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Land Use Trajectories for the Assessment and Sustainable Management of Land Degradation

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Abstract:

Land degradation (LD) implies a reduction in the economic productivity of land and in its capacity of providing ecosystem services. "Syndromes" of LD can then be evaluated in the past, and scenarios developed for the future, informing sustainable land management strategies. Land use and land cover are essential information for interpreting change trajectories associated with LD and deriving prediction rules. Methodological issues and preliminary results of a study conducted in the context of the research project AGROSCENARI are discussed in this paper, investigating the case of the Emilia-Romagna Region in Italy.

Keywords: Land degradation syndromes, land degradation assessment, land use trajectories, sustainable land management

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1. Introduction

Land degradation (LD) is regarded as one of the most important processes leading to environmental degradation. LD specifically refers to a reduction of the economic productivity and capacity of providing ecosystem services by cropland, rangeland, and woodlands. Archetypal patterns or "syndromes" of LD [1] can then be evaluated in the past, and scenarios developed for the future, informing sustainable land management strategies. Land cover is the visible result of the interactions between natural and socio-economic systems. It often reveals the occurrence of LD, either because it bears a direct effect on the processes or because it is associated with unsustainable land uses. Land use and land cover (LULC) are therefore essential for interpreting past changes associated with LD and deriving prediction rules. Whenever available, LULC data providing comparable classifications as well as the needed spatial resolution and time coverage can be derived from existing thematic cartography. In alternative, LULC data could be extracted from archive Landsat (5, 7) satellite imagery going back to the mid-eighties.

In the context of the research project AGROSCENARI (Scenarios of agriculture adaptation to climate change) promoted by the Italian Ministry of Agriculture, the research line "Land Degradation Processes and Climate Change" intends to investigate LULC trajectories and related syndromes as well as scenarios of land degradation, especially in face of climate change, in a number of test areas in the country.

Past trajectories in LULC are analysed at regional level together with trends in other relevant drivers, for investigating associated land degradation syndromes (e.g. urban sprawl and soil sealing, aridity and climatic aggressiveness, water and soil erosion, industrial and agricultural pollution) through quantitative indicators of vulnerability (e.g. ESAI-Medalus [2], ESI LADA-FAO [3]) and "narrative" interpretations of more qualitative nature (e.g. "story lines"). Climatic forecasts, population projections, as well as land use modelling are also used for developing future LD scenarios.

This paper focuses on a number of methodological issues related to the analysis of past LULC trajectories and associated LD syndromes and refers to the specific case of the Emilia-Romagna Region in Italy. A recent pan-European study showed a continuing and rapid spatial expansion of urban areas, especially in the last decade [4]. The most visible impacts of urban sprawl are in countries or regions with high population density and economic activity: Belgium, the Netherlands, southern and western Germany, and northwest of Italy, where Emilia-Romagna is located (see Figure 1). Emilia-Romagna thus represents an interesting case of study due to its land use dynamics as well as to the availability of consistent LULC data over the period 1954 to 2008.

Figure 1. Location of the Emilia-Romagna Region

2. Methods

2.1. Datasets and LULC classification harmonization

The LULC datasets were generated over the years 1976, 1994, 2003 and 2008 by the Emilia Romagna Regional Cartographic and G.I.S. Service. A 2010 edition was released, where both the geometric and the thematic contents were harmonized by the same Service. Datasets have a nominal scale of 1:25.000 and are altogether comparable in terms of spatial resolution. The classification schemes vary according to the years, but the harmonization exercise carried out by the Service and finalized for this research allows a comparison, with some adaptations, to the 3rd hierarchical level of the Corine Land Cover (CLC) classification systems [4]. For the purpose of this analysis the 1976 dataset was resampled to the other, coarser datasets, due to their finer spatial resolution. An overview of the datasets is given in Table 1.

Table 1. LULC datasets used in the analysis

Year	Nominal scale	Minimum mapping unit (ha)	Classification scheme	Number and level of classes
1954	1:25.000	2,25	ad-hoc; but made comparable with 1994	19 classes on 2 levels
1976	1:25.000	0,375	ad-hoc; but made comparable with 1994	29 on 3 levels
1994	1:25.000	2,25	CLC, up to the 3rd level	31 on 3 levels
2003	1:25.000	1,56	CLC up to the 3rd level and based on ad-hoc specifications for a 4th level	83 on 4 levels
2008	1:25.000	1,56	As above	As above

Table 2 provides a list and description of the harmonized nomenclature at the 3rd and at the 1st CLC level, for a more aggregated analysis. In this case class 1 corresponds to artificial surfaces, class 2 to agricultural areas, class 3 to forest and semi-natural areas, class 4 to wetlands and finally class 5 to water bodies.

Table 2. LULC classes after the harmonization

Description	**Code 3rd level**	**Code 1st level**
Urban areas (urban fabric, commercial units), major roads, railways	1	1
Mine, dump and construction sites	2	1
Industrial and port areas	3	1
Airports and associated infrastructures	4	1
Artificial, non-agricultural vegetated areas (green urban areas, sports and leisure facilities)	5	1
Arable land also in association with permanent crops	6	2
Rice fields	7	2
Vineyards	8	2
Olive groves and fruit trees plantations	9	2
Mixed specialized crops, orchards, greenhouses, and nurseries	10	2
Poplars and other tree plantations	11	2
Meadows also in association with permanent crops	12	2
Complex cultivation patterns	13	2
Forests and chestnut plantations	14	3
Scrubland and recent reforestation	15	3
Natural grasslands and moors	16	3
Areas with dominant bare rocks	17	3
Inland marshes	18	4
Salines (also abandoned)	19	4
Humid areas and salt marshes	20	4
Water courses	21	5
Water bodies	22	5

2.2. Analysis of land use changes and identification of trajectories

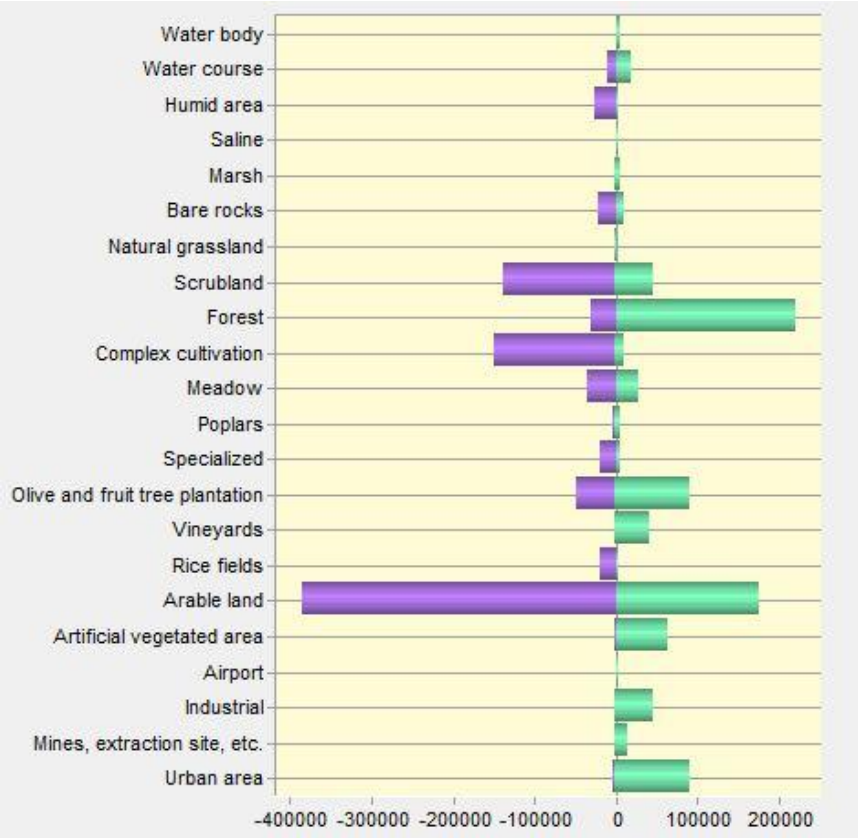
LULC changes were analyzed with the help of the IDRISI Land Change Modeler, comparing 1954 and 2008 datasets. The Land Change Modeler allows, among others, the calculation of fluxes, the generation of transition matrices and the statistical analysis of the significance of the drivers behind the changes. The interpretation of changes in terms of actual trajectories implies a profound knowledge of both bio-physical and socio-economic determinants behind the change of land cover and use.

3. Results and Discussion

3.1. Trajectories of LULC change in Emilia-Romagna

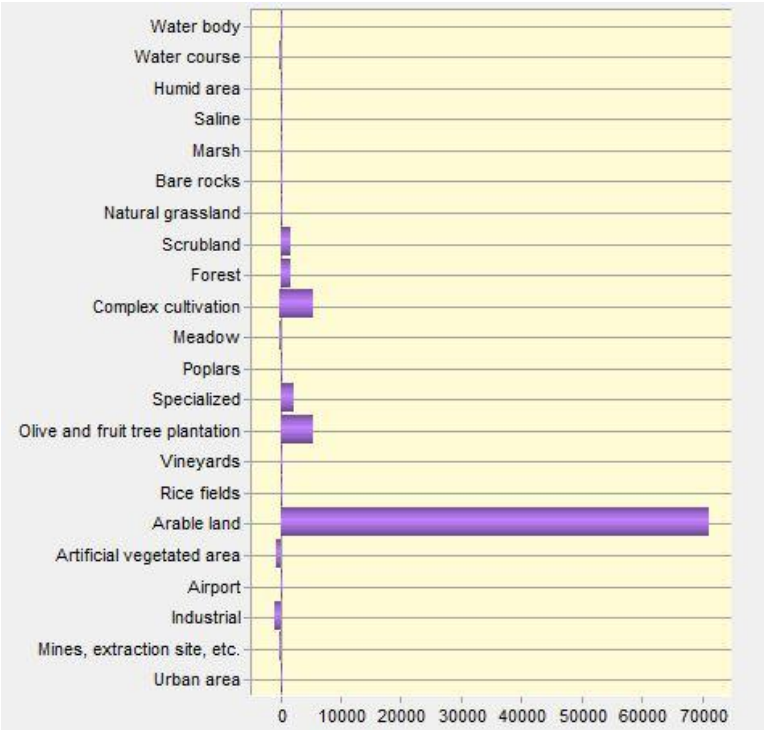
Results of gains and losses for the different classes at the 3rd level of the nomenclature are given in Figure 2 (figures on the x-axis are expressed in hectares). The two classes with highest net gains are urban areas and forest land. This corresponds to two distinctive land use change trajectories, i.e. urban growth and sprawl on the one hand and forest expansion on the other.

Figure 2. Gains and losses of the different LULC classes



The contributions of the various classes to the expansion of urban areas are shown in Figure 3 and clearly illustrate the massive transformation of arable lands and other agricultural areas (complex, or mosaic cultivations and trees plantations and only marginally, forest land) into artificial land occurred over the 54 years' time horizon: a net increase of over 87.000 ha out of a total regional area of around 2.204.500.

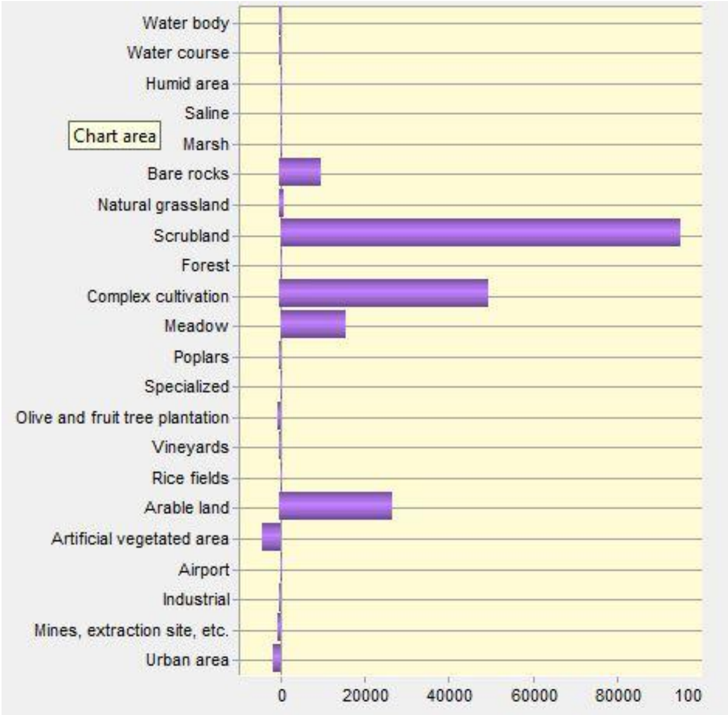
Figure 3. Contributions to the net change in urban areas



These changes correspond to very well-known processes of urban growth, occurring in different forms: densification around original urban centers and along the cost and, more recently, sprawl along communication axes and in the open, rural territory.

Forest expansion has taken place at the expenses of several classes, as shown in Figure 4: mainly scrubland, complex cultivations and once more, arable land and only marginally at the expenses of sparsely vegetated, rock outcrops areas. While in the latter case this can be ascribed to afforestation and reforestation, the latter transformation is the result of a trajectory of land abandonment, mainly occurring in the hilly and mountainous areas of the Apennines. This process of recolonisation of forests and natural vegetation is also well-known and consists of a transition from arable land, to complex land mosaics and meadows, to scrubland and finally to forest stands.

Figure 4. Contributions to the net change in forest land



The quantitative dimensions of the trajectories are summarized in Table 3; in the transition matrix fluxes from one class to the other are aggregated at the 1st level of the CLC classification.

Table 3. LULC transition matrix (values in ha)

Class description	*code*	1	2	3	4	5
artificial surfaces	1	31,558	1,543	279	10	283
agricultural areas	2	197,233	1,189,449	145,703	5,885	14,651
forest and semi-natural areas	3	16,112	37,073	476,363	817	5,434
wetlands	4	940	23,118	617	18,301	2,597
water bodies	5	2,323	3,703	4,159	227	31,557

3.2. Spatial patterns of LULC trajectories

The spatial representation of the LULC changes, confirms the nature of the trajectories. Figure 5 shows, for instance, an example of the artificialisation process occurred between 1954 and 2008 (in red) around the original urban centers (in pink). The road network is overlain on the map, showing also the sprawl along the major communication infrastructures. Both processes occurred at the expenses of good quality arable land in the flood plains of Emilia Romagna. Figure 6 depicts (in brown) the transformation from agricultural land to forest and naturally vegetated land in the south-eastern part of the Region, mainly due to abandonment in hilly and mountainous areas.

Figure 5. An example of artificialisation around urban centers and roads

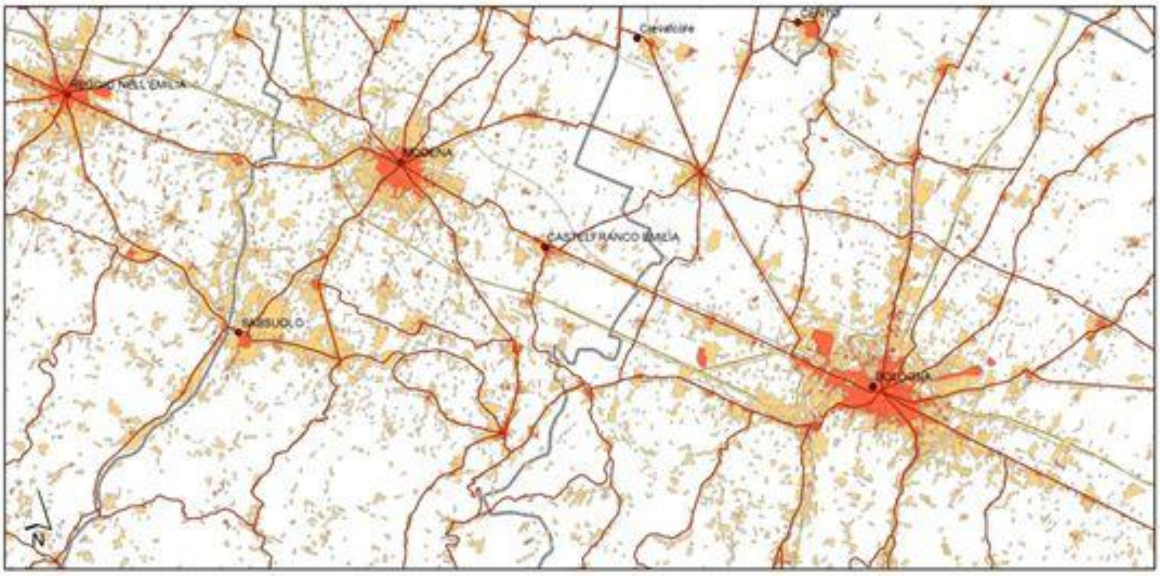
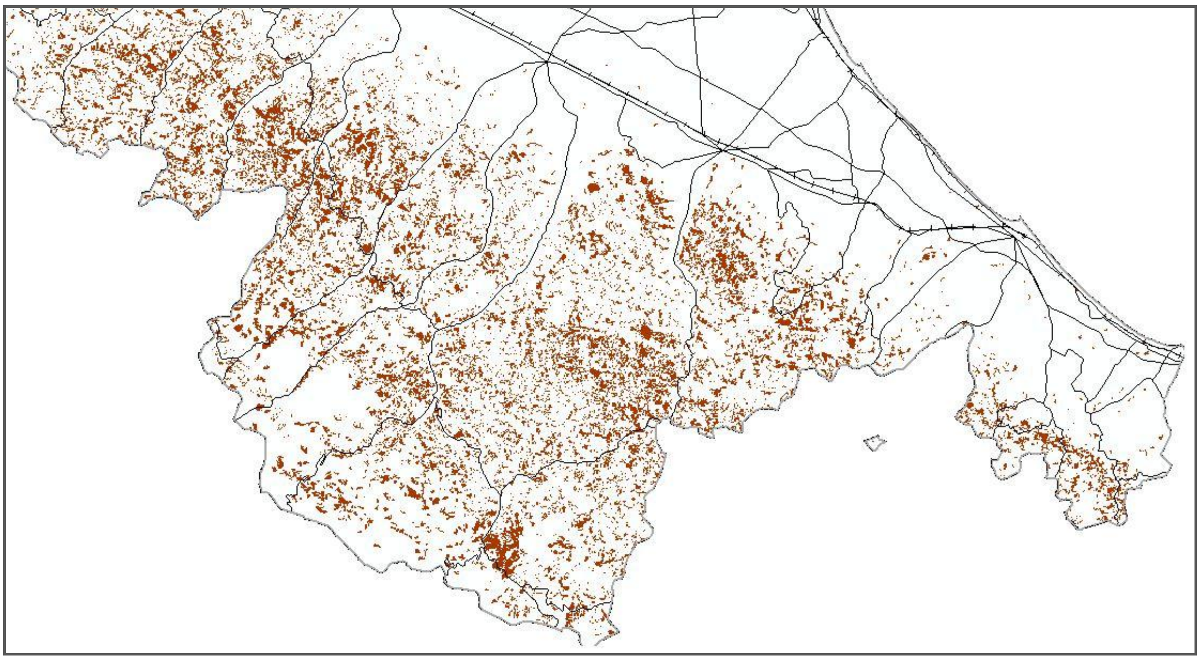


Figure 6. An example of transition to forest and natural vegetation land



3.3. Trajectories and associated LD syndromes

The LULC trajectories identified over the period 1954-2008, both in their magnitude and spatial patterns, relate to land artificialisation and abandonment. Artificialisation, occurring in the forms of urban growth and sprawl, is at the basis of a key land degradation syndrome in many areas of Europe. Apart from the physical consumption of land, often coinciding with the most fertile agricultural areas, it also indeed leads to soil sealing and compaction. These have the known effect of making the soil surface resistant to the absorption of rainfall, thus increasing run-off and, indirectly, soil erosion. As previously discussed, the abandonment of agricultural land leads to a process of succession towards complex mosaics of cultivations, fallows and natural grasslands, to scrubland and ultimately to forest land. The relative impact of land degradation (mainly in terms of soil erosion) on forest versus arable land is a widely debated issue. It very much depends on the climate, morphology and pedological conditions of the territory, as well as on conservation practices and on the type of forest succession. However, for the above mentioned reasons, land abandonment is likely to lead to land degradation in cases where vegetation cover remains poor [5]. In the study areas it is not possible to establish a clear-cut relation between land abandonment and LD, unless more information on concurring factors or direct observations of actual degradation processes is available.

4. Conclusions

The analysis of land use-land cover trajectories and associated land degradation processes over 54 years in Emilia-Romagna, showed that two key LD syndromes are of extreme importance in the region. The first is artificialisation, which occurred extensively in the region, thus reducing the agricultural production base as well as generating off-site negative effects in terms of run-off and soil compaction. Land abandonment has also been shown as an important syndrome, while its net effects in terms of LD are controversial and would need more in depth-analysis of both secondary data and field observations. Whatever the net impact of the mentioned syndromes, an understanding in both their temporal and spatial dimensions and drivers is essential information for devising focused and sustainable land management options. This paper focus on the analysis of the past, but, in the continuation of the research, LULC trajectories will be used for deriving prediction rules to construct scenarios of LD, together with external drivers such as climate change and population projections.

Conflict of Interest

The authors declare no conflict of interest.

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