SPATIAL AND TEMPORAL HISTORICAL LANDSCAPE CHANGE IN A MICRO BIODIVERSITY HOTSPOT OF GREECE

Asimina SKOUTERI[1]*, Vassilios P. PAPANASTASIS[2]

[1]Institute of Mediterranean Forest Ecosystems, Hellenic Agricultural Organization - Dimitra, 11528, Athens, Greece
[2]Department of Forestry and Natural Environment, Aristotle University of Thessaloniki, Thessaloniki, Greece
*Corresponding author: askouteri@elgo.gr

Abstract

The study of the historical landscape structure is significant because past land use changes in relation to the natural environment have been reflected in the future interpretation of the landscape. Measuring progress or change of any kind requires the use of metrics, indicators, or indices. The delimitation of biodiversity hotspots into smaller hotspots and the analytical study of them regarding landscape indices can provide information and directions for future land use planning and management. The objective of this research was to investigate how physical factors and location have influenced the historical spatiotemporal change of a landscape in the Mediterranean Basin micro hotspot. The progressive landscape change was studied in 38 municipal units in Western Crete, Greece. The research design, applied in the study, helped to address the research questions set at the beginning. Among the main findings it was found that the diversity and evenness of the landscape were temporally decreased, while dominance was increased; the plain and south landscapes were more diverse and even and the intensification of agricultural land was increased as it was expressed by intensification index. The dynamic structure of this approach permits the applicability, with future inclusion of additional indices in other areas, scales, time lags, and dimensions-and in combination with socioeconomic structure to explore the drivers of change. As a more general conclusion it could be said that more case studies and research are required to explore the influence of heterogeneity or homogeneity of landscape – as connected with land abandonment or not – on biodiversity and economic, social and ecological stability.

Key words: *landscape change, environmental indices, biodiversity, land use planning, Crete.*

Introduction

Landscapes belong to environmental resources and were initially studied under the term "available natural resources" during the decades 1960 and 1970. Landscape change operates on varied time scales, and this variety is referred to as "temporal heterogeneity" or "diversity through time". According to Andersen et al., 1996, the composition and structure of the majority of landscapes demonstrate the correlation between the natural environment and the history of land use. The knowledge of past land use is valuable for environmental planning and management of natural resources. Land use change has been recognized as the basic - key cause behind international environmental change (Riebsame et al., 1994) and is expected to have the largest global impact on biodiversity by the year 2100 (Sala et al., 2000). It involves either a shift to a different use or an intensification of the existing one and is preferred than land cover for land use planning (Turner et al., 1994). The close interaction between landscape and land use has led to a need for landscape planning to be a part of policy for land use planning (Peccol et al., 1996). Applying indices is one method to quantify landscape heterogeneity, structure, and change, and along with the documentation of these, it supports us in understanding landscape change. Critical to any study of the link between spatial pattern and ecological process is

the knowledge of the temporal dynamics of pattern, and seeking to establish the spatial pattern needed to support an ecological process is necessary (Gustafson, 1998). Change and variability are parts of ecological systems, and an understanding of what is a significant change in ecological heterogeneity is critical to understanding the consequences for ecological processes (Gustafson, 1998). Landscape ecological planning must not only consider the spatial arrangement of ecological features but also the temporal dynamics of landscape change (Selman, 1993). Landscape indices have been used in order to link biodiversity assessment with landscape structure (Ortega et al.,2004) as the landscape level is considered the most important level for the management of biodiversity and successful implementation of conservation strategies and policy (With, 2005).
This study was taken account three statements one early and two recent, from the perspective of landscape ecology, biodiversity and environmental economics. The "necessity of linking all the detailed knowledge of fine scale dynamics at case studies sites with broader scale patterns and processes for landscape planning" (Turner et al., 1990). The "necessity of delimiting of hotspots within main hotspots (nano hotspots at local scale and / or micro hotspots (regional scale) and studying them as necessary consideration towards sustainability" (Peyre, 2021). The "necessity of concentrating on national and local regulations as one of the two approaches that are expected to have the most potential for driving actions on risk reduction and preparedness over the next ten years for biodiversity loss and ecosystem collapse (approximately 56%) " (Global Risks Report 2025). This study aims to address the following research questions: 1. How do landscape indices change along the plain - to - mountainous gradient, north - to -south gradient and through time?; 2. How does the integrated method of both spatial and temporal analysis reveal more of the dynamics of historical landscape change than examining on one dimension alone (spatial or temporal)?

Materials and methods

The study area was the western Crete (38 municipal units) of approximately 49,860 ha. The study area belongs to the Mediterranean Basin biodiversity hotspot, and one surrounding area (Samaria Gorge / Lefka Ori) to the south part has been designed as a biosphere reserve. Based on the research questions, a set of 16 landscape indices, including land use types (n = 10), diversity (n = 2), evenness (n = 2), and dominance indices (n = 2), were assessed. Table 1 displays the list of indices used in the statistical analysis. Table A1 presents the sources of data. The proxy indicator of crop-fallow cycle was used for intensification (Stephenne et al., 2001). Cluster Analysis (C.A.) – Ward's method, city block distance- was performed in the present study in order to group m.us. with same characteristics.

Table 1. List of indices used in the study.

Index	Abbreviation	Unit	Equation*
Percentage of agricultural and fallow land	FARM	%	Pk
Percentage of pastures	PAST	%	Pk
Percentage of forests	FOR	%	Pk
Percentage of urban areas	URB	%	Pk
Percentage of areas occupied by water	WAT	%	Pk
Percentage of other land	OTHER	%	Pk
Percentage of annual crops	ANCR	%	Pk
Percentage of trees	TR	%	Pk
Percentage of vineyards	VIN	%	Pk
Percentage of other agricultural land	OTHERF	%	Pk
Shannon diversity index	SHDI	None	$SHDI = -\sum_{k=1}^{N} [P_k * \ln(P_k)]$
Shannon evenness index	E	None	2. $E = \frac{-\sum_{k=1}^{N}[Pk * \ln(Pk)]}{\ln(N)}$
Dominance index	D	None	3.$D = \ln(N) + \sum_{k=1}^{N} [Pk * \ln(Pk)]$

Shannon diversity index of agricultural land	SHDI	None	4.SHDI_F = $- \sum_{k=1}^{N}$ [P_k * ln (P_k)]
Shannon evenness index of agricultural land	E61_F	None	5. $E_F = \frac{-\sum_{k=1}^{N}[Pk * \ln(Pk)]}{\ln(N)}$
Dominance index of agricultural land	D61_F	None	6.D_F=ln(N) + $\sum_{k=1}^{N}$ $[Pk * \ln(Pk)]$

** Pk is the proportion of total area occupied by the k land use type; ln is the natural logarithm; N the number of land use classes.*
National Statistical Authority of Greece (ELSTAT). Distribution of the country's area by basic categories of land use, years 1961,1991
National Statistical Authority of Greece (ELSTAT). Results of the Agriculture-Livestock Census, years 1961,1971,1981,1991,2001, 2021

Results and Discussion

Between 1961 and 1991 3,389 ha of new agricultural and fallow was created. Almost all the m.us. increased this type of land use with few exceptions. The topography seems that not affect significantly the agricultural sector in this time lag while the geographical distribution is a more affecting factor. This expansion of agriculture and fallow land took place mainly into previous uncultivated lands and secondary into pastures. This procedure is similar to that was described by Stephenn et al., 2001. Once the expansion of this land use type has occupied all unused land and simultaneously with additional demand for food crops, the process of intensification would take place according to farming system research. Pastures have net losses of 917 ha and are the dominant land use type in this area, covering approximately the half of the extent. Forest land use is detected in few m.us., mainly in the central and south part, with small increases on a total percentage basis (from 1.2 % to 2.3 %). This increase consists of mainly *Quercus sp. (Quercus ilex etc)*, as it is one of the main species of this region and similar processes have occurred in other Mediterranean countries, with it to be the terminal point of secondary succession with previous steps pastures and scrublands, as a result of land abandonment (Romero –Calcerrada et al., 2004). Land abandonment has positively connected with surfaces affected by forest fires when the landscape variation was explained in socioeconomic terms (Schmitz et al., 2003). So it can be considered often as an opportunity for biodiversity conservation (Rudel et al., 2005 in Otero et al., 2015) and simultaneously as a treat for ecosystem stability and biodiversity because they go together with land homogenization (Farina, 1997 in Otero et al., 2015). More research is needed to explore the positive and negative effects of land abandonment. Decrease of water bodies - even low - can be connected with the drainage of shallow water bodies and conversion to arable land, a practice very common in Greece in this period. Urban land use has a small portion of the most m.us. and although gains of on a percentage basis in these were slightly large, the absolute gains were generally small. Urban land usually is converted by agricultural land because it is private, and the legal provisions are not strictly applied to it. These alterations are similar to these that have been described by Wear et al., 1998 indicating a filling in of the road network and expansion in the exist sting built up area rather an expansion of the network at the remote margins. Increase of urbanization has slightly increase the diversity of landscape in few m.us. in the north part, results similar to the findings of Weng, 2007. Results showed that the diversity and evenness have decreased in almost all the m.us. while dominance has increased especially in the agricultural landscape, homogenizing it (Tables 2-5). According to forest economics land use mosaics has costs and benefits. Mixed land use enterprises have economic advantages and provide some insurance against uncertain times by the increased self sufficiency of a mixed holding as the different cash flow characteristics of two or more enterprises giving a flexibility not attainable by one in isolation. On the other hand there are fixed costs attached to each type of enterprise and the mixed land use is worthwhile when the difference in Net Present Value (NPS) exceeds the fixed costs (Price, 1989). Results are in agreement with the view that land abandonment and forest expansion homogenize landscape structure (Otero et al., 2015). In relation to biodiversity, heterogeneity - within limits - a positive feature in most landscapes as diverse habitat types provides diverse resources and tends to stabilize landscape processes (SFF, 1992; Navarro et al., 2012 in Otero et al., 2015). Extreme values of diversity (i.e. in a forest ecosystem, diversity is maintained after a catastrophic disturbance as a fire or insisting on landscape heterogeneity as a management goal might lead to disregard the benefits of regenerating alternative habitats and biodiversity) can result in negative effects if habitat areas become small to be effective so a balance is required between diversity and homogeneity.

Table 2. Difference of SHDI, E, D,SHDI_F, E_F and D_F between 1991-1961, in response to geophysical features.

M.U.	SHDI6191	E6191	D6191	SHDI6191_F	E6191_F	D6191_F
Plain (22)	-0,166	-0,058	0,117	-0,670	-0,474	0,588
Semi mountainous (4)	-0,210	-0,190	0,340	-0,605	-0,43	0,5325
Mountainous (12)	0,013	-0,016	0,088	-0,483	-0,335	0,412
Total area	**-0,114**	**-0,059**	**0,131**	**-0,604**	**-0,425**	**0,527**

Table 3. Difference of SHDI, E, D,SHDI_F, E_F and D_F between 1991-1961 in response to location.

M.U.	SHDI6191	E6191	D6191	SHDI6191_F	E6191_F	D6191_F
North (23)	-0,156	-0,067	0,143	-0,675	-0,478	0,598
Center (9)	0,054	0,031	0,037	-0,572	-0,393	0,441
South(6)	-0,208	-0,160	0,227	-0,377	-0,272	0,382
Total area	**-0,114**	**-0,059**	**0,131**	**-0,604**	**-0,425**	**0,527**

SHDI, SHDI_F, E, E_F have decreased in almost all the m.us. and D and D_F have increased (Tables 2-3). The landscape has lost one part of his diversity and the agricultural landscape seems to become homogenous.

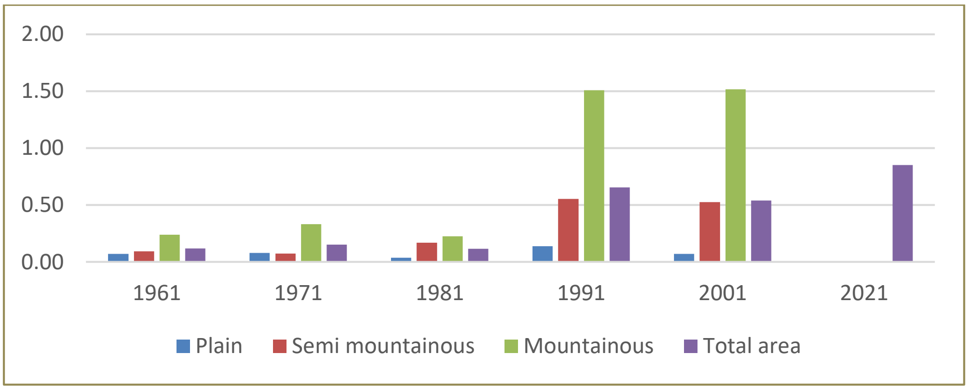

Fig. 1. Range of intensification indicator 1961-2021.

Stephenn et al., 2001, have indicated that due to the deficiencies of input and input data, the crop-fallow cycle was usually used as a proxy variable to measure intensification and expressed by the ratio between fallow area and cropland. This intensification indicator is dimensionless. Especially when the fallow period was decreased, farmers were introduced to technological inputs and advancements to maintain the soil fertility. In this study, the intensification indicator has increased (Fig. 1).

H.C.A. examining the temporal landscape indices grouped the 38 m.us. into two data clusters (distance > 10), representing two distinct types of landscape indices bundles found across m.us. Each of this two main bundle types was found in multiple m.us. (n = 24, n = 14). M.us. belonging to type-1 were in the north part of the study area and were plain. Their coverage was equal to 33% of the total area. The dominant land units of this type were agricultural lands, with a relatively low percentage of pastures. They characterized by the intensification of agriculture and high urbanization (high road density and easy proximity to urban centers). Type-2 m.us.

were mainly in the south part of the study area and represented the 67% of the total area. They are mountainous, with pastures being the dominant land units. They were characterized by abandonment and high extensification (low road density, far away from urban centers).The division of the study area into regions/locations/sites, as have done previous works (Palang et al., 1998; Wear et al., 1998), can identify regional differences. Similarly to these studies, the results showed that landscape indices are strongly influenced by the location of sites (as measured by the distance of roads, networks, towns, etc.). The topography also holds in this study a significant influence on landscape patterns, as Wear et al. (1998) did.

Conclusion – Future work

General results showed that the agricultural and fallow land, urban areas, forests and dominance increased while pastures, water bodies, other land and diversity and evenness decreased. The presented combined approach of various gradient analyses and indices analysis is an effective method to analyze the historical landscape change. Practically, although the methodology uses indices that are easy to calculate – making easy the transferability in other parts - can reveal significant trends in landscape change in combination with the exploitation of existing scientific knowledge in different disciplines and fields, can be considered a valuable tool in land use planning. It adds in existing knowledge not only as a case study in a micro biodiversity hotspot in Greece but also with the methodological approach that gives different and separate insights into the issue filling gaps and creating new ideas for further research.

As a more general conclusion, it could be said that more case studies and research are required to explore the influence of heterogeneity or homogeneity of landscape – as connected with land abandonment or not – on biodiversity and economic, social and ecological stability and prosperity. The further exploration and study of alternative methods/approaches/tools to traditional farming/practices to maintain the desirable diversity of landscapes for biodiversity, increasing landscape resilience and ensuring food security is required.

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