0.073 and 0.025 in 2019, to 0.099 and 0.066 in 2022, and in the number of pairs from 84 pairs in 2019 to 212 in 2022. This trade-off between the drop in abundance of pairs in the traditional

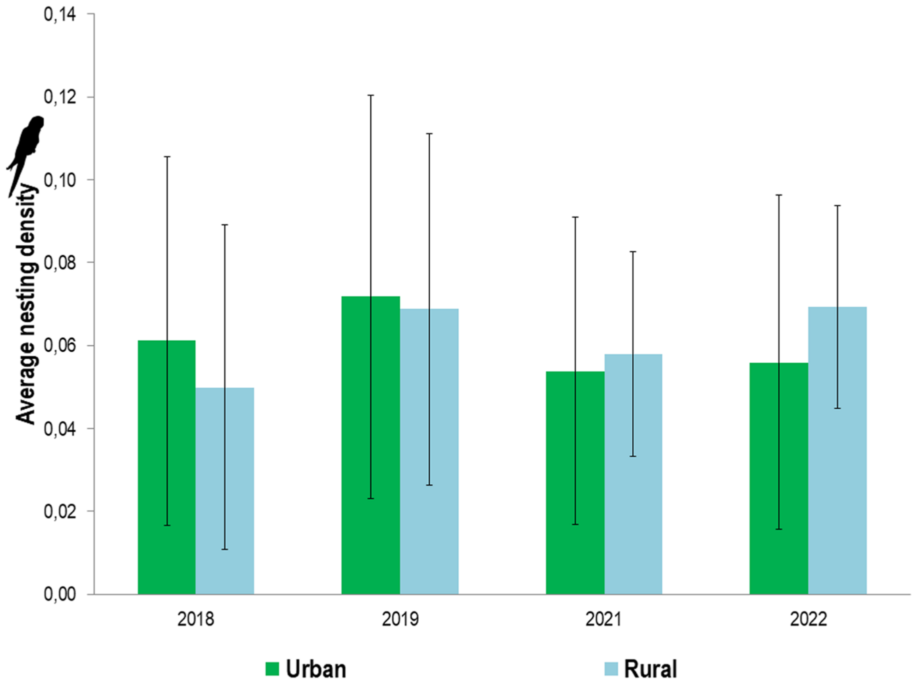

Fig. 3 Average density of Burrowing Parrot nests (active nests/m2) associated with urban and rural enviroments during four breeding seasons in the vicinity of Bahía Blanca, Buenos Aires province, Argentina. Vertical bars represent standard deviation

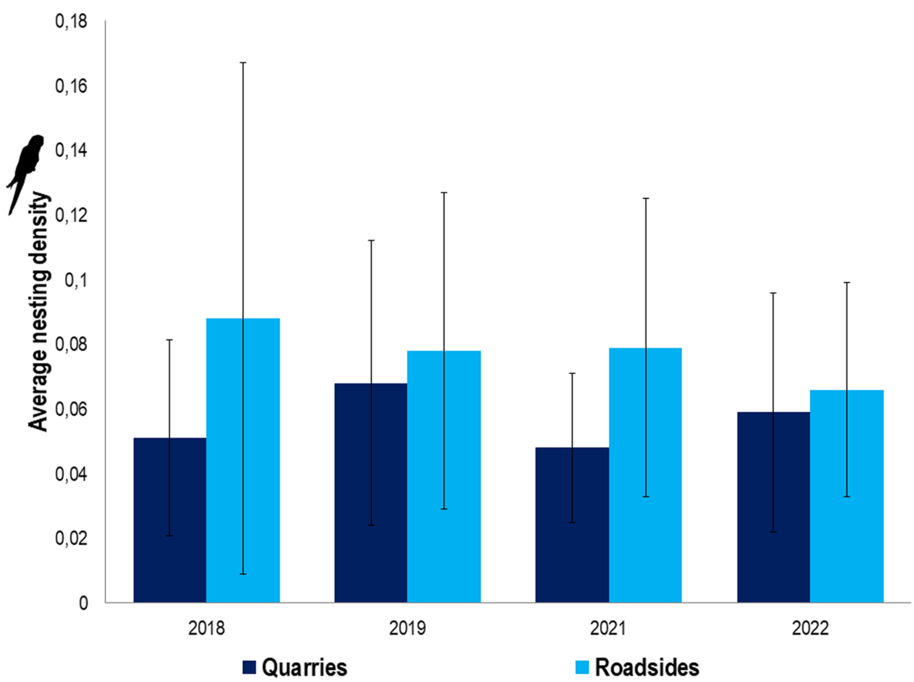

Fig. 4 Average density of Burrowing Parrot nests (active nests/m^2) associated with roadsides and quarries during four breeding seasons in the vicinity of Bahía Blanca, Buenos Aires province, Argentina. Vertical bars represent standard deviation

ravines (14 sites) and the increase in pairs colonizing the new sites could indicate a possible displacement of the parrots to these new substrates.

Although 74% of the nesting sites were associated to quarries and 26% to roadsides, the density of nests was higher on roadsides. This difference could simply be due

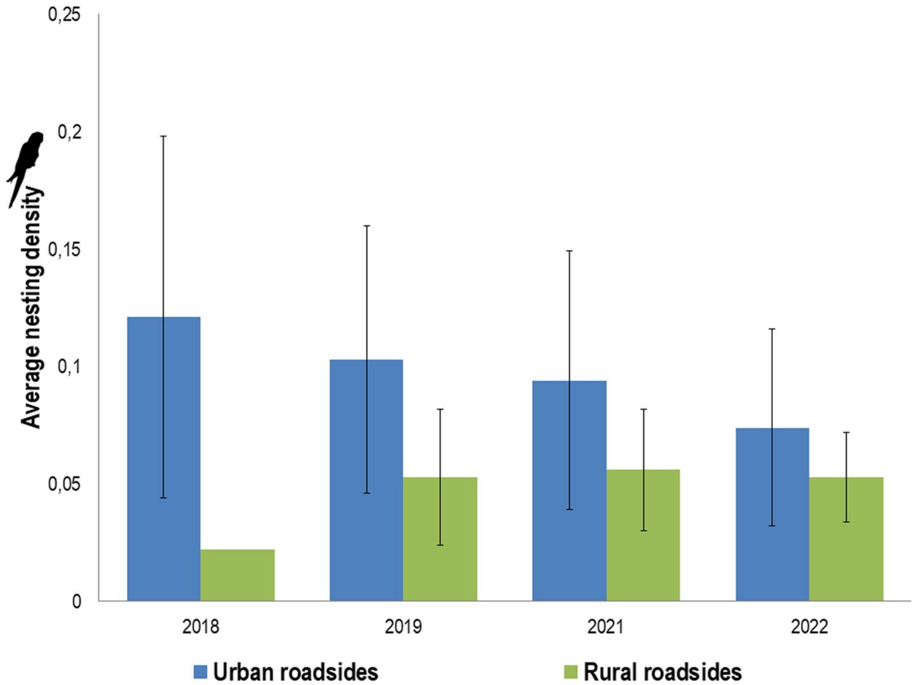

Fig. 5 Average density of Burrowing Parrot nests (active nests/m2) associated with urban and rural roadsides during four breeding seasons in the vicinity of Bahía Blanca, Buenos Aires province, Argentina. Vertical bars represent standard deviation. The lack of an error bar for the rural roadside in 2018 is due to only one colony being recorded in that type of environment during that year

to a larger available area per site in the quarries, or to an eventual preference for roadsides, possibly because of the disturbance of extractive activities associated to quarries. Whatever the cause of this pattern it deserves further study, as nesting in roadside ravines has only been described for a few avian species [2, 21, 28]. This study contributes to the knowledge of the reproductive biology of the Burrowing Parrot in anthropogenic ravines and highlights the importance of urban environments for its conservation. The importance of quarries and artificial ravines as nesting sites emphasizes the need to regulate aggregate extraction and soil movement activities in order to minimize negative effects on the reproductive activity of the species, especially considering the scarcity of natural cliffs in the study area. Artificial substrates, and in particular those inside or at the vicinity of urban environments, seem to play a key role in the number of breeding individuals at the local level and, eventually, in the species population trend.

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Authors' contributions
DNL, NC, JLT and SZ designed the study. DNL and NC carried out the field sampling. DNL, NC, JLT and SMZ carried out the design of the paper. DNL, NC and SZ carried out the analysis and writing of the paper. All authors read and approved the final version of the manuscript.

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Availability of data and materials
All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable; this is a literature review of published sources.

Competing interests
The authors declare that they have no competing interests.

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