International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 1, 2025
https://www.theaspd.com/ijes.php

Assessing habitat vulnerability, ecosystem change trends and ecological indicators for diversity conservation in PU Mat National Park, Nghean, Vietnam

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Received: 04th May 2024
Revised: 17th November 2024
Accepted: 20th December 2024

Abstract: *The study's primary outcome is an assessment of habitat vulnerability and ecosystem change trends based on an analysis of the effects of environmental hazards, socioeconomic variables, and natural processes in the surrounding areas of Vietnam's Pu Mat National Park. Six indicators from four groups indicators of vegetation cover, topography variables (elevation, slope), meteorological factors (dryness), and demographic factors (population density)–were used to estimate the vulnerability of the habitat using GIS technologies and the AHP method. The results on the trend of ecosystem change to 2030 are determined using the MOLUSCE algorithm in QGIS based on the map of ecosystem distribution in 2010 and 2020 and the major factors affecting the natural and socio-economic conditions, including terrain elevation, population density, distance to roads, distance to rivers and streams. On the other hand, the linear connection between the influencing factors is also calculated, evaluated, and noticed with the positive linear connection, and the negative linear connection. These are to protect, use the ecosystem, and preserve biological diversity in this research area.*

Keywords: *Habitat Vulnerability, ecosystem change trend, GIS, Pu Mat National Park (Vietnam)*

1. INTRODUCTION

Geographical distributions are some of the features that are critical in determining species vulnerability to changes in environmental conditions, such as habitat loss and climate change [1], [2], [3], [5]. Planning and implementing sympathetic management can be enhanced by understanding reptile ecology and habitat requirements [6],[7]. In situ management of the habitat, specifically altering the physical environment and vegetation to mitigate the impacts of climate change, is more feasible in this case. Examples of such modifications include water irrigation systems and maintaining or expanding vegetation cover [6], [9], and [14].

The assessment of natural systems' vulnerability to future climate changes will be essential for the development of effective mitigation and adaptation strategies [8]. For instance, identifying the ecosystems that are in threat might assist in establishing conservation objectives, such as which regions require restoration or protection efforts and which do not ([7] and [9]). The natural environment conditions in which the system occupies have a direct impact on the ecosystem's vulnerability [5]. The condition of the habitat provides a basis for the ecosystem's ongoing operation and is a critical factor in determining the regional ecosystem's level of vulnerability [12].

To accomplish its targets and impact its operational consequences, an ecosystem depends on its structure, which is one of its key characteristics ([3] and [11]). Accordingly, the possibility of ecological vulnerability relates to the habitat's state, structure, and function ([11]). While some previous research has considered aspects of the ecosystem, such as structure or function, they have not considered the region's natural conditions ([11 and [14]).

Regional planning and nature reserve optimization depend on knowing how to establish critical conservation areas for biodiversity and ecosystem services. Ecosystems' vulnerability to habitat degradation has significant effects on the positive impacts of biodiversity protection. Thus, assessing the ecosystems' habitat vulnerability becomes one a further significant consideration in directing the management and development of nature reserves.

2. METHOD AND MATERIALS

2.1. Study Area

Part of the Western Nghean Biosphere Reserve, Pu Mat National Park is located in three districts of Anh Son, Con Cuong Tuong Duong in Nghean province, about 130 kilometres from Vinh City. Pu Mat National Park has a high level of biodiversity, with 2494 plant species from 160 families and around 1,000 animal species. In Pu Mat National Park, rare and wild genetic resources are preserved. The national park, formerly known as the Pu Mat National Reserve, covers 194.804 hectares, of which 94.804 hectares are the core zone and 100,000 hectares are the buffer zone.

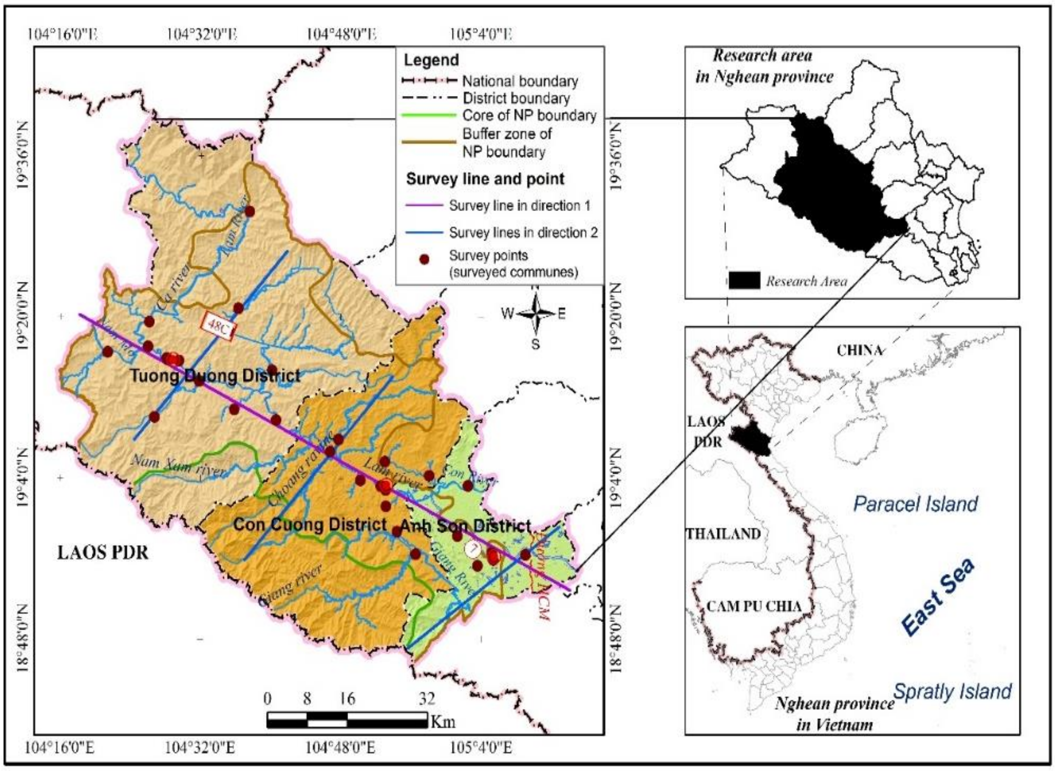


Figure 1: Position map of the research area

2.2. Materials

The input data used for this paper to assess the ecosystem's habitat vulnerability and data related to it (ecosystem change trend, ecological indicators) are the following: 1. Landsat 8 images (bands 4 and 5) (30mx30) were taken in 2023 which was downloaded from USGS systems. These images are used to calculate NDVI to determine vegetation coverage; 2. Downloaded Digital Elevation Model (DEM) of the research area from the USGS website. The DEM is used for creating topography variables (elevation, relief, slope). 4) Year Book in 2023 in three districts of the research area which obtain data for creating demographic factors (population density) provided by the Statistics Department in three districts in the research area. 5) Dryness input data for habitat vulnerability is obtained from a Map of climate in the research area which is calculated from climate data at the climate stations.

2.3. Methodology

Flowchart of Methodology is showed on Figure 2

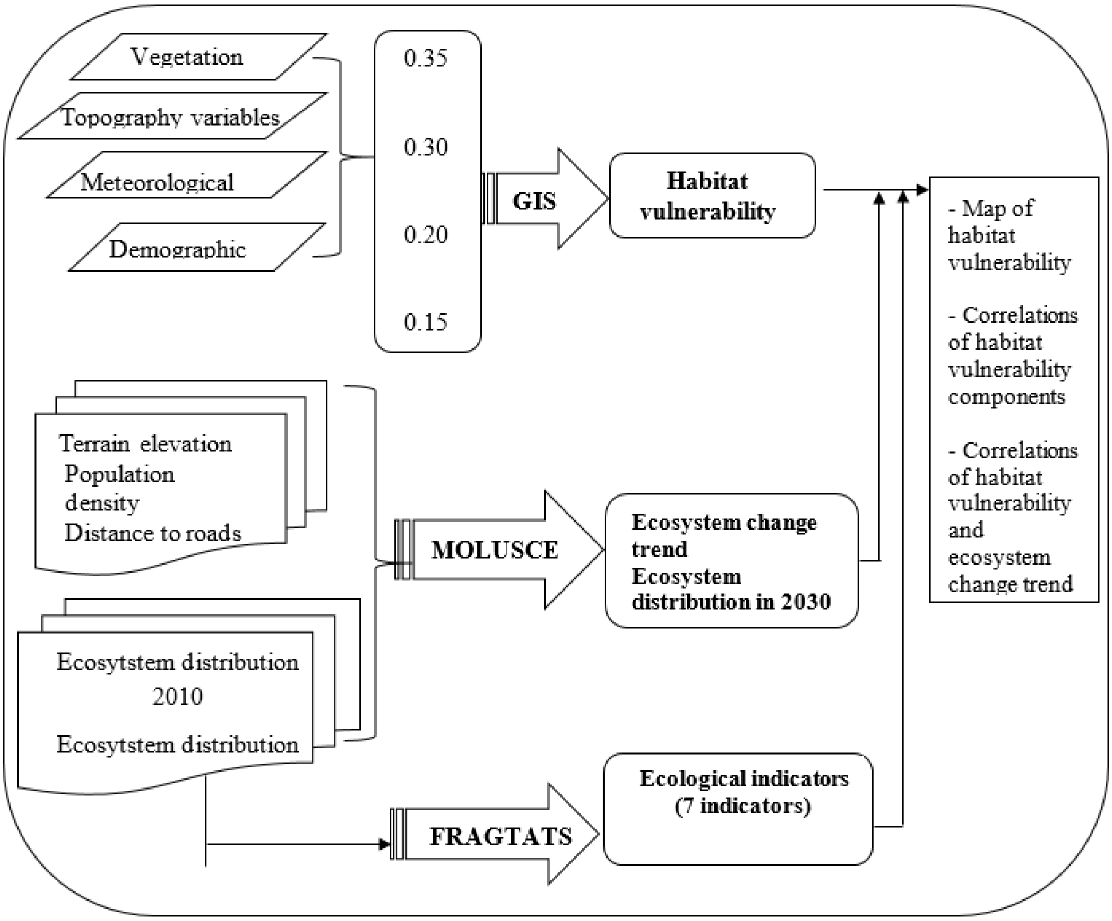


Figure 2: Flowchart of Methodology

2.3.1. Habitat vulnerability is a term that describes how sensitive risk receptors are to disturbances from the outside (Jie Gong et al.,2021; Xu et al., 2016). In this study, indicators of vegetation coverage, topographic factors (elevation, relief, slope), meteorological factors (dryness) and demographic factors (population density) were used to characterise the land surface, topography, meteorology, and population, respectively, to obtain the vulnerability degree of the habitats, based on related literature (Jie Gong et al, 2021, Metzger and Schroter, 2006) and data availability.

$$V = \sum_{i=1}^{n} w_i f_i \qquad (1)$$

Where V is the habitat vulnerability, f_i is the index of the environmental vulnerability indicator including vegetation coverage, topographic factor, meteorological factor and demographic factor, w_i is the weight of the indicator i.

Following comparable studies, the weights of vegetation coverage, topographic factor, meteorological component, and demographic factor using the expert scoring method are, respectively, 0.35, 0.30, 0.20, and 0.15 (Gong and Xie, 2018). The normalised difference vegetation index (NDVI) data can be used to determine the amount of vegetation present. The topography of Pu Mat National Park is described using topographic characteristics including elevation, slope, and topographic relief acquired from the DEM. The dry region is separated from the eco-climate map that was created for the study area using data on temperature, humidity, and rainfall. The statistics yearbooks of 2023's census data are used to determine the population density of all the villages and towns in the study area, and spatial interpolation is used to create the population density map.

2.3.2. MOLUSCE model calculation method and trend analysis: The MOLUSCE model is applied by the author to estimate the trend in ecosystem change in Pu Mat NP from the distribution of the ecosystem in 2010, 2015, and 2020 as well as component maps for natural, social, and environmental impact factors.

2.3.3. Calculate linear connection calculated by the SPSS software's analysis relationship among the data inputs, habitat vulnerability, ecosystem change trend, and ecological indicators.

2.3.4. Ecological indicators

Table 1: The ecological indicators with their parameters and meaning in the research area

Indicator		Parameters	Meaning
Cohesion indicators	$\text{COHESION} = \left[1 - \frac{\sum_{i=1}^{n} P_{ij}}{\sum_{j=1}^{n} P_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1}.(100)$	Pij = perimeter of patch ij in terms of number of cell surfaces. aij = area of patch ij in terms of number of cells. A = total number of cells in the landscape.	Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected. Above the percolation threshold, patch cohesion does not appear to be sensitive to patch configuration
Landscape Shape Index (LSI)	$LSI = \frac{E}{\min E}$ *Unit: None* *Range: LSI ≥ 1, without limit.*	E = total length of the edge in ecosystem units e in terms of a number of cell surfaces; includes all landscape boundary and background edge segments. min E = minimum total length of the edge in ecosystem units in terms of a number of cell surfaces.	LSI has a direct interpretation, as opposed to total edge, which is only useful in terms of the size of ecological units. LSI can in addition be interpreted as a measure of patch aggregation or disaggregation, as with the class-level interpretation.
Aggregation index (AI)	$\text{AI} = \left[\frac{g_{ii}}{\max \to g_{ii}}\right](100)$ *Unit: Percent* *Range: 0 ≤ AI ≤ 100*	g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the *single-count* method. max-g_{ii} = maximum number of like	Aggregation index (AI), as the previous one indicates the tendency of the types of coverage to aggregate

		adjacencies (joins) between pixels of patch type (class) i (see below) based on the *single-count* method.	
SHDI Shannon's Diversity Index	$SHDI = -\sum_{k=0}^{n}(P_i lnP_i)$	$P_i =$ proportion of the landscape occupied by patch type (class) i.	Shannon's diversity index is a popular measure of diversity in community ecology, applied here to landscapes. Shannon's index is somewhat more sensitive to rare patch types than Simpson's diversity index
SIDI Simpson's Diversity Index	$SIDI = 1 - \sum_{k=0}^{n}(P_i^2)$	$P_i =$ proportion of the landscape occupied by patch type (class) i	Simpson's index is less sensitive to the presence of rare types and has an interpretation that is much more intuitive than Shannon's index. Specifically, the value of Simpson's index represents the probability that any two pixels selected at random would be different patch types.
MSDI Modified Simpson's Diversity Index	$MSIDI = -ln \sum_{i=0}^{m} P_i^2$	Pi = proportion of the landscape occupied by patch type (class) i.	MSIDI eliminates the intuitive interpretation of Simpson's index as a probability, but transforms the index into one that belongs to a general class of diversity indices to which Shannon's diversity index belongs.
SHEI Shannon's Evenness Index	$SHEI = \frac{\sum_{i=1}^{m}(P_i * lnP_i)}{lnm}$	Pi = proportion of the landscape occupied by patch type (class) i. m = number of patch types (classes) present in the landscape, excluding the landscape border if present.	Shannon's evenness index is expressed such that an even distribution of area among patch types results in maximum evenness. As such, evenness is the complement of dominance.
MSIEI ModifiedEve	$MSIEI = \frac{-ln \sum_{i=1}^{m} P_i^2}{lnm}$	Pi = proportion of the landscape occupied by patch type (class) i.	Modified Simpson's evenness index is expressed such that an

nness Index		m = number of patch types (classes) present in the landscape, excluding the landscape border if present.	even distribution of area among patch types results in maximum evenness. As such, evenness is the complement of dominance.

(***Source:*** *Fragstat metrics research at Umass)*

3. FINDINGS AND DISCUSSIONS

3.1. Component of Ecology Habitat Vulnerability

Vegetation cover: The vegetation in the research was calculated using Landsat 8 and NDVI, with bands 4 and 5 following the equation (3). The research area is divided into four classes based on NDVI results: healthy vegetation (79.14 percent), shrubs (19.18 percent), land (0.7 percent), and water body (0.98 percent). To determine vegetation coverage, these are paired with the distribution of elevation levels. According to the findings, the area has more than 75 percent, vegetation convergence and is located on a high mountain with a steep slope. The area, on the other hand, has a 65-75 percent vegetation cover and is located in the remaining area.

Elevation: The elevation of the research area, which ranges from 7 meters to 2122 meters above sea level, is 457 meters on average. The highest elevations were found in the western and northeastern parts of the study area, resulting in a range of typical mountains between 1200 and 2122 meters. The research area's western and northeastern regions also have lower elevation areas, including 830383. 90 hectares of mountains with 700–1200 meters count 16.14 percent the research area and 86141.37 hectares of hills with 500–700 meters (count 16.17 percent the research area). The majority of the area, or 63.36 percent of the entire research area, is located in the central section of the Con River, which consists of 204316.20 hectares of hills with a height of 200–500 meters (which account for 39.60 percent of the study area) and 121857.43 hectares of plains with a height of 0 - 200 meters (count 23.67 percent of the research area). However, as a result of the investigation and the expert interaction, the elevation component in association with the vegetation cover in the study area's specific location creates the character of the national park's core region and buffer region. It was also used to determine the slope and aspect to assess the safety of site selection for the development of residential areas and agricultural areas.

Population density: Population crashes may be natural biological and ecological processes. As approaches to conservation and management are created, it is vital to recognize this. Obviously, a lot of ecological researchers are fascinated in population density because it may be used as a direct proxy for population size. This is especially true in applied ecology. The research area's highest population density (>500 people/km2) is found in the Pu Mat NP buffer zone, which is in the Anh Son and Con Cuong districts.

Meteorological factors: Dryness is calculated via the de Martonne index from monthly average temperature and precipitation [8]. High and severely dry regions are concentrated dry areas that makeup around 12.96% of the study area, or 66,722.84 hectares. They are spread throughout Tuong Duong and Con Cuong districts, which are part of the National Park's buffer zone. The region has a semi-arid climate, and deciduous and semi-deciduous trees make up the majority of the vegetation.

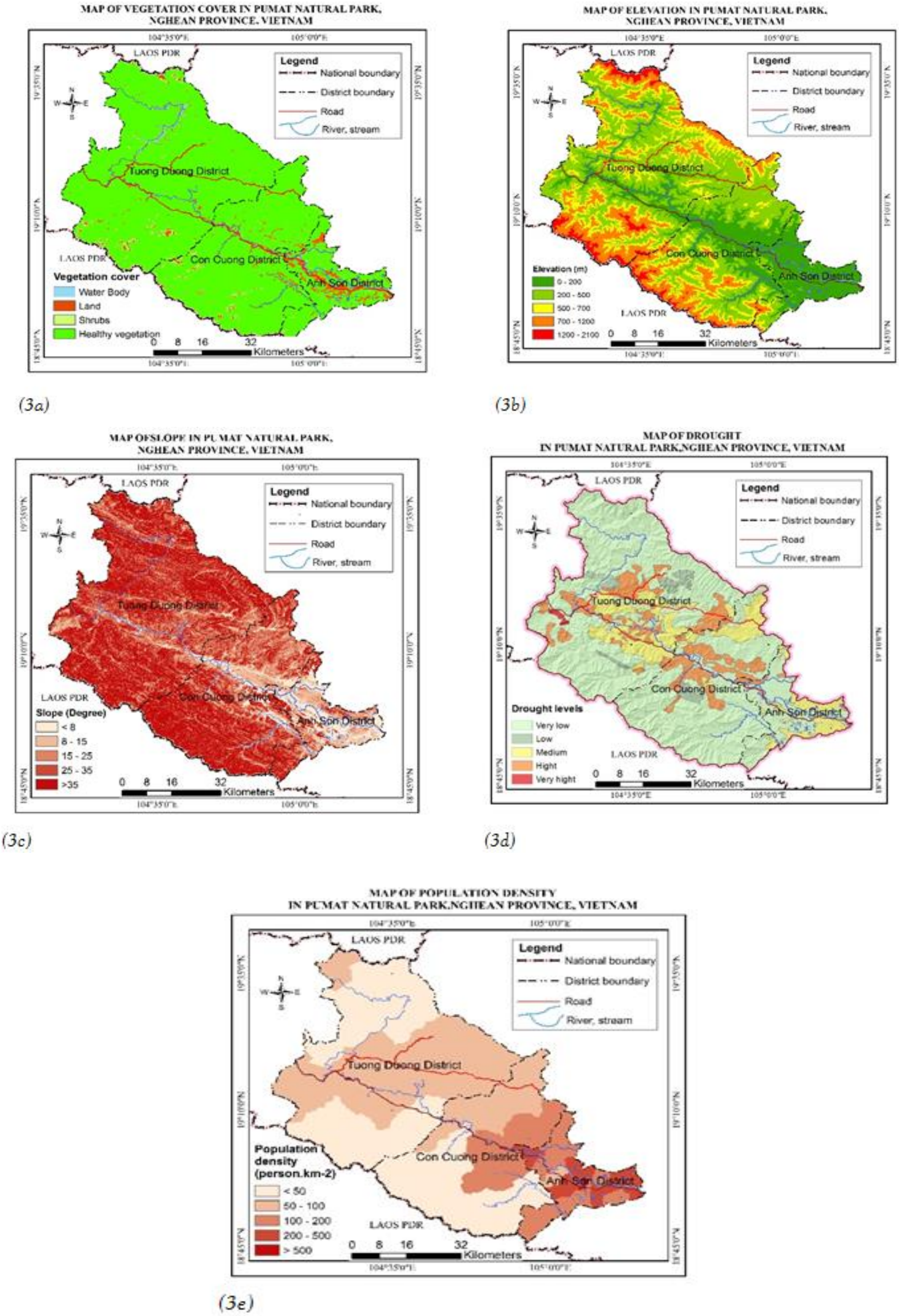


Figure 3: Map of components for habitat vulnerability in the research area (3a: Map of vegetation; 3b: Map of Elevation; 3c: Map of slope; 3d: Map of drought; 3e: Map of population)

3.2. Ecosystem's habitat vulnerability

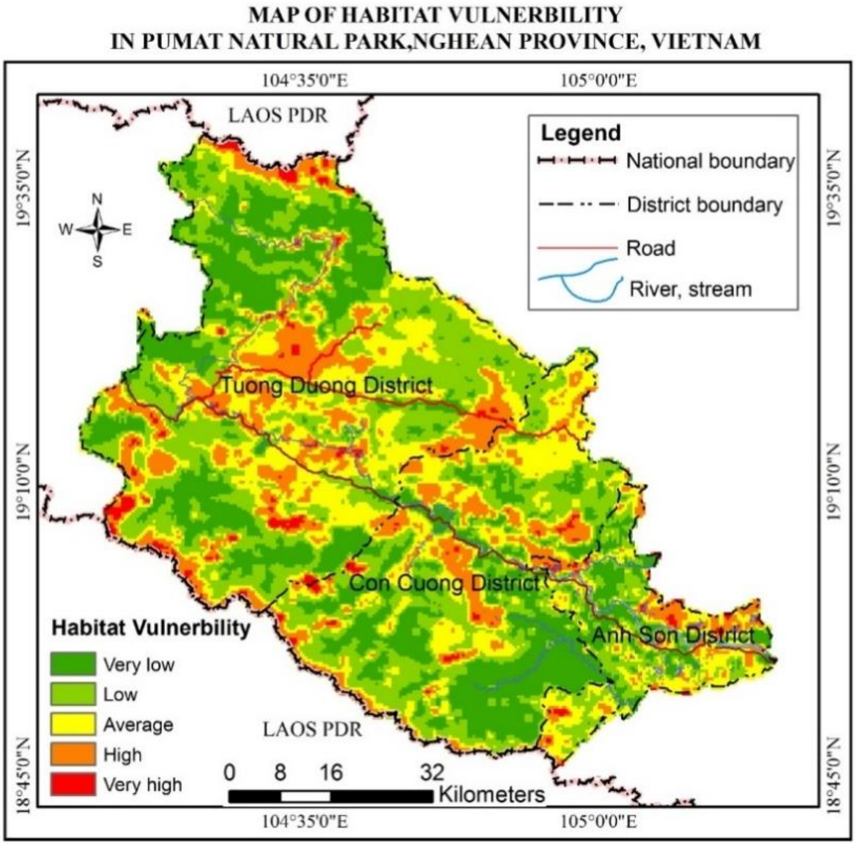


Figure 4: Map of habitat vulnerability in the research area

The mean habitat vulnerability for ecosystems in the research area ranges from 2.07 to 2.99. Ecosystem 1 is the largest, although the mean value (2.42) is rather low. Ecosystem 7 is the smallest, but it has the highest mean value (2.99), indicating greater relative significance. The lesser value is located in ecosystems 6 and 5 (2.35 and 2.33, respectively). Ecosystems 2, 3, and 4 have identical areas and variety (2.07; 2.26; and 2.45), but their different majority and minority values create tiny changes in their mean values. Overall, area size does not directly correlate with mean value, indicating that the internal characteristics of ecosystems are varied.

ECOSYSTEM	AREA	SUM	VARIETY	MAJORITY VALUE	MINORITY VALUE	MEDIAN	MEAN VALUE
Ecosystem 1	285997.06	44580	5	2	5	2	2.42
Ecosystem2	34319.65	4288	5	1	5	2	2.07
Ecosystem 3	34319.65	5075	5	1	5	2	2.26
Ecosystem 4	34319.65	5337	5	3	5	2	2.45
Ecosystem 5	57199.41	8010	5	1	5	2	2.33
Ecosystem 6	57199.41	7835	5	2	5	2	2.35
Ecosystem 7	11439.88	1209	5	3	5	3	2.99

(Note: 1) The evergreen broadleaf forest ecosystem, 2) The mixed bamboo and wood ecosystem, 3) The bamboo ecosystem, 4) The planted forest ecosystem, 5) The shrub ecosystem, 6) The agricultural ecosystem, and 7) The aquatic ecosystem

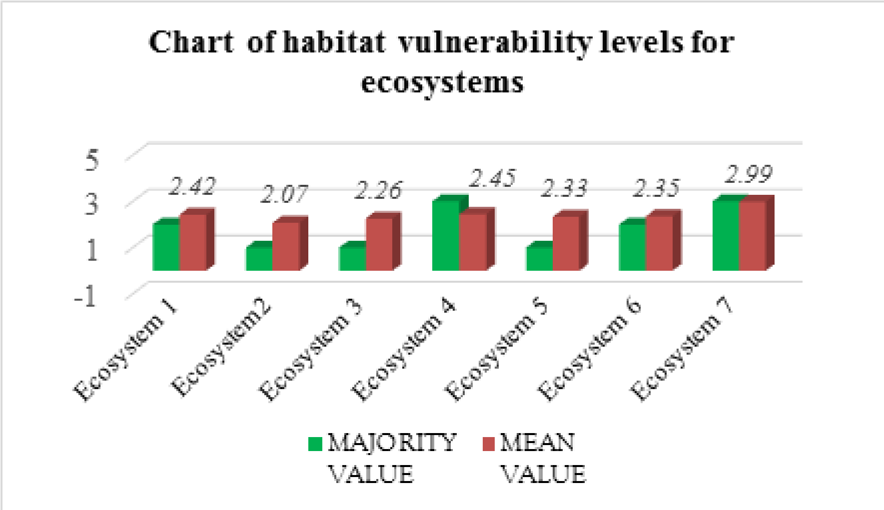
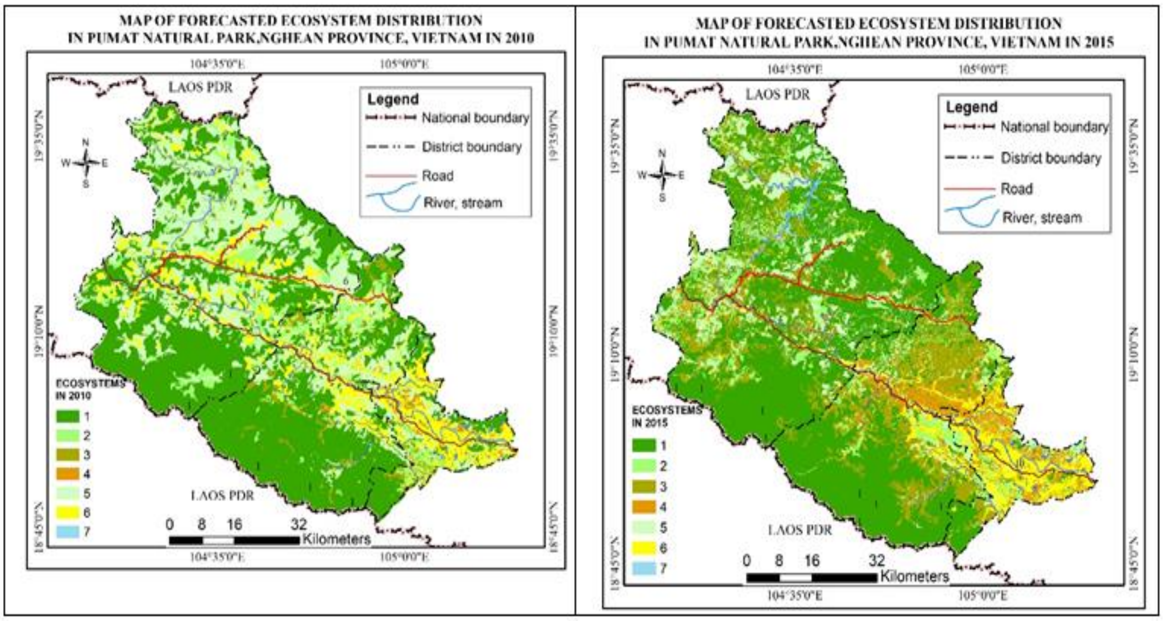


Figure 5: Chart of Ecosystems' habitat vulnerability levels

3.3. Ecosystem Change Trend

The forecasted ecosystem distribution map for Pu Mat National Park in 2030, created using the MOLUSCE model and influenced by various factors like terrain elevation and population density, distance to roads, and distance to rivers and streams highlights several key trends. Due to strict protection and biodiversity laws, the western mountainous region retains a stable evergreen broadleaf forest. Expansion of the evergreen broadleaf forest is observed in Tuong Duong district's buffer zones and specific communes in the east. Mixed wood-bamboo forests and bamboo forests grow in the northwest but decline in the eastern parts of Tuong Duong. Shrubland and grasslands decrease in high-altitude forests but increase in the valleys along the Con River due to ecological succession from human activities. Agricultural areas remain stable, reflecting the consistent use of available land for farming in a predominantly mountainous region. Further model refinement is needed to improve accuracy by incorporating additional influencing factors.



International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 1, 2025
https://www.theaspd.com/ijes.php

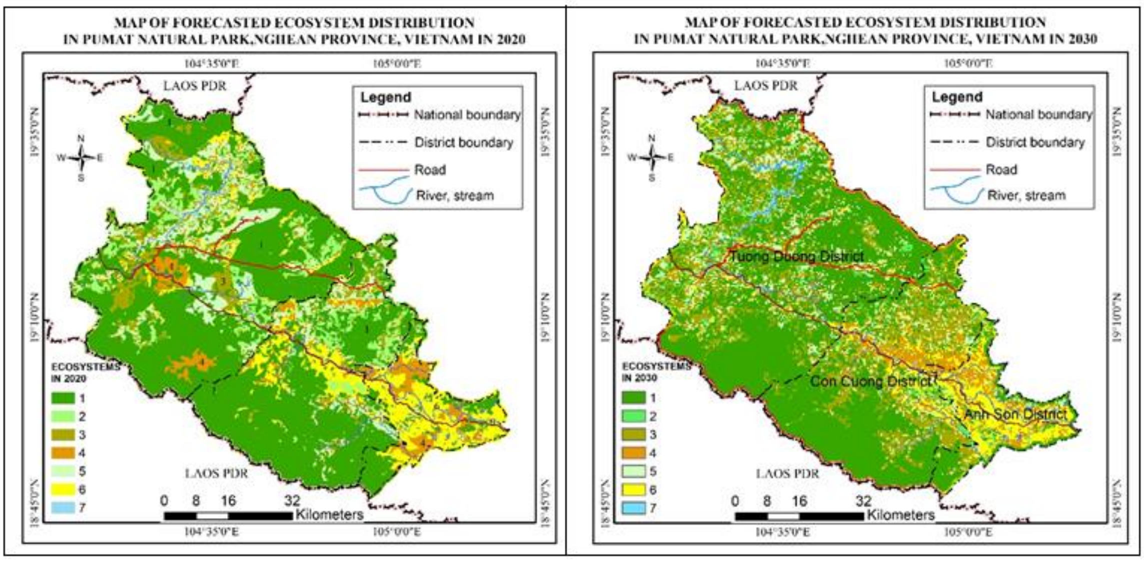


Fig 6: Map of ecosystem distribution in Pu Mat National Park

(a: in 2010; b: in 2015; c: in 2020; d: forecasted in 2030)

The following variables are used to evaluate the correlation between these impacts and habitat vulnerability: population density, drought level, vegetation cover, digital elevation model (DEM), and two additional variables related to social impact (road density) and another natural impact (river density).

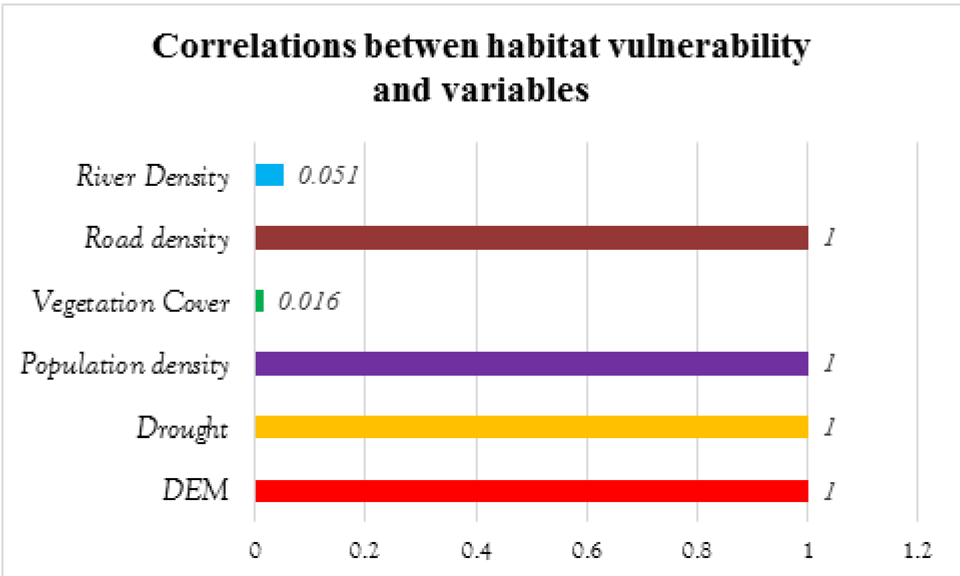


Figure7: Correlations between habitat vulnerability and variables

The values have been calculated for 220 sites, where the dependent variable was the six influencing factors and the independent variable was the level of habitat vulnerability. This suggests a perfect correlation between habitat vulnerability, population density, road density, and drought. A high positive correlation exists between vegetation cover and DEM (r = 0.834). These correlations suggest that vegetation cover is greatly influenced by elevation. River density has a minimal direct influence on habitat vulnerability, as shown by its r = 0.453.

3.4. Ecological Indicators

a. LSI Indicators

The graph illustrates changes in the Landscape Shape Index (LSI) for ecosystems from 2010 to 2030. Many ecosystems, including Ecosystems 3 and 5, reached the highest LSI peak in 2015 (with values of 43.83 and 38.50, respectively), indicating significant landscape irregularity or fragmentation at the time, followed by a decrease in later years. Ecosystems 1 and 2 remained stable at around 25.0, while Ecosystems 6 and 7 consistently had low LSI values (around 20.0 and 14.0), indicating simpler ecosystem units. These trends indicate potential relationships between land use changes, urbanization, and conservation activities, with the post-2015 decline indicating likely ecosystem unit restoration or reduced fragmentation.

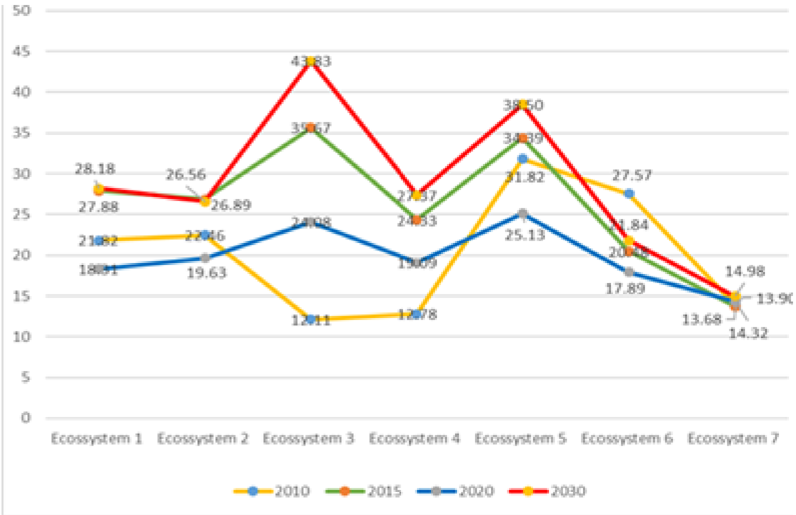
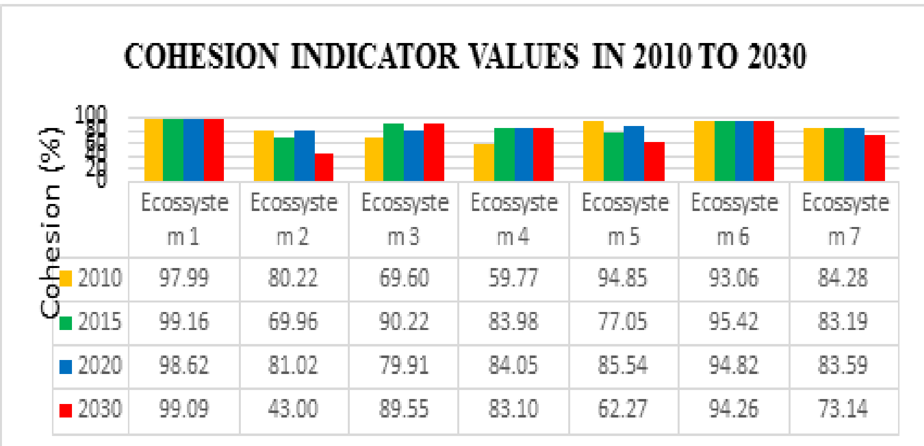


Figure8: LSI indicator's value from 2010 to 2030

b. Cohesion Indicators

The graph represents changes in the Cohesion Indicator for ecosystems from 2010 to 2030, which reflect habitat connections. Ecosystems 1 and 6 had strong cohesion throughout, indicating stable, well-connected landscapes (with values of approximately 98% and greater than 93%). Ecosystems 3 and 4 showed increasing trends, indicating that conservation efforts have resulted in enhanced connectivity. Cohesion for Ecosystem 3 increases from 59.77% in 2010 to 83.98% in 2015, then stabilizes at this level in subsequent years. Cohesion for Ecosystem 4 increases from 59.77% in 2010 to 83.98% in 2015, then stabilizes at this level in the years following.



	Ecossystem 1	Ecossystem 2	Ecossystem 3	Ecossystem 4	Ecossystem 5	Ecossystem 6	Ecossystem 7
2010	97.99	80.22	69.60	59.77	94.85	93.06	84.28
2015	99.16	69.96	90.22	83.98	77.05	95.42	83.19
2020	98.62	81.02	79.91	84.05	85.54	94.82	83.59
2030	99.09	43.00	89.55	83.10	62.27	94.26	73.14

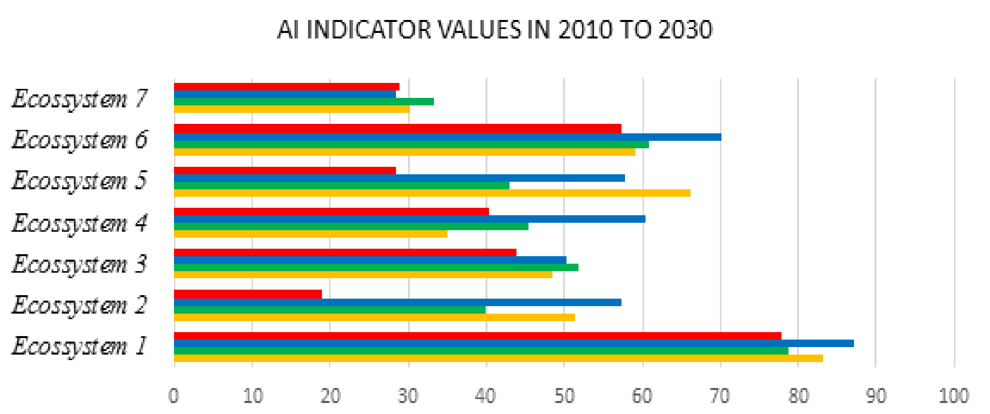
Figure9: Cohesion indicator's value from 2010 to 2030

C. Ai Indicator

Ecosystem 3 observed moderate moves around 45.0, with some improvement but ongoing fragmentation. Ecosystem 4 initially improved but then somewhat decreased (from 34.94% in 2010 to

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 1, 2025
https://www.theaspd.com/ijes.php

60.43% in 2020). Ecosystem 5 experienced chronic fragmentation with low AI values (varying from 28.29% in 2010 to 43.02% in 2020), whereas Ecosystem 7 exhibited consistently low aggregation (ranging from 28.76% to 30.27%). Overall, ecosystems with high AI values demonstrate good management, whereas those with low or deteriorating AI values require immediate restoration.



	Ecosystem 1	Ecosystem 2	Ecosystem 3	Ecosystem 4	Ecosystem 5	Ecosystem 6	Ecosystem 7
2030	77.86	18.89	43.89	40.39	28.29	57.35	28.76
2020	87.13	57.40	50.31	60.43	57.76	70.13	28.44
2015	78.70	39.86	51.90	45.47	43.02	60.83	33.25
2010	83.23	51.26	48.59	34.94	66.09	59.11	30.27

Figure10: AI indicator's value from 2010 to 2030

d. Diversity Indicators

The six diversity indicators show a general boost in diversity and evenness from 2010 to 2015, with some fluctuations and minor declines in 2020, before recovering slightly or stabilizing by 2030.

SHDI (Shannon's Diversity Index): Shows a general increase in diversity, peaking at 1.49 in 2015 and slightly decreasing in 2020 before rising again in 2030 to 1.46.

SIDI (Simpson's Diversity Index): Shows fluctuations without a distinct rising or downward trend, peaking in 2015 (0.69) and falling in 2020 (0.63) before recovering by 2030 (0.68).

MSDI (Modified Simpson's Diversity Index): Increases from 1.09 in 2010 to 1.17 in 2015, then decreases somewhat through 2020 (1.07) and 2030 (1.04).

SHEI (Shannon's Evenness Index): Shows an overall upward trend, rising from 0.68 in 2010 to 0.77 in 2015, then declining to 0.72 in 2020 before recovering to 0.75 in 2030.

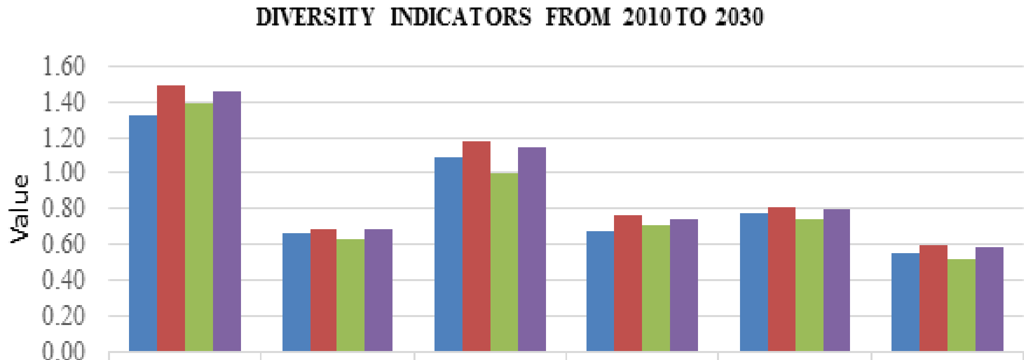
SIEI (Simpson's Evenness Index): Rises slightly from 0.77 in 2010 to 0.81 in 2015, then falls to 0.74 in 2020 before rebounding to 0.80 in 2030.

MSIEI (Modified Simpson Evenness Index): Varys minimal between 0.56 in 2010 and 0.59 in 2030, but remains constant overall.

Overall, SHDI (Shannon's Diversity Index), SIEI (Simpson's Evenness Index), and SHEI (Shannon's Evenness Index) highlight improved diversity and evenness in the community across the period. These show overall positive growth trends, indicating increasing diversity and evenness over time.

SIDI (Simpson's Diversity Index) and MSIEI (Modified Simpson Evenness Index) fluctuate without a clear trend, while MSDI shows a slight decline after 2015.

SHDI measures diversity by considering species richness and evenness. There is an increase from 2010 (1.32) to 2015 (1.49), suggesting higher diversity. A slight dip occurs in 2020 (1.39) before rising again in 2030 (1.46). - Trend: Overall positive trend from 2010 to 2030.



	SHDI	SIDI	MSIDI	SHEI	SIEI	MSIEI
2010	1.32	0.66	1.09	0.68	0.77	0.56
2015	1.49	0.69	1.17	0.77	0.81	0.60
2020	1.39	0.63	1.00	0.72	0.74	0.52
2030	1.46	0.68	1.15	0.75	0.80	0.59

Figure11: Diversity indicators' values from 2010 to 2030

3.5. DISCUSSION

This research applies Jie Gong et al.'s (2021) ecosystem vulnerability assessment method, which focuses on factors that influence vulnerability and how they manifest in natural systems. The research gives a complete understanding of habitat vulnerability in Pu Mat National Park through the analysis of geographical, climatic, demographic, and social characteristics. The vulnerability and component maps produced using DEM, satellite imagery, thematic maps, and area statistics provide accurate and actionable information. These maps show the scope and importance of vulnerability indicators, enabling more informed conservation planning and biodiversity protection.

Unlike typical biodiversity studies, which largely focus on species and ecosystem classification, this study fills a vital vacuum by investigating the relationship between habitat vulnerability, ecosystem distribution, and contributing variables. The use of GIS technologies improves accuracy, allows for updates, and allows for revisions to vulnerability maps, ensuring that the approach is responsive to changing data and conservation needs.

The findings emphasize the significance of focused conservation campaigns, with maps highlighting areas of high vulnerability and the primary drivers contributing to ecosystem degradation. These insights can help identify priority zones for biodiversity conservation and suggest mitigation strategies suited to specific threats. Furthermore, this strategy promotes efficient time management, allowing managers to swiftly identify and address sensitive sites, reducing ecological damage and supporting long-term conservation strategies.

Overall, this study highlights the importance of integrating habitat vulnerability assessments with spatial analysis for making feasible solutions for ecosystem and biodiversity conservation, as well as offering an established basis for regional planning and resource management.

4. CONCLUSION

Habitat vulnerability assesses the sensitivity of an ecosystem to external disturbances, which are impacted by vegetation, topography, drought, and population density. The vulnerability range in Pu Mat National Park is 2.07 to 2.99, with no obvious relationship between ecosystem size and vulnerability. Larger ecosystems, such as Ecosystem 1, have a low vulnerability (2.42), but smaller ones, like Ecosystem 7, have a high vulnerability (2.99). These findings highlight the necessity of measuring habitat vulnerability to direct conservation efforts, improve nature reserves, and maintain biodiversity.

The 2030 ecosystem forecast for Pu Mat National Park highlights stable evergreen broadleaf forests in protected areas, with expansion in buffer zones and declines in mixed wood-bamboo forests in certain regions. Shrublands and grasslands decrease in high-altitude areas but increase in valleys due to human activity. Agricultural land use remains steady. Habitat vulnerability analysis across 220 sites shows strong correlations with population density, road density, and drought, while vegetation cover is highly influenced by elevation. River density has minimal impact. Improved modelling is recommended for greater accuracy.

The analysis of the six diversity indicators from 2010 to 2030 indicates a strong trend toward increased biodiversity and evenness within the observed organization. While specific indicators, such as SHDI, SHEI, and SIEI, show steady positive growth, others, such as MSDI, SIDI, and MSIEI, show fluctuations or minor losses. Despite these variances, the overall trend implies that efforts to enhance ecological balance and variety have had a favourable impact, particularly in terms of species richness and evenness. The findings emphasize the need to track diversity indices to better understand ecosystem health and guide future conservation efforts.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the project: "Assessing ecological indicator for biodiversity conservation in the area of Pu Mat National Park, Vietnam", belonging to the Institute of Geography, Selective Base Mission at the Institute of Geography, with code: CSCL10.01/24-24. Project Manager: PhD. Nguyen Van Hong.

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