Using environmental metrics to describe the spatial and temporal evolution of landscape structure and soil hydrology and fertility

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Abstract: In this work a methodology using Geographical Information Systems was developed and applied to a temporal series of land cover layers (for the years 1956, 1978, 1991 and 2010) in the municipality of Vall d'Uxó, Eastern Spain. Four types of metrics were implemented (1) spatial representation of the degree of artificialisation, (2) patchiness and fragmentation, (3) fertility dynamics of soils according to their land capability, and (4) soils imperviousness and loss of water retention capacity.
Results showed that the set of metrics can efficiently represent spatial and temporal dynamics. Furthermore, a link can be distinguished between trends in the degree of artificialisation, landscape structure and soil fertility and water retention properties for the region analysed.

Keywords: Land use-cover change, anthropogenic soil sealing, land degradation, spatial landscape metrics

1. Introduction

Land use-cover change is an ongoing process in both time and space. In recent years, land cover dynamism has accelerated in urban area hinterlands, being notorious in the Mediterranean region. It has been observed that the major mechanisms of change in western Mediterranean areas are intensification and transformation, which can be integrated in the general trend of artificialisation (Pascual Aguilar, 2002). While intensification mainly concerns the change from traditional rain-fed agriculture to cash crop irrigation practices, transformation is related with the substitution of one type of land use (and subsequent cover) by another, as in the transition from cultivated fields to buildings and roads.
According to the European Union perspectives, a transformation trend known as anthropogenic soil sealing is one of the most worrying aspects of soil degradation, along with the loss of useful biota, affecting desertification in dry environments where rainfall

is scarce. One of the major impacts of soil sealing is the loss of fertility and the alteration of the water regime due to imperviousness of the top soil layers.
Approaches to help understand pattern dynamics of land use-cover changes has been developed. Less studied are the interactions between trends in such spatial metrics and the environmental effects of land use-cover dynamics on soils and their water regimes.
The general aim of this research is thus the development of a descriptive framework based on landscape and environmental metrics to assess land use-cover spatial and temporal dynamics. Specific objectives are the application of spatial environmental metrics to analyze historical trends in (1) anthropogenic soil sealing, (2) in landscape structure changes, and (3) in soil productivity and soil water dynamics.
The analysis has been applied to the municipality of Vall d'Uxó in the province of Castellón, Eastern Spain. It is located in a transition area between Mediterranean coastal plains and pre-littoral mountain ranges. In recent decades, the region has undergone an intense dynamism dominated by the transition from traditional agricultural systems to highly technified irrigated cash crops and artificial surfaces (Pascual Aguilar, 2002), both processes identified in other regions and described respectively as intensification and conversion (Lambin, 1997).

2. Materials and Methods

Several layers of information were built up using conventional Geographical Information Systems software (ArcGis 9.3). Initial maps consisted of (1) detailed (scale 1:10000) land cover layers for the years 1956, 1978, 1991 and 2010, and (2) the construction of a soil map according to FAO nomenclature from published reports (Rubio et al. 1995).
Initial data were further processed to obtain layers with artificial surface urban and infrastructures classes for the respective land cover years and, from the soil maps one layer with soil agricultural capabilities following existing well established methodologies (Antolín, 1998) and a second one with soil water retention properties were extracted from the information from samples provided in soil reports (Rubio et al. 1995).
Four different types of metrics have been developed. First, landscape structure metrics were used. A cartographic value was developed, the Synthetic Index of Landscape Artificialisation (SILA), which expresses trends of artificial covers per unit area (a representative square of 100 x 100 m). The index includes under the same landscape class both agricultural intensification and paved and concrete surfaces and is the result of calculating the percentage of this class for each representative square area.
Second, based on existing metrics (e.g. Cushman et al. 2008), landscape structure was analyzed to determine the degree of fragmentation and patchiness with the specific landscape class of paved and built up surfaces, with major impact on soils and their water regime. The metrics applied to each year were the Number of Patches (NP), the Maximum Patch Size (MxPS in hectares), the Patch Average Size (MePS in ha), and the Patch Size Variance (PSV).
Third, specific metrics were developed to obtain insight about the potential environmental impact on soils fertility, understood as their capability to produce food.
Fourth, specific metrics have been also calculated to describe the impact of soil sealing on the water holding properties of soils. Metrics developed for land capability and water

retention are: Total Surface by Land Capability Type, TSLCT (in ha); Water Retention Capacity, WRC (in m^3); Cumulative Loss of Land Capability for a given year, CLLC (in ha); Cumulative Loss of WRC for a given year, CLWRC (in m^3);Ratio between WRC and TSLCT for a given year, WRC/TSLCT, and ratio between remaining water holding capacity (m^3) and remaining total land capability land (ha) for a given year, RWRC/RTSCU.

3. Results

In 54 years a landscape character change of considerable dimensions has taken place. The SILA index graphic expression (Figure 1) shows a constant increase in time and space with almost 50% of the reference squares above 50% of change due to agricultural intensification and artificial surfaces.

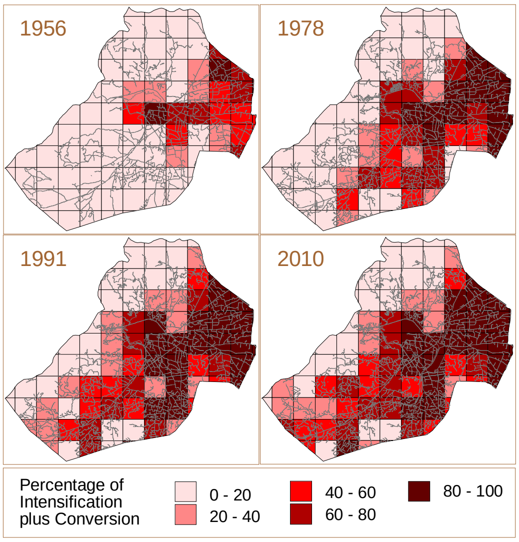

Figure 1: Cartographic representation of the Spatial Synthetic Index of Landscape Artificialisation

Landscape structure is analyzed by a set of four metrics (Number of Patches, NP; Mean Patch Size, MePS; Maximum Patch Size, MxPS; Patch Class Size Variance, PSV) (Table 1). All four series are monotone. A Mann-Kendall trend test with exact distribution of the test statistics, which is suitable for short time series (Hamed, 2009), suggests a significant trend at the 95% level for monotone series and a series length of four, as given here. We therefore regard these trends as significant, and the strength of the trend is approximated by the slope of a straight line, which is fitted to the data. The values, which are given in Table 1, suggest strong trends with constant increasing patchiness with time and consequent reduction of the remaining metrics (MePS, MxPS, and PCSV). The increase in number of patches results in the physical fragmentation of the initial landscape units and consequently, MePS, MxPS and PSV get smaller because there is a trend to reduce differences between patch sizes. Also, environmental consequences of the above trends are reflected in the reduction (the soil sealing process) of soils covered by natural or cultivated vegetation.

Relationships between landscape structure due to artificial landscape classes and soil fertility and hydrological properties are established by a new group of environmental metrics (Table 2 and Figure 2). They are related to five types of land capability to produce biota (Very High, A; High, B; Moderate, C; Low, D and Very Low, E). Fragmentation and patchiness are produced by the increment of artificial surfaces that substitute former soil covers of natural or agricultural landscape classes, which area synthesized by land capability A, B, C, D, and E types and represented by CLLC metric (Table 2). Also the anthropogenic sealing will cover the soil top layer avoiding water processes and soil moisture dynamics (CLWRC). Apparently these metrics are different for different landscape classes. For A-C the formula “the better the soil, the lower the yearly loss” can be established. However, the two lowest biota producing classes, D and E, have very low loss rates in 1960. Trends in decline in soil fertility are evident with time. Land capability classes C, D and B have lost greater proportion of soil fertility and water holding efficiency. Due to this trend, the low biota producing class D undergoes a dramatic loss of soil fertility and water holding efficiency: in 2010 it has the second-highest losses. The largest losses occur for class C. All land capability classes experience stronger losses from 1990 on. Moreover, the RWRC/RTSCU ratio reflects a general trend in the decline of both indicators. However, the trend in the ratio is not strong, as gets apparent in Figure 2.

Metrics	**Year**				**Slope of Trend**
	1956	**1978**	**1991**	**2010**	
NP: Number of Patches	274.0	789.0	1641.0	1725.0	29.2
MePS: Mean Patch Size (ha)	24.7	8.6	4.1	3.9	-0.4
MxPS: Maximum Patch Size (ha)	1583.3	1203.1	1007.1	997.2	-11.2
PSV: Patch Class Size Variance	16794.6	3549.9	1386.7	1316.8	-286.0

Table 1: Synthetic landscape structure metrics

Land capability type	**Soil fertility and soil hydrology metrics**														
	TSLCT (ha)	**WRC (m3)**	**WRC/ TSLCT**	**CLLC (%)**				**CLWRC (%)**				**RWRC/RTSCU**			
	Reference situation			1956	1978	1991	2010	1956	1978	1991	2010	1956	1978	1991	2010
A	1441.8	24077678	1670.0	3.9	4.0	4.4	10.6	3.9	4.0	4.4	10.6	1670.0	1670.0	1670.0	1670.0
B	1083.7	1809312	1669.6	5.7	8.6	10.2	18.0	5.7	8.6	10.2	18.0	1669.6	1669.6	1669.6	1669.5
C	681.3	828819	1216.6	11.8	23.3	27.1	29.6	16.0	32.1	40.2	43.7	1158.1	1077.2	997.8	972.4
D	1408.7	726233	515.5	1.2	4.4	6.9	21.7	1.3	6.9	12.8	32.0	514.9	501.7	482.9	447.5
E	2209.0	1066269	482.7	1.4	2.5	3.6	4.6	1.4	2.4	3.4	4.4	482.9	483.2	483.6	483.4
Totals	6824.4	6838400	1002.1	3.6	6.3	7.9	14.0	5.2	8.7	11.0	17.9	985.9	976.0	967.6	956.9

TSLCT: Total Surface by Land Capability Type. WRC: Water Retention Capacity. CLLC: Cumulative Loss of Land Capability for a given year. CLWRC: Cumulative Loss of WRC for a given year. WRC/TSLCT: Ratio between WRC and TSLCT for a given year. RWRC/RTSCU: ratio between remaining total water holding capacity (m^3) and remaining total land capability land (ha) for a given year.

Table 2: Metrics related to soil fertility and soil hydrology

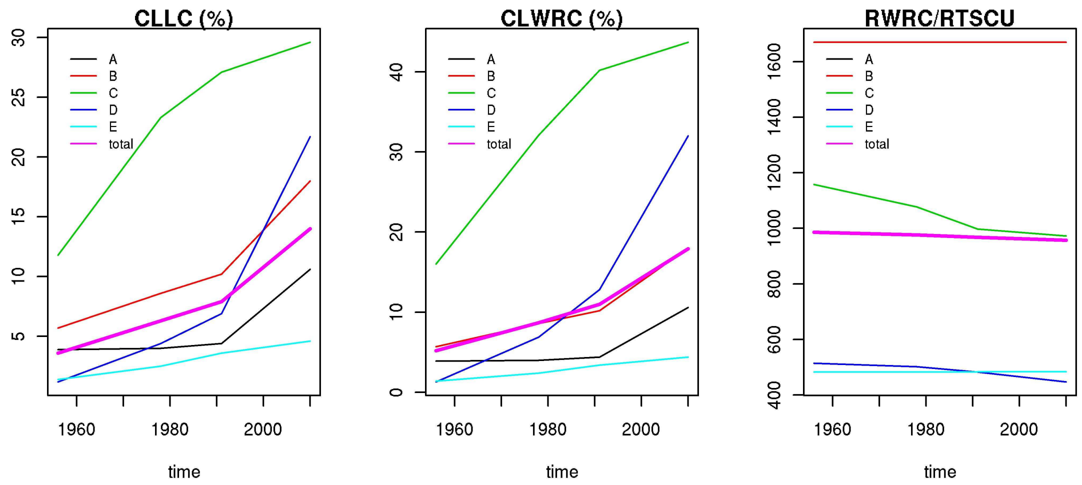

Figure 2: Metrics related to soil fertility and soil hydrology

4. Concluding remarks

Based on the process of landscape artificialisation due to land use-cover dynamics, the methodology developed a set of simple spatial metrics to relate potential impacts on soil fertility and hydrology. We found that the landscape structure for the region of Vall d'Uxó has become increasingly scattered over the last 50 years. Moreover, the link between conventional landscape pattern and structure metrics to new specific ones for land capability and water holding properties in soils describes the relation between land cover dynamics (in time and space) and their environmental interactions. We found different soil fertility and water holding capacity losses for different land types, which are distinguished according their potential to produce biota. However, an enhanced loss of all metrics within the last 20 years is identifiable for all land types.

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