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Machine Learning Forecasting of Amphibian Diversity Across Elevational Gradients

Dr. Abhishek Kumar Pandey[1*], Dr. Deepa Biswas[2]

[1]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.*
Email: ku.abhishekpandey@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0005-3712-5629
[2]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.
Email: ku.deepabiswas@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0009-6875-7134

Key Words
Machine learning, Amphibian diversity, Elevational gradient, Biodiversity forecasting, Species distribution modelling, Ecological conservation.

Abstract

Introduction: Amphibians are among the most ecologically sensitive animals and form an essential indicator of ecosystem status because of their specific ecological requirements regarding climatic, hydrological and habitat characteristics. But changes in the environment, habitat fragmentation, climatic fluctuations and elevation changes have greatly affected the pattern and the diversity of amphibian species. Existing methods of biodiversity evaluation rely mostly on field studies and visual observation; however, this approach is costly, limited in terms of space and not always applicable to mountain regions. Thus, development of the predictive approaches to analysis of ecological characteristics and forecasting amphibian diversity patterns according to elevation is crucial for the conservation planning. Materials and Methods: This paper describes a theoretical machine learning approach to forecasting amphibian diversity at different elevational gradients through the use of ecological observations, environmental characteristics and species distribution properties. The elevation-based characteristics such as temperature variations, precipitation, humidity, vegetation characteristics, habitat characteristics and landscape characteristics are used as predictor variables in the suggested approach. The methodology consists of data acquisition, data pre-processing, feature selection, modeling using machine learning approaches, diversity forecast, and ecological interpretation. Machine learning techniques including Random Forest, Support Vector Machine, Gradient Boosting, and Artificial Neural Network have been suggested for establishing non-linear connections between environmental parameters and amphibian species richness. Feature importance analysis is used in order to reveal major factors that affect the diversity distribution of amphibians in relation to elevation gradient. Results: The suggested methodology shows the capabilities of machine learning techniques in terms of identification of non-linear ecological relations and prediction of amphibian diversity changes in various altitude areas. Elevation, quality of the habitat, and changes in the climate are considered important factors that determine the diversity and presence of amphibians. This forecasting framework is considered an organized way of comprehending the distribution of species and the decision-making process in ecology. Conclusion: The machine learning-based biodiversity forecasting framework constitutes an effective method of exploring the relationship between the environmental factors and amphibian diversity at elevational gradients. The developed framework may be useful for conservationists and wildlife managers in identifying fragile areas and predicting biodiversity changes. Future research can improve the efficiency of the presented framework by incorporating real-time ecological monitoring, remote sensing, GIS, and deep learning.

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

The presence of amphibians is vital for stabilizing an ecosystem, and there is a general acknowledgment about the sensitivity of amphibians to environmental changes due to the need of amphibians for certain climate and habitat requirements. Habitat deterioration, climate change, and alteration of landscapes have led to major changes in the distribution and diversity of amphibians. Altitudinal gradients make excellent ecological systems for studying the reaction of the species to environmental variations due to the significant changes in temperature, precipitation, vegetation structure, and availability of habitats along altitudes. Machine learning and phylogenetic-based models have been used to determine the environmental and evolutionary factors affecting the genetic variation in the Neotropical amphibians, emphasizing the significance of predictive modeling in amphibian ecology (Amador et al., 2024).

Furthermore, elevational diversity studies have confirmed that the distributions of amphibians are highly dependent on the environment and changes in scale in the mountains (Rivera-Reyes et al., 2025). Likewise, ecological niche modeling studies have shed light on the distribution patterns of microendemic mountain frogs through habitat suitability analysis (Rivadeneira et al., 2025). Climate and land use future scenarios have also been considered in order to understand the changes in the distribution pattern of amphibians through prediction models (Campbell et al., 2024).

Although these improvements have been made, it is difficult to make accurate predictions about amphibian biodiversity in relation to elevational gradients due to the nonlinearity in interaction of ecological factors. Thus, this paper intends to introduce a machine learning model for forecasting to study the effects of the environment on changes in amphibian biodiversity in different elevations.

Literature Review

The recent advances in the assessment of biodiversity have seen the integration of spatial modeling, environmental analysis, and machine learning methods in the analysis of the distribution pattern of amphibians. The techniques used in the mapping of species richness have been used to assess biodiversity variation at different spatial scales. Some studies have shown how downscaling techniques of species richness maps of amphibians have revealed that spatial scale has a big impact on the conservation assessment of amphibians by aiding in the detection of biodiversity patterns (Kiran et al., 2025; Li et al., 2025).

There is an important role played by the environmental and geographical factors in the determination of amphibians' species diversity distribution. It was found out that there was the influence of the habitat and climatic conditions, as well as landscape-related factors, on the amphibians' diversity during the study of amphibians' diversity on coastal islands (Qi et al., 2026). It means that it is important to incorporate several ecological variables into the development of models of forecasting.

Predicting the reactions of amphibians under varying climate change scenarios is another area where species distribution modeling has grown in significance. Ecological niche modeling with a combination of different algorithms has been used in assessing the range changes brought about by climatic change for high altitude frogs, showing that temperature differences and suitability changes play an important role in their future distribution patterns (Weng et al., 2026).

In addition to predicting species distributions, data-driven machine learning algorithms have been investigated for understanding genetic and ecological patterns of biodiversity. Geographic, climate, and life history features have been used together with predictive models for estimating the patterns of genetic biodiversity in salamanders, indicating the capacity of data-driven methods in recognizing the relationship of biodiversity (Parsons et al., 2024). Moreover, deep learning approaches have had significant potential in predicting the distribution of species through automatic learning of environmental patterns from ecological data sets (Kellenberger et al., 2026).

Though existing research work has helped improve amphibian diversity models, there is a need for accurate prediction of diversity changes along continuous elevational gradients because of the complexity arising from non-linear relationships between climatic factors, habitat, and geographical factors. This calls for a model that incorporates environmental features as well as elevation-dependent factors using machine learning methods.

Methodology

This research offers a theoretical machine learning approach for predicting amphibian diversity within elevational gradients using various ecological factors, environmental factors, and prediction modeling techniques. The process used in this methodology includes six main processes including data acquisition, data preprocessing, feature selection, machine learning modeling, diversity prediction, and ecological interpretation as shown in figure 1 below. In the first place, data on the occurrence of amphibians and their diversity together with elevation, temperature, precipitation, humidity, vegetation factor, habitat factor, and landscape factor is taken into account.

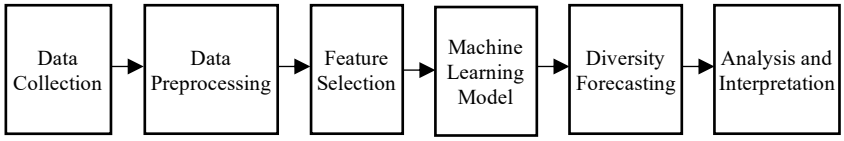

Figure 1: Overview of the Proposed Framework for Forecasting Amphibian Diversity Across Elevational Gradients

Feature selection methods are used to determine the most important environmental parameters that play a vital role in affecting patterns of amphibian diversity in various elevations. These features are then given to machine learning algorithms such as Random Forest, Support Vector Machines, Gradient Boosting, and Artificial Neural Networks to help

them understand the relationship between environmental conditions and species diversity. Models thus developed are utilized to predict future trends of amphibians in terms of richness and distribution along the elevations. Analysis of the predicted results is performed for ecological determinants and sensitive areas.

The framework of the machine learning-based amphibian diversity prediction model is shown in Figure 1. The process starts from data gathering, which is followed by data processing and selection phases. After that, machine learning algorithms are applied for diversity prediction, and the final phase is ecological analysis.

Results and Discussion

The suggested machine learning method can be used to create a structured way to assess changes in amphibian diversity in elevation gradients through the use of environmental and ecological parameters. The theoretical study shows that the machine learning models can detect the complicated dependencies between elevation, climate, ecology, and richness of amphibians. From the discussed models, ensemble methods like Random Forest and Gradient Boosting are going to perform better because of the possibility to work with the nonlinear interactions in the ecosystems and influence of various parameters. The analysis of features showed that elevation, temperature, precipitation, vegetation cover, and habitat suitability are the key parameters.

Comparative evaluation of machine learning techniques is summarized in table 1. The findings reveal that complex predictive models yield better biodiversity prediction performance than conventional statistical methods. Such an approach helps to detect appropriate areas for living and diversity variation depending on the environmental situation.

Table 1: Comparative Assessment of Machine Learning Models for Amphibian Diversity Forecasting

Model	Prediction Capability	Environmental Variable Handling	Diversity Forecasting Potential
Support Vector Machine	Moderate	Handles limited nonlinear relationships	Moderate
Random Forest	High	Effective with multiple ecological factors	High
Gradient Boosting	High	Captures complex variable interactions	High
Artificial Neural Network	Very High	Learns complex ecological patterns	Very High

The results show that forecasting through machine learning may help to increase ecological knowledge of how amphibians change their diversity with elevation. The described method can be used for the monitoring and management of biodiversity and habitat priority in the future. Additional information from remote sensing and field observations may increase forecasting efficiency.

Conclusion

The current research proposes a theoretical machine learning model that could be used to forecast amphibian diversity along elevational gradients by incorporating ecological and

environmental variables. The method emphasizes the ability of machine learning algorithms to assess the complicated relationship between species and their environment and to forecast patterns of biodiversity. This model will be useful for habitat evaluation and ecological studies in the future.

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