EFFECTS OF ANTHROPOGENIC NOISE ON REPRODUCTION IN AN URBAN POPULATION OF EASTERN BLUEBIRDS (*Sialia slialis*)

**Abstract**

With the increasing human population, expansion of industry, and rapid development of transportation networks, anthropogenic noise has become an increasingly severe problem in the 21st century. Noise pollution, from either chronic or acute sources, acts in ways detrimental to both physiological and psychological health of humans and other creatures. In this study, we used Eastern Bluebirds (*Sialia sialis*) to analyze breeding pairs’ responses to both chronic roadway noise and experimentally added acute playback of common construction noises. We hypothesized that construction and traffic noise affect hatching success. Our results suggest: 1) noise, especially high background noise, had profoundly negative influences on hatching success and disrupted natural behaviors of urban bluebirds in otherwise suitable habitat; 2) artificially added construction noise had different opposite effect in high background noise area and low background noise area.

**Introduction**

Noise pollution is usually defined as the diffusion of noise in natural or human-made environment that occurs in ways detrimental to the physiological or psychological health of humans and other creatures (Oguntunde et al., 2019). In modern society, environmental noise comes from various sources including urban traffic, power operations, transportation vehicles (land, air, and sea), construction and machinery works, and residential areas (Schomer et al., 2001). Like other forms of pollution, noise sources can be point (e.g., airports, power plants, construction sites) or non-point (traffic noises, ground and air), and noise can be chronic (constant; freeways, city traffic grids) or episodic and acute (fireworks displays, sonic booms, and mechanical tools like jackhammers). Due to human population growth, the expansion of industry, and rapid development of transportation networks over the past few decades, anthropogenic noise has become an increasingly severe problem (Ciach and Fröhlich, 2017; Madadi et al., 2017).

Anthropogenic noise can propagate far from sources creating acoustic footprints far beyond physical infrastructure. Even remote protected areas are increasingly affected by anthropogenic noise (Buxton et al., 2017) with potentially disproportionate effects on critical biodiversity resources. Critical wildlife behaviors such as foraging, mating, parental care, and avoiding predators all depend to some extent on acoustic information (Ciach and Fröhlich, 2017; Luo et al., 2015; Siemers and Schaub, 2011). Thus, disruption of communication could have significant effects on survival and reproduction of wildlife. Regarding chronic, high-volume anthropogenic noise, clear links to reduced reproduction in wildlife exist. For example, broadband noise exposure (either continuous or intermittent) dampens reproductive success of the common goby (*Pomatoschistus microps*). Under continuous noise treatment fish had increased latency to female nest inspection and spawning and decreased spawning probability (Blom et al., 2019).

Similar problems are common among bird species nesting near highways and have been linked to stress-induced hormones in adults and nestlings (e.g., reduced baseline and increased stress-induced corticosterone; Kleist et al., 2018) that change reproduction related behaviors (e.g., nest attendance) and reproductive success (Halfwerk et al., 2016; Injaian et al., 2018; Kleist et al., 2018; Madadi et al., 2017; McClure et al., 2013). Many questions arise from such findings. Some species or individuals may have personality-based tolerances leading to assortative habitat-selection occurring based on noise tolerances (Blickley 1 and Patricelli 2, 2010). Conversely, it is possible that many species have not yet evolved effective avoidance behaviors and nest as readily in noisy as in quiet areas. Indeed, in populations of noise-sensitive Western Bluebirds (*Sialia mexicana*), individuals still choose breeding sites in areas exposed to high noise levels, suggesting that the physiological and adaptive consequences of noise are largely unknown (Kleist et al., 2018). Examples such as these raise the specter of evolutionary traps (Schlaepfer et al., 2002; Rodewald et al., 2011; Francis and Barber, 2013; Robertson et al., 2013). And if high volume traffic noise represents a trap, a significant percentage of the area of most nations affected is affected by high levels of interstate highway noise that would classify as such (Grade and Sieving, 2016).

The influences of acute noise sources on wildlife responses are less well understood than highway noise (Francis and Barber, 2013). Acute noises from construction, demolition, fireworks, or sonic booms in flight training areas often exceed the threshold of ear-damaging sound pressure levels (around 65 dBA at close range for humans; Bell, 1972; Powell et al., 2006) and likely influence hormonal stress responses differently in birds than chronic noise (Shannon et al., 2016). Given varied evidence that female reproductive behavior is affected by chronic noise, it is reasonable to explore the existence of different behavioral responses for acute noise effects that ultimately affect reproductive success. In this study, I analyzed breeding pair responses to both chronic highway noise and experimentally added acute playback of common construction noises. By assessing hatching success, I sought to identify reproductive responses of breeding females that are unique to chronic versus acute noise exposure. This study addresses the overall hypothesis that noise in the urban environment can interfere with reproduction in wild birds. Specifically, I hypothesize that both construction and traffic noise impact hatching success but to different degrees. We experimentally tested the effects of construction noise added during incubation on Eastern bluebird (*Sialia sialis*) adults and their offspring across a gradient of urban background noises on the University of Florida campus. The work could help understand whether, and how, multi-characters and unpredictable noises arising during breeding can influence avian productivity along noise gradients.

**Methods**

The Eastern bluebird (*Sialia sialis*) breeds throughout the eastern half of the United States and prefers to nest in open land with a scattering of trees and sparse vegetation (Pinkowski, 1979). It is easy to find this type of habitat in the suburban or rural area in Florida, which contributes to the abundance of Eastern bluebirds in Florida. Eastern bluebirds usually nest in cavities and often prefer to use artificial nesting boxes if available. After selecting a nest site, the pair spends several days in gathering material from the ground and returning to build a nest. When the nest is built, the female lays her eggs, usually one egg per day, and the clutch size usually rang from three to seven. And after female laid her penultimate egg or the last egg, incubation begins (Cooper et al., 2005) with a period lasts 11–19 days (14 days is the most common) and has a slight variation with latitude and season (Buxton et al., 2017). Incubating is done by female bluebirds, and the male bluebirds give scattered claims based on observations of male attentiveness to incubating females or nesting cavities.

The University of Florida campus (Gainesville, Alachua County, Florida USA) and its surrounding areas are becoming increasingly urbanized. It is an agricultural land grant campus (LaCharite, 2016) and is ideal for the study because it encompasses a wide range of land uses including livestock and crop fields, open greenspace, high-rise buildings, hardscape and heavily trafficked areas (foot and vehicular), and a range of noise levels from less than 50 to more than 70 decibels (A scale). Many areas of campus are still suitable for reproductive activity by bluebirds (Malone et al., 2017). In January and February 2019, we placed 100 Gilbertson style bluebird boxes in selected experimental areas to attract breeding pairs. We insured that boxes were placed throughout the extremes of the available noise gradient by systematically visiting every area of campus to find areas that had at least a 100 m diameter grassy area at or within 100m of a suitable nest location. Open grass is a fundamental nesting nest location requirement for Eastern bluebirds (Kight and Swaddle, 2015; Plummer, Liu, and Sieving, in prep). A suitable nest location had to be in a grassy patch with no overhanging trees or climbing vegetation touching the nest pole. Such sites were available close to and far from the noisiest traffic arteries surrounding campus (Florida State Routes 441 (E), 24 (S), 121 (W) and 26 (N); Figure 1). Boxes ended up in a variety of sites, near roads, buildings, on a golf course, in pastures, and open manicured lawns. The spacing between any two nests was at least 100 m. We used stainless steel pipes (1.27 cm diameter) supported by a 4 ft piece of rebar driven halfway into the ground, and a fixed nest box height of 1.2 meters above the ground. Student volunteers checked and recorded the status of nest boxes at least once a week.

After the first eggs were laid inside a box, a nest was monitored daily until the egg number did not change for 2 days, at which point the nest was randomly assigned as a playback treatment or control nest, and the necessary equipment was set up near the box. At treatment nests, a speaker (OontZ Angle 3, 3rd gen) plus mp3 player (RUIZU X02) were also mounted on the pole. We designed a blended experimental and comparative study. Firstly, used 70 dBA as a cutoff to identify two categories of boxes with similar sample sizes: quiet and noisy. Second, we randomly assigned playback treatment to ½ of the clutches in each category of background noise to make 4 total categories of noise treatment (Table 1). Clutches in the control group, either in the quiet category or noisy category, never received playback. Each clutch in the treatment group received at least one full day of playback (up to four days; 10 hours per day) during its incubation. Construction noise was broadcast from the speakers and mp3 player mounted on the poles set 2 meters from the nest boxes. Between two adjacent playbacks, there were 2 days where playback was switched off.

**Results**

Among the 100 nest boxes we placed, 37 were occupied by nesting birds and those nests hosted 66 total nesting attempts. Among these nesting attempts, 57 were by Eastern Bluebirds, 2 were Carolina Wren nests, and 7 were by Carolina Chickadee (Figure 2). Data analyses confined to bluebird nests only. For Eastern bluebird nests, the first egg date was 26 February 2019. Eighteen nest boxes were re-used in second clutches and 47 of the 57 Eastern Bluebird nests had hatchlings whereas 9 failed before hatching. Two nests were parasitized by a brown-headed cowbird (*Molothrus ater*) so were not used. In total, 45 successful and un-parasite nests were included in the analysis. Among those 45 nests, 23 were in noisy area while 22 were in quiet area. 12 nests in noisy area and 11 nests in quiet area received playback treatment (Figure 3).

Overall, noise, either from background or playback treatment, had effect on hatching success (Figure 4). The most stable and highest hatching success was achieved by nests in quiet areas without playback treatment, and a dramatic decrease of hatching success occurred in nests in noisy area without playback (Figure 5). Impacts of playback for nests, either noisy or quiet, were not severe, but were opposite. In quiet area, adding playback significantly decreased hatching success. However, in noisy area, adding playback reversed the negative effect of background noise alone on hatching success (Figure 5).

**Discussion**

Both experimental additions of construction noise and the choice to nest in areas with high background noise caused reduced hatching success in Eastern bluebirds compared to birds without noise exposure. Eastern bluebirds living in high background noise had significantly lower hatching success than individuals living in quiet areas. This is consistent with previous work; while Ash-throated flycatchers (*Myiarchus cinerascens*) try to avoid nesting in areas affected by energy-sector noise when they do, they achieve lower reproductive success (Coe et al., 2015; Mulholland et al., 2018). We can readily conclude that noise, especially high background noise, had profoundly negative influences on hatching success and disrupted the natural behaviors of urban bluebirds in otherwise suitable habitats. Bluebirds are highly mobile birds with little fidelity to natal areas when they begin breeding (Deluca, 2008), probably as an adaptation to using short-lived snags as nest sites. Bluebirds in our study had the freedom to choose quiet or noisy areas. The fact that bluebirds chose to nest in noisy sites when quieter boxes were available raises the specter of evolutionary traps (Robertson and Blumstein, 2019). A focus on the sensory and cognitive ecology of birds in relation to chronic noise effects, along with nest site selection by personality type, would be promising frameworks for further study (Grade and Sieving, 2016; Madliger, 2012; Zhao et al., 2016).

Bluebirds are thought to search widely when selecting sites and birds in our study had an excess of nest boxes to choose from, and we assume the birds actively chose either quiet or noisy nests. Thus, we suspect as others do that the effects of background noise may have just as much to do with birds’ personality or condition or other intrinsic traits that influenced their nest box selection, than about the proximate influences of noise on behavior. Indeed, evidence suggests that personality type does drive nest site selection regarding noise environs with consequences for reproductive vigor (Zhao et al., 2016). Further, the type of noise interacts with individual personality. For example, bolder great tit (*Parus major*) females differentially reduce total visits to nests during noise compared to shyer females (Naguib et al., 2013). Our data show a similar complex of noise and nest site choice related effects. Adding construction noise had opposite impacts on the hatching success of bluebirds nested in different noise-level areas. Females that chose to nest in chronic high noise significantly improved their hatching success when playback was also applied, unlike females who nested in quiet areas. This unexpected finding shows the requirement for future studies of the effect of acute noise on wildlife. Acute noise impacts may best be addressed using frameworks addressing generalized anti-predator and stress responses at the interface of physiology and behavior (Hua et al., 2014; Robertson and Blumstein, 2019).

**Figure and Tables:**

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Figure 1. Map of the nest box locations. Locations marked for all nest boxes placed on the University of Florida, Gainesville campus. Blue dots are boxes that were occupied at least once by an Eastern bluebird pair, and yellow dots are boxes that were not occupied during the study (February through July 2019). Lake Alice (center) is located at 29.6431° N, 82.3613° W.

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Figure2. Three bird species (Carolina Chickadee, Carolina Wren, and Eastern Bluebird) occupied nest boxes and number of successful nests for each species.

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Figure 3. Sample size for each treatment group. 11 nests in group “N” (noisy area without playback), 12 nests in group “NP” (noisy area with playback), 11 nests in group Q (quiet area without playback), 11 nests in group QP (quiet area with playback)

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Figure 4. Comparing the hatching rate of Eastern bluebird nests in quiet areas (with and without playback) versus noisy areas (with and without playback).

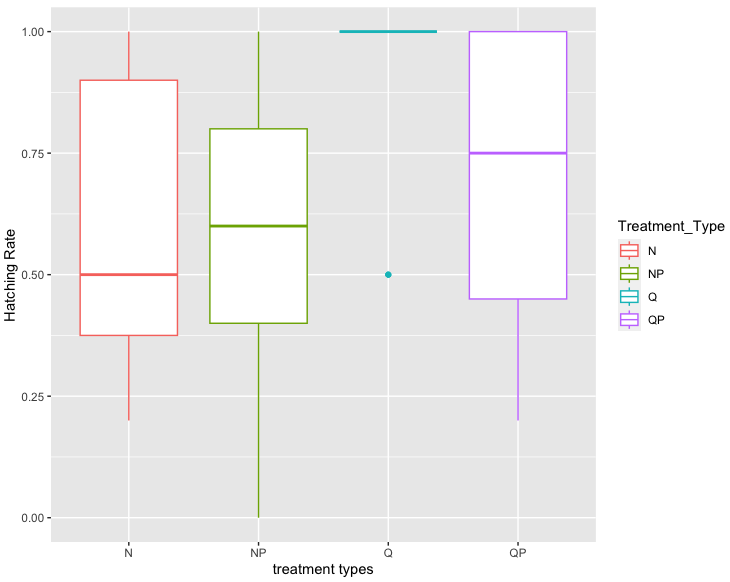


Figure 5. Hatching rate of Eastern bluebirds in 4 different noise levels (N: noisy area without playback, NP: noisy area with playback, Q: quiet area without playback, QP: quiet area with playback).

Table 1. The various noise characterization schemes defined in study design.

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| --- | --- | --- | --- | --- | --- | --- |
| Noise Scheme | Description | | Number of Levels | Level | Code | Definition |
| Background Noise | | Two levels of background noise measured at boxes. | Two | L1 | Quiet | Background noise level (without playback) < 70 dBA |
| L2 | Noisy | Background noise level (without playback) >= 70 dBA |
| Designed Noise Categories | | Combined background noise levels and treatments (with or w/o playback). | Four | L1 | QC | Quiet boxes without Playback of Construction Noise (Control) |
| L2 | QP | Quiet boxes + Playback of Construction Noise (Treatment) |
| L3 | NC | Noisy Boxes without Playback of Construction Noise (Control) |
| L4 | NP | Noisy Boxes + Playback of Construction Noise (Treatment) |
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The page limit is at most four pages, single space, 12pt font, excluding figures, tables, and citations.

The number of references is expected to be at least 10 because you are expected to 1) base your hypotheses on some existing literature/theories and 2) compare your findings with other studies.

8 points: Github site for the data and analyses is required for graduate students.

8 points: The paper clearly conveys the research ideas and results and is easy to follow.

10 bonus points for paper prepared using Rmarkdown.