The effects of increased ambient urban noise levels on the vocalization pitch of European

starling nestlings (*Sturnus vulgaris*)

By

Celina Campbell

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Dr. Colleen Barber

Supervisor

Dr. Anne Dalziel

Reader

ABSTRACT

Anthropogenic noise has had documented detrimental effects on animal health and communication within urban areas. Decreased fitness along with impaired nestling-parent communication have been detected in a few urban avian species. The purpose of this study was to examine the effects of artificially increased ambient urban noise on nestling begging calls. It was hypothesized the nestlings will increase the sound frequencies of their calls to overcome the masking effects of higher noise levels. I predicted that the nestlings would shift the sound frequencies upwards and increase the call sound frequency ranges with noise playing.

Vocalizations were recorded within 8 nests for each of two groups: a) the experimental group, subjected to artificially increased noise for 7 hours a day (3.5 continuous hours twice a day) from days 5 to 15 (day 0 is hatch day), and b) the control group. Recordings were made on day 14 in control (over one hour) and in experimental nests (an hour with extra noise being played, and an hour with no extra noise). Twenty minutes of continuous calls were selected for analysis for each group. Five values were obtained for each nest: the 5%, 25%, 50%, 75%, and 95% sound frequencies (kHz). From these, a calculated weighted mean was derived. Nestlings in the experimental nests called at significantly higher frequencies, with significantly larger call frequency ranges, when extra noise was played than in the control nests. However, there was no significant increase in call sound frequency and call frequency ranges when comparing the experimental group after the noise stopped and the experimental group with noise playing and the control group. These findings suggest that the nestlings significantly increase their call sound frequency in the immediate presence of higher noise levels to overcome the effects of masking.

INTRODUCTION

Humans are a contributing factor to the decline of animal species and the destruction of their habitats (Jaiteh et al., 2002; Hunter, 2007; Fairhurst et al., 2013). Many species have either been forced to relocate, had their population size reduced, have had to adapt to the urbanization of their habitats, or all of the above (Ditchkoff et al., 2006; Hunter, 2007; Cruz et al., 2009). Avian species in particular have experienced large negative impacts from the destruction, degradation and fragmentation of their habitats. Agricultural and urban expansion, and forestry have created unsuitable habitat and have reduced or destroyed resources (Jaiteh et al., 2002; Dooling et al., 2003; Fairhurst et al., 2013).

There have been documented long-term effects of high noise levels on passerine species. The high noise levels resulted in decreased song quality due to impaired learning during the critical stages of development (e.g. Buchanan et al., 2003; Wood & Yezerinac, 2006). Within urban areas of Nova Scotia, there are noticeable declines of smaller avian species, such as Bicknell's Thrush (*Catharus bicknelli*; Province of Nova Scotia, 2015), Rusty Blackbird (*Euphagus carolinus*; Blickley & Patricelli, 2006), and Barn Swallows (*Hirundo rustica*; Hunter 2007; Hanser et al., 2008). Other common passerine species such as Song Sparrows (*Melospiza melodia*) are not experiencing population declines; however, they do show the detrimental effects of anthropogenic stress (e.g. human activity and chronic noise) through decreased fitness (energetic costs of overcoming masking of calls and reduced mate recognition due to vocal adjustment; Marzluff, 2001; Blickley & Patricelli, 2006; Wood & Yezerinac, 2006; Hunter, 2007; Parris & Schneider, 2009). Higher noise levels result in impaired parent-nestling communication and reduced nestling fitness in many passerine species, including Tree Swallows (*Tachycineta bicolor*; Burke et al. 2012; Fairhurst et al., 2013).

Jason et al. (2012), determined that higher levels of noise in urban areas caused a decrease in the health of the human inhabitants. It can be predicted that high levels of noise would also have the same impact on the urban animal population. Morton proposed a hypothesis for this very prediction; the acoustic adaptation hypothesis (1975). This hypothesis proposed that birds will increase the sound frequencies of their calls in areas with higher noise levels to overcome the effects of masking, and will subsequently have larger vocal frequency ranges (Morton, 1975; Wood & Yezerinac, 2006). Cardoso & Hu tested the acoustic adaptation hypothesis by analyzing how twelve bird species adapted their call sound frequencies in response to increased urban noise levels (2012). Based on Cardoso & Hu's findings (2012), as well as several other studies, it was confirmed that adjusting the sound frequency of calls in louder environments (such as urban areas) was quite common among passerine species (Morton; 1975; Parris & Schneider, 2009).

European Starlings (*Sturnus vulgaris*) are an urban-thriving species. They are an oscine passerine (perching bird) species, within the Order Passeriformes (Dobkin et al., 1988b), and are a small brown-black bird, with iridescent purple and green feathers and white speckling (Feare, 1984; Collins, 2011). The European Starling is the third most numerous songbird species in North America, numbering at approximately 200 million individuals (Dobkin et al., 1988a; Stein, 2014; Cabe, 1993). Starlings are only outnumbered by Mourning Doves (*Zenaida macroura*), and the American Robin (*Turdus migratorius*). The North American population comprises approximately one third of the world's European Starling population (Feare, 1984; Dobkin et al., 1988a). In North America, as well as most other continents in which they were introduced, European Starlings rapidly expanded their populations, and were later classified as an invasive species (Bleier et al., 2007; Collins, 2011). European starlings are one of the most successful avian invasions to the continent (Feare, 1984; Cabe, 1993). They are also a significant indicator species as they exhibit many behavioural adaptations while under

anthropogenic stress, including nesting, feeding, and communication behaviours (Brunton & Schafer, 1979; Buchanan et al., 2003; Butler et al., 2012; Ferrer et al., 2012).

The adult European starling has a large vocal range with approximately 10 different calls, as well as the ability to vocally mimic up to twenty other birds species, such as the Red-tailed Hawk (*Buteo jamaicensis*), Killdeer (*Charadrius vociferous*) and the American Robin (*Charadrius vociferus*) (Cabe, 1993; Chow, 2000). They can also mimic car horns and alarms, and even some human sounds (Hindmarsh, 1984; Chow, 2000). This results in a large and complex vocal repertoire that requires constant learning starting in the nest (Cotton et al., 1996; Hunter, 2007; Parris & Schneider, 2009). Starlings can produce and perceive sounds from 0.2 to 16 kHz, though they have been recorded to reach 20 kHz on rare occasions. Starlings also have a shifting ultrasonic range based on the time of year; during the nesting months of April to June, they perceive sounds from 7 to 16 kHz as this is the range in which nestlings produce their begging signals (Frings & Cook, 1964; Beason, 2004).

Nestlings begin communicating as soon as they hatch; however, this communication, known as begging is very structurally simple (Fairhurst et al., 2013). Begging is purely dictated by hunger or external stimuli, such as the parents entering the nest (Cotton et al., 1996; Haff et al., 2010). Nestlings go through large physical developmental changes. Hatchlings weigh approximately 6.4 grams and grow to approximately 60-96 grams by 21-23 days (Feare, 1984; Cabe, 1993). Dramatic changes can be observed in starling vocalizations over this time, as seen by de Araujo et al. (2012). However, there is little research on the immediate effects of acclimatization and adaptive responses to high anthropogenic noise levels on nestling begging vocalizations (Cruz et al., 2009).

Adhering to the concepts laid out by Morton (1975) in the acoustic adaptation hypothesis, where it was proposed that birds will increase their call sound frequency and sound frequency ranges to overcome the masking effects of higher noise levels, I studied the effects

of urbanization on nestling begging calls. The ambient urban noise was artificially increased to determine whether these nestling vocalizations differed in some measureable way from vocalizations of nestlings raised under comparatively normal urban noise levels. The purpose of this study was to determine if nestlings shifted the frequency (pitch) of their vocalizations upwards under conditions of higher ambient noise levels, as it has been found to not be the most significantly effective adaptation to overcome masking effects (Brumm & Nemeth, 2010; Brumm et al., 2013; Mulder & Potvin, 2013). I predicted that nestlings exposed to increased urban ambient noise would increase the sound frequency of their calls, as well as the range of sound frequencies, as compared to nestlings raised under conditions of normal levels of urban noise, as it requires less energy than shift the frequency than the amplitude or other factors involved in producing vocalizations (Blickley & Patricelli, 2006; Cruz et al., 2009).

METHODS

I.   Study Site

This study was conducted between April and July 2015 on the Saint Mary's University campus (44.6317° N, 63.5797° W) in Halifax, Nova Scotia, Canada where starling research has been carried out for the past nine years. This site, along with a few others around Nova Scotia, have nest boxes established for nesting starlings. Nest boxes are set up in trees around the campus, approximately 6 to 10 feet off the ground, providing starlings with a secure nesting site, while also allowing access to researchers. Of the usual two broods per mating season, the starlings nested in 24 of the 39 available nest boxes for the first brood, and in 20 boxes the second brood. The boxes were chosen based on location and timing of the hatch dates.
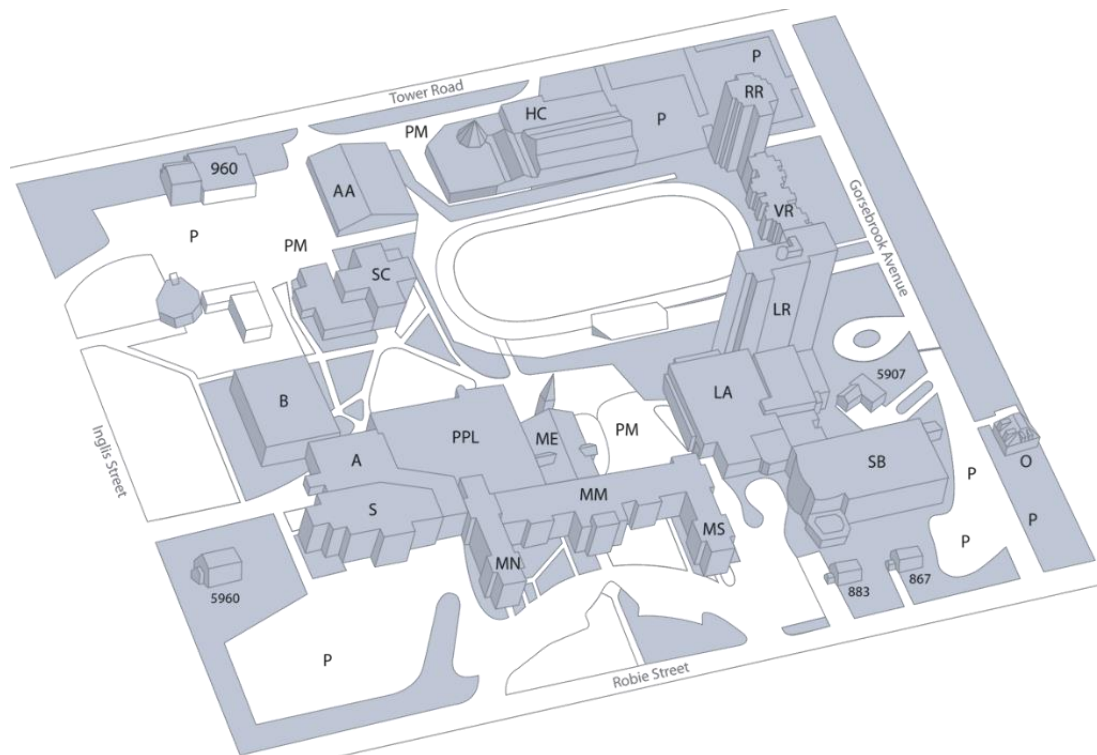

Figure 1. A graphic representation of the campus area of Saint Mary's University, Halifax NS

Halifax, Nova Scotia is a relatively small city with a population of 390,000 people (Statistics Canada, 2015). Within the city, noise levels average at approximately 65 decibels, but can reach up to 85-90 (Engineering Toolbox, 2005; Jason et al., 2012; Appendix A). Jason et al. (2012) measured these levels in various areas of Halifax, including residential, business/commercial, and industrial areas, and times of varied levels of traffic were also included (Engineering Toolbox, 2005). I found the same levels when measuring noise levels around Saint Mary's campus (Appendix A).

II.   *Experimental Setup*

Eight nest boxes from each of the first and second broods (16 nest boxes in total) were chosen based on their ability to be split into four similar pairs (same area of campus experiencing similar environmental noise levels and having similar clutch sizes). Each pair consisted of a control and an experimental nest box. Sound levels were measured at each nest box using a CheckMate SPL (Sound Pressure Level) Meter (CM-130). Maximum sound levels were measured in decibels, in thirty second intervals for three minutes, both in and outside the nest box (Appendix A). Three minutes were chosen to reflect the length of the traffic noise recording used for the experiment.

Figure 2. Nest box equipment setup: Ziploc bag containing the Zoom H1 Handy Recorder and Hipstreet Prism digital mp3 player, with attached Sony stereo headphones and NexxTech omnidirectional microphone secured to the outside of the box, with the adjacent earpieces and microphone hung inside the box.

All experimental nest boxes were equipped with a pair of Sony Natural Sound stereo headphones (MDR-E820LP) placed inside at the back of the nest box, hanging to a depth of 25 cm, and a Hipstreet Prism digital mp3 player, which was secured outside the nest box for accessibility (Figure 2). Control nest boxes were similarly equipped with an inexpensive type of headphones similar in shape and colour to the Sony stereo headphones, and a Hipstreet Prism digital mp3 player. A NexxTech omnidirectional 'Tie Clip' microphone was attached to the inside front of the nest box such that it hung 10 cm from the top of the nest box. Vocalizations inside the box were recorded with a Zoom H1 Handy Recorder, secured below the nest box. Both the mp3 and recorder were placed in Ziploc bags attached to the bottom of the box (Figure 2), to protect them from weather damage and potential vandalism.

A 3-min playback loop recording of city traffic noise (Finnolia, 2013) was played continuously within each experimental nest box for 3.5 hours in the morning, and 3.5 hours in the afternoon with a one to two hour rest over mid-day (when the mp3s were being charged). This city traffic noise was played from Days 5 to 15 of the nestling period (day 0 is day of hatch). Recordings of nestling vocalizations were made on Day 14, between 8:00am and 1:00pm. In the experimental nest boxes, there were two parts to the recordings: a) recording nestling vocalizations with the traffic noise playing at approximately 80 to 90 decibels (dB) and b) recording them immediately after the traffic noise stopped playing and conditions returned to normal (no extra urban sound was playing). This was done to discern if vocalizations differed when recorded simultaneously with noise as opposed to after the noise was stopped.

III.   Data Analysis

The recordings, originally 4 to 5 hours in length, were cut down to 20 min of continuous nestling calls using the sound analysis program, Audacity 2.1.1. A length of 20 minutes of nestling vocalizations was deemed satisfactory (Andy Horn, pers. comm.), as it was a sufficient length of time to include all types of the nestlings' calls (Fairhurst et al., 2013). The edited recordings were then entered into another sound analysis program, Raven Pro 1.4, to calculate the sound frequencies of the nestling vocalizations. Sound frequency levels were analyzed for 5 sound frequencies at the 5%, 25%, 50%, 75%, and 95% of total energy within the nestlings' calls. Due to the nature of the recordings and the analysis software, no maximum or minimum could be obtained and so the values at 5% and 95% were substituted in as robust alternatives (Huber, 2011). All the values obtained for each nest box were used to calculate weighted averages (equation can be found in Appendix B). The resulting values were then used for further analysis.

There were three groups of recordings to be analyzed: i) the experimental nest boxes with noise playing in the background, ii) the experimental nest boxes after the noise had stopped playing, and iii) the control nest boxes. The approximate range of sound frequencies produced by the nestlings was also calculated using the 5% and 95% values to determine the effects of masking (Dooling et al., 2003; Huber, 2011). Data normality was tested using a d'Agostino-Pearson test. Data were not normally distributed so a series of Wilcoxon and Mann-Whitney tests were performed (GraphPad, 2015). The groups could not be analysed with a nonparametric ANOVA because the groups were not comparable all together; the analyses had to split into paired and unpaired t-tests (GraphPad, 2015). The experimental groups with background noise were paired with the experimental groups after the noise stopped playing, for both the weighted mean sound frequencies and the range values, and were analyzed using the Wilcoxon test (paired data; GraphPad, 2015). The experimental groups with background noise and the control groups were paired together, as well as the experimental groups after the noise stopped playing and the control groups. These two combinations were analyzed using the Mann-Whitney test (unpaired data; GraphPad, 2015).

RESULTS

I.   Analysis of the weighted means of the nestlings' sound frequencies

There was a significant increase in the nestlings' vocalization frequencies when the noise was being played to them as compared to the control where there was no added noise at all (Mann-Whitney U = 8.0, n = 8, P = 0.010; Fig. 3). However, there was no significant increase in the nestlings' frequencies when comparing the experimental group after the noise stopped playing and the control (Mann-Whitney U = 19, n = 8, P = 0.20; Fig. 3), or the

experimental group during the noise playback and the experimental group after the noise stopped playing (Wilcoxon W = -22.0, n = 8, P = 0.15; Fig. 3).
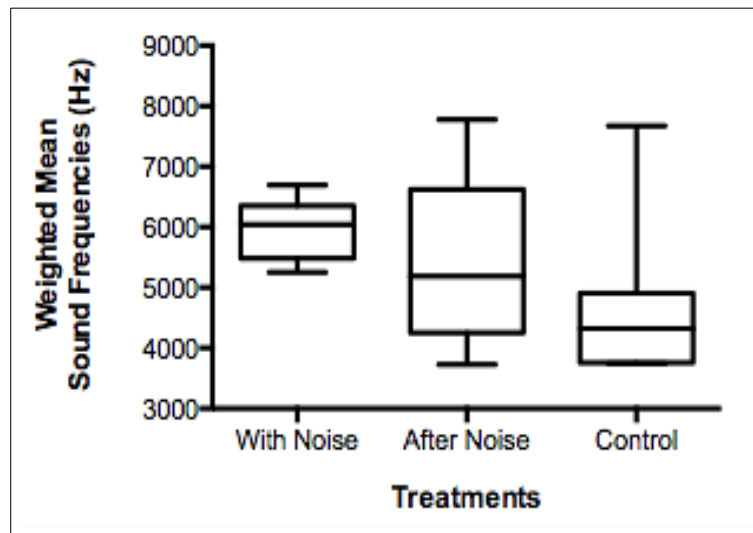

Figure 3. The weighted mean sound frequencies of nestling vocalizations at (a) the experimental nest boxes with background noise (μ = 5989.2 Hz, min = 5254.1 Hz, max = 6692.9 Hz), (b) the experimental nest boxes after background noise ended (μ = 5419.3 Hz, min = 3729.2 Hz, max = 7777.4 Hz), and (c) the control nest boxes (μ = 4646.7 Hz, min = 3742.8 Hz, max = 7673.6 Hz); total of 8 pairs = 16 nest boxes

II.   *Analysis of the range values calculated from the nestlings' sound frequencies*

There was also a significant increase in the nestlings' sound frequency ranges when the noise was being played in the background as compared to the control (Mann-Whitney U = 10, n = 8, P = 0.021; Fig. 4). However, there was no significant increase when comparing the experimental group after the noise stopped playing and the control (Mann-Whitney U = 24.0, n = 8, P = 0.44; Fig. 4), or the experimental group during the noise playback and the experimental group after the noise stopped playing (W = -20.0, n = 8, P = 0.2; Fig. 4).
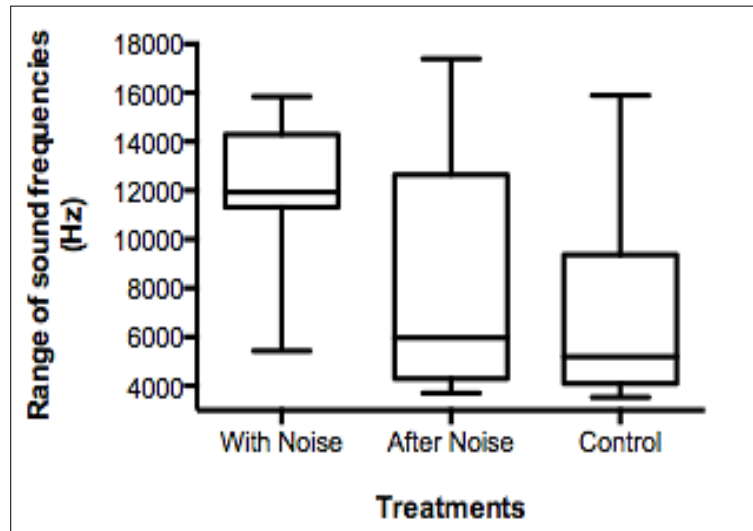
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nor did they differ between experimental nest boxes while noise was playing vs. after the noise had stopped. These findings suggest that European starling nestlings have significantly increased call sound frequencies and sound frequency ranges in response to increased ambient urban noise, supporting the acoustic adaptation hypothesis as well as my predictions.

The acoustic adaptation hypothesis proposed by Morton (1975) suggests that birds will shift the pitch (sound frequency) of their calls upwards to overcome the effects of masking in noisy environments, such as urban areas. This hypothesis was based on several passerine species' studies, and was predicted to occur in other Passeriformes. European starlings are known to be highly plastic and display behavioural plasticity, providing an explanation as to why they are able to acclimate in this particular way (Feare, 1984; Araujo et al., 2012; Cardoso & Hu, 2012). A study on blackbirds (*Turdus merula*) by Brumm et al. (2013) had similar conclusions, in that increased noise levels caused birds to increase their own call sound frequencies to overcome the effects of masking. Similarly, in a study on tree swallow nestlings (*Tachycineta bicolor*), the range of sound frequencies of their calls significantly increased under the effects of ambient noise (Horn & Leonard, 2005).

However, these findings only explain the difference between the experimental group with the noise playback and the control group. These two groups were composed of separate nest boxes, unlike the experimental groups with noise playback and after noise stopped playing, which were composed of the same nest boxes. As a highly plastic species, the starling nestlings' in the experimental group (as a whole) may have marginally increased the sound frequency of their calls as compared to the control group, but when under the influence of increased ambient noise increased their sound frequencies again, pushing the difference between the control group and the experimental group with noise playback to become significant. This suggests that while the nestlings raised in noisier environments may not have increased the sound frequencies of their calls significantly when under the effects of even more noise, it was still significantly

higher than nestlings raised in quieter environments (Brumm & Nemeth, 2010; Cardoso & Hu, 2012; Brumm et al., 2013).

As nestlings, European starlings are not fully developed physically, and therefore do not have fully developed vocal anatomy, such as the syrinx, causing their vocalizations to be limited (Feare, 1984; Beecher & Brenowitz, 2005). Starlings reach full song (vocal maturity and stability) when they reach sexual maturity at one year of age; most song syllables are learned and recognizable by 4 months, which far surpasses the 21-23 days spent in the nest, as well as the study's recordings at Day 14 (Feare, 1984; Hauser & Konishi, 2003). This may be the cause for some differences between studies on adults and nestlings (short-term vs. long-term effects of being raised in noisy environments; Hauser & Konishi, 2003; Beecher & Brenowitz, 2005).

As there are many studies on adult calling behaviour and adaptive responses to vocal masking, there is a lot of information on starlings and similar species' acclimatization in noisy urban environments (Blickley & Patricelli, 2006; Ditchkoff et al., 2006; Cruz et al., 2009; Parris & Schneider, 2009; Brumm et al., 2013). For example, there are studies surrounding the concept of birds increasing sound frequency or amplitude of their calls to overcome the masking effects of urban noise that have been done on starlings, and other species such as tree swallows (*Tachycineta bicolor*), silvereyes (*Zosterops lateralis*), and the common myna (*Acridotheres tristis*). However, all of the previously listed studies were on adult birds. There has been relatively little research on the sound frequency adaptations of passerine nestlings and the immediate behavioural effects of increased noise levels (Horn & Leonard, 2005; Cardoso & Hu, 2010; Mulder & Potvin, 2013). Sound frequency, along with amplitude, call type, call duration, and call frequency are all factors involved in how a bird produces sound (Blickley & Patricelli, 2006; Mulder & Potvin, 2013). Although my study found significant increases in the sound frequency production of the nestlings from the experimental groups, any or all of the

previously listed factors involved in vocal sound production may have also been changed in response to increased noise levels (Blickley & Patricelli, 2006; Cruz et al., 2009; Cardoso & Hu, 2010). For example, Mulder & Potvin (2013) found that Silvereyes (Zosterops lateralis) increased the amplitude of their calls, as well as the pitch, but at a higher energy cost.

CONCLUSION

This experiment supports my prediction that European starling nestlings would increase the sound frequencies and sound frequency ranges of their calls. Detrimental effects on nestling vocalizations have been linked with reduced efficiency in parent-offspring communication, diminished physiological states of the nestlings, and decreased reproductive fitness of the nestlings once they become adults (reduced song quality that leads to reduced attractiveness for mating; Buchanan et al., 2003; Dooling et al., 2003; Ditchkoff et al., 2006; Parris & Schneider, 2009; Haff et al., 2010; Horn & Leonard, 2012). However, it is yet to be determined if the nestlings' adaptive vocal response to increased ambient noise has any immediate or long-term effects. Based on previous studies, I predict the nestlings will have reduced physical fitness, both immediately and long-term, as they will expend more energy in producing vocalizations in areas of higher noise (Buchanan et al., 2003; Burke et al., 2012; Horn & Leonard, 2012; Mulder & Potvin, 2013). Further research is needed to determine how the changes made in the nestlings' calling behaviour in an environment with increased noise levels affects both their immediate state and long-term states of fitness.

ACKNOWLEDGEMENTS

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APPENDIX

Appendix A. Sound Level Measures

Brood 1.

NB	Outside	Inside
1	61.42	65
7	83.33	87.75
9	64.58	64.83
11	60.92	62.42
15	82.58	88.42
26	83.92	88
36T	62.33	62.58
37	81.33	86.25
44	59	61.33
45	81.92	87.33

Brood 2.

NB	Outside	Inside
1	77.42	83.33
4	80.58	87.5
7	80.5	87.33
11	57.75	67.17
19	60.08	66.42
25	82.17	86.92
30	64.42	68.67
36T	58.33	66.33

Appendix B. Sound Frequency Weighted Mean Equation

sfv = sound frequency value (in Hz)

a = 5% sfv

b = 25% sfv

c = 50% sfv

d = 75% sfv

e = 95% sfv

X = weighted mean

$$X = [(0.05 \times a) + (0.25 \times b) + (0.5 \times c) + (0.25 \times d) + (0.05 \times e)] / (1.1)$$