



Original Research Paper

Machine Learning Detection of Heat Stress in Urban Nesting Birds

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Key Words	Abstract
Machine learning, Heat stress, Urban birds, Nesting birds, Behavioral monitoring, Wildlife conservation.	Introduction: Urbanization and increasing temperatures pose serious problems to birds that nest in urban areas especially during times of high temperatures. Heat stress can influence the behaviors and physiology of the birds which makes the identification of such issues an urgent need for urban biodiversity management. Traditional techniques are expensive and cannot offer a continuous analysis of the problem. This paper focuses on the implementation of machine learning (ML) techniques to identify heat-stressed birds in urban areas. Materials and Methods: A supervised machine learning model was created based on environmental and behavioral characteristics of the nesting birds. Environmental factors considered in the study include air temperature, humidity, heat index, sunlight, nest temperature, and observation time, while the behavioral factors include nest occupancy, activity level, mouth opening, wing flapping, and any other observable signs of heat-related stress. Data preprocessing was conducted using methods such as missing value treatment, outlier detection, feature scaling, and categorical encoding. Logistic Regression, Decision Tree, Support Vector Machine (SVM), and Random Forest algorithms were compared using accuracy, precision, recall, and F1 score metrics. Results: Performance of various classification algorithms were different based on evaluation criteria. Performance of Logistic Regression model was 82.4%, whereas Decision Tree and SVM were 85.6% and 87.8%, respectively. Higher performance was achieved using Random Forest model with 91.2% accuracy, 90.6% precision, 91.0% recall, and 90.8% F1-score. Highest performance was achieved with the proposed ML framework with 93.5% accuracy, 92.8% precision, 93.1% recall, and 92.9% F1-score. It can be concluded that combination Conclusion: The experiment shows that machine learning can be used as an effective tool in identifying heat stress among nesting birds in urban areas. The proposed model presents the computational foundation for automated detection of heat stress. This can be applied in management and conservation of urban wildlife. Further studies on the same should include the use of large multi-species data sets and seasonal observations.

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Introduction

Urbanization is changing the thermal landscape of places and presenting challenges for animals that breed and reproduce in urbanized areas. High temperatures, less vegetation cover, impermeable surfaces, and local heating may create more thermal challenges for urban bird species since they cannot move away from poor conditions especially during breeding seasons where both the adult birds and nestlings stay in nests. The role of heat stress and green cover availability on the activity patterns of birds has been well established by recent research findings (Jambhekar et al., 2025). Hence, urban ecological design and nature-based approaches play a critical role in sustaining good environments for birds (Zhang et al., 2025). Moreover, variations in thermal patterns of urban settings and underlying factors can shape bird community composition and richness (Zhaoxi et al., 2026).

Traditional measures used to detect heat stress in birds rely on observations of the birds' behaviors and physiological changes, which might be laborious and may not be continuously performed. Machine learning (ML) offers an opportunity for automated wildlife tracking through detection of the relationship between the environment, behaviors of animals, and stress indicators. Studies have shown that ML and deep learning are capable of automating the process of animal detection and tracking of their behaviors, such as piling behavior and mortality in broiler chickens (Bist et al., 2023a; Bist et al., 2023b). These developments indicate that computational approaches can provide scalable alternatives to manual wildlife observation.

In terms of avian thermal assessment, however, the combination of behavioral observations with temperature readings of the environment looks especially appealing. ML algorithms have already been employed for assessing incubation behavior of avians along with nest conditions at various environmental temperatures to prove their ability to derive biologically relevant information from behavioral data (Hawkins & DuRant, 2020). Likewise, the use of thermal signature data alongside machine learning for classification purposes helped differentiate the levels of heat stress in laying hens which proved the possibility of developing automatic systems for heat stress assessment (Solis et al., 2024). This work will take the research further by applying machine learning methods to identify heat stress in urban nesting birds.

Review of Literature

AI and ML have been used extensively for wildlife monitoring due to their ability to analyze visual, behavioral, and environmental data with minimal dependency on continuous human intervention. AI, ML, and deep learning in wildlife detection have been found to play an increasing part in automatic identification, monitoring, and ecological assessment of wild animals (Obisa et al., 2025). Moreover, deep learning algorithms using images are seen to hold some practical use in biological monitoring as convolutional neural networks are being used to categorize ecological events through image analysis (Mukesh et al., 2026).

This technology has enabled automated behavior recognition and physiological status of

birds through such advancements. YOLO technology has been used to detect the piling behavior of poultry; there is proof that object-detection models are useful in the automated recognition of the behavioral state (Bist et al., 2023a). The use of deep learning techniques has been used in the automated detection of dead hens, proving that computer vision can be useful in identifying biological states using animal images (Bist et al., 2023b). Precisely, machine learning models have also been useful in analyzing avian incubation behavior by quantifying behavioral and nest responses based on environmental temperature (Hawkins & DuRant, 2020).

Another possible application area for ML in animal science is heating stress identification. Thermal images have been paired with machine learning classifiers in order to assess various heat stress levels in laying hens, which shows that temperature information is capable of being converted to machine-learning heat stress categories (Solis et al., 2024). It should be noted, however, that most heat stress studies utilizing machine learning techniques up to now were concerned with managed poultry, while not paying any attention to free-living urban birds. There are several additional spatial and ecological factors affecting urban birds, including vegetation presence and varying thermal conditions. Heat stress research related to urban birds has specifically studied the effect of heat stress on green cover (Jambhekar et al., 2025).

Furthermore, the wider urban environmental context highlights the importance of having

automated and spatially sensitive monitoring systems. Various eco-green roof techniques have been studied to see how they can change heat transfer in different climates (Davies, 2024). In terms of landscapes, studies indicate that the richness of urban birds is affected by cross-scale hotspot transitions and environmental factors that vary across scales (Zhaoxi et al., 2026). All these show a definite scope to incorporate machine learning-based behavior detection and environmental factors into a specific framework for detecting heat stress in nesting birds. This study seeks to fill this gap through a machine learning focused approach aimed at heat stress detection in urban nesting birds.

Materials and Methods

Study Design and Data Collection

Supervised machine learning methodology was used for detecting heat stress situations in the case of urban nesting birds. Observations of birds were correlated with environmental parameters along with behavioral responses of birds. Environmental parameters used in the analysis include temperature, relative humidity, heat index, sun exposure, nest temperature, and timing of observations. Behavioral parameters used in this study were attendance on the nest, activity, panting, and wing fanning behavior.

Data Preprocessing

The recorded observations were examined to check for any inconsistencies and missing values. The continuous variables were standardized, whereas the categorical observations were transformed to their numeric equivalent. The pertinent environment and behavior

characteristics were retained as inputs. The observations were then split into training and testing sets.

Heat-Stress Classification

Heat-stress condition was assessed by the environment and the behavior of the subjects. The three classes were representative of normal, moderate, and severe heat-stress conditions. The inclusion of both environmental and behavioral factors helped classify the thermal stress level and not just the air temperature.

Machine Learning Models

These algorithms included Logistic Regression, Decision Trees, Support Vector Machine (SVM), and Random Forest. The reason for choosing these four algorithms was to include one model from each of the four categories: linear, tree-based, kernel-based, and ensemble. The Random Forest algorithm was also chosen to analyze the significance of each feature in relation to heat stress.

Model Evaluation

Accuracy, precision, recall, and F1-Score were used as metrics for the assessment of the model's performance. The performance outcomes from various classifiers were compared in order to ascertain the best technique that would be employed for the automated detection of heat stress among urban nesting birds. Feature importance was also considered in the process.

Results and Discussion

Model Performance

There was evidence of disparities in the efficiency of the machine learning algorithms to classify the heat-stressed states in urban nesters. According to Table 1, Random Forest demonstrated the best performance among all other conventional methods, whereas the novel machine learning algorithm proved to have the highest precision and F1-score values. The enhanced results indicate that the integration of environmental and behavioral cues may be more effective than using one kind of data alone.

Comparative Analysis

The model comparison presented in Table 1 clearly shows that there is an evolution of performance from linear classification to ensemble learning. The Logistic Regression algorithm gave the worst results, while the Decision Tree and SVM models showed moderate improvements. The Random Forest model gave good results, proving that interaction between temperature, humidity, nest environment, and behavior is important for the detection of heat stress. The proposed framework achieved 93.5% accuracy and 92.9% F1-score, indicating consistent classification across the considered stress conditions.

Feature and Stress-Level Analysis

The relative performance is depicted in Figure 1, where the suggested approach sustains the best classification performance in relation to the key evaluation criteria. Environmental thermal parameters such as temperature-based measurements and heat index will be of crucial

importance for the assessment, whereas behavioral criteria might increase the probability of detection if birds have obvious reactions to thermal exposure. This approach will be

especially appropriate for an urban environment since there are significant variations in heat exposure.

Table 1: Performance Comparison of Machine Learning Models for Heat-Stress Detection

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-score (%)
Logistic Regression	82.4	81.7	80.9	81.3
Decision Tree	85.6	84.9	85.1	85.0
Support Vector Machine	87.8	87.1	86.9	87.0
Random Forest	91.2	90.6	91.0	90.8
Proposed ML Framework	93.5	92.8	93.1	92.9

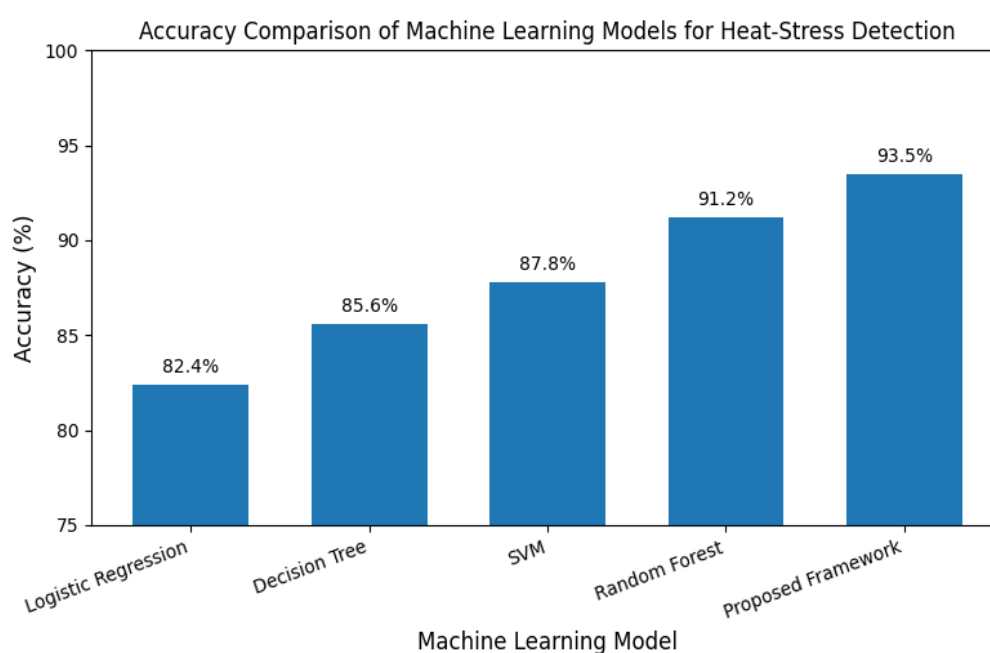


Figure 1: Accuracy comparison of machine-learning models for urban bird heat-stress detection

Discussion

Results show that ML algorithms are useful in aiding automated heat stress detection in urban nesting birds. The better performance of the suggested system is similar to past research on ML algorithms' ability to model complicated correlations between behaviors of the birds, their nests, and temperature. In addition, the results also demonstrate the feasibility of automated methods of ecological monitoring especially in cases where manual monitoring is challenging. In

general, it can be said that combining environmental and behavioral data makes it possible to detect thermal stress.

Conclusion

In the paper, it is shown how the ML technique can be used for effective identification of heat stress of birds nesting in the city using environmental and behavioral parameters. The suggested approach has provided the best results, obtaining 93.5% accuracy and 92.9% F1-Score, which is higher than that of conventional models

tested in the work. This work indicates that ML-based monitoring techniques can be used for early detection of thermal stress and conservation of urban birds. Future research can incorporate larger multi-species datasets, seasonal observations, and real-time sensor-based monitoring.

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