LSM3257 Applied Data Analysis in Ecology and Evolution

Project Report

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Anthropogenic Noise Pollution Affects Vocalization of Straw-headed Bulbul (*Pycnonotus zeylanicus*)

Abstract

Anthropogenic noise is a globally growing source of pollution that significantly affects the welfare of avifauna. In a highly urbanized city-state Singapore, the critically endangered Straw-headed Bulbul is subjected to constant noise pollution due to their proximity to the traffic. This study investigated how the traffic noise from an expressway impacts the vocalization duration as well as the number of vocalizations during the dawn chorus period of Straw-headed Bulbul. Data collected along the expressway suggest that they exhibit longer vocalizations closer to the expressway, and decrease in vocalization closer to the expressway. The result of this study could provide an insight into the appropriate conservation approaches to this species, as well as the importance of the buffer zones surrounding the nature reserves in Singapore.

Introduction

Acoustic space is the resource that different species compete for in nature. Acoustic space can be represented by the range of sound frequency and time available in the environment (Slabbekoorn, 2017). Different species use different partitioned acoustic spaces that enable them to communicate with conspecifics without interfering with other species (Hart et al., 2021). However, increasing human activities have introduced considerable anthropogenic noise into the natural environment, resulting in a reduction in the available acoustic space (Shannon et al., 2016).

Many studies have extensively investigated the effects of human-made noise pollution on wildlife (Ismail, 2018). Birds, in particular, are susceptible to noise pollution due to their dependence on acoustic cues for long-distance communication (Vitt & Caldwell, 2009). Noise pollution can interfere with sound transmission between signal transmitters and receivers via the masking effect, wherein loud sounds overpower softer sounds and dominate the acoustic space (Swanson et al., 2002). The impact of anthropogenic noise is more severe since it is loud and low frequency, resulting in low attenuation rates and greater environmental consequences (Slabbekoorn, 2017). Communication masking can limit conspecific information, thereby affecting their reproductive and survival success (DeRuiter et al., 2013).

However, recent studies have indicated that birds utilize mitigation strategies to cope with the adverse effects of anthropogenic noise pollution (Brumm & Slabbekoorn, 2005). One such strategy is a shift in vocalization timing (Fuller et al., 2007) (Fig. 1a). During periods of increased anthropogenic noise, birds may minimize their vocalizations to avoid the masking effect (Fuller et al., 2007). This mitigation approach has been frequently noted, and it has been suggested that birds' dawn chorus timing may be delayed by over an hour in highly urbanized environments (Sánchez-González et al., 2021) Another mitigation strategy is to increase the duration of vocalizations (Couter et al., 2020; Fig 1b). This may increase the chance of the acoustic signal reaching the intended recipient. This response is relatively understudied (Couter et al., 2020), as previous studies have mainly focused on the other mitigation strategies, such as changes in amplitude and vocal frequency (Brumm & Zollinger, 2011; Li et al., 2021).

Singapore is situated at the southernmost tip of the Malay Peninsula. The island has undergone significant environmental changes since the arrival of the British in 1819, with 95% of its old growth forest lost (Brook et al., 2003). Currently, the remaining vegetation consists mostly of secondary forests, which have been fragmented by various human activities such as construction of roads, housing, and industrial facilities (Corlett, 1992). Nevertheless, Singapore has a surprisingly rich avian community, with 413 bird species recorded (National Parks Board of Singapore, 2022). Despite the degraded habitats, many bird species have adapted to living in edge habitats, including the highly sought-after Straw-headed Bulbul (Pycnonotus zeylanicus).

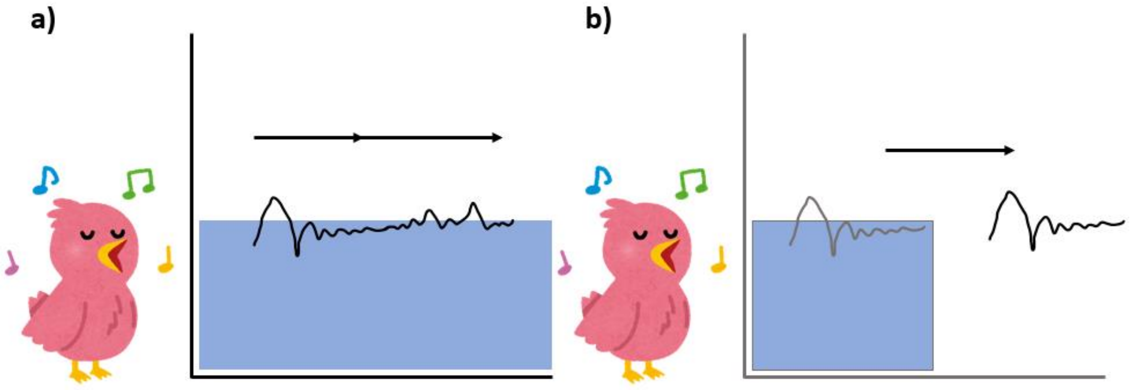

Figure 1: Potential mitigation strategies that birds may use in response to anthropogenic noise pollution. The blue shading shows the anthropogenic noise. (a) shows the increase in vocalization duration, (b) shows the shift in vocalization timing.

Straw-headed Bulbul is decreasing globally, and this species has been listed as critically endangered by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species since 2018 (Birdlife International, 2023). Singapore is home to ~500 individuals of this species, representing 20-50% of its worldwide population (Chiok et al., 2021). Their tolerance to degraded habitat and Singapore's relatively limited songbird trade activities have allowed them to thrive in this small island state (Chiok et al., 2021).

Thus, this report aims to investigate the effect of anthropogenic noise pollution on the duration and number of vocalizations of the Straw-headed Bulbul in nature parks adjacent to the Bukit Timah Expressway (BKE), where the Straw-headed Bulbul is known to reside. This study could provide insights into the extent of anthropogenic pollution on this charismatic bird in the conservation field.

Research Question

In this project, we explore the impact of anthropogenic noise on two aspects of the vocalizations of Straw-headed Bulbul. We investigated the following aspects:

1) how the duration of the vocalizations change in response to the distance to BKE,
2) and how the number of vocalizations during the dawn chorus period in response to the distance to BKE.

The dawn chorus was defined as the period between 06:00 to 10:00 following Gil & Llusia, 2020), and the period is when most of the birds are the most active.

Methodology

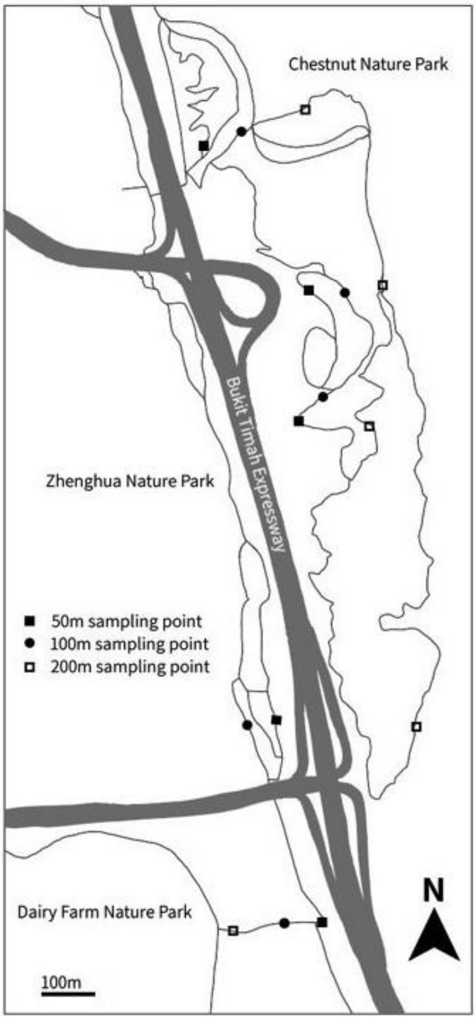

Figure 2: Map of transects plotted perpendicularly along the Bukit Timah Expressway (shown in grey). Sampling points in each transects are at 50 m (filled square), 100 m (filled circle), and 200 m (open square) to BKE.

Data Collection

The data collection was carried out in three nature parks adjacent to the BKE – Chestnut Nature Park (1°22’22”N, 103°46’49”E), Zhenghua Nature Park (1°23’7”N, 103°46’22”E), and Dairy Farm Nature Park (1°21’51”N, 103°46’35”E). Five transects were plotted perpendicularly to the BKE (Fig. 2). The sampling points were chosen along the established trails in nature parks, as permitted by National Parks Board of Singapore. At each sampling point, sound data was collected using the SwiftOne – Terrestrial Passive Acoustic Recording Units (The Cornell Lab of Ornithology; www.birds.cornell.edu). The recording units collected sound data from 0600 to 2000 every day from December 2022 to February 2023.

The collected data were processed using acoustic analysis software, Kaleidoscope Pro (Wildlife Acoustics, Inc.; www.wildlifeacoustics.com). This software uses clustering algorithms to sort the sounds in the data and recognize specific bird vocalizations. We used this software to construct a classifier for Straw-headed Bulbul vocalizations. The classifier sorts the detected vocalizations according to their dissimilarity from the ‘model’ vocalization of the Straw-headed Bulbul. To ensure that the detected vocalizations are those of the Straw-headed Bulbul, we used a 75% precision cut-off. In addition, we removed the data from Transect 2 due to the discrepancy in habitat within the transect.

Data Analysis

To understand the impact of anthropogenic noise pollution on bird vocalizations, we analyzed the data using R (R Core Team, 2021; www.R-project.org). Data were cleaned using the tidyverse package (v.2.0.0; Wickham et al., 2019) and the lubridate package (v 1.9.2; Grolemund & Wickham, 2011). The data were split into "off days," which included weekends and holidays, and "weekdays." This was because we observed less noise on off days. For our models, we had duration of detected vocalization and number of vocalizations during the dawn chorus as response variables, distance from BKE and day type as predictor variables, and transect as a random effect. For the duration analysis, I first constructed a linear mixed model with the nlme package (v3.1-162; Pinheiro & Bates, 2000) with a Gaussian distribution. If any of the assumptions were violated, we changed the distribution to negative binomial and then to quasi distribution as needed. For the dawn chorus analysis, because the vocalization is a count data, we constructed a generalized linear mixed model with Poisson distribution. The assumptions were checked using the DHARMa package (v0.4.6; Hartig, 2022). For both analyses, minimum adequate models were obtained using stepwise simplification.

Results

Duration of Vocalization

The distribution of data over different distances showed a consistent pattern (Fig. 3), so we treated distance as a continuous variable. We found that the assumptions of homoscedasticity and normality were violated for the linear mixed model (see Appendix 1, 2). Since the data could not be transformed to meet the assumption, we then used the generalized linear mixed model with negative binomial distribution. The assumption of homoscedasticity and normality were still violated (see Appendix 3), so we used a generalized linear mixed model with quasi-distribution. The minimum adequate model ($n = 2233$) showed the significant increase of 0.327 seconds on weekdays compared to off days ($p < 0.001$), and the increase of 0.00306 seconds for every 1 m closer to the BKE ($p < 0.001$; Table 1).

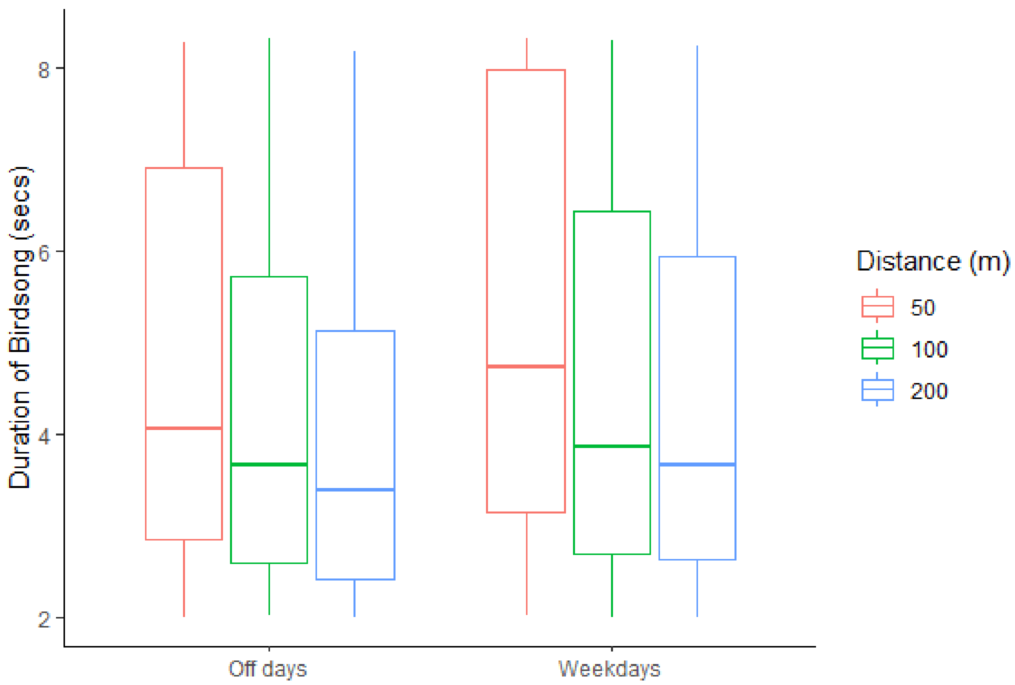

Figure 3: Duration of the vocalization of Straw-headed Bulbul at different distances to BKE on different days ($n = 2233$).

Table 1: Coefficient table from the GLMM with quasi distribution that models the duration of the Straw-headed Bulbul's vocalizations. All numbers are in 3 significant numbers.

Source of variation	Value	Std.Error	DF	t-value	p-value
(Intercept)	4.45	0.236	2227	18.9	< 0.001
distance	-0.00306	0.000801	2227	-3.82	< 0.001
days = weekdays	0.327	0.0906	2227	3.60	< 0.001

Dawn chorus analysis

The distribution of the data showed a positive relationship between 50 – 100m but a negative relationship between 100 – 200m. As such, we used a piecewise regression for this model. After the scaling of the distance variables, the obtained minimum adequate model did not show any violation of the assumptions (see Appendix 4) and all variables showed statistical significance (Table 2).

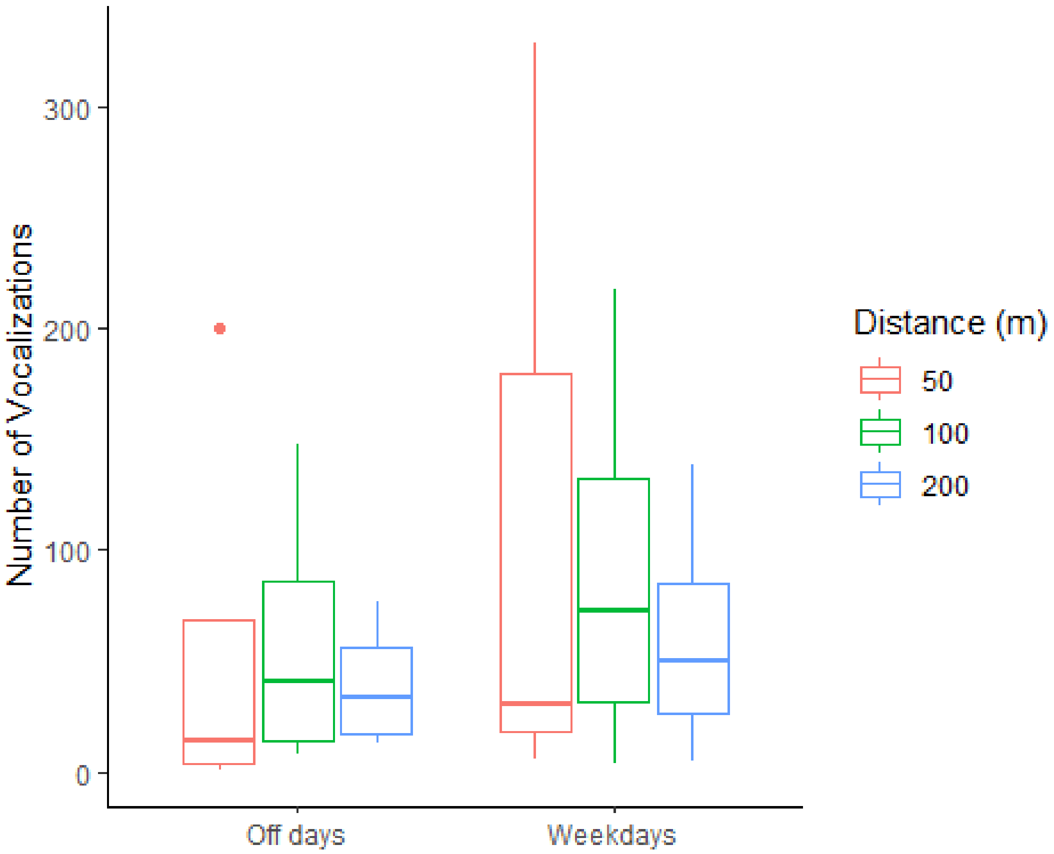

Figure 4: The number of vocalizations of Straw-headed Bulbul at different distances to BKE on different days (n = 2233).

Table 2: Coefficient table from piecewise generalized linear mixed regression with Poisson distribution. Distance are scaled. All numbers are in 3 significant numbers.

Source of variation	Value	Std. Error	z value	Pr(>|z|)
(Intercept)	3.34	0.591	5.65	< 0.001
scale(50-100m)	0.0956	0.030	3.23	0.001
scale(100-200m)	-0.155	0.0289	-5.36	< 0.001
days = weekday	0.503	0.0515	9.77	< 0.001

The model showed that between 50 and 100 m, the number of vocalizations increased by 10.0% for every 42.6 m (rescaled) distance from the BKE (p = 0.001); and between 100 and 200 m, the number of vocalizations decreased by 16.8% for every 82.5 m distance from the BKE (p< 0.001). The number of vocalizations was 1.65 times greater on weekdays than on off days.

Discussion

This project investigated how the vocal duration and number of vocalizations of Straw-headed Bulbul change in response to anthropogenic noise, using distance from BKE as a proxy for pollution levels. Our data suggested that Straw-headed Bulbul vocalized longer when they were closer to BKE; and the number of vocalizations during the dawn chorus period showed the peak at 100 m sampling points.

Increase in Duration closer to BKE.

The increase in vocal duration of Straw-headed Bulbul suggests that they may be trying to outcompete the prevailing anthropogenic noise. In terms of mitigation strategies, birds may directly counteract the masking effect (hawkish) or avoid the conflict (dovish). Outcompeting the anthropogenic noise is an example of direct counteraction. Longer vocalizations may convey more accurate information to conspecifics (Courter et al., 2020), as well as communicate the quality of the individual as well adapted to the environment. However, expending resources on vocalization may come at a cost. The bird may invest less in reproduction or territorial defence, reducing the overall fitness of the individual (Dominoni et al., 2016).

Another example of hawkish counteraction is the Lombard effect, which pertains to the phenomenon wherein birds amplify the intensity of their vocalizations. (Brumm & Zollinger, 2011). Although this strategy has been widely observed, it is difficult to test in the field because the distance from the recording unit to the bird can result in different levels of attenuation, leading to an inaccurate estimate of the amplitude of the vocalization.

Differing response on the number of vocalizations

Ecologists have been interested in studying the impact of noise pollution on bird community dynamics, as documented by Brown et al. (1990) and Bottalico et al. (2016). In cases where anthropogenic noise levels exceed thresholds specific to each bird species, the birds are compelled to limit their communication distances. This, in turn, restricts the range of bird community dynamics. The current investigation entailed the observation of a rise in the number of vocalizations from 50 to 100 m sampling points; however, there was a decline in the number of vocalizations from 100 to 200 m. Such observations may suggest that birds minimize their vocalizations when in close proximity to anthropogenic noise. Consequently, the acoustic communication of the Straw-headed Bulbul may become increasingly constrained with closer proximity to the source of anthropogenic noise.

However, the lack of a consistent pattern in the number of vocalizations along the 200 m transects may suggest that the observed differences are due to the difference in population size. It is possible that the Straw-headed Bulbul population shows the strongest preference for the habitat located approximately 100 m from the noise source. However, without information on the population density of Straw-headed Bulbul along the transect, possibly from the visual survey, it is difficult to conclude which hypothesis is true in this study.

Conservation and Future Work

The current project served as a launching point to comprehend alterations in the vocal behavior of the Straw-headed Bulbul in reaction to noise pollution created by human activity in a highly urbanized tropical environment. Over a distance of only 200 m along the examined transects, modifications in vocalization duration, and conceivably the number of vocalizations during the dawn chorus period, were already apparent. Such outcomes demonstrate the significance of buffer zones between the nature reserve and human activities. If notable changes can be detected within the 200 m transect, the actual influence over more extensive distances may be even more considerable. Given that the largest population of Straw-headed Bulbul encompasses the Central Catchment Nature Reserve, as noted by Chiok et al. (2021), this study calls for authoritative action to increase the width of buffer zones to protect the behavioral integrity of our charismatic conservation symbol, the Straw-headed Bulbul.

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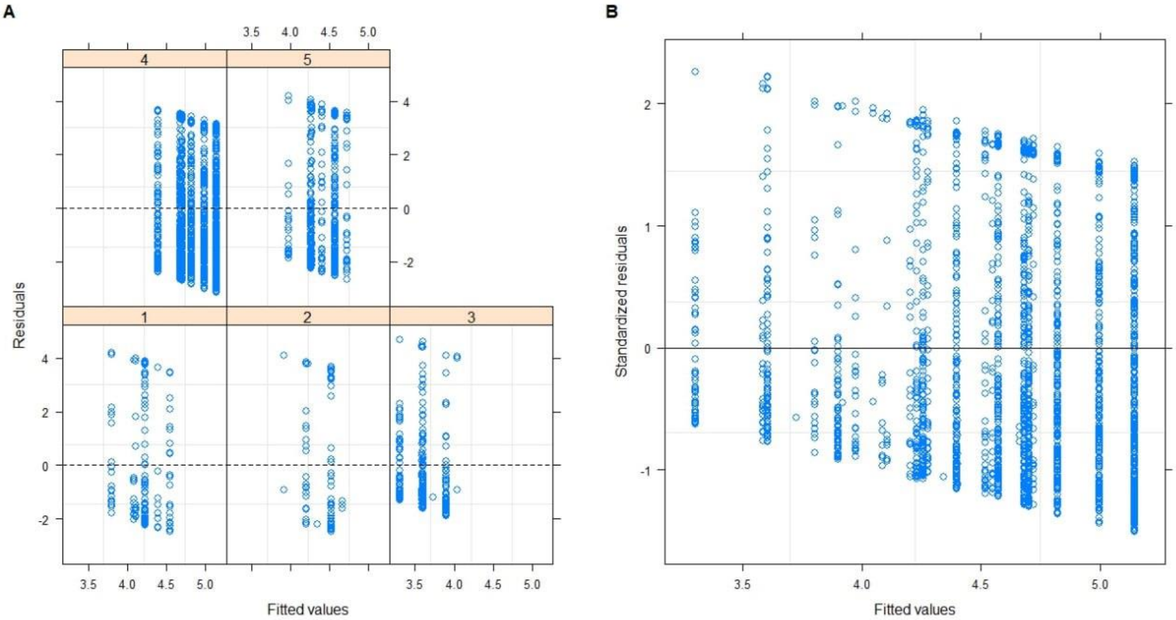
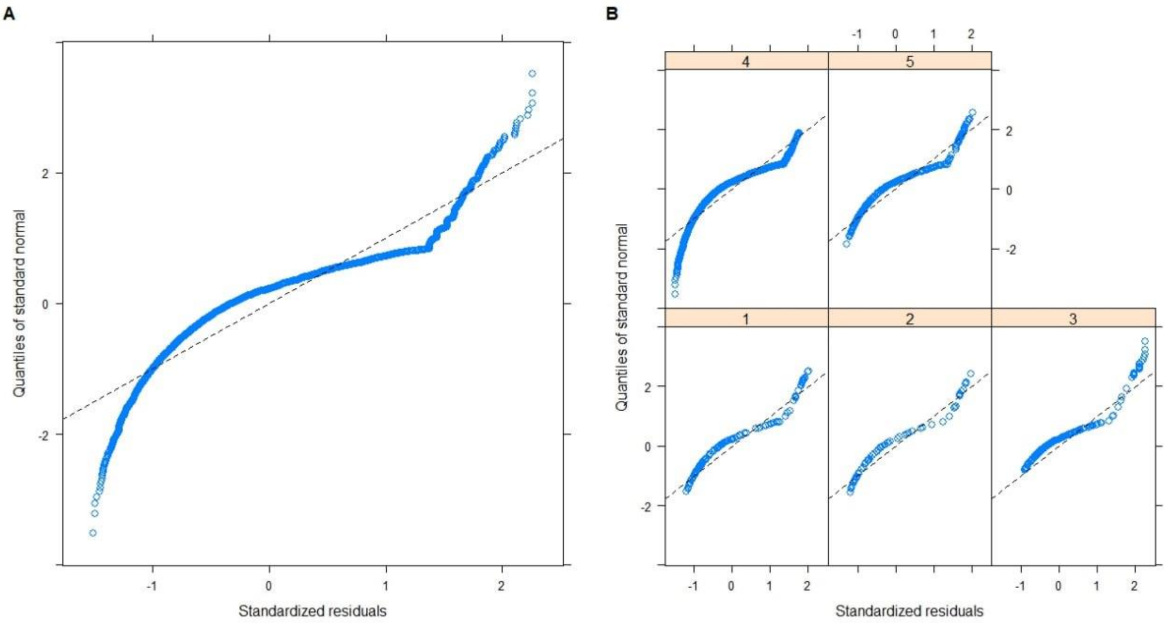
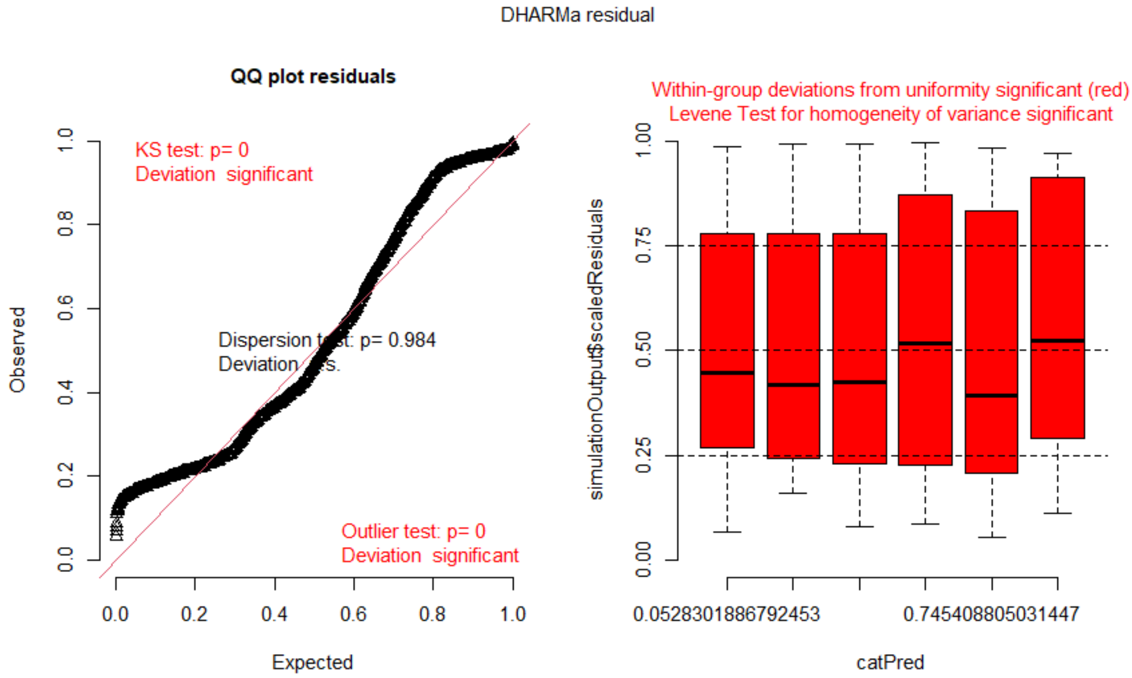
Appendix



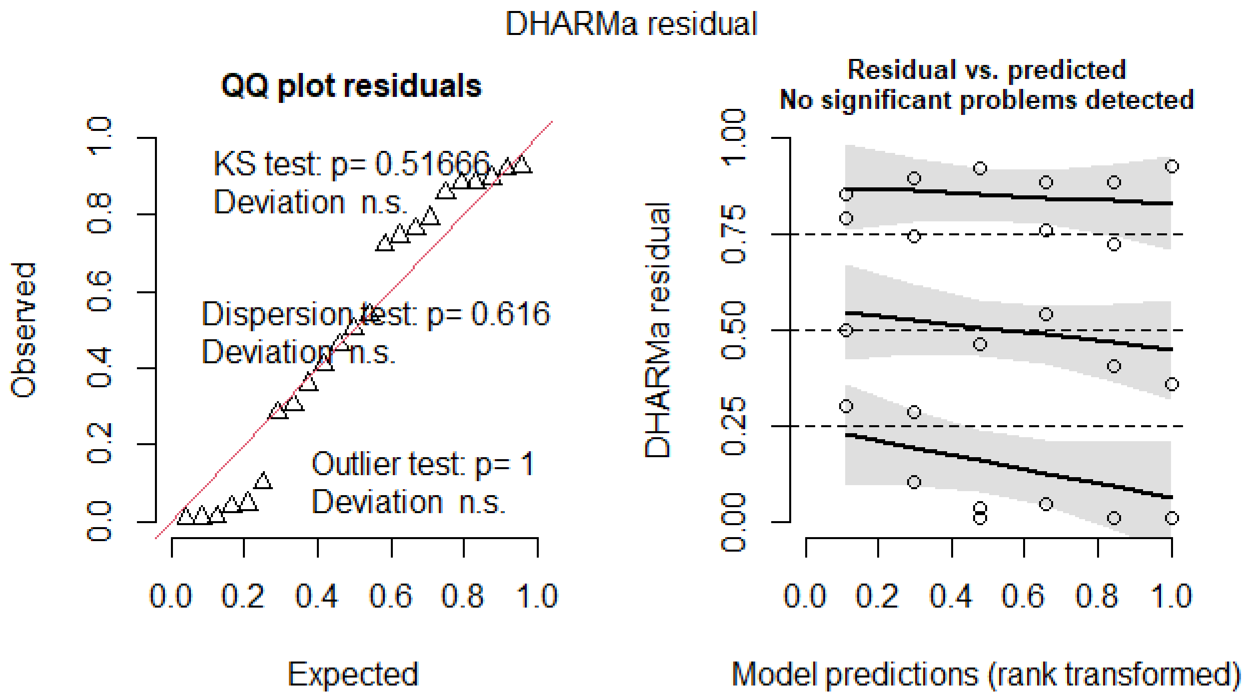
Appendix 1: Diagnostic plot for homoscedasticity for the linear mixed model for the duration of vocalizations. **A:** between different transects **B:** overall diagnostic plot. In both cases, we observed heteroscedasticity in the data (see the supporting document for codes).



Appendix 2: Diagnostic plot for normality for the linear mixed model for the duration of vocalizations. **A:** overall plot, B**:** between different transects. In both cases, we observed violation of normality assumption (see the supporting document for codes).



Appendix 3: Diagnostic plot of generalized linear mixed model with negative binomial distribution for the duration analysis. We observed the violation of homoscedasticity and normality assumptions.



Appendix 4: Diagnostic plot for the minimum adequate model of the dwan chorus analysis. All assumptions are met.