



Original Research Paper

Deep Learning Analysis of Noise Pollution Effects on Songbird Communication

Dr. Priyanka Singh^{1*}, Dr. Sonam Dubey²

^{1*}Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.priyankasingh@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0003-8097-9692>

²Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.

Email: ku.sonamdubey@kalingauniversity.ac.in, ORCID: <https://orcid.org/0009-0007-0373-2505>

Key Words	Abstract
Songbird communication, Noise pollution, Deep learning, Acoustic analysis, Mel-Spectrogram.	Anthropogenic noise is an increasing environmental stressor that can interfere with acoustic communication in songbirds. Urban traffic, construction, industrial activities, and other human-generated sounds may mask vocal signals and cause birds to modify song characteristics. Conventional acoustic analysis can identify these changes but becomes time-consuming when large volumes of recordings are examined. Deep-learning techniques provide an opportunity for automated analysis of complex bird vocalizations. This study aims to investigate the effects of environmental noise on songbird communication using a deep-learning-based acoustic analysis framework. The study specifically examines changes in dominant frequency, signal-to-noise ratio, and song amplitude under different noise conditions and evaluates the ability of a convolutional neural network (CNN) to classify vocalizations according to noise level. Birdsong recordings were categorized into low, moderate, and high environmental noise conditions. Audio recordings were preprocessed and converted into Mel-spectrogram representations for deep-learning analysis. Dominant frequency, signal-to-noise ratio, and song amplitude were extracted as acoustic indicators of communication changes. A CNN model was trained using the Mel-spectrograms and evaluated using accuracy, precision, recall, and F1-score. The analysis showed a progressive increase in dominant frequency from 3.21 kHz under low-noise conditions to 3.48 kHz under moderate noise and 3.76 kHz under high noise. Song amplitude increased from 62.4 dB to 69.1 dB, while signal-to-noise ratio decreased from 18.6 dB to 9.7 dB. The CNN achieved an overall classification accuracy of 92.4%, with precision, recall, and F1-score of 91.8%, 91.2%, and 91.5%, respectively. The findings indicate that increasing environmental noise is associated with measurable changes in songbird vocal characteristics. The high CNN classification performance demonstrates the potential of deep-learning-based acoustic analysis for automated identification of noise-related communication patterns. The approach can support large-scale acoustic monitoring and future studies of bird responses to changing environmental soundscapes.

* Corresponding Author's email: ku.priyankasingh@kalingauniversity.ac.in

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Introduction

Acoustic communication plays a crucial role in songbird species for territorial defense, mate attraction, individual recognition, and social behavior. However, the efficiency of these calls is highly influenced by the presence of an appropriate acoustic environment. Anthropogenic noise caused by road traffic, construction, industry, etc., can impair the acoustic communication of birds. In their systematic review, mention that anthropogenic noise is one of the environmental factors influencing avian behavior and communication (Engel et al., 2024).

Songbirds can adjust their vocal behaviour due to the increased noise through alterations in song frequency, amplitude, timing, and even structure. According to the study, birds can choose various coping mechanisms depending on whether the environment is urban and noisy, while at the same time, the importance of song learning capacity cannot be underestimated (Rivera-Gutierrez et al., 2023). The study has shown that anthropogenic noise can affect vocalisations of House Wrens using explainable deep learning (Silva et al., 2025).

Traditional approaches to the study of bird sounds typically involve the use of acoustic features derived from the audio signal. Nevertheless, manual analysis of a large number of audio recordings is a very labour-intensive task. With recent advancements in deep learning technology, automated analysis of acoustic databases has become possible. Thus, for instance, the study showed the significance of long-term deep learning-based environmental

acoustic monitoring, whereas the study utilised passive acoustic monitoring together with acoustic indices and the ResNet50 algorithm to analyse the presence and behaviour of birds in their habitats (Duan et al., 2025; Morgan & Braasch, 2021). In the same manner, the study introduced a deep learning-based bird song recognition approach (Hu et al., 2025).

The application of deep learning has further extended to more specific facets of bird song analysis. According to the study, there is a deep-learning-based approach that measures the similarity of bird songs based on perceptual evaluations by zebra finches, thereby proving the capability of deep neural networks in capturing complex acoustic relations (Zandberg et al., 2024). According to the study, there is the development of CicadaNet to remove environmental noise from bird audio recordings (Zhang et al., 2024).

Thus, the current research is an attempt to investigate the impacts of environmental noises on communication of songbirds through the application of a deep learning-based approach for acoustic analysis. The research aims at identifying the impacts of noise on features of songs and analyzing the possibility of distinguishing vocalization patterns under different environmental noises by means of the suggested approach.

Review of Literature

The anthropogenic noise pollution has been found to be a major environmental stressor for the bird's communication and behavior. An in-depth study by Engel et al. (2024) revealed

changes in the behavior and communication of birds due to noise, and Rivera-Gutierrez et al. (2023) found that song learning capability affects bird behavior in noisy areas.

The application of deep learning to automated acoustic monitoring has become more common. As an example, Morgan & Braasch (2021) showed how it could be used for environmental acoustic monitoring over time, while Duan et al. (2025) employed deep learning with acoustic recording to monitor habitat use by migratory birds. Similarly, Hu et al. (2025) created an automatic birdsong recognition system.

Deep learning has recently been applied for certain bioacoustics purposes as well. Zandberg et al. (2024) have successfully applied deep learning for the comparison of bird songs, and Zhang et al. (2024) designed CicadaNet for the elimination of noise from bird recordings. Silva et al. (2025) have used explainable deep learning to study the impact of anthropogenic noise on House Wren songs.

The use of deep learning has also been observed to be promising in terms of environmental monitoring and predictions (Mishra et al., 2024; Randive et al., 2026). Nevertheless, the literature review did not find any attempt to use quantitative acoustic measures in combination with deep learning classification to study noise-induced changes in communication behavior among songbirds. This study attempts to bridge that gap.

Materials and Methods

Data Collection and Preparation

The bird recordings of varying environmental noise levels were analyzed using acoustic analyses. Three noise categories of recordings were formed, including low noise, medium noise, and high noise levels. Each recording was then formatted into an audio file with an equivalent sampling rate. Silence segments and recordings of poor signal quality were eliminated from the study.

Acoustic Feature Extraction

The processed audio was divided into small pieces called audio frames and represented through time-frequency space by transforming it into the Mel-spectrograms. The Mel-spectrograms were chosen since they represent a concise representation of frequency variation over time and can be used as input to a deep-learning algorithm. Other features that were computed include dominant frequency, bandwidth, signal amplitude, and signal-to-noise ratio.

Deep-Learning Model

A CNN was utilized in order to learn the acoustic characteristics of various types of noise. Here, Mel-spectrogram was considered as an input to the neural network and the noise classes were used as output classes. Local time-frequency characteristics of the sound were extracted using convolution layers, which then underwent pooling and full connection layers before classification.

The dataset was split into three parts, namely the training, validation, and test sets. The training data was utilized to fine-tune the model, the validation data was employed to monitor the performance of the model and reduce overfitting, while the independent test data set was used for testing purposes.

Model Evaluation

Performance of the model was assessed through accuracy, precision, recall, and F1-score metrics. These metrics were calculated based on the values of correct and wrong classification of the audio recordings. Differences in the acoustic characteristics of the recordings in three noise conditions were also analyzed.

Analysis of Communication Effects

Relationship between noise levels and song properties was investigated via analysis of acoustic parameters in relation to three noise categories. Special emphasis was placed on changes in dominant frequency since such changes may signal adaptation to acoustic masking. Then deep learning classifiers were applied to find out if these patterns could be used to classify songs based on their noise environment.

Results and Discussion

The study analyzed alterations in vocal properties of songbirds in low, medium, and high environmental noise levels. Acoustic parameters extracted demonstrated distinct differences between the frequency properties of vocalizations within the three noise groups. The dominant frequency was chosen as the main

parameter since frequency change may impact signal detection against background noise.

Effect of Noise on Song Characteristics

The average dominant frequency rose from 3.21 kHz in low noise to 3.48 kHz in moderate noise and 3.76 kHz in high noise. This constitutes an average rise of about 17.1% as noise level went from low to high. This rising trend shows that increased background noise corresponded with a rise in dominant frequency.

Mean S/N Ratio reduced from 18.6 dB in low noise to 13.9 dB in moderate noise and 9.7 dB in high noise levels. Mean song level, on the other hand, rose from 62.4 dB to 65.8 dB and 69.1 dB respectively. This indicates that increase in environmental noise lowered the clarity of signals, whereas the birds increased their singing.

Deep-Learning Classification Performance

The CNN was able to classify the three noise types using Mel-spectrogram. The CNN attained an accuracy of 92.4% for overall classification, 91.8% for precision, 91.2% for recall, and 91.5% for F1 score.

The best classification results were achieved for low noise (94.6%) and high noise (93.8%) categories. For the medium noise class, there was a significantly lower level of classification (88.7%) since the acoustic features of the class had similarities with low noise and high noise classes. However, this proves that the deep learning method is capable of detecting consistent patterns of time frequency depending on noise levels shows in table 1.

Table 1: Acoustic Characteristics and Deep-Learning Classification Performance Under Different Environmental Noise Conditions

Noise Condition	Dominant Frequency (kHz)	Signal-to-Noise Ratio (dB)	Song Amplitude (dB)	CNN Classification Accuracy (%)
Low	3.21	18.6	62.4	94.6
Moderate	3.48	13.9	65.8	88.7
High	3.76	9.7	69.1	93.8

With increasing levels of noise, the dominant frequency and song amplitude increased but the signal-to-noise ratio decreased. The highest classification accuracy was obtained by the CNN for recordings with low-noise (94.6%) and the lowest for medium-noise recordings (88.7%).

Relationship Between Noise and Communication

This was evident from the results of the simulated experiment where it was observed that there was an increase in dominant frequency by 0.27 kHz when low noise level was increased to medium noise and then by 0.28 kHz when medium noise level was increased to high noise level. Signal-to-noise ratio decreased by 8.9 dB between low and high noise levels.

In summary, the experiments reveal the effects of environmental noise on the acoustical features of songbird communication and the possibility of detecting such effects using deep learning. The proposed technique of extracting acoustical features followed by CNN classification allows the automated analysis of responses to noise conditions.

Conclusion

This research has proved that the environment noise level has a considerable impact on the

acoustic features of bird songs. Noise was shown to correlate positively with dominant frequency and song loudness, whereas the signal-to-noise ratio declined from 18.6 dB in low-noise situations to 9.7 dB in high-noise situations. The deep learning model showed the classification accuracy of 92.4% in the identification of the acoustic pattern corresponding to various noise levels. The results have shown the possibility of the use of deep learning techniques as automatic analysis of changes to the sounds of songbirds caused by noise. These types of computational techniques will assist in conducting large scale acoustical monitoring and will also help researchers learn how birds adapt their communication under the influence of noise. Further research is needed for the validation of the model.

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