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HabitatFusion Model for Predicting Restoration Success in Degraded Forest Ecosystems

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Key Words	Abstract
Habitat restoration, Forest ecosystem restoration, Restoration success prediction, Degraded forests, Predictive modeling, Ecological assessment, Conservation planning.	Degradation of forests is still a challenge to biodiversity, ecosystem services, and habitat connectivity of wildlife worldwide, making predictions of successful restoration very important for conservation planning. HabitatFusion is the name of the developed predictive model that allows estimation of the probability of ecological recovery of degraded forest habitats using integration of several environmental, biological, and geographical data sources. In contrast to traditional one-parameter models, HabitatFusion incorporates information on vegetation recovery, soil quality, climate parameters, and presence of particular species into a single predictive model to reflect the multi-dimensional aspect of habitat restoration. The model was constructed based on the data from the restoration of degraded forest habitats and using the actual restoration outcomes as a basis for calibration. It is evident from the results that the proposed method demonstrates considerably greater predictability of the restoration process compared to the traditional single-factor evaluation method, and the factors of vegetation cover recovery and fauna restoration stand out as the most significant predictors of restoration success. Thus, the results demonstrate that information integration can be seen as a better predictor of restoration success compared to isolated factors. From the practical point of view, HabitatFusion can help conservation specialists, wild life agencies and restoration experts identify at an early stage of restoration work which restoration initiatives require further interventions in order to achieve successful restoration outcomes.

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Introduction

The degradation of forests worldwide continues to persist due to deforestation, agricultural development, excessive harvesting of natural resources, and the challenges presented by climate variability. In addition to reducing forest coverage, such phenomena affect the functions that enable the thriving of wildlife through the provision of breeding areas, food sources, and pathways connecting different areas of fragmented forests. With the increasing degradation in many parts of the world, restoration projects have become key priorities in the conservation and land management strategies of governments and other organizations that allocate significant financial resources towards restoring damaged habitats. Nevertheless, the effectiveness of the restoration measures greatly varies from one region to another based on the land-cover history and previous level of degradation of the area, as well as the adequacy of monitoring procedures employed to assess the process of restoration. Studies in various large regions with different types of land cover revealed that the habitat quality is extremely dependent on the land-cover dynamics, hence the significance of accounting for such factors in evaluating restoration efforts (Liu et al., 2025).

Although there is significant investment in restoring degraded lands, the assessment techniques employed remain quite limited and mostly consist of one-dimensional measurements like the percentage of tree canopy cover or rudimentary vegetation surveys. Such measurements are insufficient in assessing the recovery of the whole ecosystem since they may neglect any underlying structural and functional changes in the landscape under study. In complex topographies or semi-arid forest landscapes, for instance, vegetation recovery does not necessarily imply a suitable habitat for the return of wildlife. Studies performed to analyze landscape structures in semi-arid mountain forest regions have shown that restoration projects need to consider spatial structure, patch structure, and habitat suitability rather than only vegetation cover (Piri Sahragard et al., 2021).

The recent research on models of spatial and habitat quality change suggests that the use of different environmental layers instead of one single factor gives a more accurate description of ecological dynamics. In particular, several Bayesian network studies of the habitat quality dynamics in dynamic landscapes have shown that using multiple data sets may provide insights into the pattern of deterioration and improvement that cannot be observed using one-factor analysis (Zhang et al., 2024). In this respect, the current study aims at developing HabitatFusion, a data integration method that will use indicators related to vegetation, soil, climate, and fauna in order to predict restoration effectiveness and will help manage forest restoration activities in a more efficient way.

The current research provides a unique approach to habitat restoration success prediction based on multi-source data fusion technique that was developed specifically for this task. In contrast to existing vegetation-centered approaches, this one takes into consideration fauna return as a predictor along with other vegetation and abiotic factors thus providing a wildlife-oriented habitat quality assessment method.

The rest of this paper is organized in the following way: Section II provides a brief review of the literature on habitat quality assessment and modern technologies used in monitoring. Section III provides information about HabitatFusion framework materials and methodology. Section IV contains the results of model validation. Section V discusses ecological significance of the results and their limitations; Section VI concludes the paper with key contributions and future directions.

Literature Review

There has been tremendous advancement in the implementation of artificial intelligence within the field of forest and ecology monitoring in recent times. Artificial intelligence has been used to help identify early indicators of forest distress, disease, and climate-induced changes in vast and remote areas. The use of AI in processing complicated data sets has enabled scientists to monitor changes quickly and in a more extensive manner than through conventional manual surveys would be possible. Reviews of applications of artificial intelligence in plant and forestry sciences show that apart from helping predict diseases and monitor plant growth, AI can also help in climate adaptation strategies, which shows huge promise for their use in restoration monitoring (Xu & Jiang, 2025). In addition to AI analytics, unmanned aerial systems are becoming more common as tools in restoration ecology, offering an inexpensive, detailed, and reliable way of observing vegetation structure, accessibility of terrain, and animal presence on restoration sites. With drones, scientists can obtain data about places that are difficult to survey using traditional techniques, especially in rugged and extensive areas suffering from degradation. The examples of drone use in restoration show the increasing importance of aerial monitoring in assessing vegetation recovery, mapping of habitats, even in seed dispersal and site preparation tasks (Robinson et al., 2022). In addition to personal monitoring techniques, recent studies have increasingly highlighted the importance of multi-analytical model linkage for a comprehensive depiction of the spatiotemporal patterns of habitat quality changes and the ability to provide future projections. Multi-model linkage methods used in the study of large river basin ecosystems have shown the ability to use the combination of several analytical models for the description of spatiotemporal dynamics of habitat quality changes and provide scenario-based projections in order to provide a basis for land management planning. These studies underscore the emerging methodology trend towards multi-source analysis rather than single analytical model use or single environmental indicator (Zhang et al., 2025). As a whole, the literature reviewed here shows an evident transition from the assessment of habitat and ecosystem condition through single metrics and static evaluations to integration, technological support and multi-model approach. Research on AI-enabled forestry monitoring, UAV ecological surveys and multi-model habitat quality coupling all lead to the same conclusion, that using several types of information and analysis tools makes the evaluation more accurate and ecologically sound compared to single-method solutions. But the current literature is mostly concerned about habitat quality maps and forestry health monitoring, not about prediction of success in active restoration activities. There is a necessity for an independent restoration outcome prediction framework, such as HabitatFusion, based on the recent technological and scientific progress, yet dedicated to prediction of success in forest restoration in degraded forests, especially those focusing on wildlife-relevant indicators which are little researched in the current habitat quality literature.

Materials and Methods

HabitatFusion has been created as a means of determining whether or not restoration is successful in degraded forests. This is achieved by incorporating the data collected from different ecological realms into one evaluation system. The model does not depend on any particular indicator; rather, it combines vegetation health, soil quality indicators, climate factors, and the presence of returning wildlife into one formula based on the assumption that forest restoration is dependent on an increase in various interdependent ecological elements.

3.1 Study Sites and Data Collection

The study took place among a number of degraded forest patches which were being actively restored for different durations of time, thus making it possible to compare the early stage and advanced stage restoration sites. The data collected were from field surveys and site observations, which included measuring vegetation recovery (canopy coverage, plant density, and diversity), indicators of soil conditions (organic matter and soil water retention capability), climatic conditions (rainfall and temperature), and the presence or absence of animal species by tracking their signs or capturing their footage in the camera, if any. The success of restoration in each patch was evaluated in light of the existing ecological criteria, classifying them as advanced, moderate, and weak.

3.2 Data Integration and Model Development

The basic principle behind HabitatFusion is the fusing process itself, wherein the different indicators become one restoration success indicator and not considered independently. All ecological domains, which include vegetation, soil, climate, and fauna, are individually assessed and weighted based on the degree of their importance in contributing to the success of habitat restoration. The weights are determined by how strongly they correlated to the success of the habitat recovery process as seen in the real world. This makes sense because not all the indicators are reliable; some, such as the return of fauna, indicate real ecological recovery better than some others, such as plant growth.

3.3 Model Testing and Evaluation

To assess the validity of the HabitatFusion approach, the aggregated database was split into distinct samples used for modeling and independent validation of predictions made by the model. Predictions made by the model were assessed in comparison to the true, field-tested outcome of habitat restoration achieved in each of the study sites. This procedure was performed using several data sets to check whether the performance of the model was consistent regardless of the choice of study sites. Specifically, the assessment was focused on how successfully the model can discriminate between sites with successful, moderate, and insufficient restoration and what factors have the greatest impact on such prediction.

Results

4.1 Overall Predictive Performance of the HabitatFusion Model

The HabitatFusion model proved to have excellent accuracy in differentiating among forest plots characterized by varying degrees of restoration success. Plots individually labeled as being characterized by robust ecological recovery were also recognized accurately by the model, while limited recovery plots were differentiated equally well, thus suggesting that the fusion method was capable of capturing significant differences among restoration efforts.

4.2 Relative Importance of Ecological Indicators

Of the four domains used in this study, fauna return and plant recolonization came up as the most significant indicators for successful restoration, followed by soil conditions and climatic parameters. Where there was recolonization of both plants and animals, a higher recovery score was recorded. This indicates that fauna return is especially significant as an indicator of successful habitat restoration.

4.3 Performance Across Different Site Conditions

The model has exhibited constant prediction accuracy irrespective of the degree of maturity of the restored site and varying environmental conditions of the sites involved. This implies that the HabitatFusion technique is applicable under various conditions and not just restricted to certain environments, hence increasing its potential to be applied in practice.

Discussion

5.1 Ecological Interpretation of Model Findings

Faunal return's highly predictive nature is indicative of the general ecological concept that recovery of habitat is not only seen through regrowth of plant life but also through the recovery of functioning communities of wildlife. This underscores the notion that restoration is holistic in nature and needs to be measured as such through animal, vegetation, and soil-based measures.

5.2 Practical Value for Restoration Management

The consistent results obtained from applying the HabitatFusion framework under varied site conditions imply that the model can be utilized as a valuable early warning system by the restoration managers. The managers can take action at an early stage based on the sites where the recovery trajectory is weak, especially those in which animal return is slow, as opposed to conducting extensive plant monitoring to detect issues.

5.3 Limitations and Considerations for Broader Application

In spite of promising results, the fact that the proposed methodology heavily depends on the field-based faunal observation data poses some constraints in application of the approach in those areas which lack adequate resources for such monitoring programs. Moreover, criteria for the success of the ecosystem restoration employed in this research may not be adequate in capturing the full potential for long-term resilience of the ecosystem.

Conclusion

The current research highlighted HabitatFusion, an integrative model for predicting success in forest ecosystem restoration based on the integration of vegetation, soil, climate, and faunal characteristics into one indicator system. The results of this study reveal that the use of this multi-faceted approach can be much more accurate in predicting successful restoration than the traditional models based on only one indicator, with the fauna being the best indicator of the success of restoration. This method can help in the practical application of the knowledge in order to help in making adaptive decisions related to the forest restoration process. For future research, it is important to validate the model among different forest ecosystems and geographic locations as well as using remote sensing and drones to minimize the need for fieldwork and perfect the fusion weights method. Overall, HabitatFusion represents a meaningful step toward more holistic, wildlife-informed approaches to evaluating forest restoration outcomes.

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