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Noise Pollution and Urban Birds Breeding in the Center of the Iberian Peninsula: Effects on Diversity and Abundance

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Abstract: In an increasingly urbanized world, biodiversity, and more specifically, birdlife located in urbanized ecosystems, faces several threats. Among these, noise pollution has proven to be one of the most significant, as it affects the effectiveness and efficiency of acoustic communication. We studied the relationship between noise and the diversity and abundance of birds breeding in urban areas in the central region of the Iberian Peninsula (Spain). We analyzed how species diversity and density varied across three levels of noise pollution (high, medium, and low). Species diversity decreased in areas with high noise pollution as compared to sites with medium and low levels of noise. We analyzed the density of the most frequent species found within each category. We identified eight additional noise-tolerant species whose density had significantly increased in environments with high levels of noise (e.g., Blackbird, Eurasian Tree Sparrow, and the Coal Tit). The ten most sensitive species, such as the Common Linnet, House Sparrow, and the European Greenfinch, had significantly decreased densities when the level of noise increased. Identifying the sensitivity (the effect) of urban bird species to acoustic pollution is vital for effective conservation management measures and for the sustainable planning and management of cities.

Keywords: acoustic pollution; biodiversity; conservation; noise tolerance; urbanization

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1. Introduction

Urbanized areas are becoming more abundant and expansive, often replacing other habitat types. Urban development forecasts have predicted that urban areas will continue to grow and human populations will become increasingly concentrated in larger and larger cities [1]. This situation raises conservation concerns about urban change and its effect on wildlife [2,3], as urbanization brings many changes that can threaten wildlife, particularly birds, for example, their diet and seasonality [4–6]. Urbanization brings with it many negative effects, such as habitat fragmentation, increased stress, contact with various sources of pollution (chemical, light, and acoustic pollution, even electromagnetic), and novel structures (for example, collisions with glasses and other reflecting surfaces) [7–9]. However, urbanization can also be beneficial, leading to situations of a milder microclimate (heat island effect), increased food availability (which may be low quality), and a general decrease in predators (although the presence of cats remains a major threat) [5,10]. Despite the multiple negative effects of urbanization, some bird species are successful in cities, with large and successful populations in urban habitats—synurbic species [3,11–13].

Nevertheless, it is also known that birds are particularly sensitive to noise pollution [11,14]. Anthropogenic noise pollution (also called noise in this paper) is closely linked to human activities, and its main source is road traffic (streets, avenues, roads, highways, etc.) and noise produced from other non-vehicle motors [15–18]. Generally, anthropogenic acoustic pollution is characterized by low-frequency noise, starting from 2 KHz and downwards [11,16]. Birds use acoustic communication as one of the main communication routes to communicate with conspecifics and individuals of other species [14,15]. This acoustic communication is extremely important to different activities of birds, such as territory defense, mate attraction, parental care, and communication in cases of danger, among others [18,19]. Noise can prevent proper and efficient acoustic communication between individuals by masking their vocalizations [14,15,20]. This increase in noise leads to different negative effects for birds, such as increased stress and predation, increased time spent on territory defense, mate attraction, feeding, and vigilance [21–24]. Noise is an important stress factor for birds and can lead to a decline in their populations as their normal life cycles are hampered [16,18]. Noise can even produce a barrier effect, preventing some birds or bird species from accessing places with high noise pollution [19,25,26]. Urban birdlife has declined in Spain in recent decades [27,28], and a similar trend has been observed in other cities around the world [8]. Acoustic pollution (noise) can mask bird vocalizations, but it does not affect all bird species equally. It depends on the individual characteristics of each species (e.g., body size) and their song (vocal range, frequencies, etc.) [16,18,29,30]. Alternatively, several studies have found that some species can adapt to noise, for example, with changes in their songs and vocalizations or their behavior [14,20,31,32].

The main objective of the present study is to assess the effects of noise on the diversity and density of bird species living and breeding in urban areas in the center of the Iberian Peninsula (Spain). We compared the diversity and density of birds between sites with three different levels of noise (high, medium, and low). We test whether noise has a negative effect on the urban bird population in our study areas. Moreover, we aim to identify which species populations are negatively or positively affected by noise and to study the effect of anthropogenic acoustic pollution on urban bird assemblages.

2. Materials and Methods

2.1. Study Area

Sampling was carried out in 9 cities and towns in the center of the Iberian Peninsula (Spain) (Figure 1), in an area of approximately 1400 Km^2 with a Mediterranean climate. The cities and towns were different in population and geographical size. The selected cities and towns were Madrid (324.7 Km^2, 3,332,035 inhabitants), Parla (9.1 Km^2, 133,004 inhabitants), Aranjuez (7.5 Km^2, 60,668 inhabitants), Pinto (10.7 Km^2, 55,208 inhabitants), Carranque (2.3 Km^2, 5274 inhabitants), Casarrubuelos (0.79 Km^2, 4062 inhabitants), Lominchar (1.1 Km^2, 2639 inhabitants), Palomeque (0.26 Km^2, 1143 inhabitants), and Batres (0.25 Km^2, 1872 inhabitants). The study area included a wide variety of urban sites: small and large parks, ranging from squares to streets with minimal vegetation (to ensure a minimum number of bird recordings). We categorized the study area according to anthropogenic acoustic pollution (noise). For prior categorization, we used noise maps and decibel (dB) measurements during previous visits to each location. In addition, we made noise pollution measurements at each bird sampling visit and averaged them before analysis. We measured noise decibels for 1 min using an Extech Instruments sonometer model 407,736 (with an A-weighted filter), one meter above the ground. Noise measurements were taken at each point and each visit, covering different times throughout the morning. These categories were validated by statistical analysis using the Kruskal–Wallis test ($H = 928{,}742$; $p < 0.001$). The categories with their characteristics were the following:

- High level of acoustic pollution, where noise pollution levels were high and continuous: mean 56.1 dB (range: 49–66 dB).
- Medium level of acoustic pollution, where noise pollution levels were medium to low, with peaks of high noise pollution corresponding to the start and end of work, schools, rush hours, etc.: mean 49.6 dB (range: 45–59 dB).
- Low level of acoustic pollution, where noise pollution remained low: mean 43.3 dB (range: 39–48 dB).

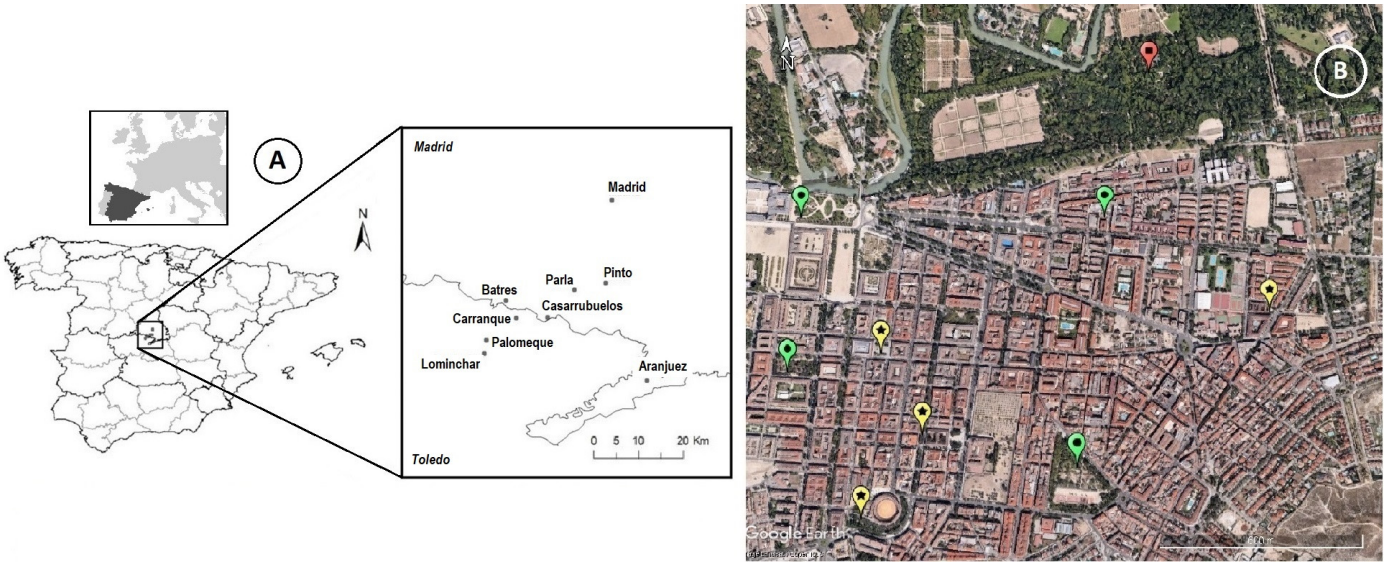


Figure 1. (**A**) Map of the study area in central Spain detailing the location of the cities and towns where the point-count stations were located. (**B**) Zoom in on the location of some point-count stations in one of the towns included in the study (Aranjuez): yellow stars (high-noise level); green circles (medium-noise level), and red squares (low-noise level). ArcGIS, Google Earth, and Eurostat maps were used to produce the maps.

2.2. Bird Sampling

The sampling unit used was a point-count station with a 25 m fixed radius. This method was selected because it provides a standardized protocol, especially at sites with high environmental heterogeneity [33]. In this study, only a 25 m radius was used to avoid the problem of decreasing species detectability at farther away distances. We established 72 point counts, divided into three categories of acoustic pollution, high, medium, and low, with 24 count points per category. The point counts were established according to town size, ranging from 22 (the biggest city, Madrid) to 3 (the smallest, Batres, Lominchar, and Palomeque). The 72 point-count stations were at least 250 m apart to avoid overlapping and duplicated point counts. The locations of the point-count stations were randomly selected, and the three groups of points had similar and comparable characteristics. Several habitat factors were considered, primarily to balance the sampling points between different noise levels. These main factors were vegetation cover area, urban cover area, building type (approximate height and age), presence or absence of the three strata types, existence of sandy surfaces, presence of water, use of mulch in gardening, human activity (type and quantity), the area of the municipality, and the distance to the municipal border. The bird species, either heard or seen, and their abundance were recorded for 10 min. This sampling time frame was chosen because it was proven optimal for collecting a complete bird count without overestimating in previous studies. Sampling was conducted early in the morning, before sunrise, until noon (or 10 am during the hottest months), in optimal weather conditions, with no or low wind and no rain [33]. Sampling was conducted during

the breeding season between March 2019 and August 2021 (15 March to 15 August). Sixteen sampling visits were made to each point-count station, and between 1 and 2 samplings were performed per month (a total of 8 visits in 2019, 6 in 2021, and only 2 visits in 2020 because of COVID-19 restrictions).

2.3. Statistical Analysis

We estimated the species diversity and density of each species for each noise level. To estimate species diversity, we calculated species richness using species accumulation curves. Species accumulation curves for each plot were constructed to measure the completeness of the sampling and to compare the species richness [34,35]. These curves enabled us to establish a compromise among the different plot surveys since counts exclusively based on the number of species observed without reference to the effort invested would have obtained false results [36]. The number of point counts was taken as a measure of the sampling effort and randomized 100 times to construct smoothed accumulation species curves [36]. We constructed and used 95% confidence intervals of the curves to compare species diversity among the three smoothed accumulation species curves [37,38]. We used EstimateS v 9.1.0 software to construct the smoothed species accumulation curves [35].

Moreover, we also calculated the density of the 33 most frequent species, those species that had a greater presence in the total number of count points and samples. We chose these most frequent species to ensure a sufficient data set for analysis. To calculate the density (individuals per hectare) per species and point, we used the following equation proposed by Shiu and Lee [39]:

$$D = n/(\pi r^2) \times 10{,}000, \quad (1)$$

where D is the density, n is the number of individuals of a species, and r is the sampling unit radius (in meters).

We analyzed the density of each species for the three categories of acoustic pollution using a non-parametric Kruskal–Wallis test [40]. For species that showed significant differences, a pairwise Dunn test with Bonferroni correction was performed to detect which pairs of noise levels were significantly different. All statistical analyses were performed using IBM SPSS Statistics v 28.0.1.1 software.

3. Results

3.1. Species Diversity

A total of 29,934 individuals from 81 species belonging to 37 families were recorded (Tables 1 and A1). The comparison of species diversity for the three levels of noise produced smoothed species accumulation curves with a 95% confidence interval, as shown in Figure 2. Sites with a high noise level had fewer species and less diversity (49 bird species) than the sites with a medium or low level of noise (with 71 and 67 bird species, respectively). In our analysis, the 95% confidence interval of the high noise level curve did not overlap with the confidence intervals of the other two curves. Of the 81 species, 17 species were absent in at least one noise category, such as the Hawfinch (*Coccothraustes coccothraustes*), which was not registered in the high-noise sites (Tables 1 and A1). On the other hand, 19 species were unique to a particular noise level and appeared in only one of the categories (Table A1). For example, the European Crested Tit (*Lophophanes cristatus*) was only recorded in sites with a low level of noise. The analysis of trends in population size over the last decade showed that 21 species (Tables 1 and A1) were in decline in all Spanish territories, such as the House Sparrow (*Passer domesticus*), Eurasian Magpie (*Pica pica*), European Serin (*Serinus serinus*), Common Linnet (*Linaria cannabina*), Eurasian Tree Spar-

row (Passer montanus), White Wagtail (*Motacilla alba*), and the Iberian Green Woodpecker (*Picus sharpei*) [41]. Although these species are experiencing a decrease in population size, they can be found in urban habitats. Of the 81 species, 15 species are listed in the Spanish legislation as endangered or near endangered (Tables 1 and A1), such as the Barn Swallow (*Hirundo rustica*), which is classified as vulnerable (VU), and the Western Jackdaw (*Corvus monedula*), classified as endangered (EN) [42]. We also found two rare species: Hawfinch and Pied Flycatcher (*Ficedula hypoleuca*) [27]. Three allochthonous species were recorded, including the Monk Parakeet *(Myiopsitta monachus*), which was one of the most frequent and abundant species found. Another species observed was the Common and Pallid Swift (*Apus apus* and *A. pallidus*); however, they were not included in the density analysis because of their biology, as they spend most of their lives away from the ground and noise.

Table 1. The 33 most frequent and abundant bird species whose densities were analyzed. The table lists the common name of each species recorded, as well as its scientific name, conservation status (c. status), and the number of times it was recorded in each of the three noise categories (high, medium, and low) included in this study. The asterisk (*) marks those species whose populations are in decline in Spain, and ALLOC is the allochthonous species in Spain. In c. status are the IUCN (The International Union for Conservation of Nature) categories of LC (Least Concern), NT (Near Threatened), VU (Vulnerable), and EN (Endangered).

English Name	Scientific Name	C. Status	High Level	Medium Level	Low Level	Total
Common Wood Pigeon	*Columba palumbus*	LC	24	24	24	72
Common Blackbird	*Turdus merula*	LC	24	24	24	72
House Sparrow	*Passer domesticus*	LC *	24	24	24	72
Spotless Starling	*Sturnus unicolor*	LC	18	24	24	66
European Greenfinch	*Chloris chloris*	LC	21	23	22	66
Eurasian Magpie	*Pica pica*	LC *	23	23	18	64
European Goldfinch	*Carduelis carduelis*	LC	20	22	21	63
European Serin	*Serinus serinus*	LC *	19	20	22	61
Barn Swallow	*Hirundo rustica*	VU *	16	22	20	58
Eurasian Collared Dove	*Streptopelia decaocto*	LC	15	20	20	55
Rock Dove	*Columba livia*	LC *	21	19	13	53
Common House Martin	*Delichon urbicum*	LC	12	21	19	52
Common Linnet	*Linaria cannabina*	LC *	12	19	19	50
Eurasian Blue Tit	*Cyanistes caerueleus*	LC	19	16	8	43
Great Tit	*Parus major*	LC	16	14	10	40
Coal Tit	*Periparus ater*	LC	18	15	5	38
White Wagtail	*Motacilla alba*	LC *	12	15	7	34
Monk Parakeet	*Myiopsitta monachus*	ALLOC	19	11	3	33
European Robin	*Erithacus rubecula*	LC	12	12	8	32
Black Redstart	*Phoenicurus ochruros*	LC	6	11	12	29
Common Chaffinch	*Fringilla coelebs*	LC	8	12	8	28
Eurasian Blackcap	*Sylvia atricapilla*	LC	9	8	9	26
Short-toed Treecreeper	*Certhia brachydactyla*	LC	13	6	6	25
Stock Dove	*Columba oenas*	LC	9	6	7	22
Sardinian Warbler	*Sylvia melanocephala*	LC	7	8	7	22
Eurasian Tree Sparrow	*Passer montanus*	NT *	10	5	7	22
Iberian Green Woodpecker	*Picus sharpei*	LC *	9	5	2	16
European Pied Flycatcher	*Ficedula hypoleuca*	LC	4	7	5	16
Long-tailed Tit	*Aegithalos caudatus*	LC	3	4	4	11
Spotted Flycatcher	*Muscicapa striata*	LC	2	2	6	10
Western Jackdaw	*Corvus monedula*	EN *	2	3	3	8
Crested Lark	*Galerida cristata*	LC *	0	2	5	7
Mistle Thrush	*Turdus viscivorus*	LC	0	2	5	7

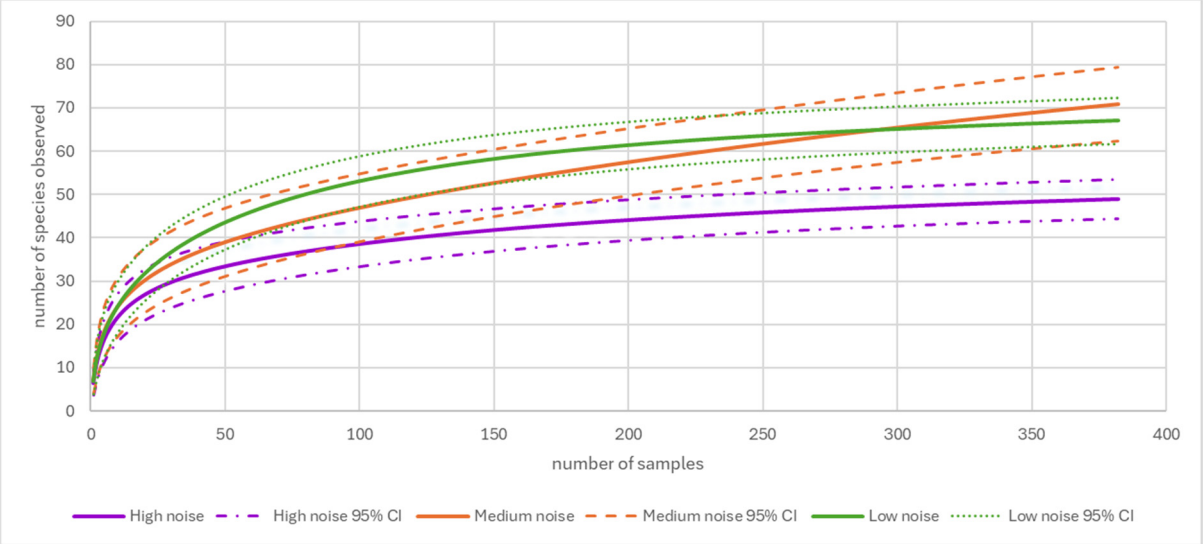


Figure 2. Smoothed species accumulation curves and their 95% confidence interval for each level of noise: high (purple), medium (orange), and low (green).

3.2. Response to Noise

In the density analysis, we observed that birds responded differently to the level of noise. Out of the 33 species studied, only 18 species showed a clear response. For the other 15 species, significant results were not obtained from the statistical analysis, or the results did not clearly explain the response of these species to noise. Moreover, the species that did show a clear result could be divided into two groups or responses. One group or response consisted of species whose density responded negatively to noise. The density of these species was higher when the noise level was low than when it was high (Figure 3). This group had statistically significant values and consisted of 10 bird species (Table 2): European Greenfinch (*Chloris chloris*), Common Chaffinch (*Fringilla coelebs*), Barn Swallow (*Hirundo rustica*), Common Linnet (*Linaria cannabina*), Spotted Flycatcher (*Muscicapa striata*), House Sparrow (*Passer domesticus*), Black Redstart (*Phoenicurus ochruros*), European Serin (*Serinus serinus*), Eurasian Collared Dove (*Streptopelia decaocto*), and the Spotless Starling (*Sturnus unicolor*). Table 2 shows the results of the pairwise analysis of noise levels for each species.

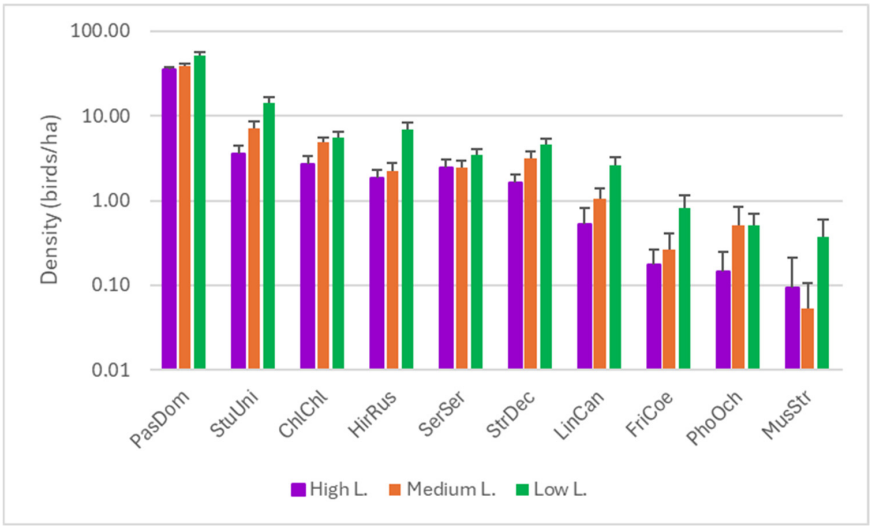


Figure 3. Species with the highest density (birds/ha) at sites with a low level of noise. Average density at sites with high (purple), medium (orange), and low (green) levels of noise for each bird

species. Also, error bars are shown. PasDom, *Passer domesticus*; StuUni; *Sturnus unicolor*; ChlChl, *Chloris chloris*; HirRus, *Hirundo rustica*; SerSer, *Serinus serinus*; StrDec, *Streptopelia decaocto*; LinCan, *Linaria cannabina*; FriCoe, Fringilla coelebs; PhoOch, *Phoenicurus ochruros* and MusStr, *Muscicapa striata*.

Table 2. Results of the Kruskal–Wallis test for the species with the highest density at sites with a low level of noise. The table shows the results of the analysis among the three noise levels and the pairwise analysis. The species with a *p*-value of >0.05 are indicated as ns.

Species	H	*p*	High–Low		High–Medium		Medium–Low	
			H	*p*	H	*p*	H	*p*
Chloris chloris	41.242	<0.001	−116.04	<0.001	−121.268	<0.001	5.228	ns
Fringilla coelebs	12.965	0.002	−32.284	<0.001	−6.079	ns	−26.204	0.006
Hirundo rustica	103.128	<0.001	−186.353	<0.001	−32.721	ns	−153.632	<0.001
Linaria cannabina	48.4	<0.001	−101.727	<0.001	−40.32	0.006	−61.406	<0.001
Muscicapa striata	9.351	0.009	−15.057	0.008	0.034	ns	−15.091	0.008
Passer domesticus	17.486	<0.001	−96.139	<0.001	−23.732	ns	−72.408	0.003
Phoenicurus ochruros	15.315	<0.001	−37.286	<0.001	−18.221	ns	−19.065	0.045
Serinus serinus	9.603	0.008	−54.047	0.004	−8.738	ns	−45.039	0.016
Streptopelia decaocto	34.98	<0.001	−109.415	<0.001	−77.382	<0.001	−32.034	ns
Sturnus unicolor	114.837	<0.001	−230.449	<0.001	−122.383	<0.001	−108.066	<0.001

The other group or response consisted of species whose density responded positively to noise. The density of these species was greater when the noise level was high than when it was low (Figure 4). This group had statistically significant values and consisted of eight bird species (Table 3): Rock Dove (*Columna livia*), Common Wood Pigeon (*Columba palumbus*), Monk Parakeet (*Myiopsitta monachus*), Eurasian Tree Sparrow (*Passer montanus*), Coal Tit (*Periparus ater*), Eurasian Magpie (*Pica pica*), Iberian Green Woodpecker (*Picus sharpei*), and the Common blackbird (*Turdus merula*). Table 3 shows the results of the pairwise analysis of noise levels for each species.

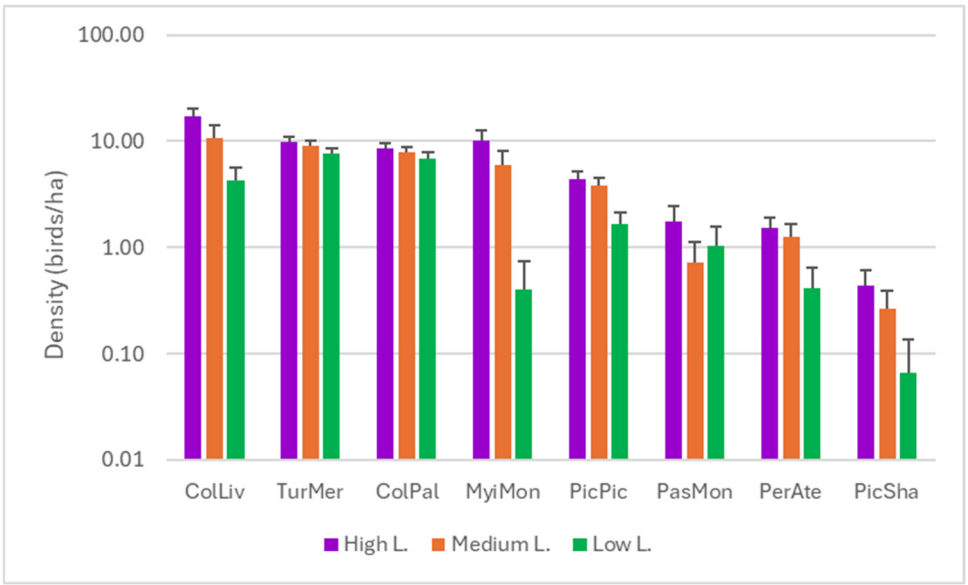


Figure 4. Species with the highest density (birds/ha) at sites with a high level of noise. Average density at sites with high (purple), medium (orange), and low (green) levels of noise for each bird species. Also, error bars are shown. ColLiv, *Columba livia*; TurMer, *Turdus merula*; ColPal, *Columba palumbus*; MyiMon, *Myiopsitta monachus*; PicPic, *Pica pica*; PasMon, *Passer montanus*; PerAte, *Periparus ater* and PicSha, *Picus sharpei*.

Table 3. Results of the Kruskal–Wallis test for the species with the highest density at sites with a high level of noise. The table shows the results of the analysis among the three noise levels and the pairwise analysis. The species with a *p*-value of >0.05 are indicated as ns.

Species	H	*p*	High–Low		High–Medium		Medium–Low	
			H	*p*	H	*p*	H	*p*
Columba livia	104.682	<0.001	201.109	<0.001	132.379	<0.001	68.73	<0.001
Columba palumbus	7.883	0.019	63.723	0.005	38.488	ns	25.234	ns
Myiopsitta monachus	155.597	<0.001	207.849	<0.001	110.104	<0.001	97.745	<0.001
Passer montanus	12.597	0.002	27.934	0.008	35.703	<0.001	−7.77	ns
Periparus ater	36.389	<0.001	79.773	<0.001	23.836	ns	55.938	<0.001
Pica pica	65.316	<0.001	154.809	<0.001	37.082	ns	117.727	<0.001
Picus sharpei	17.168	<0.001	34.521	<0.001	13.604	ns	20.917	0.013
Turdus merula	13.5	0.001	85.383	<0.001	36.145	ns	49.238	0.035

4. Discussion

A total of 81 breeding species belonging to 37 families were recorded. This diversity was to be expected based on similar studies on urban avifauna [43–45]. Even though urban habitat is one of the most altered with several sources of stress for birds [5], we found bird species classified as being endangered, rare, or declining in population [27,41,42]. These results were expected and are in line with other similar studies [44,46,47] and highlight the role of the urban ecosystem in maintaining bird diversity and conservation [48,49]. The species that stand out because of their density and frequency are similar (Table 1, Figures 3 and 4) and are typically urban species (synanthropic species). Other similar studies highlight these species for their high frequency and abundance [47,50–52]. We see that the frequency and density of species decrease rapidly, a finding that is coherent with the effect of urbanization on the homogenization of biodiversity, with synanthropic species being the most abundant and frequent [18,53]. One of the most abundant species found in this study was the invasive exotic species Monk Parakeet (*Myiopsitta monachus*). This and the other invasive exotic species found, despite not being in their natural habitat, have succeeded mainly due to changes caused by urbanization [5,53,54], which has caused problems for other bird species and even humans [55].

We found lower bird diversity at sites with high noise levels. Noise seems to negatively affect bird diversity, rarefying some species and even making them absent in places with a high level of noise [9,25,30]. This rarefying of species with increasing noise was also observed by Herrera-Montes and Aide [56], who found that some species disappeared in areas close to the noise source (road) and reappeared when the noise decreased. In this study, we obtained a similar species diversity at low and medium noise levels. High species diversity has been related to medium and low disturbance levels in several studies [25,51,53,57]. In this case, noise (anthropogenic acoustic pollution) is detrimental to birds because it masks their vocalizations, and this noise can be a barrier to their dispersion [11,14,18,58]. However, this relationship between species richness and noise is not always clear; for example, Ghadiri Khanaposhtani et al. [26] show that avian richness could decrease in some cases and increase in others in relation to noise increments.

In this study, the response of species to noise differed. These differential responses were expected based on the literature, which indicates that the response depends on many species-specific factors, such as the vocalization characteristics of each species [16,18,30]. We found two main groups: species that, at high noise levels, decreased or increased in density. The species whose density was negatively affected by noise behaved as noise-sensitive species. For these species, it could be possible that acoustic pollution impedes their proper communication by masking their vocalizations and may produce a barrier effect on their distribution, making these areas with high noise pollution inaccessible [11,20,59]. The

species whose density increased with increasing noise behaved as noise-tolerant (or less sensitive) in this study. The increased density of some species may be explained by them occupying the niche space left by more sensitive species, increasing avian homogeneity [53,58]. We found results similar to this study for several species [23,25,43,44,57]. Despite similar results in the literature, we also found other studies with different, sometimes opposite, results for the same bird species [25,44,57], for example, blackbird, which, in some studies, is more abundant in non-urban places.

On the other hand, we identified species with no clear relationship with noise, which is frequently reported in the literature [17,56,57]. These species seem to not be affected, either negatively or positively, but the reason behind this depends on each species, its characteristics, and its history [3,18,58]. These results may change with a larger pool of data or with specific or more concrete studies on these species without a clear relationship to noise. Discrepancies and species with no clear relationship may be due to a lack of knowledge about song characteristics and how noise affects them. Species may not be equally susceptible to masking by noise (anthropogenic acoustic pollution), and this will depend on their song characteristics [14,18,60], which may also be an explanation for some noise-tolerant species in this study. Another possible factor for these discrepancies may be the differences between road and city noise (more localized and continuous, and usually more intense). Another cause of discrepancies is the possible song adaptation of the species [20,30,58], which may blur the relationship with noise. This may be the case of the Great Tit. In our study, its density did not vary with the level of noise, and several studies have found that Great Tits can adapt their vocalizations to avoid masking by noise [11,18,61]. The acoustic adaptation hypothesis [19] may also be a reason for the increased density of tolerant species. These species can avoid the negative effects of noise and increase their population where other species cannot. Song adaptation has been described in different species by various authors; for example, the great tit, the blackbird [14,62,63], the European robin [31,64,65], and other species [23,66,67]. What is not clear is whether these changes are permanent or not [32,68,69]. These adaptations can be found in different song characteristics [20,60,70], and these changes can give rise to various dialects in different populations [71]. Song adaptation to acoustic pollution is a broad topic, and although there are numerous studies on the subject, there is a need to further improve our knowledge.

In this study, only noise pollution was considered by comparing three different noise categories (high, medium, and low). However, this research should be complemented using other multivariate studies, where different characteristics of the urban habitat are evaluated simultaneously, as well as the effect of other collateral noise (stress, energy expenditure) [23,72] on each species. The urban ecosystem is a heterogeneous environment, and many urban variables can affect birds. We randomly choose points with different characteristics to balance the urban characteristics and make the categories comparable. Although in our study, we aim for the chosen points to be a representative sampling of urban ecosystems, we cannot rule out stochastic random effects. This point is a weakness of our study; however, we believe that the differences found are caused by differences in acoustic pollution. This type of study should be combined with other studies that analyze noise with other characteristics of the urban ecosystem and how it affects birds. Another important focus for urban bird conservation, aside from our study, is the quality of the populations regardless of abundance and how cities can become ecological traps [72]. Urban bird conservation is an important issue that can be addressed using various strategies, which underline the need for further research and expanding our knowledge on this topic.

Despite the dependency of birds on effective and efficient acoustic communication, only 54.5% of the species tested responded clearly to noise. Similar results can be found in different

studies [23,44,57], although other authors report a higher proportion [26]. This highlights the complexity of the relationship between noise and birds and the need for further research to test whether these birds have adapted their songs or other factors important for their survival.

Recently, urbanization efforts have shifted toward integrating cities into the natural environment, creating "greener" and more eco-friendly cities [73,74] through structures and tools such as green roofs, vertical gardens, and biodiversity corridors [75–77]. Part of the studies on urban biodiversity are focused on being a management tool for "ecofriendly" cities [78,79]. More eco-friendly management of cities, together with a general decrease in noise pollution linked to urbanized environments, promotes an increase in biodiversity and the role of cities in conservation [46,74,76]. These changes would also benefit city dwellers, who would have a better quality of life, both physically and mentally. This eco-friendly approach promotes the well-being of inhabitants [80], connects them to nature, and produces benefits through various ecosystem services (temperature regulation and mitigation, cleaning up air pollution, etc.) [74,81]. Identifying the sensitivity (how it is affected) of bird species to acoustic pollution may allow urban birds to be used as bioindicators of noise. The use of birds as bio-indicators of human health and quality of life and as a useful tool for urban management and biodiversity conservation [82] is becoming increasingly common.

5. Conclusions

Noise pollution seems to be a key factor for birds, as well as other animal species, that can lead to evolutionary pressure or increased energy expenditure. Noise decreased the diversity of birds and increased their homogenization, and some species also experienced a decrease in density. The variety of responses to noise pollution may be due to several factors, including the song characteristics of each species, their adaptive capacity, and other possible factors, such as behavior adaptation. The characteristics of urban environments are similar in many cities around the world, making the management of cities and their green spaces relevant to the adjacent landscape for their biodiversity conservation.

The effects of noise on birds need to be taken into account, especially when managing green spaces, planning cities, and promoting less noisy cities. Various actions can be taken to reduce the level of noise pollution on several fronts, promoting less use of motor vehicles (mainly private), encouraging the use of other non-noisy transport (such as bicycles), pedestrianizing more streets, and better planning of infrastructure (main roads, etc.) are actions that reduce noise pollution. Noise barriers can also be palliative measures, which can be artificial or natural, such as lines of vegetation on the edges of large parks. These are just a few concrete examples, as more and more research is being carried out to reduce noise pollution and its propagation in urbanized environments with different and new focuses.

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Appendix A

Table A1. The bird species that were recorded but not used for the density analysis. The table lists the common name of each species, as well as its scientific name, conservation status (c. status), and the number of times it was recorded in each of the three noise level categories (high, medium, and low). The asterisk (*) marks those species whose populations are in decline in Spain, and ALLOC is the allochthonous species. E marks those species excluded from the density analysis. In c. status are the IUCN (The International Union for Conservation of Nature) categories of LC (Least Concern), NT (Near Threatened), VU (Vulnerable), and EN (Endangered).

English Name	Scientific Name	C. Status	High Level	Medium Level	Low Level	Total
White Stork	*Ciconia ciconia*	LC	4	6	3	13
Western Bonelli's Warbler	*Phylloscopus bonelli*	LC	4	5	4	13
Iberian Chiffchaff	*Phylloscopus ibericus*	LC	6	4	1	11
Mallard	*Anas platyrhynchos*	LC *	4	4	2	10
European Bee-eater	*Merops apiaster*	LC	2	1	7	10
Eurasian Hoopoe	*Upupa epops*	LC *	2	1	7	10
Black Kite	*Milvus migrans*	LC	2	2	4	8
Iberian Chiffchaff	*Phylloscopus collybita*	NT	2	2	4	8
Great Spotted Woodpecker	*Dendrocopos major*	LC	2	2	3	7
Common Nightingale	*Luscinia megarhynchos*	LC	0	1	5	6
Eurasian Nuthatch	*Sitta europaea*	LC	3	1	2	6
Red-rumped Swallow	*Cecropis daurica*	LC	0	1	4	5
Zitting Cisticola	*Cisticola juncidis*	NT	0	2	3	5
Red Kite	*Milvus milvus*	EN	0	1	4	5
Hawfinch	*Coccothraustes coccothraustes*	LC	0	1	3	4
Eurasian Wren	*Troglodytes troglodytes*	LC	0	2	2	4
Common Reed Warbler	*Acrocephalus scirpaceus*	LC	0	1	2	3
Carrion Crow	*Corvus corone*	LC	1	1	1	3
Eurasian Golden Oriole	*Oriolus oriolus*	LC	1	0	2	3
Rose-ringed Parakeet	*Psittacula krameri*	ALLOC	1	1	1	3
European Stonechat	*Saxicola rubicola*	LC *	0	0	3	3
Garden Warbler	*Sylvia borin*	LC	0	1	2	3
Greylag Goose	*Anser anser*	LC	0	1	1	2
Montagu's Harrier	*Circus pygargus*	VU *	0	0	2	2
Corn Bunting	*Emberiza calandra*	LC *	0	1	1	2
Peregrine Falcon	*Falco peregrinus*	NT	1	1	0	2
Common Kestrel	*Falco tinnunculus*	EN *	0	0	2	2
European Crested Tit	*Lophophanes cristatus*	LC	0	0	2	2
Spanish Sparrow	*Passer hispaniolensis*	LC	1	1	0	2
Common Redstart	*Phoenicurus phoenicurus*	LC	1	1	0	2
Common Firecrest	*Regulus ignicapilla*	LC	0	1	1	2
Song Thrush	*Turdus philomelos*	LC	0	0	2	2
Red-legged Partridge	*Alectoris rufa*	VU *	0	1	0	1
Little Owl	*Athene noctua*	NT *	0	1	0	1
Muscovy Duck	*Cairina moschata*	ALLOC	0	0	1	1
Cetti's Warbler	*Cettia cetti*	LC	0	1	0	1
Lesser Kestrel	*Falco naumanni*	VU	0	1	0	1
Common Moorhen	*Gallinula chloropus*	LC	0	0	1	1
Griffon Vulture	*Gyps fulvus*	LC	0	0	1	1
Woodchat Shrike	*Lanius senator*	EN	0	1	0	1
Red Crossbill	*Loxia curvirostra*	LC	0	1	0	1
Great Cormorant	*Phalacrocorax carbo*	LC	0	1	0	1
Wood Warbler	*Phylloscopus sibilatrix*	DD	0	1	0	1
Willow Warbler	*Phylloscopus trochilus*	DD	0	1	0	1
Common Whitethroat	*Sylvia communis*	LC *	0	0	1	1
Dartford Warbler	*Curruca undata*	EN	0	1	0	1
Common Swift	*Apus apus*	VU *	E	E	E	E
Pallid Swift	*Apus pallidus*	LC	E	E	E	E

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