Relationship Between Landscape Pattern and Human Disturbance from 1990 to 2018 in Mainland Portugal

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Abstract

The land use/land cover pattern of landscapes as the main element of the landscape structure has an important role in landscape management, nature conservation, and preservation, considering its ability to provide valuable information about the spatial distribution and changes in land cover that occur on the Earth's surface. On the other hand, human activities have caused significant impacts on ecosystems, resulting in a loss of biodiversity, increased risks of erosion and soil degradation, and wildfires. In the last few decades, the growing trend of occurrence of negative effects on land use/land cover has not contributed to the achievement of sustainable development goals (SDGs), considering that the relationship between humankind and the environment is an extremely fragile equilibrium. In recent decades, large-scale land use and land cover (LULC) patterns have shown stability, but there have been significant dynamics observed specifically in forest areas and agricultural land. Among these changes, the conversion of maritime pine to eucalyptus stands out as the most relevant transition in terms of forest and agroforestry use classes. This conversion is a result of economic incentives available, which have contributed to the gain in forested areas. This study intends to verify how the alteration of the landscape configuration, represented by different metrics of configuration and diversity, is related to the intensity of human disturbance. The objectives of the study are: (1) to quantify the change in land use/land cover (LULC) patterns and the degree of human disturbance in Mainland Portugal between 1990 and 2018, and (2) to study the relationship between LULC configuration and the impact resulting from human disturbance under different levels of intensity, to understand how changing trends in landscape pattern can serve as indicators to estimate landscape changes resulting from human actions. The Hemeroby index (HI) was calculated to quantify the impacts on ecosystems resulting from disturbance caused by human actions. Based on the Hemeroby index value analysis for the period between 1990 and 2018, the level of naturalness increased in 58% of the country, mainly in the south and east of Portugal. The landscape pattern was quantified using a set of metrics, namely Mean Patch Size (MPS), Mean Shape Index (MSI), Total Edge (TE), Mean Patch Fractal Dimension (MPFD), and Mean Perimeter-Area Ratio (MPAR). To identify the existing statistical correlations between the geometric parameters of the landscape and the HIs values, the Spearman method was used. At the landscape level, the metrics TE and MSI have a strong negative correlation with HI. This suggests that landscapes with greater structural complexity are good indicators of low levels of hemeroby. At the class level, edge density (ED) and mean patch size (MPS) showed a significant correlation with the Hemeroby index for seminatural areas (all metrics), artificial surfaces and forests (TE, MSI, and MPS), agricultural areas (TE, MPS, and MPFD), and Bare Ground (TE, MSI, and MPFD).

Keywords: land use, landscape pattern, human disturbance, portugal

Introduction

The impact of human activities on the structure and functionality of the landscape is a growing concern, and its monitoring has become one of the critical points and essential areas of research in landscape ecology [1,2]. 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 [3, 4].

To achieve sustainability, it is essential to employ suitable approaches that consider its diverse dimensions, including the environmental, economic, and social aspects at various spatial and temporal scales [5-6]. Then, understanding how societies use, manage, and interact with land is crucial [7-8]. For this reason, a combined and comprehensive approach to land use, employing integrated sectoral policies and targeted policy instruments, implies many compromises [9].

In terms of the transformation of agroforestry spaces in mainland Portugal, during the Estado Novo regime, there was an increase in agricultural occupation and production forestry, culminating in the 50s/60s, with the arable area reaching its limit in terms of occupation of medium to high-capacity soils [10]. The policies to encourage cereal crops and the high population density in rural areas contributed to this. The promotion of production forest occupation was also implemented during the Estado Novo, with the aim of compensating for the decrease in native forests over the previous centuries [10].

At the end of the XX century and beginning of the XXI, in view of the land abandonment of rural spaces (Rural Exodus) and the entry of Portugal from the EU, resulting in the implementation of the reform of the CAP (Common Agricultural Policy) in 1992, with the intentional removal of agricultural land from the productive system, there was an implementation of a set of agro-environmental measures resulting in a growing extensification of production systems [10].

In terms of urban dynamics, between the 1960s and 1980s, as a result of the rural exodus, the metropolitan areas of Lisbon and Porto, and other cities located on the coastline, sought to live and work. In these areas, urban growth of great magnitude and little sustainability was witnessed, combined with inefficient municipal planning, in which real estate interests asserted themselves, jeopardizing the balance of ecological systems. After the change to a democratic regime in Portugal, a phase of territorial planning was entered, with the creation of instruments for management and spatial planning, gradually leading to more efficient regulation of land occupation, namely the generalized implementation of municipal planning plans and the creation of the National Ecological Reserve and the National Ecological Reserve, starting in the 1980s [11].

According to the pattern/process paradigm, it is believed that ecological processes are affected by the pattern of the landscape [12], and landscape structure metrics are appropriate for measuring these patterns, which represent the spatial configuration of the landscape mosaic [13]. Landscape metrics tools are used to support landscape planning and management decisions by offering a comprehensive view of landscape structure. 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 [14]. With advances in remote sensing, Geographic Information Systems (GIS), and computation, the analysis of large datasets representing various aspects of landscape patterns has become more feasible.

Also, the Hemeroby index (HI) is an indicator that has been used in different studies (e.g., [3-4, 15]) to quantify the intensity of changes in landscape structure and function resulting from human activities in a landscape [16]. There is a directly 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 [17]. The degree of hemeroby serves as an integrative measure for the impacts of human activities on ecosystems, whether intended or not. It measures the human impact level/naturalness of an area, indicating the deviation from potential natural vegetation [18]. The higher the level of hemeroby, the greater the extent of human influence, leading to increased disturbance and transformation of the landscape. [3]. The Hemeroby index is measured using indicators such as the share of neophytic and therophytic species, morphological and chemical soil features, and land use types. It can be classified into seven levels concerning the degree of naturalness [19].

Several authors emphasize that their class-level landscape pattern can be used more effectively in the estimation of human disturbance level than those landscape-level analyses that were calculated based on the total number of patches [3]. Therefore, it is important to complement the analysis of the relationships between the alteration of the landscape mosaic and the degree of hemeroby at the landscape level with the changes at the level of the LULC classes in order to achieve a more detailed analysis of the LULC tendencies and to select the more suitable indicators. In this study, we used both approaches (landscape and class level) to better understand the phenomena.

In short, environmental indices are valuable tools for understanding the impact of human interventions on ecosystems and landscape patterns. They aid in decision-making, monitoring environmental changes, and formulating effective landscape management policies promoting sustainable development.

The aim of this study is: (1) to quantify the change in LULC patterns and the degree of human disturbance in Mainland Portugal between 1990 and 2018, and (2) to study the relationship between landscape metrics and the impact resulting from human disturbance under different levels of intensity, to understand how changing trends in landscape pattern can serve as indicators to estimate landscape changes resulting from human actions.

Materials and methods

The study area encompasses the entire mainland Portugal, which covers an area of 89,073 km^2 and is situated in the western part of the Iberian Peninsula. Mainland Portugal has a population of 10,352,042 inhabitants, with over 60% of the population residing in the metropolitan areas of the two major cities, Lisbon, and Porto.

According to the Köppen classification, mainland Portugal's climate is divided into two regions: one encompasses the central and northern parts of the country and has a temperate climate characterized by a rainy winter and a dry and hot summer (Csa), and the other region covers the southern parts of Portugal and has a temperate climate with a rainy winter, and a slightly hot and dry summer (Csb). The northwestern mountains receive an average annual precipitation of approximately 3500 mm, while the southeastern areas of the country receive around 500 mm. Conversely, the average annual temperature follows the opposite pattern, with the highest values recorded in the southern region and the lowest values in the northeastern region.

In terms of altimetry, Mainland Portugal is divided between the mountainous terrain, in the north of the country, and the hills and plains, predominant from the center-south to the southernmost lands. This separation between two distinct geomorphological regions is made by the Tagus River, which crosses the country from west to east through the center. The average altitude is 372 meters.

Based on the CORINE Land Cover (CLC) data from 2018, the land cover distribution in Portugal can be summarized as follows: Approximately 3.8% of the country's land consists of artificial surfaces, 47.8% is designated as agricultural land, and 46.5% is covered by forests. The remaining portion comprises wetlands and water bodies (Figure 1) [20].

The territorial system in mainland Portugal is characterized by two different types of rural property regimes. The Northwest presents the smallholdings, in which the property is very divided, which contrasts with the Alentejo region, located in the south of the country, with large properties (latifundia). This dichotomy is associated with different bioclimatic influences and population densities. This contrast has persisted over the centuries and persists even considering the more recent context of changes, namely the land abandonment and the change in cultivation systems [21].

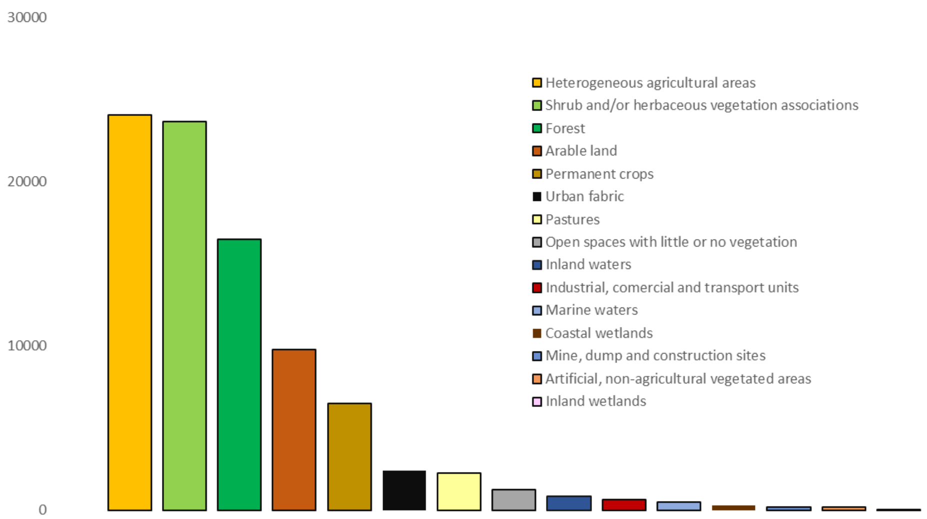

Fig. 1. Land use in mainland Portugal - 2018.

The Corine Land Cover databases (CLC 1990; CLC 2006; and CLC 2018) were used to calculate the values referring to the different landscape indices. Class-level and landscape-level metrics were calculated 163 quadrats of 25 km^2 each, corresponding to a grid covering Mainland Portugal. The Patch Analyst extension included in the Arc GIS 10.8 software was used to calculate the landscape metrics.

The LULC classes were transformed into a scale representing different levels of hemeroby, ranging from ahemerobic (no anthropogenic influence) to metahemerobic (destroyed biocenosis). This seven-point scale enabled the classification of LULC based on their corresponding degrees of hemeroby, as indicated in Table 1 [22]. Subsequently, an average value was computed for each 25 km^2 grid using the following equation:

$$M = \sum_{h=1}^{n} \text{fn} * h \quad (1)$$

n – Number of categories of hemeroby (here: $n = 6$)
fn – Proportion of the area of the category n
h – Hemeroby-factor
M -Hemeroby index

Tab. 1. Assignment of LULC types onto the Hemeroby scale.

Degree of hemeroby	LULC types
Oligohemerobic weak human impacts	Potential natural vegetation (PNV) forest. Natural habitats and other seminatural areas, like dunes and inland marshes.
Mesohemerobic moderate human impacts	Forest stands (not PNV). Scrub and/or herbaceous vegetation associations. Sparsely vegetated areas.
B-euhemerobic Moderate to strong human impacts	Pastures. Green urban areas. Inland waters. Heterogeneous agricultural areas with natural vegetation.
A-euhemerobic strong human impacts	Arable land and permanent crops. Artificial, non-agricultural vegetated areas
Polyhemerobic very strong human impacts	Discontinuous urban areas. Mine, dump, and construction sites
Metahemerobic Excessively negative human impacts	Continuous urban areas. Industrial, commercial and transport units.

The structure of the landscape was quantified through a set of landscape metrics shown in Table 2.

Tab. 2. Landscape metrics used in the study.

Structural feature	Index	Name	Description
Edges	TE	Total Edge	The total length of edges in a landscape involving a specific patch type includes the edges along the landscape boundary as well as the background segments associated with that patch type.
Area	MSI	Mean Shape Index	The measurement of average patch shape (complexity) refers to quantifying the spatial structure of patterns, typically land cover, within a specific class or for all patches present in the landscape.
	MPS	Mean Patch Size	The Mean Patch Size is calculated by dividing the total area occupied by patches in the landscape (or a specific class) by the count of patches within that area.
Shape complexity	MPFD	Mean Patch Fractal Dimension	MPFD characterizes the complexity of a patch based on its perimeter and area, describing the relationship between the size and shape of the patch.

Those landscape metrics were selected based on some criteria, namely: (1) these should represent and define the dimensions of the characteristics of spatial patterns; (2) these should be easily calculated and not be redundant; and (3) that they were previously adopted in similar studies considered relevant.

Metrics that describe the patch area distribution, such as the Mean Patch Size (MPS), allow for characterizing the area distribution between patches at the class or landscape level. Mean Shape Index (MSI) describes the patch structure in the landscape as that of the average patch characteristic and indicates the level of landscape fragmentation. Total Edge (TE) includes all edges in the landscape, and it measures the configuration of the landscape. Mean Patch Fractal Dimension (MPFD) describes landscape complexity [23].

The correlation between landscape metric values and the values associated with the Hemeroby index at both the landscape and class levels was assessed using IBM SPSS Statistics 22 software. The Shapiro-Wilk test was initially applied to assess the normal distribution of the variables. However, most of the variables did not follow the normal distribution. Hence, a non-parametric Spearman's correlation coefficient was utilized [24]. Using LULC maps from 2000, 2006, and 2018, the study identified landscape metrics that showed a statistically significant relationship with the Hemeroby index at a significance level of 0.01.

Results and discussion

The LULC maps for the years 1990, 2006, and 2018 are presented in Figure 2, and along with the changes in the surface area of the LULC classes between 1990 and 2018 are shown in Figure 3.

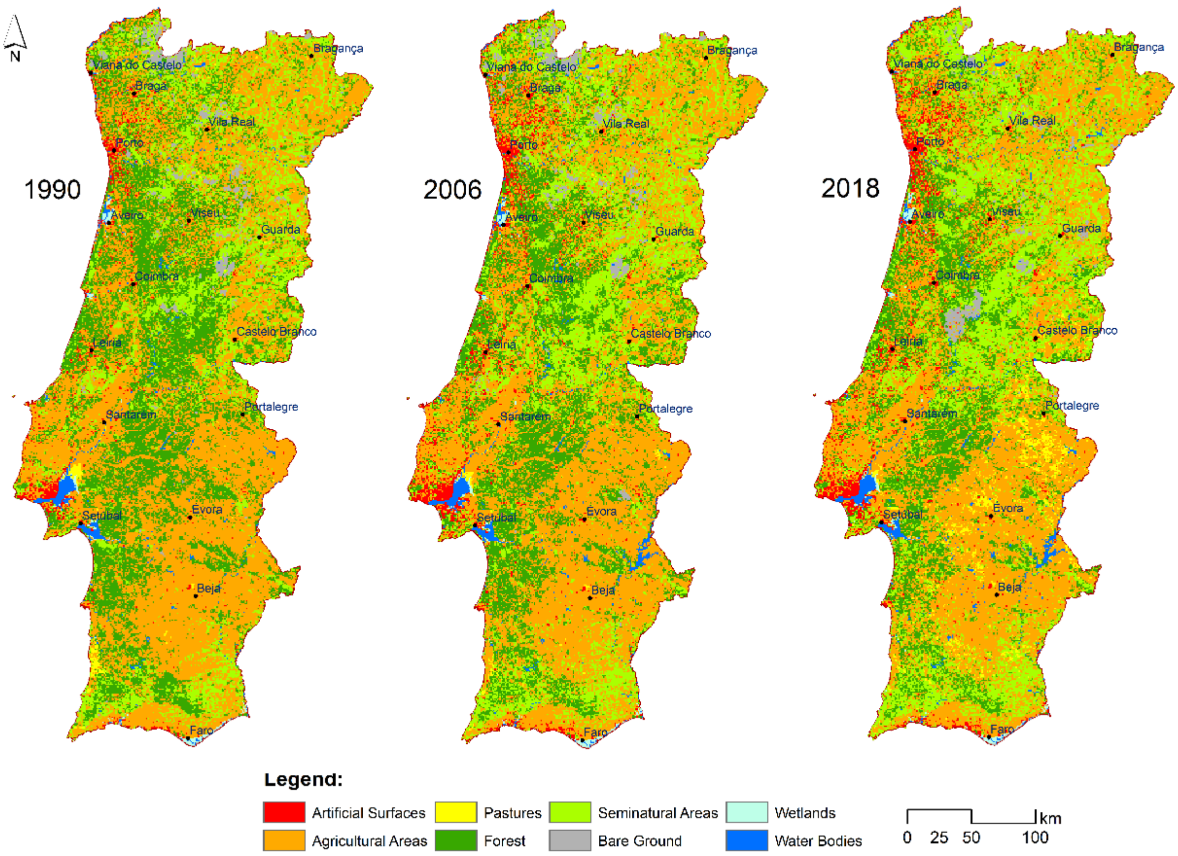

FIGURE 2. LULC changes between 1990 and 2018.

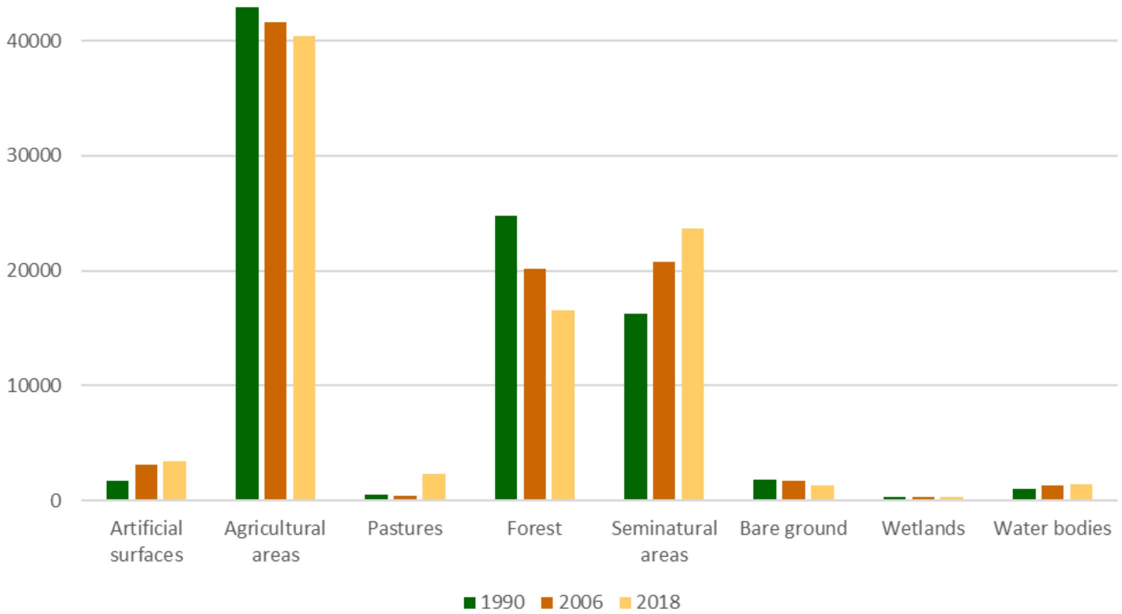

Fig. 3. LULC maps; (b) total area per LULC (km^2).

In the studied period the LULC categories that increase were seminatural areas, artificial surfaces, pastures and waterbodies, and forest and agricultural areas decreased.

The transitions from forest to seminatural areas correspond to 35% of all LULC changes in Portugal, with a significant area 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 period studied.

The reduction of agricultural land was not so high 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).

During the study period, the average Hemeroby index value for Portugal maintained stable. In 1990, the index value was 3.88 ± 0.42, then slightly increased to 3.90 ± 0.42, 3,835 ± 0.759 in 2006, and maintained in 3.90 ± 0.41 in 2018. These values correspond to a β-euhemerobic level, indicating moderate to strong human impacts (Figure 4).

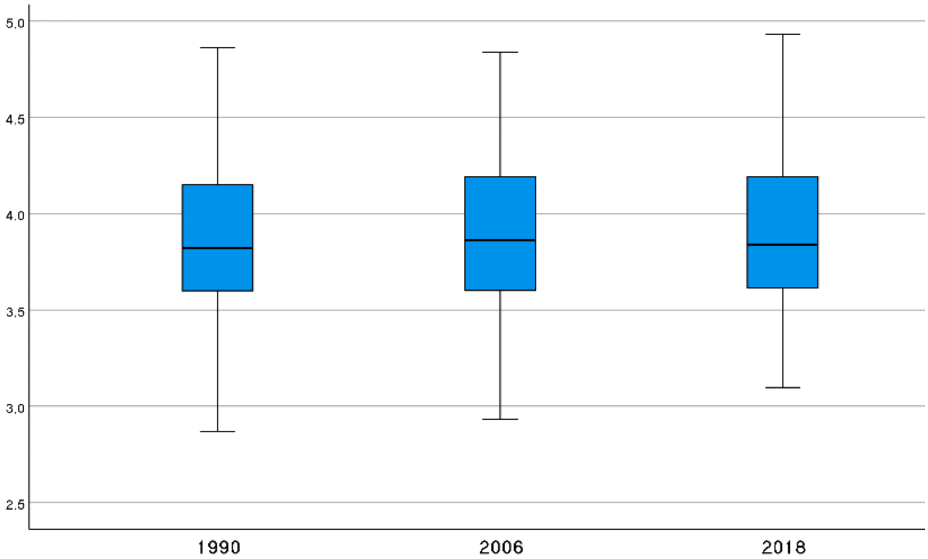

Fig. 4. Box-plots of the hemeroby index value by year.

The change of the average values for the landscape metrics obtained at a landscape level and at a class level are presented in Figure 5.

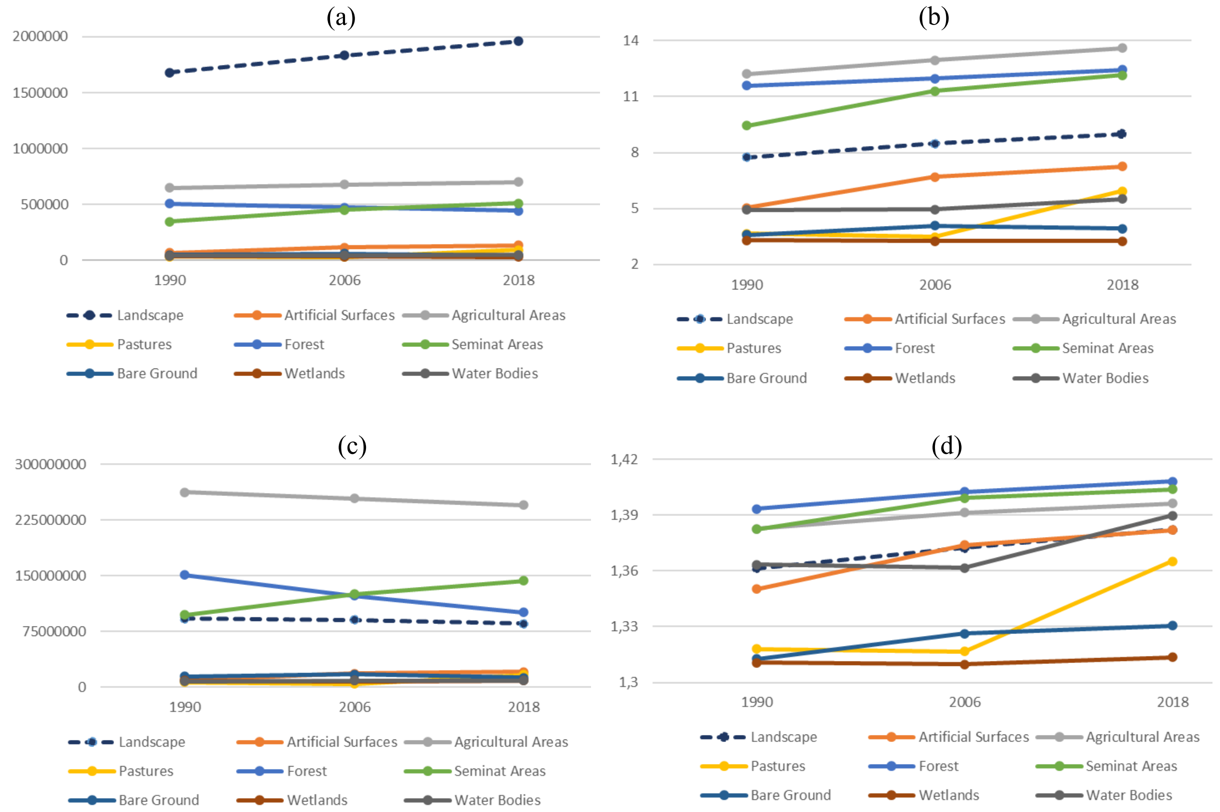

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Fig. 5. Landscape pattern indexes value change between 1990 and 2018: (a) Total Edge (TE); (b) Mean Shape Index (MSI); (c) Mean Patch Size (MPS); (d) Mean Patch Fractal Dimension (MPFD)

At a landscape level TE, MSI, and MPFD values increased during the 28 years' period, which indicates an increase in landscape complexity. On the other hand, MPS value decreased slightly corresponding to a reduction in the patch dimension. At a class level there is an increase in complexity in most classes, however, it is more expressive in pastures and in seminatural areas.

Table 3 presents the results of the analysis conducted to examine the correlation between the Hemeroby index and landscape pattern indexes. The findings reveal that, at the landscape level, two metrics, namely Total Edge (TE) and Mean Shape Index (MSI), exhibited a strong negative correlation with the Hemeroby index ($p < 0.01$) in the years 1990, 2006, and 2018. This suggests that complex landscapes are associated with lower levels of hemeroby. However, no significant correlation was found between the Hemeroby index and the other two metrics.

At a class level, significant correlations were observed between the Hemeroby index and TE and MSI for various land cover types, including artificial surfaces, forests, seminatural areas, bare ground, and agricultural areas. Additionally, TE showed a significant correlation with agricultural areas, while MPS showing a significant correlation with the Hemeroby index for artificial surfaces, agricultural areas, forests, and seminatural areas. Furthermore, MPFD correlated significantly with the Hemeroby index for agricultural areas, seminatural areas, and bare ground.

Tab. 3. Correlations between the Hemeroby index and the landscape metrics in 1990, 2006 and 2018.

	TE			**MSI**			**MPS**			**MPFD**		
	1990	**2006**	**2018**	**1990**	**2006**	**2018**	**1990**	**2006**	**2018**	**1990**	**2006**	**2018**
Landscape level (All classes)	**-0.393***	**-0.352***	**-0.294***	**-0.388***	**-0.401***	**-0.281***	0.010	-0.044	-0.005	**-0.266***	**-0.294***	-0.130
Class level												
Artificial surfaces	**0.296***	**0.303***	**0.335***	**0.240***	**0.233***	**0.295***	**0.169***	**0.206***	**0.244***	**-0.372***	-0.138	-0.176
Agricultural areas	**0.727***	**0.656***	**0.638***	-0.114	-0.053	0.047	**-0.523***	**-0.456***	**-0.381***	**-0.781***	**-0.472***	**-0.642***
Pastures	-0.165	-0.207	0.152	-0.244	-0.262	0.130	**-0.328***	**-0.303***	0.081	-0.183	-0.099	-0.214
Forest	**-0.472***	**-0.444***	**-0.410***	**-0.422***	**-0.410***	**-0.432***	**-0.293***	**-0.311***	**-0.313***	**0.299***	0.152	**0.357***
Seminatural areas	**-0.512***	**-0.593***	**-0.647***	**-0.438***	**-0.510***	**-0.532***	**-0.325***	**-0.336***	**-0.267***	**0.558***	**0.461***	**0.689***
Bare ground	**-0.439***	**-0.447***	**-0.492***	**-0.375***	**-0.406***	**-0.391***	**-0.251***	**-0.299***	-0.216	**0.430***	**0.401***	**0.512***
Wetlands	-0.040	0.076	0.146	-0.013	0.113	0.160	0.074	0.158	0.150	0.082	-0.039	-0.131
Water bodies	-0.024	0.092	0.075	-0.053	0.056	0.062	-0.041	0.044	0.078	0.094	-0.061	-0.041

* Correlation is significant at the 0.01 level.

By analyzing the changes in the Hemeroby index value between 1990 and 2018 (Figure 6), it was observed that the level of naturalness increased in 58% of the studied areas, while it decreased in the remaining areas. Notably, there was a moderate to high increase in the Hemeroby index in the metropolitan areas of Lisbon and Porto, which is consistent with the significant urbanization rates observed in and around these major cities in Portugal.

Is also clear a difference between the central and northern regions, where the hemeroby level slightly increase in most of the land, and the south of Portugal, where the naturalness degree increase.

The observed trend in seen in central and northern Portugal for a slight increase in the degree of hemeroby is due to the positive balance between the implementation of new agricultural crops and forest stands in intensive exploitation mode and the abandonment of land with less productive potential.

In the southern part of Portugal the trend may be associated with the phenomenon of land abandonment, which has led to an increase in semi-natural areas in the southern region of the country and a rise in intensive mode production forests in the central and northern parts of Portugal.

The areas where the hemeroby level highly decreased are in the region of Baixo Alentejo. This increase in naturalness degree is due to the higher increase in forest and agroforestry areas compared with other regions in Portugal.

Conclusion

Based on the results the response of landscape pattern to human disturbance was different depending on the scale. At a landscape level the hemeroby index has a significant negative correlation ($p < 0.01$) with landscape pattern indexes that are good indicators of landscape complexity (TE, MSI, and MPFD). This suggests that the decrease in human disturbance would lead to more complex landscapes. At a class level, a tendency to increase LULC fragmentation and complexity was also verified, especially for pastures and in seminatural areas. Other studies showed the same relation between hemeroby level and landscape complexity.

By analyzing the correlation between hemeroby and landscape metrics across various LULC classes, it was determined that the impact of human disturbance on landscape patterns is more pronounced in eco- and agrosystems with low to medium-level hemeroby, including forest, agricultural areas, and seminatural areas. Consequently, it is advisable to prioritize the monitoring of existing agroforest ecosystems, as they exhibit a higher sensitivity to human disturbances in terms of their ecological quality.

We can conclude that the landscape metrics work as good indicators of the quality of the landscape mosaic, being appropriate to describe its degree of hemeroby and allowing us to anticipate possible changes in natural-ness/artificialization based on LULC at a regional scale, confirming the results of previous studies developed in different countries.

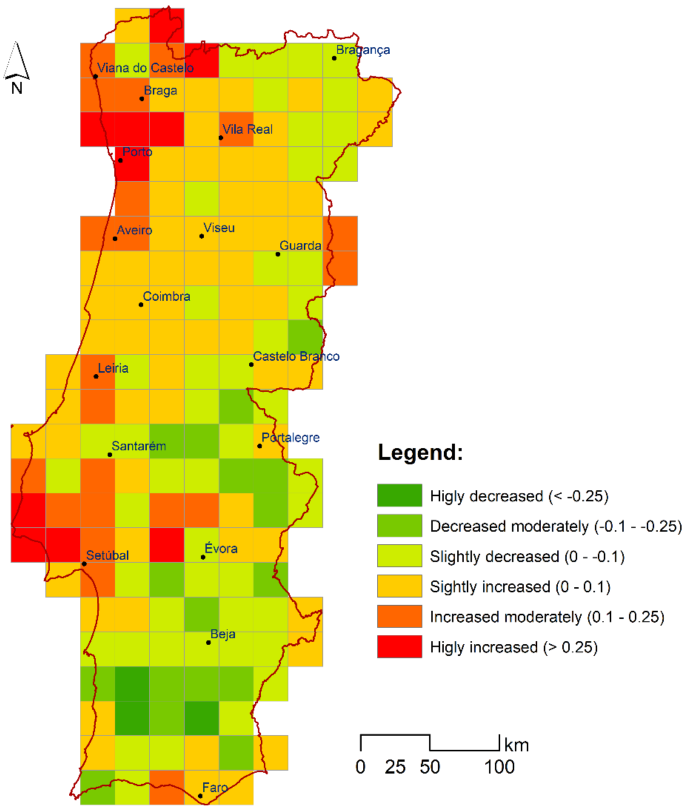

Fig. 6. The estimated change in the Hemeroby index values between 1990 and 2018.

No index is interpretable by itself, as there is a wide range of elements of uncertainty regarding ecological interpretation. Only an approach using various spatial metrics and indicators, including the Hemeroby index, allows a comprehensive analysis of trends in changing use and its consequences.

The results obtained through the application of different indicators of the state of the environment and LULC can be integrated into a nationwide system for monitoring the implementation of spatial planning measures and their impact on land systems. Hence, performing regular calculations of the presented indicators over time could significantly contribute to both qualitative and quantitative portrayals of LULC dynamics in Portugal. This approach would furnish decision-makers and the interested public with intricate insights into the transformations unfolding across the territory at varying scales. This continual assessment of indicators over time 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. By adapting planning models based on these indicators and the relations between them, they can effectively prevent and mitigate anthropic impacts on the ecosystem.

In a broader way, the theoretical explanation of the relationship between landscape patterns and human disturbance lies in landscape metrics, disturbance theory, and human-environment interactions. Through these theoretical frameworks, we can understand how human activities shape landscape patterns and, in turn, how landscape patterns influence the distribution and impacts of human disturbance on ecological systems. This knowledge is essential for guiding landscape management, conservation efforts, and sustainable development strategies that balance human needs with environmental protection.

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