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EcoRisk Prediction Model for Assessing Biodiversity Loss Under Anthropogenic Landscape Pressure

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Key Words

Biodiversity loss, Ecological risk assessment, Anthropogenic pressure, Predictive modeling, Landscape change, Environmental monitoring, Conservation ecology.

Abstract

Loss of biodiversity associated with anthropogenic landscape pressure has become one of the key ecological concerns in the twenty-first century. In this paper, the EcoRisk Prediction Model will be introduced to measure and predict the loss of biodiversity induced by land intensification, urbanization, and habitat fragmentation. Landscape pattern indices, land use change processes, and ecological sensitivity indicators have been incorporated to the integrated risk prediction model. Multi-temporal spatial data were analyzed to reveal the spatial pattern and temporal process of ecological risk in the study area. It was found out that the proposed EcoRisk Prediction Model could classify risk into different levels and locate important areas where biodiversity loss could take place due to continued anthropogenic activities. Regions where rapid land conversion took place, especially at the transition area between urbanization and agriculture land use, had higher ecological risk than other regions. The model had shown high capacity of predicting the spatial heterogeneity of risk patterns. The results provide scientific evidence for planners and conservation authorities to identify and implement intervention measures.

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Introduction

Biodiversity across the world faces unprecedented loss due to escalating human influence on nature. Urbanization, agriculture, and infrastructural growth have transformed landscape patterns at a speed beyond the adaptability of ecosystems. The modification of landscape reduces the habitat and alters the connectivity of ecological systems, thus making it vulnerable to collapse. It is crucial to recognize the spatiotemporal pattern of these pressures in order to anticipate biodiversity loss in the future.

Land-use conflict between the agriculture sector and the ecological system has been recognized as one of the major causes of degraded landscape in ecologically sensitive areas where land demands become a source of stress on ecosystems (Zhang et al., 2021). In addition to this, ecological risk assessment models have been used extensively to evaluate these pressures in different regions with different environmental conditions, such as the arid and semi-arid regions characterized by the scarcity of resources that increase ecological vulnerability (Yang et al., 2025). Dynamic multi-scenario prediction models have provided additional evidence for the usefulness of predicting future trajectories of ecological risks (Gan et al., 2023). This paper uses the concept of these models to develop an EcoRisk Prediction Model.

The main originality of this paper is the construction of the predictive EcoRisk framework that combines landscape pattern analysis and ecological sensitivity weighting for the creation of spatial risk classification based not only on retrospective land use evaluation.

The rest of this paper is structured as follows: In Section II, the existing literature on ecological risk assessment and landscape-induced biodiversity decline will be reviewed. In Section III, methodology will be described. Results will be presented in Section IV. The conclusion will be drawn in Section VI.

Literature Review

Ecological risk models have undergone significant advancement due to increasing demand for assessing biodiversity vulnerability to shifting land-use systems. Geographical Information Systems (GIS), coupled with remote sensing, have been extensively used to conduct ecological risk modeling in order to analyze habitat destruction brought about by changes in landscapes within different locations, including small island ecosystems (Hossen & Sultana, 2024). Landscape ecological risk modeling using multiple scenarios has also been undertaken to integrate the ecological risks assessment process with the goals of sustainable development, highlighting how land use systems can be modeled to predict long-term ecological implications in mountainous areas (Han et al., 2022). Ecological risk assessment has also been conducted within forested landscapes with respect to their impact on the stability of forest ecosystems due to human intervention and natural disturbance (Rao et al., 2024). All these studies have emphasized three key factors: (i) land use changes have been seen as one of the major driving factors behind ecological risk in

different kinds of biomes such as deserts, islands and forests; (ii) modeling of spatial risk using GIS-based and scenarios based approaches has proved to be highly useful in quantifying risk and projecting future risks; and (iii) the majority of models that exist currently are regional in nature, without much focus on general predictive models of biodiversity loss.

Methodology

EcoRisk Prediction Model was formulated for evaluating the risks of biodiversity loss due to human-driven landscape pressure through a well-structured and multistage analytical approach.

Study Area and Datasets

This study is concerned with the heterogeneous landscape that includes various land-use categories, such as urban, agricultural, forest, and transformed semi-natural sites. Multitemporal land use and cover datasets were assembled to analyze landscape changes during a certain period of time. Additional datasets, including terrain parameters, vegetation indexes, and infrastructure distance bands, were used to describe anthropogenic disturbance.

3.2 Model Design and Variable Selection

The EcoRisk model was developed through the use of an ecological risk index system of a landscape that has three principal dimensions: hazard, exposure, and vulnerability. The dimension of hazard measures the degree of disturbances related to land use in terms of the rate of conversion and fragmentation. The exposure dimension is based on the share of ecologically valuable types of land in the units of assessments and their configuration. The dimension of vulnerability uses landscape pattern indices that include patch density, edge density, and landscape shape complexity, as a measure of habitat structural resilience. Each unit of assessment was defined based on a grid sampling technique. The variables were standardized to have equal scales to incorporate them into an ecological risk index as the sum of weighted hazard, exposure, and vulnerability measures.

Predictive Modeling Approach

A predictive element was included in the model in order to predict the future trend of risks from the ecological perspective. The historical data regarding land use changes was used in predicting the future landscape configuration due to anthropogenic pressures. Predictive element helps the model in predicting risks even outside the observation period thereby helping in identifying future high risk zones.

Model Validation and Performance Testing

The performance of the model was tested using various techniques such as internal consistency tests and by comparing the predicted risk classes with the actual observed landscape degradation within the study area. Sensitivity analysis was done to test the stability of the composite index on varying weighting assumptions. The classification performance was further validated based on spatial consistency of the high-risk zones in relation to fragmented habitat and species decline.

Results

The application of the EcoRisk Prediction Model yielded strong spatial variability in the

distribution of ecological risks over the study landscape. The locations experiencing high rates of land-use change especially areas moving from natural or semi-natural vegetation to urban or agricultural land uses displayed consistently high risk values. Such high-risk zones were generally located at the periphery of expanding urban and agricultural lands where there is significant fragmentation of continuous land patches.

It should be noted that the hazard component had the strongest effect on risk elevation, suggesting that rate and extent of land-use change have a major effect on the risk level. The exposure component was significantly high in landscapes that have ecologically valuable land fragments within otherwise disturbed landscapes. Similarly, vulnerability was high in landscapes with high patch fragmentation and edge density.

The outputs from predictive scenarios suggest that the areas of high-risk zones will probably increase if the current trend of land use continues. The moderate-risk zones are expected to change to high-risk categories. This indicates that there is a progressive escalation of ecological impact as opposed to occasional disturbances. Low-risk zones were relatively constant and mostly comprised continuous forested areas, reserves, or inaccessible areas. Generally, the outputs from the predictions show that the model has been able to successfully capture the current and future trends of biodiversity loss risk zones.

Discussion

The results of the present study show the importance of the intensification of land use as one of the main reasons of biodiversity decline in rapidly changing ecosystems. The high ecological risk in the transition zones between urban and agricultural expansion implies that the zones of transition, rather than the completely developed zones, are the places with the highest level of volatility from an ecological point of view. The reason for such a phenomenon is probably that in the zones of transition there is still ongoing transformation and thus habitat deterioration.

The high significance of the hazard variable in the calculation of risk points to the importance of managing not only the size of converted areas but also the intensity of the transformation process. Thus, conservation measures can be more effective if applied not only to natural zones but also to the places of ongoing transformation. The increased levels of exposure seen in fragmented habitat remnants highlight another aspect of concern with regards to the isolation of ecologically important fragments within disturbed habitats. This may limit movement, gene flow, and functionality, despite seemingly adequate levels of total natural habitat within a landscape. The importance of landscape connectivity must, therefore, be considered in conservation planning, rather than merely preserving isolated fragments of natural habitat. The potential outcomes of this predictive scenario have significant implications for the development of proactive landscape management techniques. Instead of reacting to changes in biodiversity in response to environmental disturbance, the forward-looking capacity of the model can inform planners about where action needs to take place. This changes

the focus of the conservation approach from reactive restoration to proactively mitigating risk. In conclusion, these findings indicate that ecological risks are not evenly distributed across regions and are instead found within dynamic landscapes that need to be managed differently than an entire region.

Conclusion

Through this study, an EcoRisk Prediction Model was designed and used to assess risks of biodiversity loss due to anthropogenic landscape pressure by incorporating hazards, exposures, and vulnerabilities into predictive spatial framework. It was found out through this research that the risks of ecological loss are highly concentrated in landscapes that are currently experiencing change. Particularly, ecological risks of landscape changes tend to increase especially in areas surrounding expansion of urbanization and agricultural lands. Thus, the predictive aspect of this model will prove useful in proactively identifying zones of high ecological risk. It is important to highlight that successful biodiversity conservation involves considerations beyond the loss of habitats. The rate of landscape changes, as well as the connectivity of remaining ecological patches, are other critical factors in biodiversity conservation. Although the EcoRisk model showed good spatial consistency and predictability, the accuracy of its predictions depends on the quality of the input land-use data and could benefit from future validation in more types of landscapes. Furthermore, future studies might investigate the inclusion of fine-scale remote sensing datasets, other biodiversity indicators, and climate stressors into the model to improve its predictive accuracy.

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