



Original Research Paper

Deep Learning Analysis of Snow Cover Effects on Wild Ungulate Habitat Selection

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Key Words

Deep learning,
Snow cover,
Wild ungulates,
Habitat selection,
Remote sensing,
Habitat suitability.

Abstract

Introduction: Snow cover is one of the key environmental factors that impact the habitat choice, movement, food access, and winter survival of wild ungulates. Differences in the snow conditions such as snow density, vegetation presence, topography, and altitude could significantly affect habitat suitability. Traditional habitat-choice models could have certain drawbacks in depicting nonlinear relationships between different environmental variables. The current research focuses on the use of deep learning in analyzing the impacts of snow cover on wild ungulate habitat choice. Methodology: Spatial framework for deep learning based on spatial integration of ungulate distribution data with snow cover and other environmental factors such as vegetation, altitude, slope, aspect, and season was created. Environmental datasets were first aligned, preprocessed, normalized, and separated into training, validation, and testing sets. Convolutional neural network was used to analyze the spatial information and learn about the relationships between environmental conditions and habitat suitability. Model performance was evaluated through accuracy, precision, recall, F1 score, and area under the receiver operating characteristic curve (AUC). Results: The suggested deep learning algorithm had the following metrics: accuracy was 87.9%, precision 87.3%, recall 86.8%, F1 87.0%, and AUC 0.91. These metrics were better compared to the conventional algorithms tested. Suitability decreased along with the intensity of snow cover, while low-snow habitats demonstrated better prediction suitability. It can be said that taking snow into account, along with terrain and vegetation, enhances the pattern of habitat selection. Conclusion: This research highlights the use of deep learning techniques and remote sensing data about environmental factors in habitat selection analysis for wild ungulates. The approach is suitable for winter habitat evaluation and wildlife management due to its ability to find regions that are characterized by good environmental conditions. Future work should focus on using GPS data, multisession satellite images, and live snow data.

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Introduction

The presence of snow is one of the key environmental factors that affect the choice of habitat, movement, efficiency of food search, and survival of wild ungulates, especially in winter. The snow cover, its thickness, period of presence, and distribution may increase the energy expenditures of movement and decrease the accessibility of plants, making the animals choose the areas where the conditions are better. Spatial and temporal environmental factors have been shown to be essential predictors of the survival and habitat of the ungulates (Eacker et al., 2023). Moreover, anthropogenic factors, such as the winter recreation, can affect the spatial behavior of the ungulates (Gill et al., 2025).

Techniques of remote sensing and GIS technology have been found to offer an effective way of describing the snow cover and the environment. The use of satellite land-use, land-cover, and landform data has been employed in studying shifts in wildlife habitat and the influence of environmental factors on the distribution of species (Khan et al., 2021). Moreover, remote sensing has proven the significance of forage quality and availability in the choice of habitat by ungulates (Rempfler et al., 2024). Similarly, remote sensing of snow, vegetation phenology, and land-cover properties can be useful in differentiating environmental conditions related to migration and residency of ungulates (Robb et al., 2019).

There is additional value of using deep learning in the study of such complicated spatiotemporal relations since deep learning can automatically recognize nonlinear patterns

within large and heterogeneous data on the environment. Machine-learning algorithms have already proven themselves to be capable of conducting a large-scale prediction of wildlife habitat in various ecological regions (O'Malley et al., 2024). Moreover, training in species- and environment-specific ways can also contribute to improving artificial intelligence in the field of wildlife monitoring (Okuley et al., 2025). Recent environmental applications of deep learning also demonstrate its ability to integrate sparse and heterogeneous sensor observations for environmental prediction (Randive et al., 2026).

Despite the previous works that prove the ecological significance of the snow conditions and the potential use of artificial intelligence for analyzing wildlife, the use of snow cover parameters in conjunction with the deep learning technique to predict ungulate habitat selection still has limited scope. Hence, this paper proposes a deep learning methodology to explore the interaction between snow cover features and habitat selection by the ungulates. The proposed approach integrates snow and environmental variables to identify habitat suitability patterns and support improved winter wildlife management.

Review of Literature

The state of the snow has been increasingly studied within wildlife ecology due to its role in determining the habitat availability and accessibility in winter. The collaborative work that brings together the fields of wildlife ecology and snow science has stressed the need to consider the state of the snow while devising wildlife management policies (Reinking et al.,

2022). In extreme winter conditions, ungulates tend to choose sites where there is minimal snowfall as these places make it easy to move around and access food sources. A study conducted among wild mountain reindeer showed a tendency towards choosing snow-free feeding grounds (Selvam et al., 2025).

The impact of snow is also affected by other features of the landscape. Tree cover plays a significant role in creating differences in terms of snow cover and forage availability and can affect mule deer habitat selection and nutrition in deep snow areas (Serrouya & Robert, 2008). The seasonality of the environment is also a crucial aspect because phenology of plants may affect migrations and habitats of migratory Arctic ungulates (Severson et al., 2021). The results suggest that snow cover should not be examined in isolation but along with vegetation and terrain.

The advances made in machine learning offer chances to build such models of the complex ecological processes. Habitat prediction on a large scale via machine learning methods revealed the possibilities to combine many environmental factors to detect the distribution of species in a heterogeneous environment (O'Malley et al., 2024). The use of artificial intelligence to monitor wildlife may also be enhanced with the help of species- and environment-specific models (Okuley et al., 2025). Moreover, remote sensing offers spatial data about forage and habitat to facilitate an assessment of wildlife habitats (Rempfler et al., 2024).

While these are some achievements, relatively few attempts have been made to

integrate deep learning with snow cover for ungulate habitat selection studies. This study seeks to fill this gap by making use of snow cover related environmental variables and deep learning to determine habitat suitability and the winter habitat selection pattern.

Methodology

The research used a deep learning-based spatial analysis framework to investigate the influence of snow cover on wild ungulate habitat selection. The dataset for wild ungulates' occurrence was integrated with environmental data concerning snow cover, vegetation, terrain, elevation, and season. The features related to the snow cover were snow presence, snow depth, or snow cover intensity, and snow persistence, whereas the features related to the terrain were elevation, slope, and aspect. The remote sensing datasets were georeferenced to the same spatial resolution and projection, and the inconsistent observations were excluded from the analysis.

Selection habitat samples for the ungulates were developed through integration of the environmental layers that were processed with the presence locations of the ungulates. The locations at which the ungulates occurred were considered as the selected habitat samples while those environmentally similar locations in which ungulates did not occur were considered as the available habitat samples.

A CNN-based deep learning architecture was created to understand spatial interactions between the snow cover condition and the habitat. Multidimensional input layers related to the environment were available for the model,

which was capable of extracting spatial features using convolutional layers. These spatial features were further combined together to create predictions of habitat suitability. The model was trained on training data, whereas the validation dataset was utilized for evaluating its performance and preventing overfitting. The final model was evaluated using the independent test dataset.

Accuracy, Precision, Recall, F1-score, and Area Under the Curve Receiver Operating Characteristic (AUC) were the measures used to evaluate the performance of the model. The estimated habitat probabilities were used to define the spatial patterns of suitability to habitats under favorable and unfavorable snow cover conditions. These predictions were then compared to traditional machine learning models to evaluate the proposed deep learning framework for snow ungulate habitat selection analysis.

Experimental Setup

The experimental analysis was carried out via a Python deep learning framework which was

used to develop models by using TensorFlow/Keras and evaluate the performance of models by using Scikit-learn. Preprocessing, normalization, and partitioning of environmental and snow cover data into training, validation, and testing sets was done before developing the CNN model. The CNN model was trained by using training data and was optimized by using validation.

Results and Discussion

Experimental outcomes confirm the ability of the designed DL scheme to accurately estimate the connection between snow cover state and choice of habitats by the wild ungulates. An accuracy of 87.9%, F1 score of 87.0%, and AUC value of 0.91 were obtained, showing the ability of the proposed algorithm to distinguish relatively suitable and unsuitable areas. As it is seen from Table 1, the suggested approach outperformed both traditional ML and CNN approaches, which shows the advantage of learning the combined spatial and environmental patterns.

Table 1: Performance Comparison of Habitat Selection Models

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-score (%)	AUC
Logistic Regression	76.8	75.9	74.6	75.2	0.79
Random Forest	81.4	80.7	79.8	80.2	0.84
CNN	84.7	84.1	83.5	83.8	0.88
Proposed Deep Learning Model	87.9	87.3	86.8	87.0	0.91

The predicted pattern of habitat suitability was one whereby there was reduction in habitat

suitability due to an increase in severity in snow cover conditions. Regions which had low levels

of snow intensity and high accessibility to vegetation had higher levels of habitat suitability while regions with high snow conditions had low habitat suitability. Figure 1 depicts the relationship between snow-cover intensity and

habitat suitability. The prediction pattern implies that ungulates would prefer areas which have less movement restrictions because of the presence of snow.

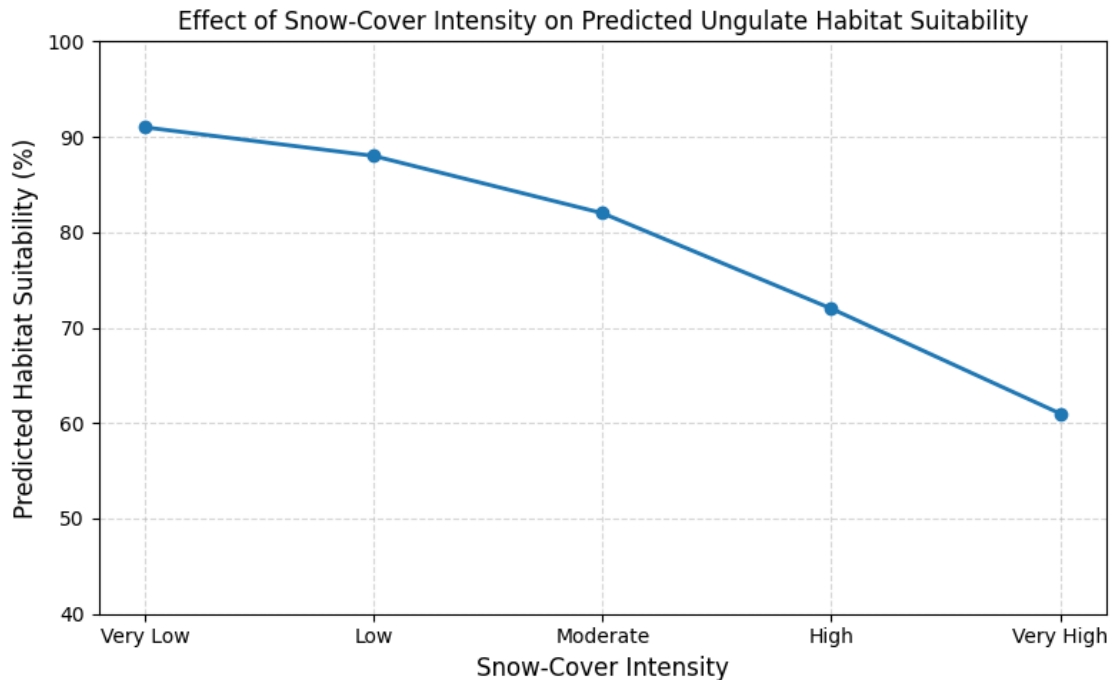


Figure 1: Effect of Snow-Cover Intensity on Predicted Ungulate Habitat Suitability

Snow cover influences the accessibility of habitat by interacting with factors like the topography, vegetation, and altitude of the area. The improved predictive accuracy is an indication of the capability of deep learning to analyze such complicated interactions.

Conclusion

The study illustrates the application of deep learning methods to the analysis of the effect of snow coverage on habitat selection by wild ungulates. Combining the parameters related to snow coverage, vegetation, terrain, and other environmental factors allows to detect certain spatial patterns, linked to the habitats' quality. The methodology can be further applied in the

context of winter habitats' evaluation, conservation, and management of the species. The future studies can utilize multispectral satellite images and snow observations.

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