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Recent Land Use Land Cover Change Tendencies in Continental Portugal: Are They Sustainable?

Luís Quinta-Nova

Abstract

The Land Use Land Cover (LULC) pattern is fundamental to the structural framework of landscapes, playing a key role in effective landscape management. Additionally, the growing impact of human activities on the ecological environment has become a significant concern. This study aimed to investigate the relationship between human disturbance intensity and the configuration and quality of landscape patterns. The objectives were to analyze the spatiotemporal dynamics of landscape changes and human disturbance associated with land-use changes in Continental Portugal from 1990 to 2018 and to examine how landscape change trajectories relate to human disturbance and naturalness metrics, assessing their potential as sustainability indicators. Landscape configuration was evaluated by using various land-use metrics, including Mean Patch Size, Mean Shape Index, Total Edge, and Mean Patch Fractal Dimension. These metrics were derived from LULC data obtained from the Corine Land Cover databases (1990, 2006, and 2018). Patch and landscape-level metrics were calculated for 163 quadrats of 25 km² each, covering the country, using the Patch Analyst plugin in ArcGIS 10.8. The Hemeroby Index (HI) was used to quantify the degree of human-induced disturbance in the landscape. Correlation analysis was performed to identify statistical relationships between changes in landscape metrics and HI. The results revealed a negative correlation between the Total Edge metric changes and human disturbance, suggesting that greater landscape complexity corresponds to lower disturbance levels. These findings support using landscape metrics as indicators of human disturbance,

aligning with previous research. Integrating structural and quality indicators can provide valuable insights for planners and decision-makers, aiding in analyzing regional land-use trends and supporting sustainable landscape management.

Keywords

GIS · Landscape pattern · LULC change · Sustainability

1 Introduction

The impact of human activities on the structure and functionality of landscapes is an increasing concern, making its monitoring a key focus and essential area of research in landscape ecology (Geri et al. 2010; Li et al. 2017). Some scientific studies have focused on the spatial variability of disturbance resulting from human action and its relationship with the differentiation and evolution of landscape patterns (Szilassi et al. 2017; Wu et al. 2021).

To attain sustainability, strategies must account for multiple dimensions, including environmental, social, and economic factors across different temporal and spatial scales (Villeneuve et al. 2017). Understanding how societies utilize and manage land to achieve specific land use outcomes is essential. Therefore, adopting a holistic approach to land use—incorporating integrated sectoral policies and targeted policy instruments—necessitates various compromises (Vulevic et al. 2022; European Environment Agency, 2019).

The pattern/process paradigm suggests that ecological processes are influenced by landscape patterns, and landscape structure metrics serve as effective tools for measuring these patterns, reflecting the spatial configuration of the landscape mosaic (Wrbka et al. 2004; Liu et al. 2020). Landscape metrics tools support landscape planning and management decisions by offering a comprehensive view of landscape structure.

L. Quinta-Nova (✉)
School of Agriculture, Polytechnic University of Castelo Branco,
Castelo Branco, Portugal
e-mail: lnova@ipcb.pt

They assess the quantification of the arrangement and content (diversity and abundance) of a landscape, as well as the spatial arrangement (features, placement, or orientation of patches) of its components (Forman 1995).

Also, the Hemeroby index (HI) has been used in different studies (e.g., Szilassi et al. 2017; Wu et al. 2021; Jalas 1955) to quantify the changes in landscape structure and function caused by human activities (Sukopp 1976). There is a direct proportional relationship with a positive sign between the degree of hemeroby and the level of disturbance and transformation of the most disturbed landscape due to human causes (Tian et al. 2020).

Environmental and spatial indicators are essential for assessing the impact of human activities on landscapes and ecosystems. They support decision-making, facilitate ecological monitoring, and guide the development of effective landscape management policies that promote sustainable development.

The aim of this study is (1) to analyze the spatiotemporal dynamics of landscape in Continental Portugal between 1990 and 2018, and to relate it to the implementation of a set of agri-environmental measures resulting in a growing extensification of production systems following Portugal's entry into the EU, which resulted in the implementation of the reform of the CAP (Common Agricultural Policy) in 1992; and (2) to explore the link between LULC change trajectories and anthropic disturbance/naturalness metrics, highlighting how trends in landscape pattern changes can serve as indicators of sustainability.

2 Materials and Methods

2.1 Study Area

The study area encompasses the entire mainland Portugal, which covers an area of 89,073 km² and is located in the western part of the Iberian Peninsula. Mainland Portugal has a population of 10,352,042, with over 60% residing in the metropolitan areas of the two major cities, Lisbon and Porto.

2.2 Methodology

The Corine Land Cover databases (CLC 1990, 2006, and 2018) were used to derive values for various landscape indices. Landscape-level and class-level metrics were quantified across 163 quadrats, each covering 25 km², forming a grid spanning Mainland Portugal. Landscape metrics were computed using the Patch Analyst extension within ArcGIS 10.8. Land-use and land-cover (LULC) classes were converted into a hemeroby seven-point scale, spanning from ahemerobic (no human influence) to metahemerobic

(completely altered biocenosis). Based on that classification, an average value was then calculated for each 25 km² grid cell.

We proceed to the quantification of the structure of the landscape using a set of landscape metrics. The selection of landscape metrics was guided by several criteria: (1) they should effectively represent and define the dimensions of spatial pattern characteristics; (2) they should be easily calculable and nonredundant; and (3) they should have been previously used in relevant similar studies.

Metrics describing patch area distribution, such as Mean Patch Size (MPS), characterize the area allocation among patches at both class and landscape levels. The Mean Shape Index (MSI) represents the average patch structure within the landscape and indicates landscape fragmentation. Total Edge (TE) includes all edges in the landscape, and it measures the configuration of the landscape. Mean Patch Fractal Dimension (MPFD) quantifies the level of complexity of a landscape (McGarigal and Marks 1995).

The correlation between landscape metric values' temporal change and the changes in Hemeroby index values was assessed using IBM SPSS Statistics 22 software. The Shapiro-Wilk test was first applied to test the variables' normality. However, the nonparametric Spearman's correlation coefficient was used since most variables do not follow a normal distribution (Sokal and Rohlf 1969).

3 Results and Discussion

In the studied period, the increased LULC categories were seminatural areas, artificial surfaces, pastures, and waterbodies, while forest and agricultural areas. The transitions from forest to seminatural areas correspond to 35% of all LULC changes in Portugal, with a significant amount of agricultural land also changing to seminatural areas (14% of total changes). The change from other LULC classes to seminatural areas corresponds to 54% of total changes in the country in the studied period.

The reduction of agricultural land was low due to the gain in surface mainly from the forest (15% of total changes) but with losses to urban growth (6% of total changes). The increase in urban areas was relatively low (8% of total changes).

The country's average Hemeroby index value remained stable during the study period. In 1990, the index value was 3.88 ± 0.42 , then slightly increased to 3.90 ± 0.42 , 3835 ± 0.759 in 2006, and maintained at 3.90 ± 0.41 in 2018. This corresponds to a β -euhemerobic level, which indicates moderate to high human impacts.

The LULC and Hemeroby Index change trajectories identified in Portugal between 1990 and 2018 are presented in Fig. 1.

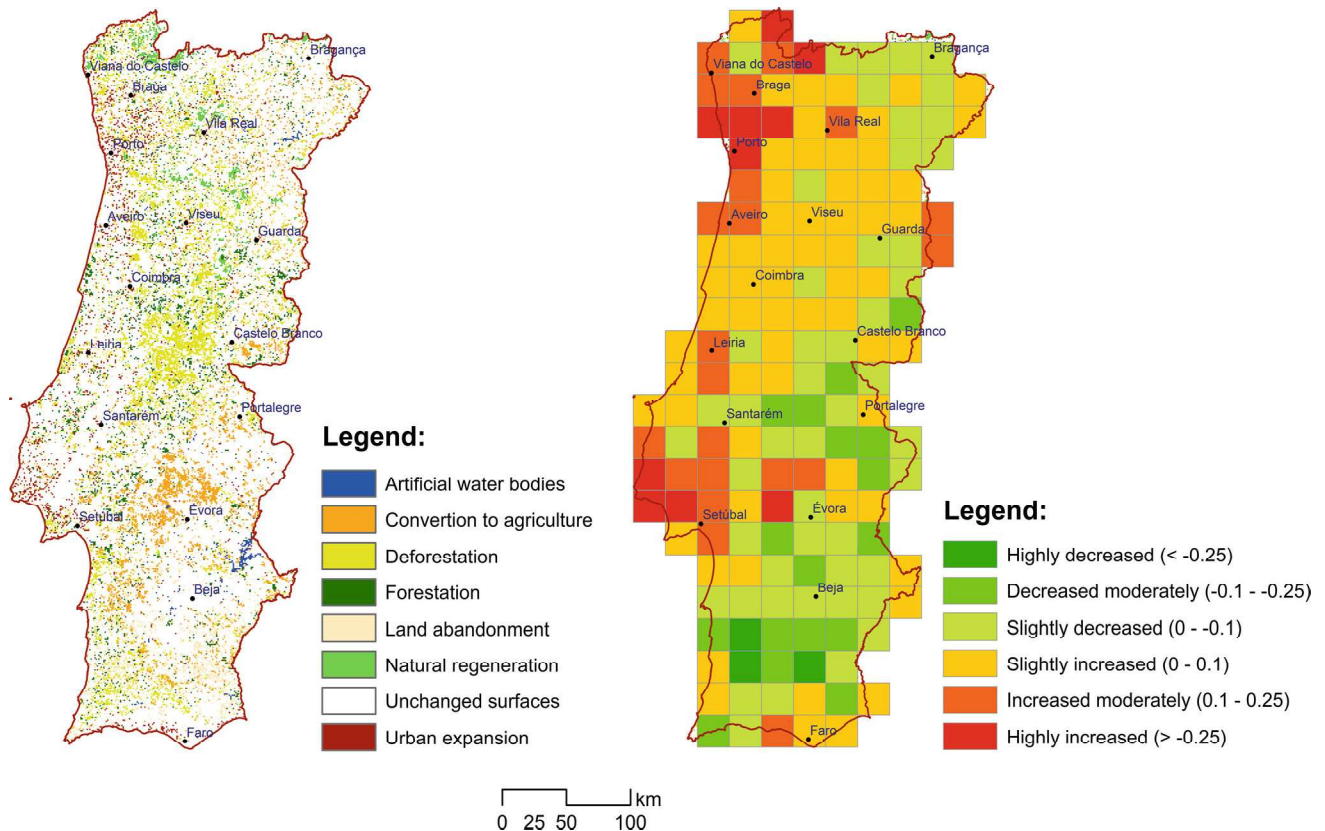


Fig. 1 LULC and Hemeroby level trends for 1990–2018

Based on the analysis of changes in the LULC, the main alteration in use corresponds to the reduction of the forest area (35.9% of the total alterations), followed by the conversion to agriculture (20.6%). Land abandonment and urban expansion also have some expression corresponding to 14.5% and 13.7%, respectively.

The reduction in forest area was due to the larger forest fires that occurred in 2017 in the central region of Portugal, while there was, on the other hand, a significant increase in forest area in the other regions. Also, the conversion into agricultural areas corresponds to the implementation of the irrigated area of the Alqueva Reservoir, with the installation of olive groves in intensive and super-intensive modes in the Alentejo region.

By analyzing the changes in the Hemeroby index value between 1990 and 2018 (Fig. 1), we observed that the level of naturalness increased in 58% of the studied areas, while it decreased in the remaining.

Concerning the variation in the average values of landscape metrics, TE, MSI, and MPFD values increased during the 28 years, indicating an increase in landscape complexity. Conversely, the MPS value declined, indicating a reduction in patch size (Fig. 2).

The results of the analysis conducted to examine the correlation between the Hemeroby index change and the LULC pattern indexes show that Total Edge (TE) exhibited a moderate negative correlation with the Hemeroby index ($\rho = -0.438, p < 0.01$). This suggests that complex landscapes are associated with lower levels of hemeroby. No significant correlation was found between the Hemeroby index and the other metrics.

4 Conclusions

This study conducted a comprehensive analysis using GIS-based spatial techniques and spatial pattern metrics to examine LULC change trajectories and their impact on sustainability in Continental Portugal.

Landscape metrics and the Hemeroby Index are essential tools for analyzing LULC changes and validating findings from previous studies in various countries. A combination of structural and hemeroby indicators of landscape patterns can support planners and decision-makers in assessing regional trends and developing policies to minimize human impacts on ecosystems.

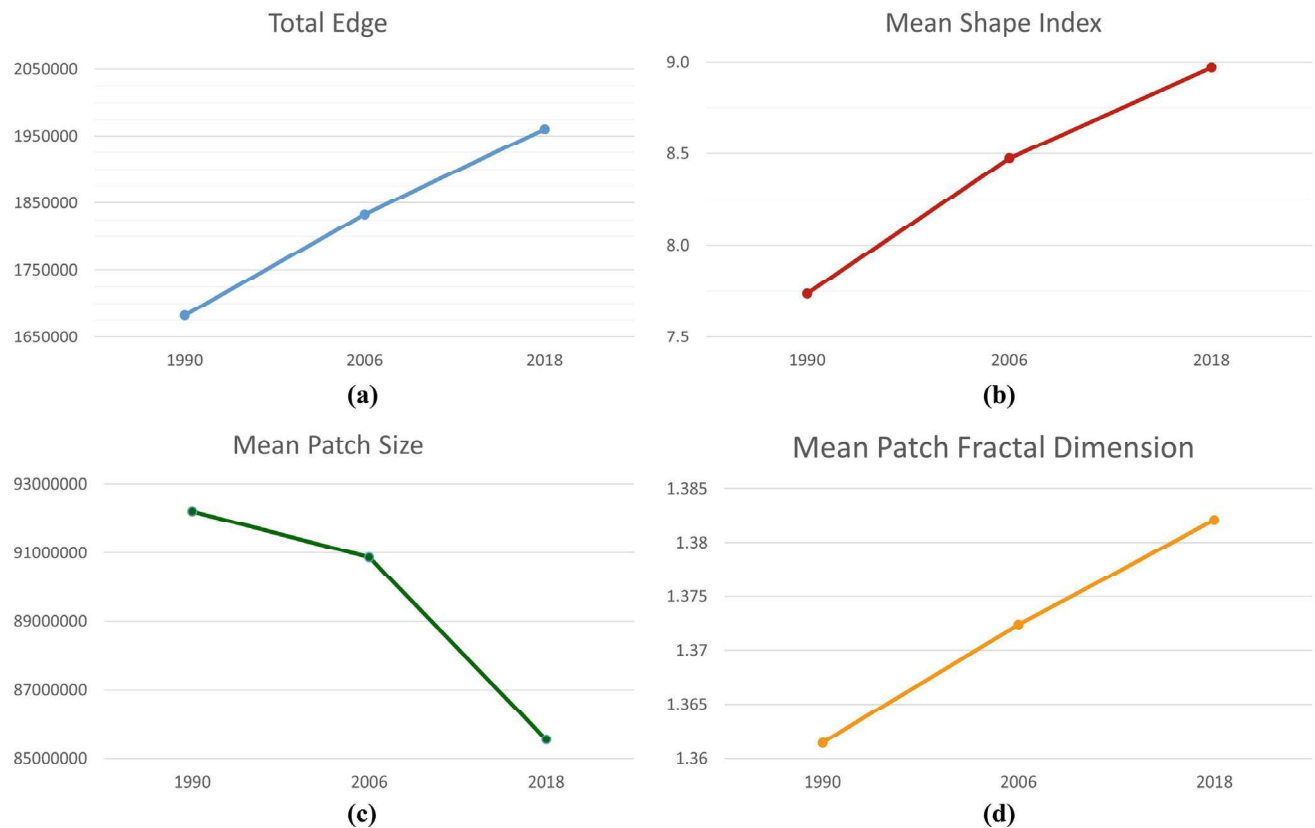


Fig. 2 Change in landscape pattern indices values between 1990 and 2018: **a** total edge; **b** mean shape index; **c** mean patch size; **d** mean patch fractal dimension

The results obtained from quantitative and qualitative LULC metrics can be incorporated into a nationwide system to monitor the execution of spatial plans and their effects on land systems.

This approach would give decision-makers intricate insights into the transformations unfolding across the territory at varying scales. Over time, this continual assessment of indicators would facilitate a comprehensive understanding of the changes occurring in LULC patterns, allowing for a more informed analysis of the impact on the environment and a basis for effective policy formulation and planning.

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