

## Urban Bird Species in Virginia Increase the Frequencies of Songs and Calls in Areas of Higher Anthropogenic Noise

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### Abstract

North American bird populations are declining due to human-influenced activities, including urbanization. Urbanization has varied effects on bird species as the expansion of cities disturbs forests, wetlands, and coastal ecosystems. One important effect of urbanization is an increase in ambient noise caused by human activity (i.e., anthropogenic noise). I examined the influence of anthropogenic noise on vocal communication in the Northern Cardinal (*Cardinalis cardinalis*), Carolina Wren (*Thryothorus ludovicianus*), and Song Sparrow (*Melospiza melodia*) at 12 study sites in northern Virginia. I conducted sound analyses of these birds' vocalizations to test the hypothesis that minimum and maximum song or call frequencies (i.e., pitch) have increased in response to anthropogenic noise. Results show that both minimum and maximum song frequency of Carolina Wrens, and maximum song frequency of Song Sparrows were higher in areas with higher levels of anthropogenic noise. Likewise, minimum call frequency of Northern Cardinals was also higher in areas with higher levels of anthropogenic noise. These results are consistent with other studies that show that birds shift the frequencies of their songs and calls up in louder habitats to avoid the masking effects of low-frequency anthropogenic noise. Effects of ambient noise on bird vocalizations are likely influenced by other variables such as vegetation structure, competition for breeding sites, and predation risk.

### Introduction

Since the late 20th century, North American bird populations have been declining due to human-influenced activities (NABCI 2022). One aspect of human activity that has gotten recent attention by scientists is anthropogenic noise in the form of construction, road and air traffic, and industrial and residential activity. The increased level of noise has dramatic effects on vocal communication in birds because it masks or otherwise interferes with song and call frequencies (Dowling et al. 2012). Avian communication is essential for territorial defense, group coordination, and reproductive success (Catchpole and Slater 2008, Nemeth et al. 2013), and increased levels of ambient noise are likely to interfere with successful communication. In

sexual competition, for example, bird songs are crucial in mating rituals because specific song characteristics are used by females to choose potential mates (Slabbekoorn and Ripmeester 2008). Further, males may be forced to improve detection of their songs or calls by manipulating amplitude or frequency, thereby potentially making them more conspicuous to predators (Zwart et al. 2016).

Increasingly, evidence shows that birds respond to anthropogenic noise by altering components of their songs and calls. In urban settings, Northern Cardinals (*Cardinalis cardinalis*) and American Robins (*Turdus migratorius*) often increase the frequencies of their vocalizations to increase their detection (Seger-Fullam et al. 2011). Both species exhibit high vocal plasticity with individuals altering their minimum frequency during a song bout when aware of masking by ambient noise (Seger-Fullam et al. 2011). Similarly, male Black-capped Chickadees (*Poecile atricapillus*) produce higher song frequencies when ambient noise increases and reduce song frequencies as noise levels decline (LaZerte et al. 2016).

These changes in the way that birds produce songs and calls in response to anthropogenic noise may have negative fitness consequences. Altering vocalization frequency to counteract anthropogenic noise increases energy allocation to singing because producing higher frequency notes is more strenuous physiologically (Lambrechts 1996). As a result, birds must compensate by allocating more time to foraging, which may then increase predation risk (Lima and Dill 1990). Alternatively, birds may spend less time foraging for food and exhibit increased vigilance behavior against potential predators in noisy environments because noise makes it more difficult for them to detect predators using auditory cues (Quinn et al. 2006, Sweet et al. 2022). Such behavioral shifts may then decrease the ability of birds to provision nestlings adequately, thereby leading to reduced reproductive success (Slabbekoorn and Ripmeester 2008, Merrall and Evans 2020).

Anthropogenic noise may also force birds away from particular areas or shift the timing of when they sing. When North American migratory birds in rural areas were exposed to broadcasts of recorded road noise, for example, their abundance declined by 25% compared to

control areas, and some species such as the Yellow Warbler (*Setophaga petechia*) completely avoided the area around the simulated road (McClure et al. 2013). European Blackbirds (*Turdus merula*) sing up to five hours earlier in the morning in highly urbanized, noisy areas compared to rural, quiet areas to avoid the masking effects of artificial noise (Nordt and Klenke 2013). Similarly, European Robins (*Erithacus rubecula*) have switched to singing at night in urbanized areas that are noisy during the day (Fuller et al. 2007).

The research presented here assesses the effects of anthropogenic noise on vocal communication in three species of birds that breed and overwinter in Virginia: Northern Cardinal, Carolina Wren (*Thryothorus ludovicianus*), and Song Sparrow (*Melospiza melodia*). These three species have generalized diets and similar habitat preferences including dense shrubby fields, forested edges, and bushy thickets. In terms of sociality, Northern Cardinals form short-term pair bonds during the breeding season, and they forage within mixed-species groups (Cornell University 2019). By comparison, Carolina Wrens and Song Sparrows retain pair bonds outside of the breeding season, and in the fall, juvenile Song Sparrows form foraging groups (Cornell University 2019). Considering these behavioral traits, pair and group communication is essential in these species. Specifically, I tested the hypothesis that the level of anthropogenic noise influences the minimum and maximum frequencies (i.e., pitch) of vocalizations in these three species. Because higher frequency sounds are more conspicuous against background noise, I predicted that both minimum and maximum frequencies of the

vocalizations of these three species would be higher in areas with greater anthropogenic noise.

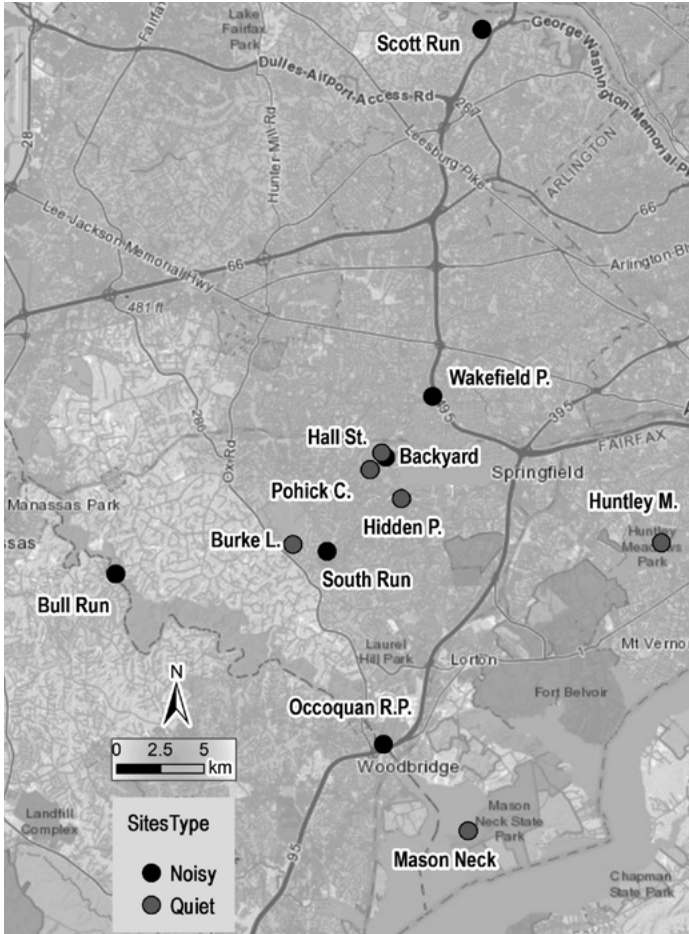
### Methods

I recorded random calls and songs for each species and observed their behavior at twelve study sites in the Fairfax area of Northern Virginia. Calls are identified as 'chip' notes that are usually one syllable in length. Songs are longer sequences of notes that are more detailed and vary in duration, frequency, amplitude, and overall syllabic arrangement. I selected the study sites based on perceived noise levels, ranging from more quiet to more noisy environments. I used a KASUNTEST KT 202 sound level meter to collect noise level measurements in decibels. Sites with a range of 40 to 48 decibels of noise (natural background noise) were designated as areas of low noise, whereas sites with a range of 49 to 60 decibels of anthropogenic noise (e.g., traffic) were designated as areas of high noise (Table 1). Low-noise sites were located within parks and farther from major roads, whereas high-noise sites were either near highways with heavy traffic or close to urbanized areas (Fig. 1).

I recorded bird vocalizations from 0700-0900 between 7 October 2018 and 2 February 2019. I used a tripod-mounted Canon Powershot 60 HS camera to record bird songs and calls and boosted the audio recording using a VideoMicro microphone with wind muff (RØDE). Following Dowling et al. (2012), I recorded bird songs and calls in the first three minutes of each of twelve successive 10-minute intervals at each site, and I visited each site only once. I reviewed the

**Table 1.** Noise level measured in decibels (mean  $\pm$  1SD) at low-noise and high-noise study sites in the Fairfax, Virginia area between October 2018 and February 2019.

Sites	# of samples	Mean	Standard Deviation
<b>Low-noise</b>			
Burke Lake	5	43.5	0.75
Hall Street	13	44.9	1.54
Hidden Pond	6	46.5	1.50
Huntley Meadows	8	42.4	0.89
Mason Neck	8	42.0	1.25
Pohick Creek	6	42.7	0.73
<i>Low-noise sites mean</i>	6	43.7	1.73
<b>High-noise</b>			
Backyard	10	53.9	4.18
Bull Run	8	52.9	9.60
Occoquan Regional Park	5	57.7	2.96
Scott Run	3	51.0	2.50
South Run	12	48.5	2.61
Wakefield Park	11	52.0	1.13
<i>High-noise sites mean</i>	6	52.7	3.08



**Figure 1.** Map of the Fairfax, Virginia area showing the sites at which bird songs and calls were recorded and the classification of those sites as having lower or higher levels of anthropogenic noise.

recordings for songs or calls of Northern Cardinals, Carolina Wrens, and Song Sparrows. Typically, between zero and three distinct individuals of a species were identified from the recordings at any single site. Multiple unique bird songs and calls were determined from a single recording only when they were readily distinguishable as different song structures or pitches, when it was observed that different individuals were engaging in counter-singing, or when the phrasing of the songs were sufficiently different to assume they were from separate individuals. Table 2 shows the number of songs and calls recorded at each site. I recorded a total of 28 songs and seven calls of different individual Carolina Wrens, 18 songs and eight calls of Song Sparrows, and nine songs and 25 calls of Northern Cardinals.

I used Camtasia (TechSmith), a video editing program, to separate and convert the audio into .wav files. Raven Lite 2.0 (Cornell Laboratory of Ornithology) was used to generate spectrograms from the .wav files. I used these spectrograms to determine minimum and maximum frequencies for each distinct song and call identified in the recordings. I used one-tailed t-tests to compare 1) minimum frequency and 2) maximum frequency of song and calls for which there were sufficient data between areas of low and high anthropogenic noise ( $\alpha \leq 0.05$  for all statistical tests). Because I recorded so few Carolina Wren and Song Sparrow calls, my analysis focused only on songs for these two species. In contrast, my sample size for Northern cardinal songs was low, so I only analyzed Northern Cardinal calls.

**Table 2.** Number of songs and calls of three bird species recorded at each high-noise and low-noise study site in the Fairfax, VA area between October 2018 and February 2019.

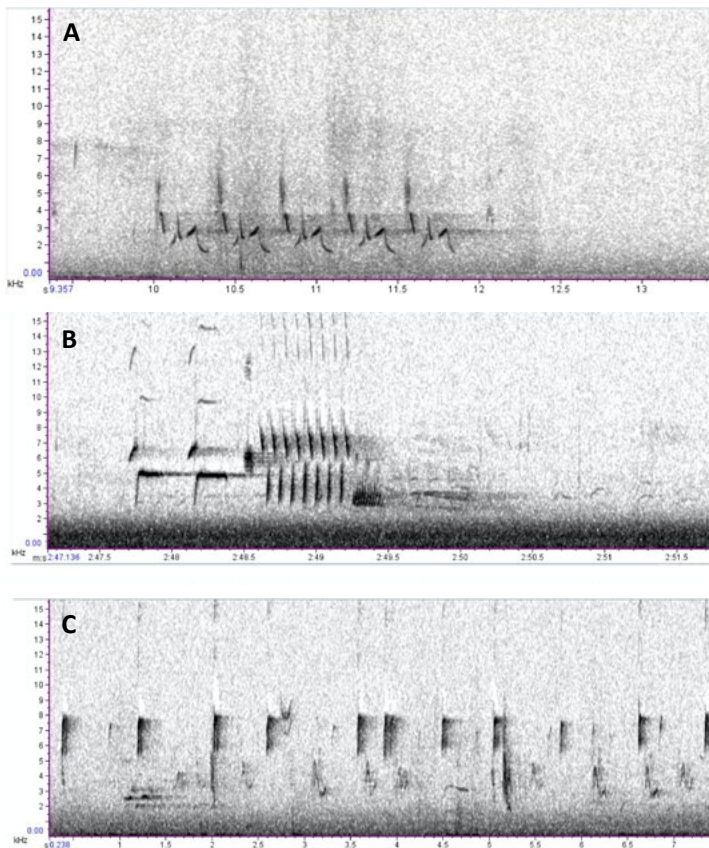
Sites	Carolina Wren		Song Sparrow		N. Cardinal		Total	
	Song	Call	Song	Call	Song	Call	Song	Call
<b>Low noise</b>								
Burke Lake	2	1	0	1	0	1	2	3
Hall Street	2	0	4	0	6	1	12	1
Hidden Pond	4	0	0	0	0	2	4	2
Huntley Meadows	2	0	1	1	1	3	4	4
Mason Neck	4	0	1	2	0	1	5	3
Pohick Creek	2	0	0	1	0	3	2	4
<b>Totals</b>	<b>16</b>	<b>1</b>	<b>6</b>	<b>5</b>	<b>7</b>	<b>11</b>	<b>29</b>	<b>17</b>
<b>High noise</b>								
Backyard	2	1	6	0	0	1	8	2
Bull Run	2	1	0	1	2	2	4	4
Occoquan Regional Park	2	0	0	0	0	3	2	3
Scott Run	1	1	0	0	0	1	1	2
South Run	2	0	6	2	0	2	8	4
Wakefield Park	3	3	0	0	0	5	3	8
<b>Totals</b>	<b>12</b>	<b>6</b>	<b>12</b>	<b>3</b>	<b>2</b>	<b>14</b>	<b>26</b>	<b>23</b>

## Results

Minimum frequency for Carolina Wren songs ranged from 1.50–2.70 kHz (mean  $\pm$  SD =  $1.94 \pm 0.35$  kHz) and maximum frequency ranged from 3.10–8.60 kHz ( $5.14 \pm 1.14$  kHz) (see example spectrogram, Fig. 2a). Minimum frequency for Song Sparrow songs ranged from 1.40–3.40 kHz ( $2.23 \pm 0.55$  kHz) and maximum frequency ranged from 4.30–8.20 kHz ( $7.20 \pm 1.13$  kHz) (see example spectrogram, Fig. 2b). Minimum frequency of Northern Cardinal calls ranged from 4.60–6.70 kHz ( $5.48 \pm 0.48$  kHz) and maximum frequency ranged from 7.50–9.20 kHz ( $8.25 \pm 0.46$ ) (see example spectrogram, Fig. 2c).

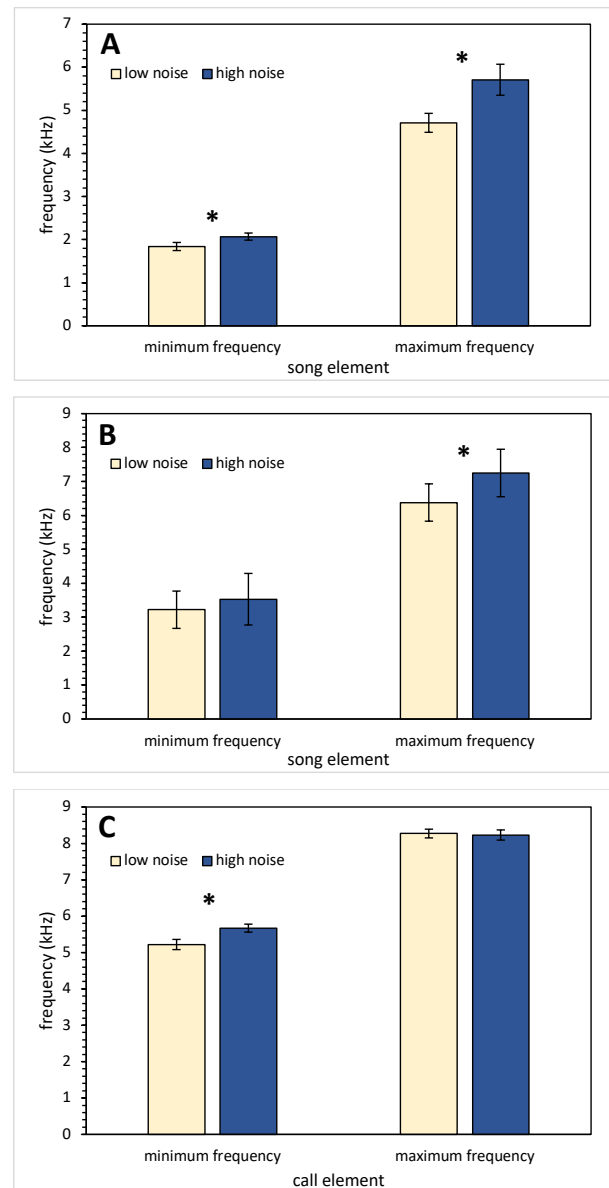
minimum frequency of their songs ( $t_{16} = -0.106$ ,  $p = 0.46$ ) between low-noise sites and high-noise sites (Fig. 3b). As with Carolina Wrens, however, the mean maximum frequency of Song Sparrow songs was significantly higher ( $t_{16} = -1.851$ ,  $p = 0.04$ ) at high-noise sites than at low-noise sites (Fig. 3b).

The mean maximum frequency of Northern Cardinal calls did not differ ( $t_{23} = 0.196$ ,  $p = 0.42$ ) between low-noise and high-noise sites, but Northern Cardinals produced calls with a significantly higher mean minimum frequency ( $t_{23} = -2.52$ ,  $p = 0.01$ ) at high-noise sites than they did at low-noise sites (Fig. 3c).



**Figure 2.** Sample spectrograms for songs of a Carolina Wren (A, recorded 28 October 2018 Pohick Creek, Springfield, VA) and a Song Sparrow (B, recorded 29 October 2018, South Run, Springfield, VA), and for a Northern Cardinal call (C, recorded 27 January 2019, Hall Street, Springfield, VA). Spectrograms were created using RavenLite 2.0, Bioacoustics Research Program, Cornell University. The vertical axes delineate frequency (in kHz) and the horizontal axes delineate time (in seconds).

Carolina Wrens produced songs with a significantly higher mean maximum frequency ( $t_{26} = -2.49$ ,  $p = 0.01$ ) at high-noise sites than they did at low-noise sites (Fig. 3a). Mean minimum frequency was also higher at high-noise sites than at low-noise sites, but this difference just bordered on statistical significance ( $t_{26} = -1.705$ ,  $p = 0.05$ ) (Fig. 3a). Song sparrows, in contrast, showed no difference in mean



**Figure 3.** Mean (+ 1 SE) minimum and maximum frequencies (kHz) of songs of Carolina Wrens (A), Song Sparrows (B), and of calls of Northern Cardinals (C) in sites with low and high levels of anthropogenic noise. Asterisks indicate significant differences between adjacent columns (i.e., low noise vs. high noise).



### Discussion

The purpose of this study was to assess whether anthropogenic noise affected minimum and maximum frequencies of vocalizations produced by three bird species that commonly live in and near highly developed areas. Overall, the data are mostly consistent with my hypothesis that anthropogenic noise causes changes in the vocalizations of these species. Northern Cardinals increased the minimum frequency of their calls, while Carolina Wrens and Song Sparrows increased their maximum frequency of their songs in areas of greater noise. The fact that all three species made frequency adjustments to their calls or songs suggests a consistent pattern to avoid masking by anthropogenic noise.

My results are consistent with numerous observational and experimental studies that show that many bird species alter their vocalizations by shifting frequencies of their songs upwards in response to lower frequency anthropogenic noise (Slabbekoorn 2013, Roca et al. 2016). More specifically, however, my results are only partially consistent with those reported in a previous study that included Northern Cardinals, Song Sparrows, and Carolina Wrens. Similar to what I found with Northern Cardinal calls, Dowling et al. (2012) found that Northern Cardinals increased the minimum frequency of their songs in response to higher noise levels. Dowling et al. (2012) also found that Carolina Wrens increased the minimum frequency of their songs as noise levels increased, but only in rural habitats, whereas I found that this species increased both their minimum and maximum song frequencies. Further, Dowling et al. (2012) found no effect of anthropogenic noise on the minimum frequency of Song Sparrow songs, which is consistent with my results. Dowling et al. (2012) argue that bird species with higher minimum song frequencies (e.g., Song Sparrows) are less likely to alter their vocalizations because of less frequency overlap with lower frequency ambient noise; however, my results showed that Song Sparrows significantly increased the maximum frequency of their songs.

Birds evaluate multiple factors when selecting territories. In addition to the intensity of human activity, other important factors include predation risk, availability and quality of food resources, competition, and vegetation structure (Huhta and Jokimaki 2000, Kurucz et al. 2021). Future research should also consider energy costs of vocal communication in high-noise environments because it is metabolically expensive to produce high-amplitude and high-frequency songs (Read et al. 2014). As a result of having to increase the frequencies of calls or components of songs, Northern Cardinals, Carolina Wrens and Song Sparrows in the Fairfax, VA area may require more time foraging to compensate for such energy loss. This might represent a challenge in highly urbanized environments where predation risk may be higher and food

resources may be lower.

Birds are presented with a choice, however, as background or ambient noise increases. In the immediate term, individual birds can alter the structures of their vocalizations (e.g., by shifting frequencies or increasing amplitude) to increase detectability (Slabbekoorn 2013). Assuming the benefits of doing so in terms of avoiding masking outweigh associated costs (but see Luther et al. 2016), this can lead to an evolutionary response that characterizes the entire population in an area (Riechard et al. 2020). Alternatively, birds can move elsewhere to avoid loud areas leading to local extirpation and homogenization of bird communities in highly urbanized environments (Slabbekoorn 2013). Although a lack of capacity to adapt might eventually contribute to population decline, some bird species such as omnivores (e.g., blackbirds) and cavity nesters (e.g., wrens) have been quite successful due to their plasticity, behavioral flexibility, and cognition (Patankar et al. 2021). In fact, a recent study found that White-crowned Sparrows (*Zonotrichia leucophrys*) rapidly responded to the reduction in anthropogenic noise during the 2019 Covid-19 pandemic shutdown in the San Francisco Bay area by producing higher performance songs at lower amplitudes, thereby demonstrating the capacity of birds to respond adaptively to changes in the soundscape of their environment even after decades of noise pressure (Derryberry et al. 2020). Further study of how avian vocalizations change in response to anthropogenic noise provides important insight into the environmental and biological factors behind such change, and ultimately, in the evolution of avian communication (Kroodsma 1996).

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