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The effects of urbanization on the songs of the Black-Capped Chickadee and Tufted Titmouse

Abstract

Urbanization may play a role in frequency-shifting of passerines songs in order to counteract the effect of masking by anthropogenic noise. The purpose of this study is to analyze the effects of urban environments on various song features of two closely related species of songbirds, black-capped chickadees (*Poecile atricapillus*) and tufted titmice (*Baeolophus bicolor*). We hypothesized that urban black-capped chickadees would shift the frequency of their songs upwards. We find that black-capped chickadees in urban environments do not have relatively higher frequency songs compared to those in rural environments, contrary to previous findings, but do alter their song rhythm singing shorter, more numerous syllables. Surprisingly, we also find that tufted titmice in urban environments do sing at higher frequencies and also alter their song rhythm singing shorter bouts with a higher concentration of syllables.

Introduction

Humans have profound impacts on the natural world. A significantly incomplete list includes activities such as resource harvesting, foreign species introduction, and urbanization. Urbanization affects ecological balances in the forms of habitat loss, contamination, and anthropogenic noise. Anthropogenic noise, including that from traffic, construction, industrial machinery, etc., is a particularly important aspect of the habitat for organisms which heavily depend on acoustic communication, such as passerines, also known as songbirds. While there is evidence that urban noise puts a selective pressure on birds with relatively higher-frequency songs (Rheindt 2003; Slabbekoorn and Ripmeester 2007; Hu and Cardoso 2009), a large problem that arises for many songbird species is *masking*, or when the noise overlaps the same frequency as the vocalization (Kump 1996; Brumm and Slabbekoorn 2005). Various species adjust their song frequencies in urban environments (Slabbekoorn and Peet 2003; Brumm and Zollinger 2013). Some species show immediate flexibility in urban noise (Verzijden *et al*. 2010). It is also possible to learn the higher frequency song (Moseley *et al*. 2018). The adaptive mechanism depends on the bird species vocal plasticity capabilities.

The vocal adjustment capabilities of black-capped chickadees (*Poecile atricapillus*) have been studied extensively (Ratcliffe and Weisman 1985; Mennill and Otter 2007). With only a single song-type repertoire, black-capped chickadees shift the frequency of their simple 2-note songs, ‘fee-bee’. Playback experiments show that this pitch-shift serves a form of song matching (Horn *et al*. 1992) and also reduces the masking effect due to ambient noise (LaZerte *et al*. 2016). It is important to note that this frequency-shift in black-capped chickadees is caused by a change in noise, not structure of the environment (LaZerte 2015; Proppe *et al*. 2015). Tufted Titmouse (*Baeolophus bicolor*) songs, phonetically ‘peter peter’, are also relatively simple but not nearly as studied and to our knowledge no research has been conducted regarding the effect of urbanization on tufted titmouse song production despite the fact that these birds are found in urban areas. However, this species has a relatively larger repertoire of about 8-15 song types and it has been shown to match the song type during countersinging interactions rather than the frequency of the song (Schroeder and Wiley 1983; Duguay and Ritchison 1998; Mennill and Otter 2007).

The purpose of this study is to analyze the effects of urban environments on various song features of these two closely related species of songbirds. Given that black-capped chickadees adjust their songs in urban environments whereas no evidence to date supports tufted titmouse frequency-shifting capabilities, we hypothesize that black-capped chickadee song properties will be affected by urban environments but tufted titmice song properties will not be affected; more specifically, the minimum frequency of black-capped chickadee songs will increase in urban environments but that of tufted titmice will be the same in urban as that in rural environments.

Materials and Methods

Subject Recordings

Recordings of black-capped chickadees and tufted titmice were queried from the citizen-science Xeno-Canto database using the warbleR package in RStudio. Recording type was specified to include “song” and those qualified recordings were downloaded. Of the 262 black-capped chickadee recordings, 102 were songs; of the 239 tufted titmouse recordings, 113 were songs. A meta dataset was compiled of recording information such as location, date, time, recordist, and bird identification. 2 tufted titmouse birdsong recordings were also collected at Vanderbilt University using a Tascam DR-05 handheld recorder and downloaded. A campus meta dataset was compiled of recording information and bird identification.

Individual song bouts were parsed from downloaded song recordings in Audacity. 3-10 bouts were parsed from each song. Black-capped chickadee bouts were qualified as very stereotypical 2 syllable repeats (Fig 1A); Tufted titmouse bouts were qualified as 2-4 syllable repeats (Fig 1B). Each bout was subject to analysis using Chipper software; some bouts were tossed due to excess background. Of 47 black-capped chickadee songs, 137 bouts were analyzed; of 43 tufted titmouse songs, 127 bouts were analyzed. Each bout was segmented into syllables and submitted. During Chipper analysis, data was collected and compiled into an dataset of 45 variables including bird identification, average note frequency modulation, average lowest-note frequency, average lowest-syllable frequency, average syllable duration, etc.

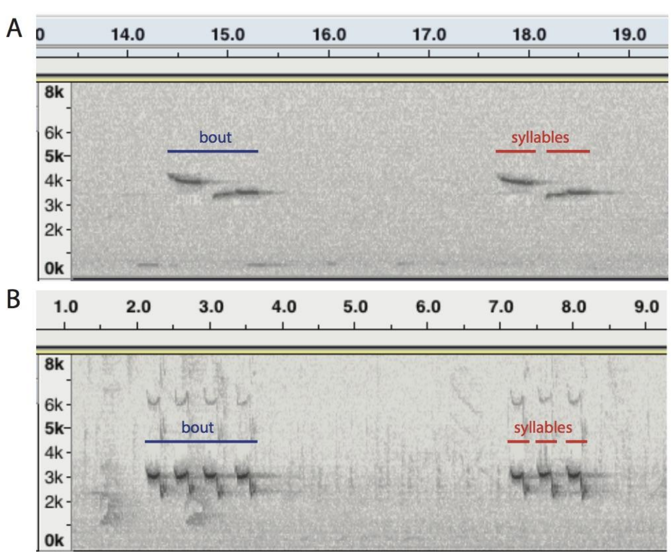

Figure 1. Typical Song Bouts of Black-capped Chickadee and Tufted Titmouse.
A. Spectrogram in Audacity of 2 bouts from a Black-capped Chickadee; each bout has 2 syllables. **B**. Spectrogram in Audacity of 2 bouts from a Tufted Titmouse; the bout from about 2-4 sec has 4 syllables and the bout from about 7-8 sec has 3 syllables.

Data analysis

Chipper output data was checked for normality and log transformed. A new dataset was compiled in RStudio using Xeno-Canto ID number to bind the recording information with the corresponding the output data from Chipper. Birds were classified as rural if the recording distance to the nearest city was greater than 10km, and urban if the recording distance to the nearest city was less than 10 km. Nonparametric Wilcoxon Rank Sum tests were performed in RStudio to test for differences between rural and urban song characteristics. Differences in means were considered statistically significant if $p \leq 0.05$. Boxplots were constructed in RStudio to show differences.

Results

Urban Black-capped Chickadees do not shift their song frequency

Urbanization produces a constant hum at a relatively low frequency. Previous studies have found that black-capped chickadees shift the frequency of their songs to avoid the effect of masking (LaZerte 2015). Therefore, we hypothesized that data collected from Xeno-Canto recordings should reflect this pattern where birds in urban areas shift the frequency of their lower notes upwards. Surprisingly, we find that there is no difference in most song features pertaining to frequency between black-capped chickadees in rural vs. urban environments (Fig 2). Particularly of interest, the average lowest syllable frequency was no different in rural and urban black-capped chickadees (Fig 2E).

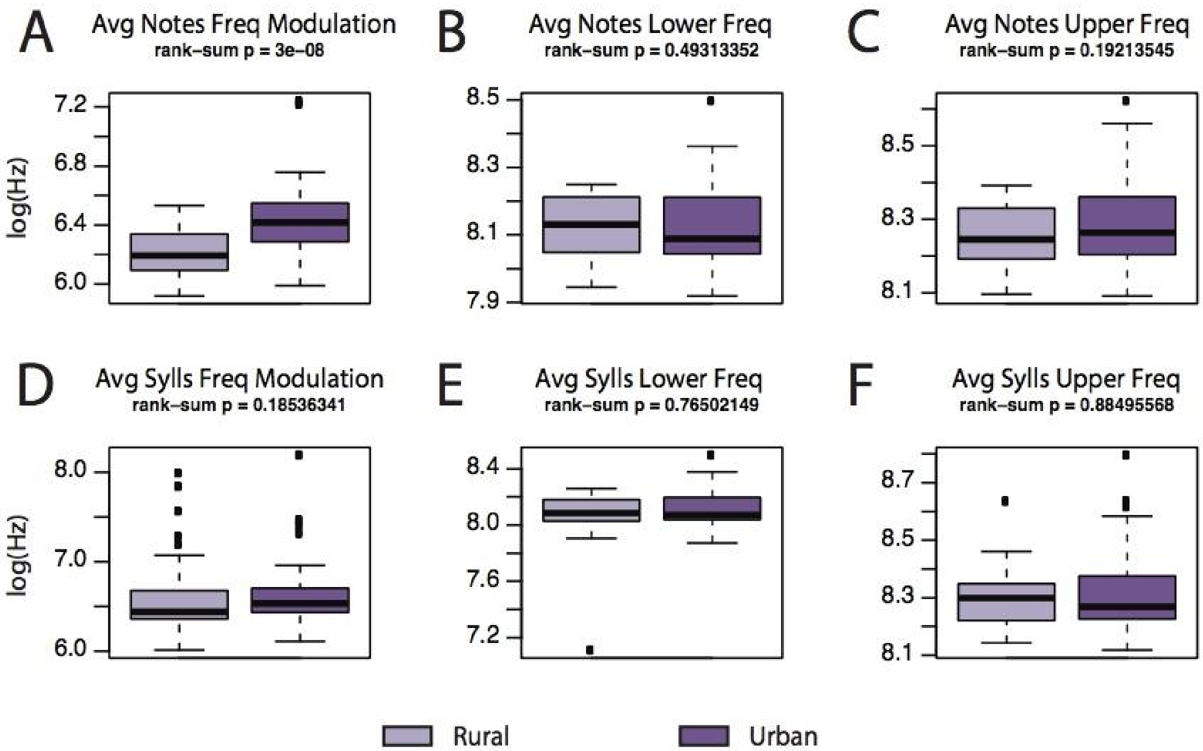

Figure 2. Song Frequency in Rural vs Urban Black-capped Chickadee.
A-C. Frequency of song notes. **D-F**. Frequency of song syllables.

Urban Black-capped Chickadees alter their song rhythm

While there is much research on the frequency-shifting capabilities of black-capped chickadees, less research has been conducted on song timing in this species (Mennill and Otter 2007). It is known that black-capped chickadees respond more aggressively not only to frequency-matched playback recordings, but also to temporally-matched songs (Otter *et al*. 2002). Interestingly, we do find that black-capped chickadees in urban environments alter the rhythm of their songs, singing shorter, more numerous syllables (Fig 3). This is evident by the significantly shorter syllable duration (Fig 3C) and increased number of syllables (Fig 3F) yet similar bout duration (Fig 3D), consistent with the larger number of syllables per bout duration (Fig 3E).

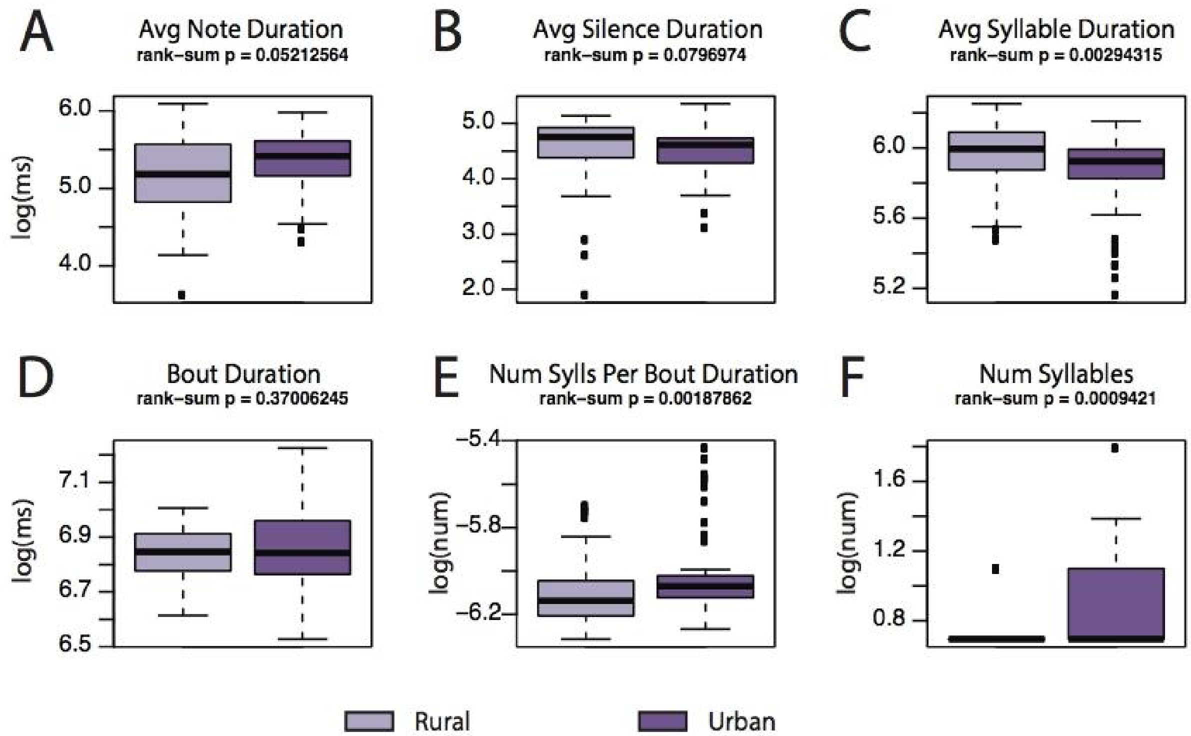

Figure 3. Song Rhythm in Rural vs Urban Black-capped Chickadee.
A-C. Duration of song characteristics. **D-F**. Concentration of song syllables.

Urban Tufted Titmice shift their song frequency higher than rural conspecifics

As previously mentioned, there are no currently published investigations of the effects of anthropogenic noise on tufted titmouse song production. However, a previous study found that auditory filters were generally narrower in Tufted Titmice, a woodland species, than those of open-habitat species (Henry and Lucas 2010). This suggests that tufted titmice might adapt to a particular environment at the level of perception and would not need to shift the frequency of their song output. Given this and the fact that there is no evidence that this species has the capability to frequency-shift songs, we hypothesized that there is no difference in song frequencies in rural vs urban tufted titmice. Interestingly, we find that urban tufted titmice significantly lower the upper frequency of their songs (Fig 4C,F). This is surprising, not only because urban tufted titmice indeed display a difference in song frequencies, but it is in the opposite direction as predicted for black-capped chickadees. Data from the Vanderbilt University campus recordings are included; however, with only a sample size of 2, we can not make any conclusions about individuals in campus environments as it did not change the significance levels of any differences when only the rural and urban data were analyzed.

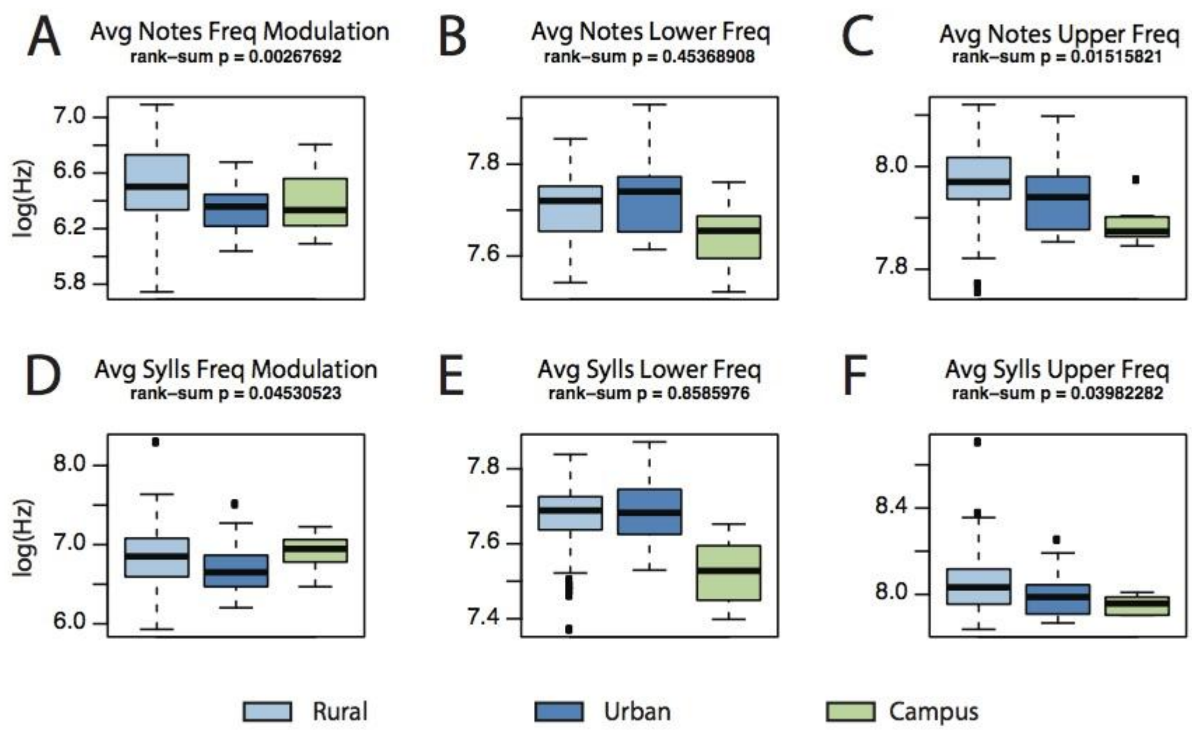

Figure 4. Song Frequency in Rural vs Urban vs Campus Tufted Titmouse.
A-C. Frequency of song notes. **D-F**. Frequency of song syllables.

Urban Black-capped Chickadees alter their song rhythm

The evidence that woodland species have narrower auditory filters supports the acoustic adaptation hypothesis which predicts that slower frequencies and amplitude modulations are favored in forested habitats because they are less degraded by reverberation during transmission (Henry and Lucas 2010). Urbanization may provide a similar construct where slower modulations in frequency and amplitude of the tufted titmouse song are more advantageous that faster modulations. Surprisingly we find that tufted titmice in urban environments alter rhythm of their songs, singing shorter songs with a higher concentration of syllables (Fig 5). This is evident by the significantly shorter bout duration (Fig 5D) yet similar number of syllables (Fig 5F), consistent with the larger number of syllables per bout duration (Fig 5E). We also find shorter silence duration (Fig 5B) and shorter syllable duration (Fig 5C) in urban tufted titmice.

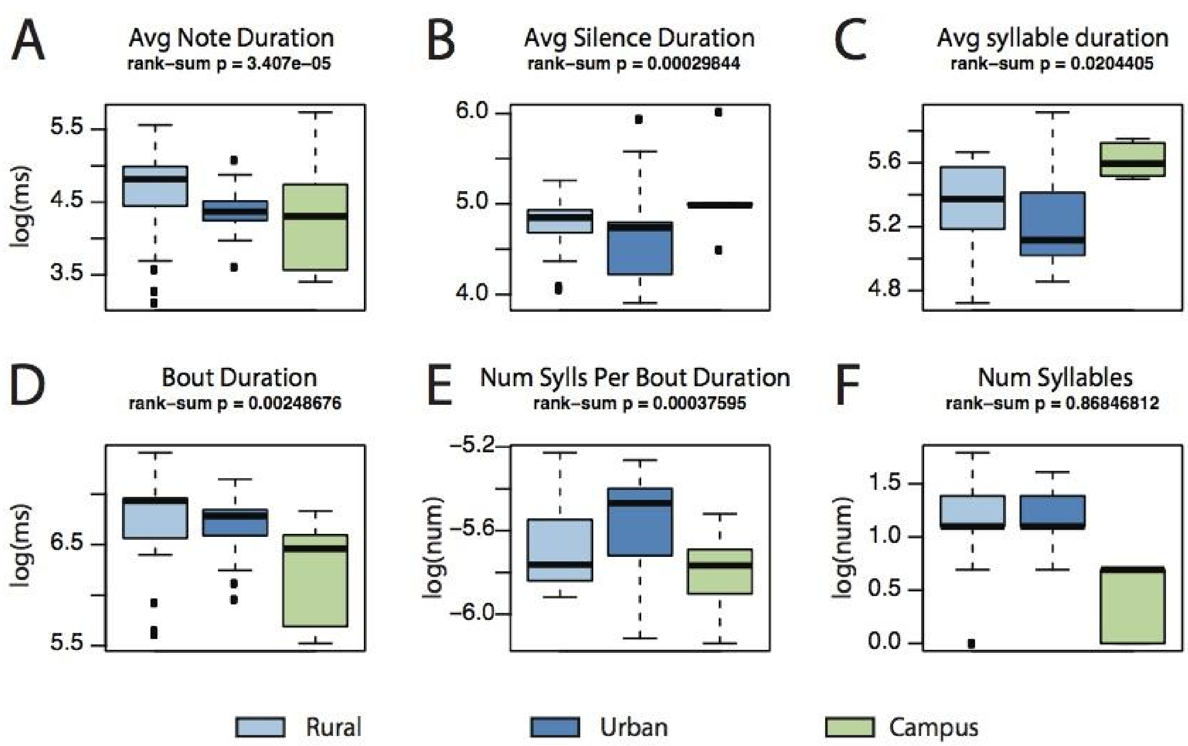

Figure 5. Song Rhythm in Rural vs Urban vs Campus Tufted Titmouse.
A-C. Duration of song characteristics. **D-F**. Concentration of song syllables.

Discussion

Our study found no difference in frequencies between rural and urban black-capped chickadees. We particularly consider syllable frequency because of the way the songs were parsed (Fig 1A); these syllables could be qualified as notes and in fact many descriptions of the black-capped chickadee song highlight stereotyped structure of the “two-note” ‘fee-bee’. Our results are not consistent with previous research showing that black-capped chickadees shift the frequency of their songs to avoid the effect of masking both with experimental manipulation (LaZerte 2015; LaZerte *et al*. 2016) and field observations (Proppe *et al*. 2012). This could be due to limitations in recording and parsing songs. It is possible that recordists were only collecting birdsongs during quiet times in order to reduce background in the spectrogram for analysis. Another possibility, which is less accusatory of our generous citizen recordists of biasing the sample, is that these birds simply limit their singing to periods of low noise. While playback studies demonstrate that black-capped chickadees are able to rapidly shift their song frequency in noisy conditions, it is possible that the preferred adjustment is in the timing of their songs. It would be interesting to examine if there was any effect of time on frequency properties of songs.

We also see changes in their song rhythm to sing shorter, faster syllables. A few ecological factors might offer explanations. For example, if black-capped chickadees are singing at quieter times, perhaps these birds are trying to optimize their communication volume during transient lulls in noise. Another possibility is that urbanization may affect the distribution of individuals in a population such that more interactions arise. Given that black-capped chickadees are territorial birds that show greater variability in song length and song timing when their song is overlapped by an intruder (Mennill and Ratcliffe 2004), it would be interesting to examine if there was any effect of distance of conspecific individuals on song features pertaining to rhythm. Unfortunately, due to the limitations of our collection methods, this data is not currently available and would be hard to acquire. Another logical attempt to explain this alteration in song rhythm could be to use the acoustic adaptation hypothesis previously mentioned; that is to say, the habitat structural changes due to urbanization cause these birds to change the speed of their song elements in order to avoid reverberations during long-range transmission (Naguib 2003). However, studies have shown that habitat structure weakly predicts acoustic structure of black-capped chickadee songs, whereas noise does seem to cause frequency-shifting (Proppe *et al*. 2012; LaZerte *et al*. 2016). In fact, our finding here might seem contradictory to the acoustic adaptation hypothesis, where it seems faster modulations in frequency and amplitude are unfavorable in certain environments where reverberations are a risk. Thus, other ecological factors, such as time or distance of conspecifics, should be considered and might offer explanations for this alteration in song rhythm.

A similar study investigating whether habitat structure is associated with bandwidth of auditory filters provided evidence that in part supported the acoustic adaptation hypothesis, where woodland species, such as tufted titmice, have narrower auditory filters to optimize frequency resolution (Henry and Lucas 2010). There is an evident trade-off between frequency resolution and temporal resolution in auditory processing (Henry *et al*. 2011). Thus, we expected that in urban structurally complex environments birds sing slower songs at higher frequencies. To our surprise, we find that tufted titmice in urban environments sing shorter bouts with faster syllables. We were also surprised to find that tufted titmice shift their song frequency downwards. Again this seems contradictory to the trend that songbirds shift the frequency of their songs upwards in order to avoid masking. However, studies have shown that tufted titmice tend to match song-type. It is possible that tufted titmice contain particular songs in their repertoire that are lower frequency but shorter and faster. With narrower auditory filters (Henry and Lucas 2010), tufted titmice might be able to resolve their own low-frequency songs from background low-frequency urban noise. At the cost of temporal resolution, shorter songs might advantageous if individuals sing at certain times of the day, and it may be that these shorter song-types in their repertoire are lower-frequency. Ecological factors such as time of day and inherent structural differences may explain our unexpected results.

Urban noise poses a serious threat to the the communication success of songbirds. Several studies have demonstrated this, including a behavioral study in which black-capped chickadees responses depend on the frequency of the input in the presence of ambient noise (LaZerte *et al*. 2017). More research is needed to fully understand how communication success is affected by urbanization. Our study shows differences between species in vocal adjustments in urban environments. Knowing the capabilities of different songbird species might help the conservation effort by tailoring urban development to minimize ecological disruptions.

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