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Spatio-temporal changes analysis (1984 – 2017) of a grazed Cretan landscape using Landsat satellite images

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Abstract. Research on spatio-temporal changes on grazed landscapes of Greece in general and of Crete specifically, indicates that forests, as in all Mediterranean, are expanding. Nowadays, such studies often use digital image analysis methods applied on multispectral satellite images. The recent open access availability of ground reflectance products derived from historical Landsat imagery, which have been geometrical and atmospheric corrected, is expected to increase their use for land use/land cover change research. The aim of this paper was to study the spatio-temporal changes of a typical Cretan landscape (Municipality of Sfakia) and to test the efficiency of the recently available Landsat products, for these purposes. Landsat images of 1984, 2001 and 2017 were processed by classification techniques using remote sensing and GIS software. Forest orthophoto maps and relevant inventory data were also collected, and landscape metrics were calculated. Data analysis of spatio-temporal changes showed a gradual expansion in size and density of forest in silvopastoral areas and of silvopastoral areas in phrygana, increasing landscape heterogeneity. The abandonment of marginal agricultural areas, in combination with the reduction of wood harvesting, are the most important factors of landscape changes in relation to animal husbandry evolution. If this trend continues, it is possible for this Cretan landscape to degrade.

Keywords. Sfakia - remote sensing - open access data - landscape metrics.

Analyse des changements spatio-temporels (1984 – 2017) d'un paysage crétois pâturé à l'aide d'images satellite Landsat.

Résumé. Les recherches sur les changements spatio-temporels sur les paysages pâturés de la Grèce en général et de la Crète en particulier, indiquent que les forêts, comme dans toute la Méditerranée, sont en expansion. De nos jours, ces études utilisent souvent des méthodes d'analyse d'images numériques appliquées sur des images satellites multispectrales. La récente disponibilité en libre accès des produits de réflectance du sol dérivés de l'imagerie historique Landsat, géométriquement et atmosphériquement corrigées, devrait augmenter leur utilisation pour la recherche sur l'utilisation des terres/les changements de couverture terrestre. L'objectif de cet article était d'étudier les changements spatio-temporels d'un paysage crétois typique (Municipalité de Sfakia) et de tester l'efficacité des produits Landsat récemment disponibles, à ces fins. Les images Landsat de 1984, 2001 et 2017 ont été traitées par des techniques de classification à l'aide de logiciels de télédétection et de SIG. Des orthophotocartes forestières et des données d'inventaire pertinentes ont également été recueillies, et des mesures du paysage ont été calculées. L'analyse des données des changements spatio-temporels a montré une expansion progressive de la taille et de la densité de la forêt dans les zones sylvopastorales et des zones sylvopastorales dans les garrigues, augmentant l'hétérogénéité du paysage. L'abandon des zones agricoles marginales, conjugué à la réduction de l'exploitation du bois, sont les facteurs les plus importants des changements du paysage en relation avec l'évolution de l'élevage. Si cette tendance se poursuit, il est possible que ce paysage crétois se dégrade.

Mots-clés. *Sfakia – télédétection - données en libre accès - métriques de paysage.*

I - Introduction

Research on the grazed landscapes of Greece shows that they have undergone significant changes over time. These changes are mainly concern the size and distribution of their land use/ cover units and have as a result the large expansion of forests and shrublands (Chouvardas, 2007; Chouvardas *et al.,* 2013; Rapti *et al.,* 2018; Nasiakou *et al.,* 2021). These changes have strong anthropogenic causes (e.g., land abandonment due to socio-economic changes), follow similar changes of the Mediterranean landscapes and are considered very important for the evolution of grazing landscapes, such as those of Southern Crete (Papanastasis, 2012). Specifically, for the landscapes of southwestern Crete (White Mountains - include part of Municipality of Sfakia), Papanastasis (2012), reports that they have undergone drastic changes due to population abandonment, which for the period from 1945 to 1989 resulted forests' expansion at the expense of shrubland and phryganic areas.

Studies of spatio - temporal change of landscapes and vegetation types in general are usually conducted through photointerpretation analysis of time series set of aerial photographs (Chouvardas, 2007), through digital processing of multispectral satellite images with a variety of techniques (Lu *et al.,* 2004), or more recently through object recognition technics of remote sensing (Perakis *et al.,* 2015).

Multispectral images of Landsat satellites are the oldest and most popular series of satellite products. Being available since 1972, they are suitable for the study of changes over a long period of time. This popularity was promoted significantly after 2008 when the US Geological Survey (USGS) allowed free access of Landsat products, causing a significant increase in their use (Miller *et al.,* 2013). Pre-processing stages of the digital processing of multispectral satellite images such as Landsat images, usually cause technical difficulties, specifically in geometric and atmospheric corrections (Song *et al.,* 2001; Perakis *et al.,* 2015), becoming less attractive for non-specialized remote sensing researchers (Young *et al.,* 2017). In March 2017, USGS announced the free distribution of a new satellite Landsat product which was geometrically and atmospherically corrected (C1-Level 2 - ground reflectance, US Geological Survey, 2018), promoting even more the use of satellite imagery for applications such as the study of landscape evolution.

The present research aimed to study the spatio - temporal changes of a typical landscape of southwestern Crete (Municipality of Sfakia) in order to collect information about the diverse Cretan landscapes promoting the knowledge especially for the grazed silvopastoral and phryganic areas, and to examine the possibilities of using the new geometrically and atmospherically corrected open-accessed Landsat multispectral satellite products.

II - Materials and methods

The Municipality of Sfakia (M. Sfakia) in the prefecture of Chania, Crete was selected as study area. M. Sfakia includes nine main settlements of 1889 inhabitants in total covering a total land area of 46,700 hectares. The landscape of the study area is dominated by silvopastoral and phryganic areas, which are mainly grazed by sheep ang goats. Silvopastoral areas are dominated in the upper story mainly by *Pinus brutia* Ten. (Pine), *Cupressus sempervirens* L. (Cypress) and in a lesser extent by *Quercus coccifera* L. Phryganic areas are dominated mainly by *Sarcopoterium spinosum* (L) Spach., *Euphorbia acanthothamnos* Heldr. Sartori ex Boiss. and *Verbascum spinosum* L. Pine and Cypress are also dominate at the forests, mixed or unmixed. The altitude of the area ranges between 0 to 2453 meters, while forest boundaries reach 1600 meters. Finally, the main productive activities the area are agriculture, animal husbandry and tourism.

In order to identify and evaluate the spatio - temporal changes among the different land use/cover types of the landscape, three multispectral satellite images of Landsat (C1-Level 2, ground reflectance) were collected for three time periods: the oldest available was in 1984 (TM5), the intermediate was in 2001 (TM5) and the newest was in 2017 (OLI8). All three images

were produced during summer and had no cloud cover. Supervised classification technique was applied to all satellite images using the algorithm of maximum likelihood (Perakis *et al*., 2015), in Erdas Imagine software. All spectral channels except thermal infrared (TM5, OLI8) and ultra-blue (band -1, OLI8) were used. Accuracy assessment was conducted in stratified random sampling of 300 points for each time period (Congalton, 1991). Several additional data were used as support material for the selection of the training areas, but also for the assessment of the classification accuracy. This material included a) satellite images from Google Earth from 1984 to 2017, b) digital images of unsupervised classification (K - MEANS) of 8 classes for each time period, c) orthophoto maps of 1991 and d) the digital maps of the Corine Land Cover. In order to assess the accuracy of the 1984 classification, assumptions of non-change of land use were made in some cases, based on the orthophoto maps of 1991. A total of 72 training areas were selected (7 to 22 per class), considering the total area and vegetation variety of the classes. The selected classification classes consisted of 6 categories of land use/cover types: agricultural areas (including settlements), water bodies, barren or sparsely vegetated areas, phryganic areas, silvopastoral areas (tree coverage 10 - 40%) and forests (40 - 100% tree coverage). Silvopastoral areas contained a small percentage of kermes oak shrubs. Finally, a post-processing data methodology was applied in ArcGIS software to the outcomes of the final classification; process which included the application of majority filter and an increasement of the minimum cartographic area to 1 hectare (Generalization tools, ArcGIS).

In order to examine the effect of socio-economic changes (population development, employment data) and pastoral activities (number of sheep and goats) on landscape evolution, statistical data were collected from the Hellenic Statistical Authority (1961 - 2011) and from the Payment and Control Agency for Guidance and Guarantee Community Aid (PCAGGCA, 2021). Field visits were also organized in order to collect information directly from the local population.

Finally, the ArcGIS Patch Analyst software was used to analyze landscape pattern (landscape metrics, McGarigal and Marks, 1995). In details, six indicators of spatial heterogeneity in landscape level were calculated: Number of Patches (NumP), Mean Patch Size (MPS, ha), Edge Density (ED, m/ha), Interspersion Juxtaposition Index (IJI, %), and Shannon' s Diversity and Evenness Index (SDI and SEI) (McGarigal and Marks, 1995; Chouvardas, 2007).

III - Results and discussion

The estimation of the classification accuracy was considered satisfactory with the percentages of total accuracy ranging from 89.67%, 85.3% and 88.67% for the time periods of 1984, 2001 and 2017 respectively. The kappa statistical coefficient also showed values of 0.8665, 0.8115 and 0.8573, respectively. The evolution of the categories of land use/ cover types for the research period are given in Table 1.

Table 1 data reveled that land use/ cover types that increase in area during the time period (1984 and 2017) are forests (> 40%) and agricultural areas (> 30%) and in a lesser extent silvopastoral areas. An exception to the above trend is the significant reduction by 20% of phryganic areas. Barren or sparsely vegetated areas and water bodies remained practical unchanged. The above changes are presented in the maps of Figure 1 (A, B and C) of the land use/ cover type evolution. In these maps a gradual conversion of silvopastoral areas to forests in the central and western parts of the landscape is observed, along with a gradual conversion of phryganic areas to silvopastoral areas to the east. By further analyzing the results of landscape changes over the time period (1984 to 2017), it emerged that from the initial surface of the landscape of 1984, 72% remained unchanged (Fig. 1, D – stable landscape), compared to a 28% of area that underwent same kind of change (Fig. 1, D – transformed landscape).

Table 1. Temporal evolution (1984 - 2017) of land use / cover types in M. Sfakia landscape of Southwest Crete

Land use/cover types	Area (Ha)			Change (%)
	1984	2001	2017	1984 - 2017
Agricultural areas	1630.71	1729.89	2150.28	31.86
Phryganic areas	21,116.07	19,243.98	16,535.43	-21.69
Silvopastoral areas	8239.86	7914.33	9366.57	13.67
Forest	6350.22	8350.83	8987.22	41.53
Barren or sparsely vegetated areas	9010.71	9013.68	9120.87	1.22
Water bodies	5558.49	5547.87	5659.83	1.82
Total	51,906.06	51,800.58	51,820.20	-0.17

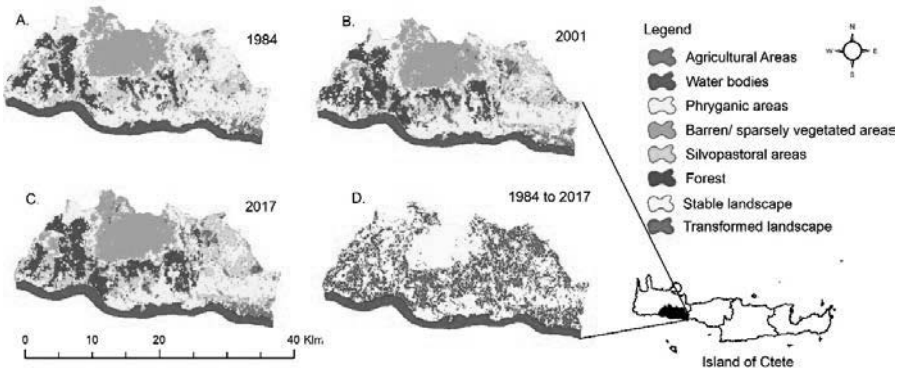

Fig. 1. Spatio - temporal distribution of land use/cover types in M. Sfakia landscape of Southwest Crete for A) 1984, B) 2001, C) 2017 and D) 1984-2017

According to figure 1, the stable part of the landscapes occupies areas of barren/ sparsely vegetated and phryganic areas in the north-center and south-east territories, respectively. Overall, the above data (Table 1, Figure 1), suggest that the conversion of phryganic areas into silvopastoral areas can be consider a transitional stage of development that will lead in the future to their further transformation into forests.

Table 2 presents the results of the landscape metrics of M. Sfakia landscape over time. The differences of NumP and MPS values indicate that the landscape becomes intertemporal fragmented and therefore presents an increase of its heterogeneity.

Table 2. Landscape metric value for M. Sfakia landscape for the period 1984 to 2017

Years	NumP[1]	MPS[2]	ED[3]	IJI[4]	SDI[5]	SEI[6]
1984	714	72.70	31.92	51.17	3.34	0.51
2001	807	64.19	35.13	51.11	3.60	0.54
2017	926	55.96	35.2	52.27	3.78	0.55

[1]Number of Patches, [2]Mean Patch Size (ha), [3]Edge Density (m/ha), [4]Interspersion Juxtaposition Index (%), [5,6] Shannon' s Diversity and Evenness Index

At the same time, ED values increase, indicating an increase of ecotone length per unit area, while the IJI index shows a slight improvement of patch distribution in the landscape. Finally, the SDI and SEI indices show increased diversity over time. The above results are in contrast with the trend of evolution of many other Greek landscapes, where the expansion of forests causes reduced landscape diversity and produce homogeneous landscapes (Chouvardas, 2007;

Chouvardas *et al.,* 2013; Rapti *et al.,* 2018; Nasiakou *et al.,* 2021).

Statistical data showed that local population of the M. Sfakia decrease by 24% between 1981 and 2011 with a limited aging trend, while the percentage of employees in the primary economic sector decreased for the same period from 69% to 57% of the economically active population. The above demographics suggest that the traditional land management practices (agricultural activities and extensive pastoral activities) are probably preserved. In addition, statistics show (Table 3) that farm animals (mainly sheep and goats) have shown a continuous increase since 1971, an increase which reaches the maximum total number in 2011 (more than 150,000 sheep and goats). The total increase of sheep and goats between 1991 - 2011 was 16%, Table 3.

Table 3. Temporal evolution of the numbers (heads) of farm animals and percentage (%) of their change in M. Sfakia landscape between 1971 to 2017

Farm animals	1971	1991	2000	2011	2017	% of change 1991 - 2011	% of change 2011-2017
Sheep	28,862	66,362	76,349	113,001	83,181	+15.05	-26.39
Goats	10,193	33,521	39,259	37,023	26,540	+17.12	-28.31
Total	39,055	99,883	115,608	150,024	109,721	+15.74	-26.86

Farm animals decreased since 2000 for goats and since 2011 for sheep (total reduction of farm animals between 2011 - 2017 was 27%, Table 3). The above fact is confirmed by the reports of the local population to the researchers during the summer of 2017. From the same reports, as well as from the Spatio - temporal distribution data (Figure 1), it is found that forest expanded in many marginal agricultural areas mainly in the central parts of the landscape. Also, the same reports of the local people suggested that there was a significant reduction over time in the collection of firewood and building timber from forests, which promoted a further forest expansion. The latter trend was also confirmed in an earlier study concerning the development of the landscape of Western Crete / White Mountains (Papanastasis and Kazaklis, 1998).

The above results suggests that the strong trend of forest expansion in the landscape can be mainly attributed to land abandonment and the reduction of firewood and timber collection and less to the impact of livestock activity over time that has remained high over time. It is noted that the reduction in sheep and goats over the last decade (2011 to 2017, Table 3) and the possible continuation of this trend in the future, is expected to negatively affect landscape evolution, causing a further expansion of forests and even greater reduction of phryganic areas. These changes, if they are confirmed as in other Greek landscape, will probably lead to a significant reduction of landscape diversity, and eventually transform this greatly heterogeneous landscape to a homogeneous one.

IV - Conclusions

Image processing of the geometrically and atmospherically corrected open-access satellite Landsat products provided satisfactory results for the spatio - temporal change analysis at M. Sfakia's landscape. Data analysis showed a trend in gradual transformation of silvopastoral areas into forests and of phryganic areas into silvopastorals. These changes resulted an increase of landscape heterogeneity, which promoted landscape diversity. These results were mainly attributed to land abandonment and the reduction of firewood and timber collection. Livestock activities remained high over the time period of 1991 to 2011 and had less significant impact to landscape transformations. Farm animal numbers reduced over the last decade (2011 – 2017) and its possible further reduction in the future will probably promote forest expansion and may eventually lead to a significant reduction of the landscape diversity and heterogeneity. This trend of change should be investigated in the future, especially under the influence of the

effect of the global climatic changes in semiarid environments, as those of southwestern Crete.

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