

Artificial Green Corridors in an Andean City as Effective Support of Avian Diversity

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Abstract: Ensuring connectivity in the countryside and cities is a key element of nature protection, allowing genetic fluxes between populations in fragmented ecosystems. We tested the hypothesis that artificial green corridors are effective for birds in the city of Cochabamba (Bolivia). We compared the following aspects of natural corridors, with generally preserved vegetation, to those of artificial corridors, constituting parks and gardens in a matrix of streets densely planted with trees: species abundance and richness, functional diversity, and the traits of bird communities. We used canonical redundancy analysis to relate species abundance to the corridor type, noise, tree vegetation structure, richness, and functional diversity. We also tested the explanatory factors for relationships with bird species richness, functional diversity, and traits. We found that most species were shared between the corridor types; the corridor type, nevertheless, had significant effects, with bird species in the green corridors being more common and heavier and having a lower beak depth/mass. By contrast, noise-reflecting urbanization deeply affected all of the studied traits, indicating large shifts in species composition. In conclusion, green corridors seem reliable enough to maintain birds at a level almost comparable to that in linear corridors, but noise is a limiting factor for efficiency for both types.

Keywords: functional diversity; morphological traits; ecological traits; noise; habitat analysis; connectivity

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1. Introduction

Over the course of the last century, human population growth and technological developments have greatly modified land use worldwide, accounting for ever-growing cities, urban sprawl, increasing surfaces devoted to agriculture, and degraded ecosystems. These conditions all reduce the space left for wildlife. Besides strengthening land management by preventing the degradation or destruction of ecosystems, promoting restoration, and creating conservation areas, understanding the cohabitation between humans and wildlife in generally anthropized areas is also important. These areas also host wildlife, and taking supporting actions could be fruitful (e.g., [1]). The loss of habitat space is one of the main factors responsible for the erosion of biodiversity, and, further combined with the loss of connectivity, it prevents genetic fluxes between populations in fragmented ecosystems. Therefore, extreme importance lies in anthropized areas constituting ecological corridors, i.e., geographical spaces that facilitate the daily movements, migration, and dispersal of species and that establish a functional link between core conservation habitats [2].

Birds in cities have received considerable attention (e.g., 1344 documents in the Scopus database found with a combination of the following keywords: “(urban OR city) AND bird diversity”, obtained on 7 December 2022). Urbanization selects for omnivores, granivores, and aerial and ground-foraging insectivores, and it favors cavity-nesting species

and residents over migratory species [3,4]. It decreases species richness and increases the population size of invasive species, and the divergence between undisturbed and urbanized areas grows with the amount of time that has passed since the beginning of urbanization. Losses in the vegetation structure, volume, and composition (with an increasing occurrence of exotic species), increases in fragmentation and decreases in patch size, and increases in the proportion of the cover of buildings, pavement, and residential areas have all been found to affect birds, owing to shifts in resources for resting, feeding, and nesting. The consequences are generally a decrease in fecundity (although with the exception of, for instance, raptors or exotic species) and a decrease in survivorship. Additional factors of urbanization, such as heat islands, may increase the range size and the overwintering of climate-sensitive species, but the human persecution of selected species, collisions with vehicles, and noise also have negative effects. Urbanization has also been shown to lower habitat specificity [5], color number [6,7], functional diversity [6,8], frugivory, invertivory, [8–11], and commonness [12,13]. However, the responses of some features, such as wing and tarsus lengths or body mass, to urbanization could be site-dependent [14] in such a way that, for instance, mass decreases in urbanized environments [5,6] and favors insectivory [3].

Wildlife suffers from its immersion in an urban environment, even in a favorable matrix. In addition, cities and suburbs may constitute broad ecological barriers in landscapes, notably when they occupy valleys. For these reasons, keeping and managing ecological corridors in these spaces are important. Three types of corridors can be encountered [15]: (1) linear corridors, which follow natural, continuous paths, such as forest remains along streams; (2) stepping-stone corridors, which are made of networks of small patches of suitable habitats, such as parks and gardens, in generally green areas; and (3) interlinked landscapes, which combine different habitats, only providing enough resources when together. The permeability of the urban environment depends on species specificity [15–18], and therefore, corridors with certain characteristics seem critical for the efficiency of the ecological network. The positive effects of green infrastructures on bird diversity and on the occurrence of rare species have been demonstrated [19], and analyses of bird preferences in cities for different types of features—in particular, the vegetation structure, ground cover, and water—help in designing corridors [20,21].

In the city of Cochabamba (Bolivia) in the Andes, valleys going through the city constitute natural corridors (linear corridors) of generally preserved vegetation interlinking in the northeast of the National Park of Tunari, with other natural areas to the south (Figure 1). However, in order to sustain the ecological network, suggestions have been made to create a framework of green or artificial corridors (stepping-stone corridors) based on parks and gardens in a matrix constituting streets with low levels of traffic, regularly planted with trees [22]. The objective of the present work was to test the hypothesis that these stepping-stone corridors could indeed provide useful habitats for bird life and constitute efficient artificial corridors in addition to the existing natural corridors. For this purpose, we conducted repeated bird surveys in several sections of artificial corridors and compared them to the existing “natural” corridors in the Andean city of Cochabamba. As co-factors, we characterized tree vegetation according to taxonomy, size, and a functional diversity index. We considered sections of corridors in a gradient of recorded urban noise, considering it a proxy for the intensity of human activities. We then tested the effects of the section type, the degree of urbanization, vegetation characteristics, and noise on the bird communities using a canonical redundancy analysis (CRA). We further determined which traits of the bird communities were influenced by the explanatory factors selected in the CRA and how different the bird traits were as a function of the factors identified by the CRA.

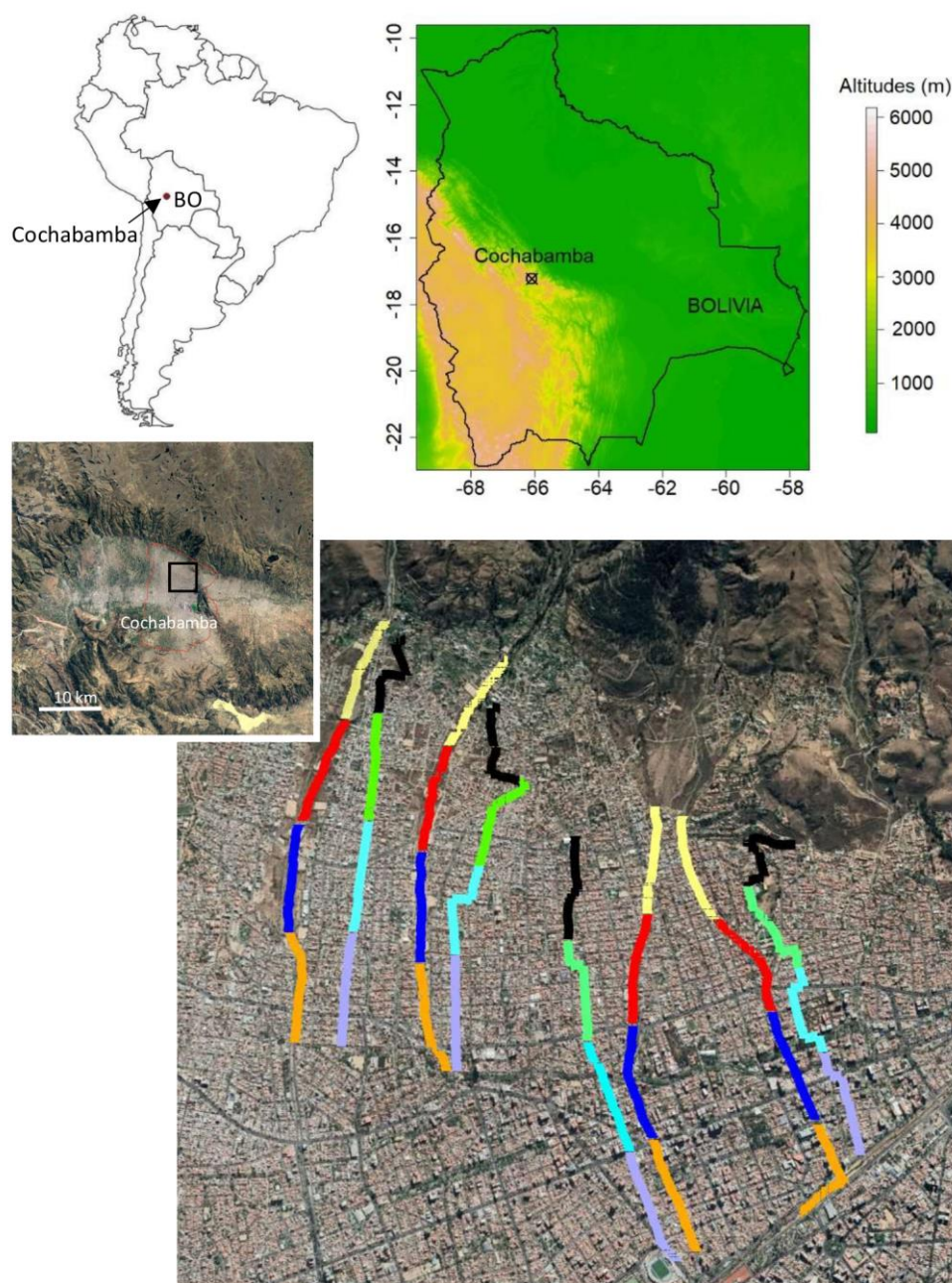


Figure 1. Cochabamba in Bolivia (BO, South America) is located at an altitude of 2,570 m a.s.l. The studied corridors begin on the border of the National Park of Tunari (750 m long sections; natural corridors: yellow, red, blue, and orange; sections of artificial corridors: black, green, light-blue, and purple).

2. Materials and Methods

2.1. Study Site

We carried out this study in the city of Cochabamba, located in the inter-Andean dry valleys of Bolivia at 2570 m a.s.l. The climate is cold semi-arid (*Bsk* climate in the Köppen classification), with an annual mean temperature of 15.58 °C and annual precipitation of 922 mm for the period of 1991 to 2021. Composed of seven municipalities, the city spans an area of 45,528 ha, with a population of one and a half million inhabitants [23]. It is the only city in Bolivia that is next to a protected area, The National Park of Tunari (NPT), which reaches the northern limit of the city. This national park's mountains range from

2650 to 5035 m a.s.l. and have alluvial fans and many water courses (mountain streams) flowing into the city to the Rocha River, crossing the city center and the urban lake Laguna Coña Coña as closed channels. The vegetation along these mountain streams has been left as natural as possible, particularly in the northern part of the city.

2.2. Corridor Survey

We chose four natural corridors, each 3 km long, mainly constituting vegetation belts on both sides of mountain streams (Torretera Pintumayu, Torretera Pajcha, Torretera Cantarana, and Torretera Aranjuez). In the northern part of the city, at the limit of the NPT, they are 100 m wide on average, whereas toward the city center (going south), they are only 40 m wide. Three of these natural corridors at their southern ends connect with the Rocha River, which flows through the city center and eventually toward a rural agricultural valley (Valle Bajo), and one connects with the peri-urban agricultural area of La Maica. The two corridors on the west side of the city become discontinuous (southern end), as they are eventually channeled under a cement cover of about 4 km before reaching the Rocha River and the La Maica agricultural area; however, they maintain native and planted vegetation cover throughout their course. For the natural corridors, we separated each into four sections along the east sides of the mountain streams, each 750 m long and 20 m wide. For the artificial corridors, we chose four paved street sections of the same size, parallel to and at a distance of around 200 m from the natural corridors. The vegetation survey consisted of a tree census. We included individuals that were on the boundary line. In the artificial sections, we included the east and west sidewalks (cement) planted with trees, as well as trees from house gardens along the streets. Of notable importance, in Cochabamba, a municipal regulation requires a 3 m garden in front of all houses, except in the city center. We conducted the identification of specimens either through direct observation or on parts collected for later examination and determination, following another study [24].

We recorded noise with a sonometer (Sper Scientific 840,029 Digital Type 2) for fifteen minutes at the beginning, middle, and end of each section for the first bird survey. We then used the mean of all records by section.

2.3. Bird Surveys

Because the availability of the observers was only in March and April 2022, we conducted five bird surveys along the natural and artificial corridor sections, beginning at 7 am and finishing at 12 pm. Two teams of two observers completed the censuses at the same time in different corridors. Over the course of the 5 surveys, we varied the observers and the starting times between the corridors. Each census involved a slow, constant-paced walk along each corridor section while recording all birds, except those that flew behind the observers, noting both the species and their abundance. We conducted the identification on-site, using a field guide when needed, which was followed for taxonomy [25].

2.4. Data Analyses

We computed all statistics with R3.6.3 in RStudio 2021.09.2+382 “Ghost Orchid” Release (2022-01-04) for Windows. For all tests, we used 0.05 as the critical p -value.

The corridor survey allowed us to construct an explanatory factor dataset with the following variables: corridor type (natural or artificial), noise, weather condition (sunny or cloudy), and tree traits (i.e., diameter at breast height (DBH), coefficient of variation (CV of DBH), number of species, number of native species, tree density, native tree density, and tree functional diversity index). We computed the functional dispersion (FDis) with the *dbFD* function in the “FD” package [26]. This index is the most sensitive among the different indexes of functional diversity. We used species abundance with fruit size, fruit type (dry or fleshy), flower color (blue-purple, green, orange, pink, red, white, or yellow), leaf length, leaf type (simple, compound, or needle-scale), and maximum height

(Table S1) and allocated the same weight to each trait. We collected these data from the flora short notes available in World Flora Online [27], which we also used to update the taxonomy. We found species statuses in the Bolivia catalog provided by the Tropicos database [28]. Correlations between explanatory factors were lower than 0.7, except that of the native tree density with the tree density, the former of which was then removed from the explanatory dataset. Noise was not correlated with the urbanization degree. We compared the means of the explanatory factors in the sections of the natural and the artificial corridors using variance analyses.

We tested the effects of the explanatory factors on the structures of communities of bird species, finding shelters in the sections by using CRA with functions in the “vegan” package [29]. We first applied the Hellinger transformation to the abundance data (function *Hellinger* of the “labdsv” package [30]) and ran the full model with the *cra* function. We then carried out forward variable selection with the *ordiR2step* function with $P_{in} = 0.01$ and $P_{out} = 0.05$, wrapping *cra*. To determine the significance of the selected model and its coefficients, we performed Monte Carlo randomizations while taking into account dependence that may have ensued from repeated observations in the same sections. As the adjusted R-squared values provided the proportion of variance explained by the factors, we sequentially removed them from the formula to assess their contributions. We ranked each species according to its sensitivity to the explanatory factors using the norm of the orthogonal projection on the vectors of the explanatory variables in the space defined by the first two constraining axes (Tables S2–S4).

To explain the traits of the bird communities, we further tested the linear effects of the explanatory factors selected in the CRA. We combined traits to compute FDis for the birds using the bird abundance in the computations. We considered the following traits: beak length/mass, beak width/mass, beak depth/mass, tarsus length/mass, wing length/mass, tail length/mass, mass, habitat (forest, grassland, human-modified, rock, shrubland or wetland, or woodland habitats), primary trophic niche (aquatic predator, frugivore, granivore, terrestrial herbivore, invertivore, nectarivore, omnivore, or vertivore), primary lifestyle (aerial, generalist, insessorial, or terrestrial), color (gray, black, white, brown-cream, yellow-orange, red-pink, green, or blue, each one coded as 0 or 1), and color number (Table S5). We extracted these data from the table of means AVONET1_BirdLife.csv of the database AVONET [31], except for the colors and the numbers of colors, which we determined according to our own experience. We divided organ sizes by mass to reduce covariance. We weighted the traits equally for the following categories: beak, tarsus, wing, tail, mass, habitat, trophic niche, primary lifestyle, and color. The set traits allowed for the identification of small variations in bird communities in terms of functional diversity and individual traits, beyond the species list and abundances, according to the variations observed in urbanized environments, as described in the Introduction. Tail elongation is considered a marking attribute but has an aerodynamic cost [32]. Because birds in cities seem more discrete with less color [6,7] and are more exposed to flight crashes [3], we assumed that they may have shorter tails. Tarsus and wing lengths and masses allowed us to estimate bird size. Smaller birds may escape predators more easily [33], so we assumed that these traits would be more abundant in the natural sections.

We tested the effects of the explanatory factors on continuous traits with linear mixed models using the *lmer* function in the “lme4” package [34] and on qualitative traits with logistic mixed models using the *glmmTMB* function in the “glmmTMB” package [35]. For the logistic models, we scaled the explanatory factors to avoid numerical problems. We included the explanatory factors as fixed effects and the corridor section as a random intercept. The computation of Moran’s I index of the descriptors taken by the survey with the *moransI* function in the “lctools” package [36] showed that spatial autocorrelation was negligible (Table S6). The continuous traits of the bird communities were as follows: the number of species, the number of birds, FDis, and the community-level weighted means of the range size, color number, and organ size divided by the body mass. The qualitative

traits were the proportions (number of occurrences/number of birds) of each habitat, trophic niche, primary lifestyle, and color. We did not compute models for rock and wetland habitats or for the aquatic predator trophic niche because their frequencies were too low.

3. Results

The habitat survey showed that the natural and artificial corridors contained a comparable number of tree species, as well as a comparable number of native tree species. However, as expected, the natural sections had higher densities of trees (Figure 2, Table 1). Contrary to expectations, the FDis was higher in the artificial sections (Table 1). Noise, DBH, and the CV of DBH were not significantly different between the two types of sections.

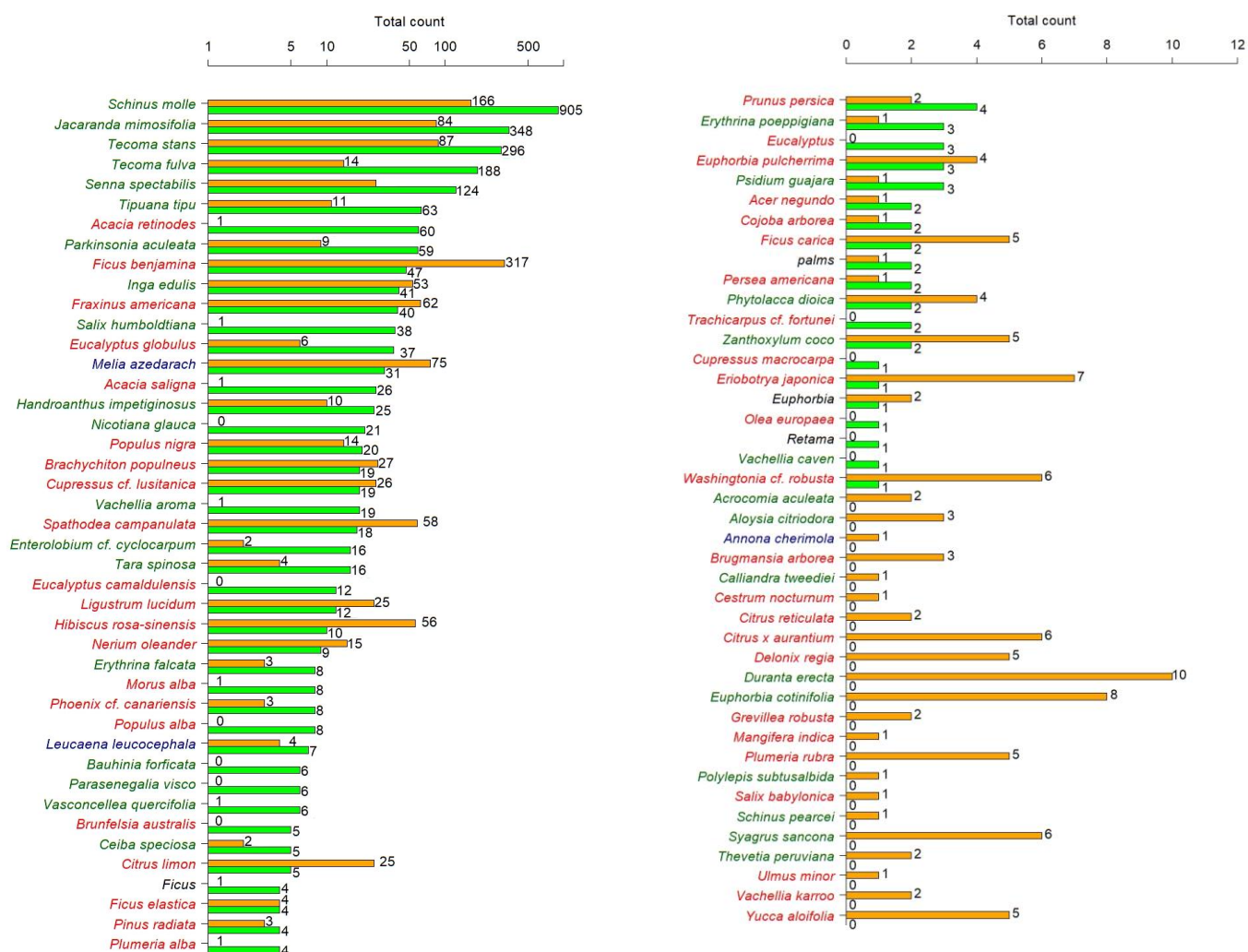


Figure 2. Total counts of tree species individuals in artificial (orange) and natural (green) sections, with color of species names indicating status (green: native; red: cultivated; blue: cultivated/naturalized; black: unknown).

Table 1. Comparisons of following habitat characteristics of natural and artificial sections: means of number of tree species, tree density, number of native species, native tree density, tree functional dispersion (FDis), diameter at breast height (DBH), coefficient of variation (CV of DBH), noise, and variance analysis ($F_{1,31}$ and p -value).

	Natural	Artificial	$F_{1,31}$	p -Value
Tree species number	18.19	14.94	2.388	0.132
Tree density (number/ha)	110.3	54.53	15.11	0.0005
Native species number	8.06	7.67	0.181	0.673
Native tree density (number/ha)	91.71	21.63	29.23	<0.0001
FDis	0.130	0.162	13.38	0.001
DBH (cm)	60.5	50.82	2.721	0.109
CV of DBH (%)	81.95	83.67	0.060	0.809
Noise (db)	56.11	51.69	1.783	0.192

The five bird surveys allowed us to identify 60 bird species. We observed 17 of these only once, and we observed 4 of them over 1000 times (Figure 3). We observed 16 species only in the natural sections and 10 only in the artificial sections; all of these species were rather rare (fewer than 6), except *Geospizopsis plebejus*, which was abundant in the natural sections and absent from the artificial ones. The abundance was largely dominated by passerines and Columbiformes, regardless of the corridor type, with some Psittaciformes (Psittacidae) and Apodiformes (Trochilidae). This abundance is characterized by species living in arid or semi-arid habitats, often living in semi-open clearings or forest edge habitats. We only observed three aquatic species (two wading birds and one Laridae) in a natural corridor due to the presence of a river. In terms of species diversity, passerines (with 40 species among 15 families) dominated the number of observed species in both types of corridors. The number of Columbiformes (Columbidae) was limited to four species, with two very abundant anthropophilic species (*Zenaida auriculata* and *Columbia livia*). The other observed families (without the aquatic species) were Trochilidae (five species), Psittacidae (four species), three raptors (two in Accipitridae and one in Falconidae), and one Picidae. All species were ranked as “least concern” in IUCN assessments, except *Amazona aestiva*, which was ranked as “near threatened”. We observed it twice in natural sections, but it had likely escaped from captivity.

The CRA identified that, among the tested factors, bird communities were mainly shaped by the section type, noise, and the CV of DBH (Table 2). However, together, these three factors only explain 14.4% of the bird dataset variance. The CV of DBH accounts for 0.9%, the corridor type accounts for 3.8%, and noise accounts for 9.7%. The section type allowed us to clearly identify differences in bird communities, and noise influenced all bird communities almost independently of the section type and the CV of DBH (Figure 4).

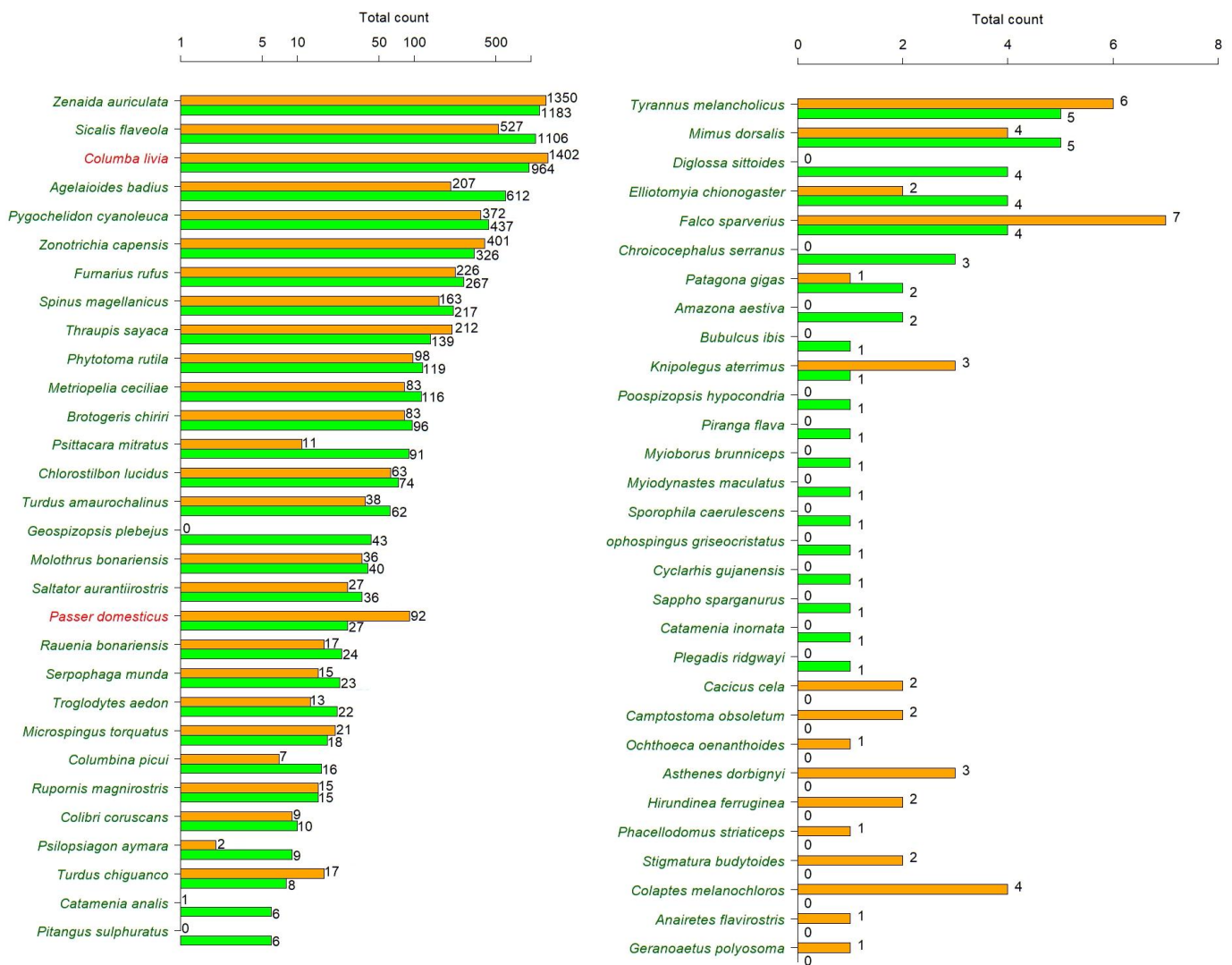


Figure 3. Total counts of bird species individuals in the natural (green) and artificial (orange) sections, with the color of the species names indicating status (green: native; red: introduced).

Table 2. Output summary of the canonical redundancy analysis of bird communities (formula: matrix of bird observations ~ noise + section type + CV of DBH).

Variance Partitioning				
	ddl	Variance	F	p-Value
Model	3	0.0483	9.8855	0.001
Residuals	156	0.2542		
Test for Significance of the Model				
	Inertia			Proportion
Total	0.3026			1.0000
Constrained	0.0483			0.1597
Unconstrained	0.2542			0.8403
Tests for Significance of the Coefficients				
	ddl	Variance	F	p-Value
Noise	1	0.0311	19.06	0.001
Section type	1	0.0131	8.006	0.001
CV of DBH	1	0.0042	2.587	0.009
Residuals	156	0.2542		

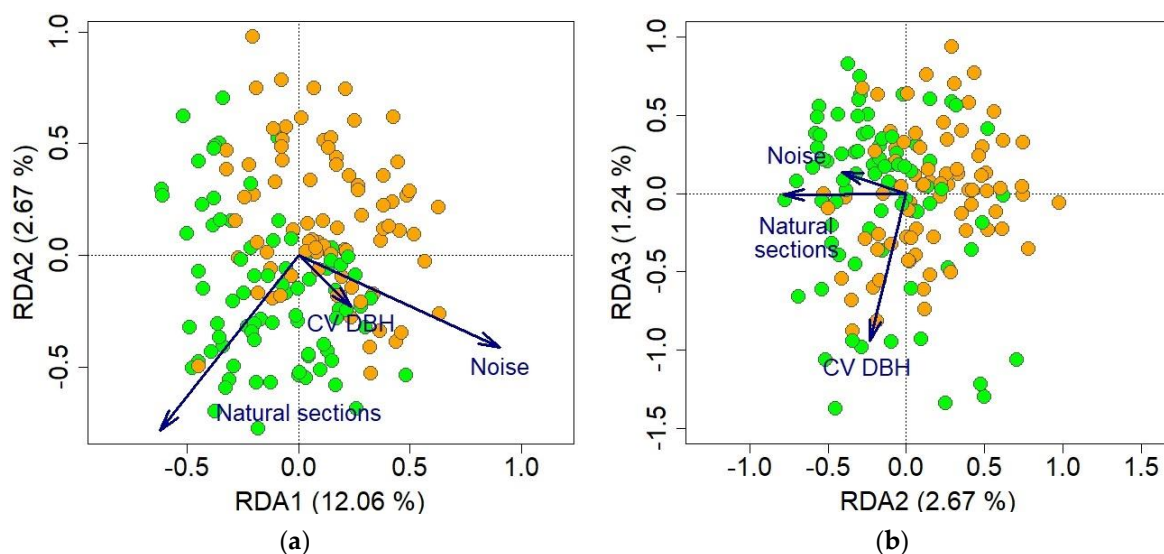


Figure 4. Projections of bird communities in the natural (green) and artificial (orange) sections in constrained spaces: (a) RDA1 and RDA2, (b) RDA2 and RDA3, with vectors showing the direction and the intensity of the three selected explanatory factors.

The analyses of bird community traits with the explanatory variables identified by the CRA confirmed the dominating effect of noise (Tables 3 and S7–S9), which had a significant positive effect on the prediction of the mass, range size, and frequencies of human-modified and shrubland habitats, granivores, terrestrial lifestyle, and the color gray. However, noise also had a negative effect on most of the other traits. The section type had a less significant effect, and the effects of the natural section were almost all opposite to those of noise. The beak depth/mass was higher in natural sections, and body mass and range size were lower in natural sections. The frequency of birds living in forest habitats was higher in the natural sections, and the frequency of birds restricted to human-modified habitats and the frequency of the color gray were lower in the natural sections. The CV of DBH also had less significant effects than noise, and those effects were also generally opposite to those of noise, except for two colors.

Table 3. Summary of the effects of the three explanatory factors selected in the CRA—noise, section type (natural section), and coefficient of variation of the diameter at breast height (CV of DBH)—on the traits describing bird communities (model summaries in Tables S7 and S8). Direction (↑/↓) and significance levels (***) 0.001, (**) 0.01, (*) 0.05, (-) >0.05.

	Noise	Natural Section	CV of DBH
Species number	↓ ***	-	-
Bird number	-	-	-
FDis	↓ ***	-	-
Beak length/mass	↓ ***	-	-
Beak width/mass	↓ ***	-	-
Beak depth/mass	↓ ***	↑ *	-
Tarsus length/mass	↓ ***	-	-
Wing length/mass	↓ ***	-	-
Tail length/mass	↓ ***	-	-
Mass	↑ ***	↓ *	-
Range size	↑ ***	↓ ***	-
Color number	↓ ***	-	-
Forest habitat	-	↑ ***	↑ *

Grassland habitat	-	-	-
Human-modified habitat	↑ ***	↓ **	↓ **
Shrubland habitat	↑ ***	-	-
Woodland habitat	↓ ***	-	-
Frugivore	↓ **	-	-
Granivore	↑ ***	-	↓ **
Terrestrial Herbivore	↓ **	-	-
Invertivore	↓ ***	-	↑ **
Nectarivore	↓ ***	-	-
Omnivore	-	-	↑ *
Vertivore	-	-	-
Aerial primary lifestyle	↓ ***	-	↑ **
Generalist primary lifestyle	↓ **	↓ *	-
Insectorial primary lifestyle	↓ **	-	-
Terrestrial primary lifestyle	↑ ***	-	↓ ***
Gray	↑ **	↓ **	-
Black	↓ ***	-	-
White	↓ ***	-	↑ **
Brown-Cream	-	-	↓ ***
Yellow-Orange	↑ **	-	↑ ***
Red-Pink	-	-	-
Green	↑ **	-	↑ ***
Blue	↓ **	-	↑ ***

4. Discussion

The city of Cochabamba has a bird community of approximately 180 species. However, around 100 of these are not annual residents and have different migration regimes (austral, boreal, altitudinal, or seasonal) [37]. Additionally, the presence of three urban lakes and two rivers conditions a large group of aquatic species in the city. Therefore, our results of 60 species from natural and artificial corridors share 60% of the ~80 resident and terrestrial species and only a small proportion (19%) of migrant species in the city. Possibly, urban agricultural areas, lacking in corridors, could account for other unregistered resident terrestrial species.

Contrary to what we expected, we found that the differences between the artificial and natural corridors were not so marked; the natural corridors had higher tree and native tree densities. However, contrary to expectations, more native tree species were not there, nor were more tree species (Table 1). This likely explains why the FDis was higher in the artificial sections. The vegetation structure indicator (DBH), the indicator of the variety of conditions offered by trees (CV of DBH), and the noise reached comparable levels in both section types. The differences in bird assemblages between the artificial and natural sections were also limited in extent, likely because a large proportion of species was shared, thus limiting the changes in FDis and in weighted mean trait values or proportions. The CRA highlighted that, among the studied factors, three variables shaped the bird communities and their traits: noise, the nature of the corridor, and the CV of DBH. However, even together, these three factors only explain less than 15% of the variation in species abundance. We only measured noise once, but it may vary according to the hour of the day, meaning that we may have underestimated its contribution. The nature of the section allowed us to separate the bird communities, but noise obviously affected them all, far more than the section type and the CV of DBH. Additionally, noise altered almost all bird traits, which confirmed its importance. The effects of passing from a natural to an artificial section on bird traits were comparable to the effects of noise but to a lesser extent, and the effects of the CV of DBH were generally opposite to those of noise.

We expected that the vegetation would be richer and more diverse in the natural sections than that in the artificial sections. Indeed, such fragments of remaining natural vegetation are often considered to be the pillars of biological diversity in cities [38], and their composition can remain stable for years [39]. However, in other places, marked homogenization occurs, leading to a reduction in differences between vegetation plots by replacing native species with a small assortment of exotic species [40]. The spread of exotic plant species originates mainly from gardens, so the diversity of exotic species in cities could be greater than that of native species [41], as the FDis shows here.

The observed tree vegetation differences between the artificial and natural sections were limited, possibly explaining why they also had little influence on the bird communities, accounting for less than 1% of the variance. Here, the influence may occur through the structure, as observed with the effect of the CV of DBH. This effect is independent of the section type. Conversely, the nature of the sections had a greater influence on the birds (3.8% of the variance), but this did not unveil which characteristics of the habitats, unrelated to the trees, were relevant. We hypothesized that the differences in bird communities could be the result of other biotic interactions, which could occur in the natural sections. In particular, these sections are mostly covered by loose soil, contrasting with the impervious soils frequently found in artificial sections. This provides more space for prey and predators, who are dependent on local conditions. For instance, the abundance of arthropods [42] promotes urban bird diversity [43]. Furthermore, natural sections also contain more complex habitats with spontaneous shrub and herbaceous plant growth, and they could also include particularities, such as large trees, berry-producing shrubs, or access to water, which are all important factors for bird diversity [44–46]. These environmental characteristics of the natural sections likely select for bird species that are less adapted to urban environments and more adapted to forests, i.e., smaller and less common birds with stronger beaks. In sparrows, the beak height decreases with the degree of urbanization [47], and in finches, species with deeper beaks eat larger seeds that are more difficult to crack [33,48]. At a local level, body size and mass could decrease with species richness and resource limitation, denoting competition for resources [49], but this is not always so [14]. Reduced body size also improves their ability to escape predators [50]. Therefore, these traits, more abundant in the natural sections, suggest adaptations to narrower niches.

In cities, the noise intensity can be predicted by the street location, urban land use, street geometry, road traffic, and public and private transportation [51]. It is also a good predictor of air pollution [52,53]. From these points of view, noise intensity can be considered a proxy for human activities and urbanization, which can be used to evaluate the disturbance of wildlife. As such, noise is also a direct factor of disturbance, particularly for birds. For instance, it could mask parent–offspring communication, hamper the transmission of mate quality information through bird songs, reduce the quality of the territory, induce physiological stress in chicks, impair their development [54], and alter the perceptions of predators [55] or prey [56]. Noise can also induce shifts in the frequency of vocal signals to visual or physical ones [57], direct modifications of song characteristics, higher frequencies of bird singing in noisy environments [58], and even the cultural evolution of songs [59,60]. However, tolerance to noise and other human disturbances varies across species and should also reflect adaptations to urban environments, as the consequence of species turnover is not random [56]. In this study, as induced by increasing noise, changes in bird traits in the communities underline these phenomena. Similarly, increasing noise when passing from natural sections to artificial sections induced the same kinds of changes: increased body mass and commonness, decreased beak depth/mass, an increased frequency of synanthropic bird species, and a decreased frequency of forest birds. These effects of noise were more intense (9.7% of variance) than those of the corridor type and of the CV of DBH because the changes affected more traits. Our results are in accordance with other studies, which have shown that, in urbanized environments, noise reduces species richness [61–66] and functional diversity [8,64]. Urbanization, without

specifically considering noise, has been shown to lower habitat specificity [5], color number [6,7], functional diversity [6,8], diversity, frugivory, and invertivory, and it has also been shown to increase size, granivory [8–11], and commonness [12,13], as shown in this study.

5. Conclusions

The bird communities in the artificial sections comprise more common and less specialized species compared with those in the natural sections. However, species shifts between section types were limited, for instance, in terms of functional diversity. Tree vegetation characteristics explained little of the selection of bird species communities by section type. Selection by section type likely occurs through the properties of the substrate, the undercover, or other features, such as the presence of water or particular trees. Furthermore, the results highlight that noise—regarded as an indicator of the intensity of human activities—induced the main variations, notably increasing the proportion of common species. We thus concluded that artificial corridors may also constitute efficient support for avian diversity. Importance, therefore, lies in checking for their continuity throughout the city and remedying possible hindrances. Artificial corridors, as described here, may be improved by increasing the surfaces devoted to loose soils and shrubs by improving birds' access to water and by letting some trees grow older. The establishment of such corridors should be recommended to urban managers and planners so that trees in cities provide other direct benefits to inhabitants, such as shade, cleaner air [67], significant CO₂ immobilization [68], and habitats for species other than birds. Moreover, proximity to wildlife has also been shown to improve human well-being [69–71]. We also recommend (1) conserving cities' natural corridors and other natural areas that provide the best support for wildlife; (2) considering policies for the soft re-wilding of spaces or, at least, policies avoiding soil sealing to improve the quality of green infrastructure; and (3) most evidently, engaging in noise reduction, because it is the main factor of perturbation or is at least an indicator thereof.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/d15020302/s1>: Table S1: Tree species list with trait values for the computation of the functional diversity index; Table S2: Ranking of bird species according to their sensitivity to noise, as determined by canonical redundancy analysis; Table S3: Ranking of bird species according to their sensitivity to the “natural” section type, as determined by canonical redundancy analysis; Table S4: Ranking of bird species according to their sensitivity to the coefficient of variation of DBH, as determined by canonical redundancy analysis; Table S5: Bird species list with trait values from the AVONET1 database [31] and personal contributions to colors for the computation of the functional diversity index; Table S6: Moran's I test for the spatial autocorrelation of bird community traits according to surveys; Table S7: Summary of testing linear mixed models for relationships between the bird weighted mean, bird community traits (continuous traits), and the explanatory factors selected in the canonical redundancy analysis; Table S8: Summary of testing logistic mixed models for relationships between the mean bird community traits (frequency traits) and the explanatory factors selected in the canonical redundancy analysis; Table S9: Means and community-level weighted means of bird traits between natural and artificial sections.

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