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AI modeling to predict vegetation diversity of protected rangelands in national parks

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Abstract

The impact of livestock and tourism on vegetation includes a reduction in biodiversity and in some instances, species extinction. To assess these stressor-effect relationships and provide a management tool for protected rangelands of Iran's Lar National Park, we created a multilayer perceptron (MLP) artificial neural network model to forecast vegetation diversity in relation to human activities. Recreation and restricted zones, representing areas with the highest and lowest human impact, were chosen as sampling sites. Vegetation diversity, indicated by the number of species, was recorded in 210 sample plots. Additionally, twelve landform and soil variables were documented and utilized in developing the model. Sensitivity analyses revealed that the intensity of human activity (in four classes of livestock and tourism population) and soil moisture were the most critical inputs affecting the MLP. The MLP demonstrated strong performance, with R2 values of 0.91 for training, 0.83 for validation, and 0.88 for test datasets. A graphical user interface was created to integrate the MLP model into an environmental decision support system for protected rangelands managers, allowing them to predict impacts and formulate proactive plans to manage human activities affecting vegetation diversity.

Introduction

In Iran, the primary objective of national park management is to mitigate the adverse effects of human activities, particularly tourism and livestock husbandry. These activities have been linked to a range of negative impacts on vegetation, including biodiversity loss, degradation of plant communities, diminished plant regeneration, and, in some cases, species extinction. Numerous studies have documented a decline in species richness with increasing human activity in grasslands. Moreover, livestock grazing and tourism have been shown to negatively impact plant regeneration and elevate the risk of extinction for certain species (Newsome et al. 2013). To address these challenges, mathematical and quantitative methods are essential for analyzing the conditions of national parks where human activities are causing vegetation degradation. Recent advancements have led to the development of mathematical models for environmental impact assessment (Jahani 2016), which consider both human activities and ecosystem characteristics. This study aims to apply a Multi-Layer Perceptron (MLP) neural network model to predict the effects of human activities, such as livestock grazing and tourism, on vegetation diversity in Lar National Park, Iran.

Methods

To evaluate the effect of human activities on vegetation diversity, sampling areas were strategically chosen to represent sites with maximum (recreation zone) and minimum (restricted zone) human impact. Two sampling grids were employed, resulting in the selection of 105 sampling locations across the study areas. Given that the restricted zone covered a larger area compared to the recreation zone, the sampling sites were more widely spaced in the restricted zone. The grid dimensions were 200 × 500 meters in the recreation zone and 600 × 500 meters in the restricted zone. Plant species were identified and counted within 2 × 2-meter sample plots at each sampling location, and the number of species recorded served as a measure of vegetation diversity.

Species identification in each plot was conducted using local plant identification resources (Lar National Park Group, 2012). Additionally, 12 landform and soil variables were recorded at each 2 × 2-meter sample plot, including altitude (m), plot slope (%), hill direction exposure (north, east, south, and west), soil depth (cm), percentages of clay, silt, and sand in the soil texture, soil organic matter content (%), soil electrical conductivity (dS/m), soil porosity (%), and soil moisture (%). Four qualitative classes of human activity intensity were estimated by local park rangers: 1) no presence of livestock and tourists, 2) sporadic presence of tourists, 3) intensive presence of livestock and tourists, and 4) intensive presence of livestock and tourists with overnight stays. These predictor variables were used to develop a model to estimate the expected vegetation diversity (species count) in the sample plots, which served as the model output.

The dataset was randomly divided into three subsets: a training dataset comprising 60% of all samples (126 samples), a validation dataset comprising 20% of all samples (42 samples), and a test dataset comprising the remaining 20% of samples (42 samples). The ANN function in MATLAB (2018) was employed to design the MLP model structure and test the outcomes.

Results

In this study, a total of 210 sample plots were analyzed to assess vegetation diversity in both the recreation zone (characterized by maximum human activities) and the restricted zone (characterized by minimal human activities). Various combinations of layers and neurons, along with different activation functions for both hidden and output layers, were tested to optimize the ANN. Initially, the optimization process involved experimenting with a hidden layer containing between 5 and 30 neurons, selected randomly. Subsequently, the performance of the MLP was evaluated in configurations with 2 and 3 hidden layers, each containing the same number of neurons.

During neural network training, different numbers of hidden layers and neurons per layer were explored. The coefficients of determination (R^2) indicate the accuracy of these networks in predicting vegetation diversity based on the input variables. According to the results, Model with a structure of 12-6-6-1 (12 input variables, 6 neurons in each of the hidden layers, and 1 output variable), achieved the highest R^2 values across the training, validation, and test datasets (0.95, 0.87, and 0.93, respectively). This model demonstrated the best performance in structure optimization.

The MLP model demonstrated exceptional accuracy in predicting vegetation diversity in national parks, with the optimal network achieving a coefficient of determination (R^2) of 0.88 during the test phase. This indicates that the MLP is highly effective for assessing human impact in areas where vegetation cover is most affected by human activities. Consequently, a sensitivity analysis was conducted on the predicted outputs of the optimal MLP. Figure 1 highlights the sensitivities of the MLP to various input variables, revealing that the intensity of human activities and soil moisture were the most influential factors affecting the MLP's outputs.

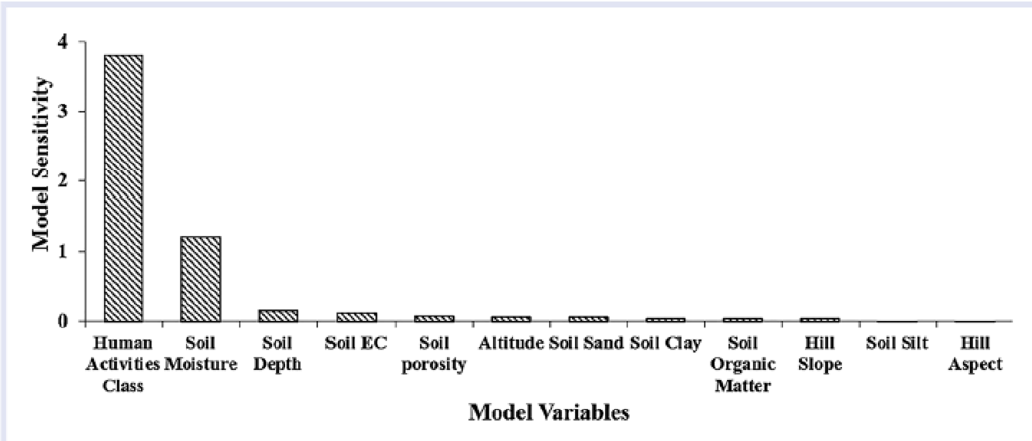

Figure 1: Sensitivity analysis of MLP model for prediction plant diversity

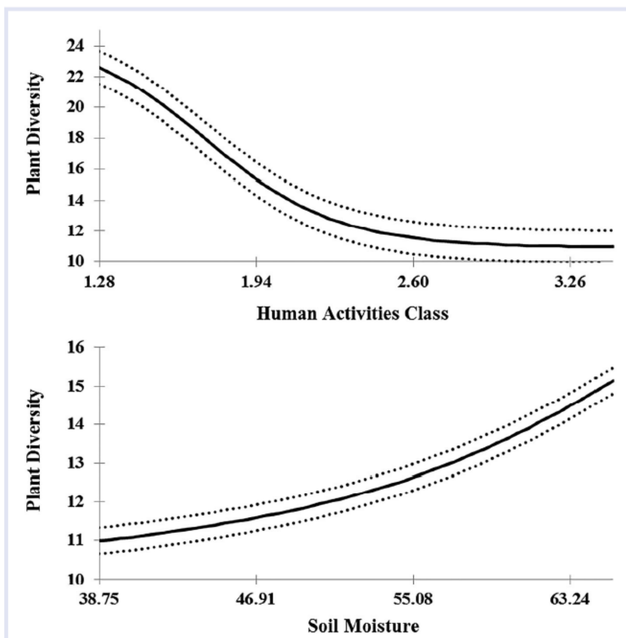

Figure 2: The trend of plant diversity changes in respond to human activity class and soil moisture.

The sensitivity analysis results show that the intensity of human activities and soil moisture had the greatest impact on vegetation diversity. Figure 2 illustrates that as the intensity of human activities increases, vegetation diversity declines; specifically, a 2-unit increase in activity intensity leads to a 10-unit decrease in vegetation diversity. This means that higher levels of human activity result in a significant reduction in the number of plant species observed in the sample plots. Additionally, an increase in soil moisture correlates with a rise in vegetation diversity—specifically, a 25% increase in soil moisture leads to an approximately 5-unit increase in vegetation diversity. Thus, higher soil moisture levels contribute to an increase in the number of plant species in the area.

Discussion [Conclusions/Implications]

In this study, an MLP model was developed to predict how human activities affect natural vegetation diversity. The goal is to aid managers in estimating the potential impact of human activities while balancing ecological conservation goals in national parks. Using MATLAB (2018) and appropriate validation techniques, the model described here is applicable to areas with ecological conditions similar to our study area in Iran. For regions with different ecological conditions, the model can be adapted by incorporating new data sets. From a planning perspective, areas with higher soil moisture are better able to withstand human activities and are more likely to recover quickly. This should be considered in national park management planning. The data used in this study are robust, consisting of 210 sample plots that provide reliable information on the impact of human activities and land properties, which were used to develop the quantitative model for predicting vegetation diversity.

Human activities have been used as variables in predicting environmental impacts to inform management decisions. Jahani et al. (2016) previously assessed the accuracy of neural network models in evaluating forestry impacts using the optimized forest degradation model (OFDM) with MLP, applied to predict forest degradation from human activities like livestock grazing and tourism.

Our study highlights the influence of both human activities and habitat conditions on vegetation diversity. De Vries et al. (2010) argue that expert-based models estimate plant diversity responses to environmental variables. Models developed for specific regions like the Netherlands (Wamelink et al. 2005) have shown promise, emphasizing the importance of measuring variables such as landform, soil acidity, and nutrient and water availability. Our research, alongside Jahani et al. (2020), found that soil organic matter and moisture are crucial factors influencing plant diversity after human activities.

In Lar National Park, tourist activities tend to compress soil and vegetation, making shrubs more sensitive to human activities than herbaceous plants (Whinam and Chilcott 2003). Soil conditions, such as moisture and nutrient availability, affect vegetation damage and ecosystem regeneration potential. Soils with higher moisture support greater plant diversity (Whinam and Chilcott 2003), which aligns with the MLP model's sensitivity analysis results. For example, a 25% increase in soil moisture (from 38% to 63%) could lead to an additional 4 plant species (11 to 15) in the habitat. Given that soil moisture in Lar National Park ranges from 25% to 80%, our model effectively assessed the impact of soil moisture on plant diversity.

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