

Road Traffic Noise Masks Bird Vocalizations and Disrupts Communication in Atlantic Forest Understory Birds

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Abstract

Anthropogenic noise generated by road traffic has emerged as an important environmental stressor capable of disrupting acoustic communication in birds, potentially affecting territory defense, mate attraction, and habitat use. We investigated the effects of highway traffic noise on the acoustic communication of six understory bird species in the Sooretama Biological Reserve, an Atlantic Forest remnant in southeastern Brazil. Playback experiments were conducted along sixteen transects established perpendicular to either a highway or pasture edge, with sampling points located at increasing distances (10–800 m) from habitat edges during both breeding and non-breeding seasons. Ambient noise levels were recorded at each sampling point, and the probability of a rapid behavioral response (≤ 1 min) to conspecific vocalizations was analyzed using generalized linear mixed-effects models. Response probability increased significantly with distance from the habitat edge, regardless of edge type, indicating that acoustic communication became progressively more effective as traffic noise decreased. However, birds exhibited consistently lower response probabilities near highway edges than near pasture edges, demonstrating that road traffic noise reduces the detection and behavioral response to acoustic signals. Responses were also significantly more frequent during the breeding season. The negative influence of traffic noise was most evident within approximately 200 m of the highway, where acoustic masking likely reduced communication efficiency. These findings indicate that roads function not only as physical barriers but also as functional acoustic barriers, altering behavioral responses and potentially influencing territory establishment, habitat occupancy, and spatial distribution of forest birds. Mitigating traffic noise should therefore be considered an important component of conservation strategies for bird communities inhabiting road landscapes.

Introduction

Animals rely on communication to exchange information essential for survival and reproduction. Every form of communication involves a sender and a receiver, and signals may be chemical, visual, or acoustic in nature (Vielliard 2004; Bradbury and Vehrencamp 2011). Among these modalities, acoustic communication is one of the most widespread, as many animal species exhibit species-specific vocalization patterns (Summers et al. 2011; Shannon et al. 2014). Each taxonomic group produces vocal signals through specialized anatomical structures that reflect its unique biology (Vielliard 2004). However, acoustic communication is strongly affected by environmental noise (Brumm and Todt 2002; Shannon et al. 2014; Da Silva et al. 2014), as noise can mask acoustic signals and reduce the likelihood that they will be detected by the intended receiver (Brumm and Todt, 2002). Such noise may originate from biotic sources, including other organisms, or from abiotic sources associated with rainfall, wind, urban environments, and road traffic (Shannon et al. 2014). In response to elevated background noise, many animals exhibit the Lombard effect, whereby signalers increase the amplitude of their vocalizations to compensate for acoustic interference and ensure that their signals reach the intended receiver (Brumm 2004).

Sound intensity is measured in bels (B); however, the decibel (dB), corresponding to one-tenth of a bel (1 B = 10 dB), is the standard unit used to quantify sound intensity (Lacerda et al. 2005). Based on this scale, several thresholds have been established to assess the biological effects of noise. Sound levels up to 50 dB are generally considered acoustically comfortable. Between 51 and 65 dB, auditory performance declines, accompanied by an increase in the Lombard effect. At levels ranging from 66 to 70 dB, physiological alterations may occur, whereas prolonged exposure to sound levels exceeding 70 dB may compromise the functional and physiological integrity of organisms (Lacerda et al. 2005). Natural forest environments typically exhibit ambient sound levels below 50 dB, whereas highways with heavy traffic commonly generate noise levels ranging from 65 to 85 dB (Brumm 2004; Patricelli and Blickley 2006; Arévalo and Newhard 2011). Consequently, forest habitats intersected by roads become substantially affected by traffic-generated noise (Rheindt 2003; Parris and Schneider 2009). As a result, roads impose significant acoustic impacts on adjacent ecosystems, particularly on organisms that rely on acoustic communication to perform essential ecological functions (Parris and Schneider 2009; Shannon et al. 2014).

In birds, vocalizations are produced by the syrinx, a specialized vocal organ that plays a central role in acoustic communication, particularly during the breeding season (Sick 1997). Avian communication is regarded as one of the most complex and sophisticated communication systems in the animal kingdom, with some species exhibiting remarkably extensive vocal repertoires, highlighting the critical role of vocal signals in a wide range of biological processes (Sick 1997; Marler and Slabbekoorn, 2004). However, this communication can be substantially impaired by noise that interferes with the frequency and/or amplitude of acoustic signals (Brumm 2004; Patricelli and Blickley 2006; Arévalo and Newhard 2011).

Among abiotic sources of noise, road traffic is one of the most intense and pervasive, generating sound levels that can significantly affect organisms that depend on vocal communication (Andrews 1990; Spellerberg 1998; Brumm and Todt, 2002; Goodwin and Shriver 2011; Summers et al. 2011). In this context, traffic noise can alter the ecology, behavior, and physiology of birds, with many of these responses associated with the Lombard effect, whereby individuals increase the amplitude of their vocalizations in noisy environments (Brumm 2004; Patricelli and Blickley 2006). The intensity of traffic noise is directly related to traffic volume, thereby influencing the composition and distribution of bird communities inhabiting areas adjacent to roads (Arévalo and Newhard 2011; Forman and Alexander 1998). Consequently, road-associated noise acts as an ecological filter, favoring taxonomic groups capable of tolerating these conditions while excluding species that are less tolerant of acoustically disturbed environments (Oliveira et al. 2011; Kociolek and Clevenger 2009). As a result, road-adjacent habitats tend to be occupied by species with greater behavioral plasticity in acoustic communication or by those capable of exploiting the environmental conditions imposed by road infrastructure (Forman and Alexander 1998; Rheindt 2003).

Based on the hypothesis that acoustic communication is impaired in habitats adjacent to highways with intense traffic, we predicted that responses to acoustic stimuli would become progressively more

effective with increasing distance from the road. The objective of this study was to evaluate the influence of road traffic noise on acoustic communication in bird species inhabiting an Atlantic Forest reserve. Specifically, we sought to determine the distances over which traffic noise interferes with the transmission and reception of avian acoustic signals within the forest section intersected by the highway.

Methods

The study was conducted in the Sooretama Biological Reserve (SBR), a strictly protected area located in the municipalities of Sooretama, Linhares, Vila Valério, and Jaguaré, in northern Espírito Santo State, southeastern Brazil. The reserve encompasses approximately 24,250 ha between 18°53'–19°05' S and 39°55'–40°15' W (Fig. 1). The regional climate is classified as tropical monsoon (Am) according to the Köppen classification, with a mean annual precipitation of 1,403 mm and a dry season extending from May to September, during which monthly rainfall may decline to as little as 33 mm in July and August. Mean annual temperature is 23.6°C, ranging from an average minimum of 15.6°C in July to an average maximum of 27.4°C in February. Based on the Mohr seasonality index ($Q = 33.3$), the region is classified as transitional between humid and weakly seasonal climates (Paula and Soares 2011). Within the reserve, sixteen sampling transects were established at 1-km intervals. Eight transects were positioned perpendicular to the highway (road modules), whereas the remaining eight were established along forest edges adjacent to pasturelands and outside the influence of the highway (pasture modules). Each transect was 800 m in length and contained five sampling points located at 10, 200, 400, 600, and 800 m from the highway edge or the forest–pasture interface. Playback experiments were conducted at each sampling point using vocalizations of six understory bird species: *Myrmotherula axillaris*, *Drymophila squamata*, *Thamnophilus ambiguus*, *Xiphorhynchus fuscus*, *Dendrocincla turdina*, and *Setophaga pitiayumi*. The experimental design encompassed both the breeding and non-breeding seasons. Two sampling campaigns were carried out during each season, totaling four sampling events. Field surveys were conducted over five consecutive days during May (dry season) and November (wet season) of 2014. Daily sampling began at 05:30h and ended at 10:00h, corresponding to the period of peak vocal activity for most bird species.

FIGURE 1

Ambient noise levels were measured at each sampling point using a DEC-300 sound level meter. Mean sound pressure levels (dB), as recorded directly by the instrument, were used in subsequent analyses. For each playback trial, the vocalization of a given species was broadcast three consecutive times, with 30-s intervals between broadcasts. Response time (s) was measured from the end of the first playback broadcast, regardless of subsequent repetitions. After the initial broadcast, observers remained at the sampling point for up to 3 min, recording either silent approaches or vocal responses by the focal species. Responses were considered positive when individuals either produced vocalizations or silently approached the loudspeaker to within a 10-m radius, both of which were interpreted as behavioral responses to the acoustic stimulus. All playback recordings were obtained previously within the study

area to ensure ecological representativeness and minimize potential biases associated with geographic variation in vocalizations. Response time was measured using a digital stopwatch, and vocalizations were broadcast using a portable MP3/MP4 loudspeaker. This standardized experimental design allowed us to evaluate the effects of environmental noise on both the detection of acoustic signals and the behavioral responses of birds across a gradient of distance from the highway.

Because 75% of playback trials elicited a response within 1 min of playback onset, we used generalized linear mixed-effects models (GLMMs; glmmTMB package) to evaluate variation in the probability of a rapid response to playback (≤ 1 min after playback onset) across the six bird species analyzed collectively. The fixed effects included: (1) habitat-edge type (road or pasture), (2) distance from the habitat edge (m), (3) the interaction between habitat-edge type and distance from the habitat edge, and (4) season (breeding and non-breeding). Random effects consisted of sampling campaign (four levels) and species identity (six levels), both fitted as random intercepts. Models were fitted assuming a binomial error distribution with a logit link function. Model performance was assessed by visual inspection of simulated residuals generated using the simulate Residuals function from the DHARMA package. All statistical analyses were conducted in R version 4.5.3. The available sample size and variance structure were insufficient to obtain convergent species-specific models; therefore, all six species were analyzed jointly in a single hierarchical model.

Results

The probability of responding to playback increased significantly with increasing distance from the habitat edge ($\beta = 6.43 \pm 1.36$, $p < 0.001$), regardless of edge type (distance $\times$ edge-type interaction: $\beta = -1.72 \pm 1.31$, $p = 0.19$; Fig. 2). However, the probability of response was higher along pasture edges (0.99) than along road edges (0.79) ($\beta = 2.84 \pm 0.79$, $p = 0.002$; Fig. 1). In addition, birds were more likely to respond during the breeding season than during the non-breeding season ($\beta = 1.94 \pm 0.45$, $p < 0.001$).

FIGURE 2

Discussion

Our findings support the hypothesis that acoustic communication is impaired in habitats adjacent to highways, reducing communication efficiency among birds. This pattern is reflected in the lower probability of responding to playback in road-edge habitats, particularly within approximately 200 m of the highway, where traffic noise appears to reduce the detection of acoustic signals and, consequently, vocal responsiveness (Halfwerk et al. 2011; McClure et al. 2013). High levels of anthropogenic noise can compromise organisms that rely on vocal communication for essential intra-specific functions, such as mate attraction and territory defense (Brumm 2004; Brumm and Todt, 2002). Consequently, species inhabiting noisy environments must either modify their acoustic signals or rely on alternative communication strategies to maintain effective interactions with conspecifics (Summers et al. 2011). However, for many forest birds, particularly those that are more sensitive to anthropogenic noise, such

compensatory mechanisms may be limited, resulting in acoustic masking, reduced communication efficiency, and the avoidance of habitats located near highways. As a consequence, the detectability of many bird species may be substantially reduced by intense traffic noise, with important implications for territory establishment, habitat use, and spatial distribution. Our results therefore suggest that highways function not only as physical barriers but also as functional acoustic barriers for forest bird communities (Halfwerk and Slabbekoorn 2009).

As the distance from the highway increased, traffic noise levels declined substantially, resulting in improved acoustic communication efficiency among the study species, consistent with the findings of Summers et al. (2011). The effects of traffic noise on the avian community were most pronounced within approximately 200 m of the highway, where birds exhibited a lower probability of responding to playback than at sampling points located farther from the road. Although noise levels gradually decreased with increasing distance, our results indicate that traffic noise continued to influence birds' responsiveness across this spatial gradient. These findings suggest that highway noise reduces both the detection of acoustic signals and the subsequent behavioral response to vocalizations, thereby potentially disrupting communication between conspecific individuals. Previous studies have reported that the direct ecological effects of roads on bird communities may extend up to 1,000 m from the road edge (Forman and Alexander 1998; Benítez-López et al. 2010). However, our results demonstrate that traffic noise significantly affected acoustic communication at least 200 m into the adjacent forest habitat. The persistence of reduced playback response probabilities within this zone indicates that road traffic noise compromises acoustic communication over ecologically meaningful spatial scales, acting as an ecological filter that influences habitat occupancy and behavioral patterns in areas adjacent to highways. Taken together, these findings demonstrate that highways represent not only physical barriers within the landscape but also functional acoustic barriers for forest birds. By reducing the probability of vocal responses in habitats adjacent to roads, traffic noise may directly affect ecological processes that depend on acoustic communication, including territory establishment, mate attraction, and the maintenance of social interactions.

Declarations

Ethics statement

Not applicable.

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Author Contribution

José Nilton da Silva (JNS): Autor principal, o qual coletou em campo todos os dados amostrados, refinou e planilhou-os, além de ter elaborado o título do manuscrito e a escrita após a compilação das ideias e contribuição dos demais autores do trabalho, sendo por todos acordado que o mesmo deveria submeter e permanecer como primeiro autor do trabalho, devido a sua substancial contribuição para que este trabalho pudesse ser concluído e escrito. Pedro Diniz (PD): Rodou as análises, além de contribuir substancialmente nas interpretações dos resultados e na discussão, teve papel fundamental no fornecimento de referencial, elaborou o layout do gráfico (figura 2) para o manuscrito. Charles Duca (CD): Auxiliou na ideia e nas coletas dos dados, além das análises estatísticas, também foi o principal fornecedor dos materiais para as coletas e auxílio nas modelagens e tabulações dos dados. Aureo Banhos (AB): auxiliou nas revisões e ideias para discussão, além de contribuir para as coletas de dados em campo e modelagem das planilhas.

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Data Availability

Predicted probability of a rapid response (≤ 1 min) by birds to playback of conspecific vocalizations as a function of habitat-edge type and distance from the habitat edge. Solid lines represent model-predicted mean probabilities, and shaded areas indicate the corresponding 95% confidence intervals (95% CI) estimated from a generalized linear mixed-effects model (GLMM).

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Figures

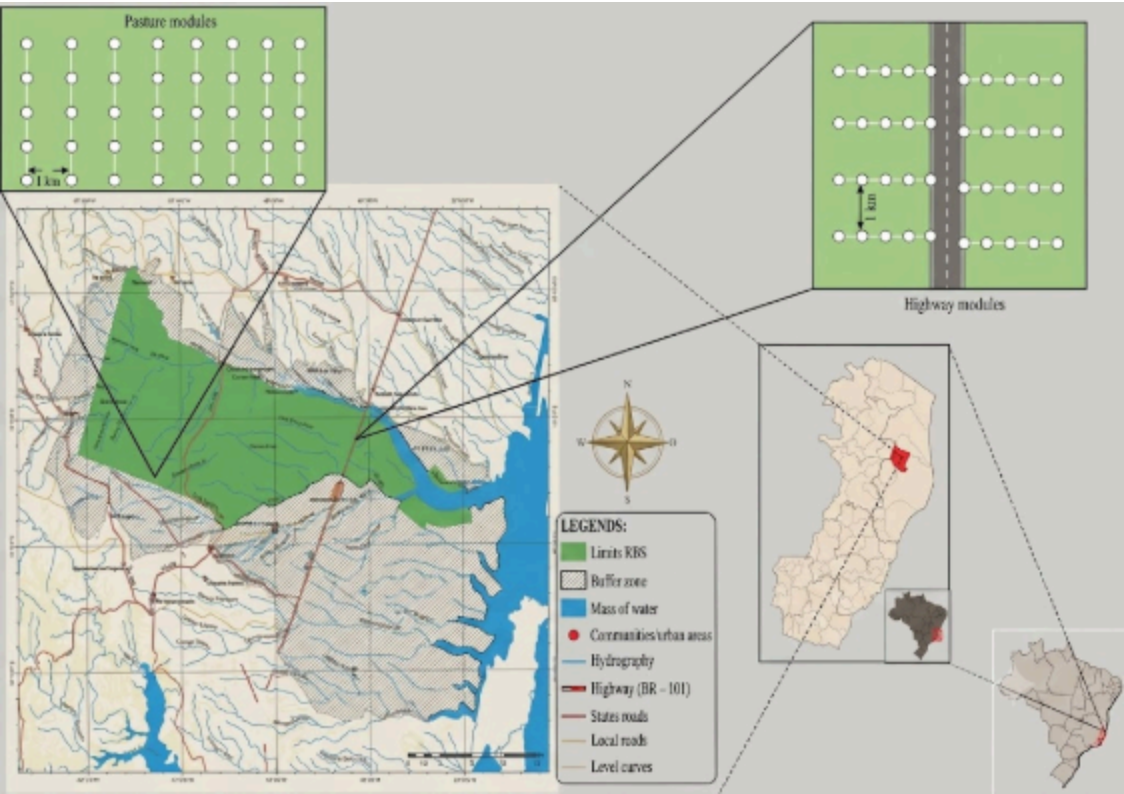


Figure 1

Study area showing the sampling design and the locations of the sampling points where field data were collected.

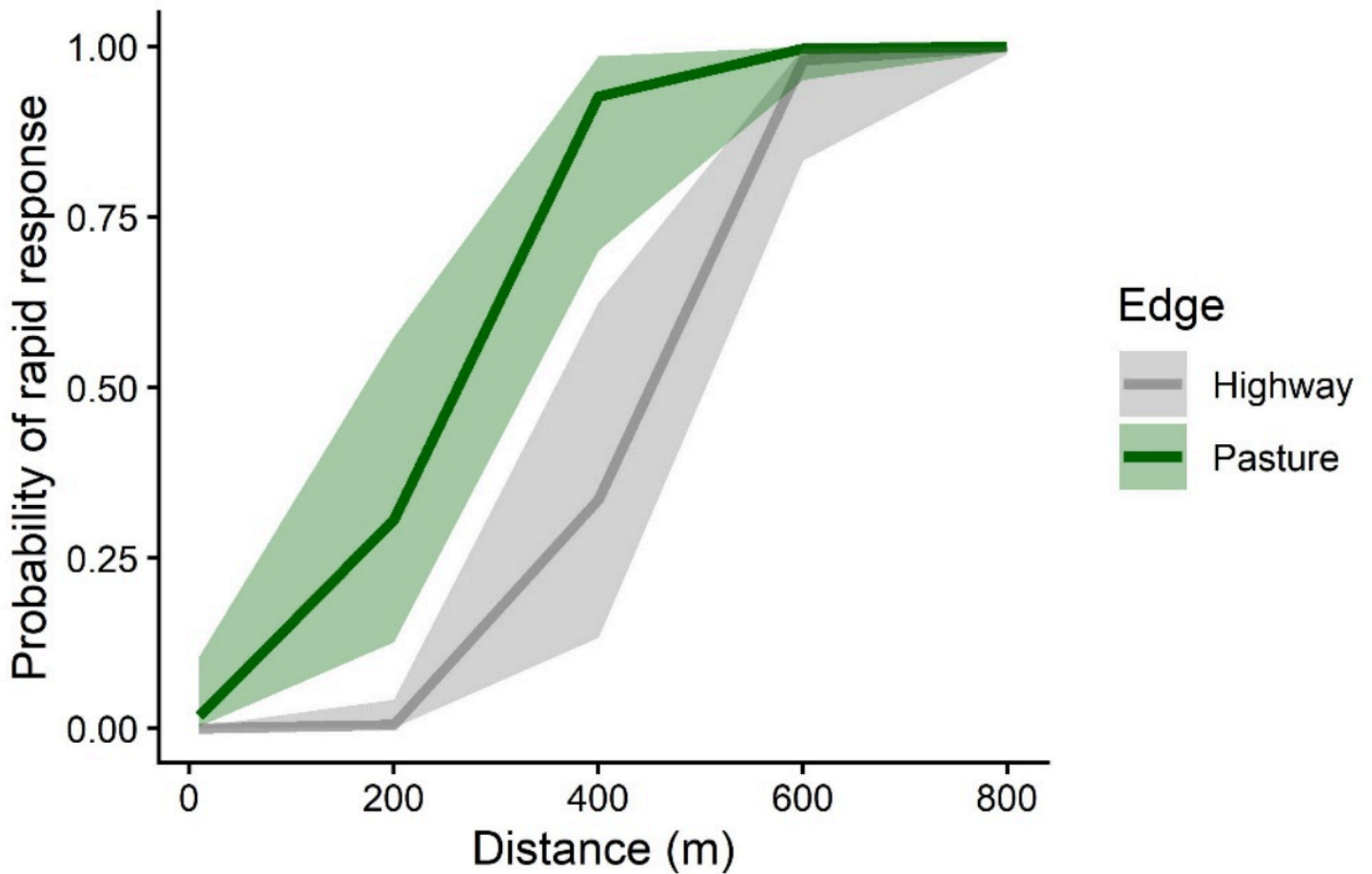


Figure 2

Predicted probability of a rapid response (≤ 1 min) by birds to playback of conspecific vocalizations as a function of habitat-edge type and distance from the habitat edge. Solid lines represent model-predicted mean probabilities, and shaded areas indicate the corresponding 95% confidence intervals (95% CI) estimated from a generalized linear mixed-effects model (GLMM).

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