Land-Use Trajectories and ‘Syndromes’ of Land Degradation in Northern Italy

Tomaso Ceccarelli*, Luca Salvati*, Sofia Bajocco†, Luigi Perini†

(Paper first received, January 2013; in final form, September 2013)

Abstract

The expression Land Degradation (LD) refers to a reduction in the productivity of land and the provision of ecosystem services. By linking trajectories of Land Use and Land Cover (LULC) and LD processes, the paper evaluates degradation ‘syndromes’ in the past, and develops future scenarios for sustainable land management. Emilia Romagna is a region characterized by major economic transformations reflected in its landscape. By analysing LULC over 54 years, two trajectories were identified and linked to LD ‘syndromes’: (i) urban expansion and (ii) abandonment of farmland. The result is a loss of farmland which has impacted negatively on the primary sector.

Keywords: urban sprawl, spatial analysis; sustainable land management.

JEL classification: Q01, Q24, R14, R23.

Le ‘sindromi’ di degrado delle terre nel Nord Italia

(Articolo ricevuto, gennaio 2013; in forma definitiva, settembre 2013)

Sommario

Il degrado delle terre implica riduzione della produttività economica delle stesse nella capacità di fornire servizi eco-sistemici. Collegando traiettorie di uso/copertura del suolo e processi di degrado delle terre è possibile valutare ‘sindromi’ di degrado nel passato e prospettare scenari futuri, supportando la gestione sostenibile del territorio. L’Emilia Romagna è caratterizzata da trasformazioni economiche importanti che si riflettono in quelle del paesaggio. Analizzando uso/copertura del suolo per 54 anni due traiettorie sono state identificate e poste in relazione alle sindromi: (i) espansione urbana e (ii) ‘abbandono’. Il risultato è una perdita di terreni agricoli, con impatto negativo sull’intero settore primario.

Parole chiave: diffusione urbana; analisi spaziale; sostenibilità.

Classificazione JEL: Q01, Q24, R14, R23.

* Consiglio per la Ricerca e la Sperimentazione in Agricoltura (csa) - Unità di ricerca per la Climatologia e la Meteorologia applicate all’Agricoltura (csa), Via del Casaralta 78/a, 00186, Roma, Italy, e-mail: cma@enteca.it; sofia.bajocco@enteca.it; luigi.perini@enteca.it.
† Consiglio per la Ricerca e la Sperimentazione in Agricoltura (cra) - Centro di ricerca per lo studio delle Relazioni tra Pianta e Suolo (pras), Via della Navicella 2-4, 00184 - Roma, Italy e-mail: rps@enteca.it. Corresponding author: e-mail luca.salvati@enteca.it.
1. Introduction

Land Degradation (LD) is regarded as one of the most important processes leading to environmental deterioration and biodiversity loss (Imeson, 2012). The consequences of LD specifically refer to the decline in the primary production and ecosystem services provided by cropland, rangeland, and woodlands. LD processes include soil erosion, hydrological instability, land take and soil sealing, protracted soil aridity, soil salinization, soil compaction, point and diffuse soil contamination, or those resulting from wildfires. ‘Syndromes’ of LD are single, or they may often be ‘bundles’ of processes which occur in specific territorial contexts. Syndromes can be evaluated in the past and projected in the future to inform sustainable land management strategies (Hill et al., 2008).

Sustainability requires the integration of three dimensions – environmental quality, social equity, and economic demands – in order to achieve a development strategy which meets the needs of the present generation without compromising the ability of future generations to fulfill their own needs. Various degrees of environmental sustainability can be achieved when humans closely monitor and contain their impacts on earth’s natural environment (Imeson, 2012).

Land-use is the visible result of (in) sustainable interactions between natural and socioeconomic systems on land. The use of land often reveals the occurrence of LD, either because it exerts a direct effect on the degradation processes (as in the case of land take and soil sealing) or because it is associated with unsustainable land husbandry practices occurring on fragile soil and landscapes. Land Use and Land Cover (LULC) diachronic mapping is therefore essential in order to derive past trajectories of change which can be associated with specific LD processes and further characterized as syndromes. The same trajectories also provide prediction rules for land-use scenarios.

The European Topic Centre on Terrestrial Environment of the European Environment Agency (EEA) has developed the LEAC (Land and Ecosystem Accounts) in order to assess the stock available for each land cover class and to monitor the changes that have occurred in the past between different coverage of land-use datasets (in this case the Corine Land Cover pan-European cartography). These changes are further classified into land cover flows corresponding to relevant land-use processes (Gómez, Ferran Páramo, 2005).

In principle, the requisite data can be derived from existing thematic cartography. However, sufficiently long LULC time series with comparable spatial resolutions and classification systems are seldom available. Alternatively, LULC data can be extracted ex novo from archive satellite imagery in the past, LandSat imagery, for instance, is now freely available and covers a period of around thirty years starting from the mid-1980s. However, a number of problems still have to be solved before this solution can be applied operationally to derive datasets with the requirements needed (see, for instance, Bajocco et al., 2012 and references therein). In the future, a number of new sources of earth observation remote sensing data will become available. Especially the EU Sentinel programme (namely Sentinel 2) and the LandSat 8 – continuity missions (LDCM) will hopefully guarantee such continuity in generating LULC datasets, for free or at low costs, in the coming years.

Land-Use Trajectories and Syndromes of Land Degradation in Northwestern Italy

Owing to their environmental and economic implications, two types of LULC change are regarded as especially important in the European context: (i) urban expansion (in the form of both dense and dispersed urban growth) and (ii) land abandonment. These trajectories are also important for LULC assessment. As far as urban expansion is concerned, a pan-European study has shown a rapid growth of urban areas especially in the past decade (European Environment Agency, 2006). According to this study, the most visible environmental impacts are in countries (or regions) with high population densities, economic activities, including Belgium, the Netherlands, southern and central Germany, and northern Italy. The LD processes most directly linked to this trajectory of land-use change are the physical consumption of land (i.e., take), the soil sealing and landscape fragmentation (Johnson, 2001; Allen, 2003; 2005; McGregor et al., 2006; Cabral et al., 2011). The European Commission has recently published guidelines for monitoring and containing soil sealing in the continent (European Commission, 2012).

Farmland abandonment is a trajectory of land-use change to natural, possibly forest creation, especially in mountainous and hilly areas. This abandonment and modification usually takes the form of a transition from arable land to mosaic of transitional woodland-shrub, and eventually to forest creation. This trajectory, which is strictly associated with the decline of agriculture, investigated separately from other types of withdrawal from agriculture and is the rise to forest creation such as forestation. Additional information is given to distinguish between the two processes (e.g. forestation plans, forestry composition, etc.) and until this aspect is clarified, it is more appropriate to refer more generically to forest creation (Pelleri, Sulli, 1999; Kilic et al., 2010; Yilmaz, 2010).

The case of forest creation is more controversial in that it may lead to forest creation, hydrological instability and forest fires, but it may also result in a decrease of LD processes. The degree of these processes depends on topography, although the degree of vegetation cover is regarded as playing a key role, and also the need for further characterization of the abandonment process (e.g. type of agriculture at the origin of the process, landscape type, and severity and severity of the abandonment, socioeconomic context).

Given these considerations, this study pays special attention to two land-use change trajectories: (i) urban expansion (i.e. in the form of both dense and dispersed urban growth) and (ii) land forest creation, possibly related to land abandonment. Emilia-Romagna, in north-eastern Italy, is an interesting study case because of its LULC dynamics observed over the past sixty years. Land-use trajectories are causing a substantial loss of agricultural land, with consequences both the national scale (Biancalani et al., 2011). Emilia-Romagna also plays a fortunate exception from the point of view of LULC data, since it contains high-resolution datasets covering the period between 1954 and 2008, mainly available for quantitative applications.

2. Methodology

2.1. Study area

The area investigated is the Emilia-Romagna NUTS-2 region, which is located in north-eastern Italy and includes more than 300 municipalities. The region covers around 22,120 km² with varied morphology and landscapes ranging from the Adriatic coast, to the Po River Valley, to the Apennine mountainous range. Especially after World War II, Emilia-Romagna, one of the most affluent regions in Italy, experienced economic development, with the transformation of the productive structure into manufacturing industry, high-tech services, tourism, and high-income agriculture.

2.2. Datasets and harmonization of the LULC classification

The LULC datasets were generated over the years 1954, 1976, 1994, 2003 and 2008 by the Regional Cartographic and Geographic Information System Service of Emilia-Romagna (Cortiselli et al., 2011). A 2010-2011 mission was released in which both the geometric and the thematic contents were harmonized by the same service. The datasets have a nominal scale of 1:5,000, and they are all comparable in terms of spatial resolution, with the exception of the 1976 dataset. For the purpose of the analysis reported here, the 1976 dataset was therefore re-sampled to the other, spatially less detailed datasets because of its finer spatial resolution. The classification schemes vary according to the year, but the harmonization exercise carried out by the same Service and finalized for this research enables comparison, with some adaptations of the third hierarchical level of the Corine Land Cover (CLC) nomenclature (EEA, 2002). An overview of the datasets is given in Tab. 1.

Tab. 2 provides a list and description of the classes based on the harmonized nomenclature. This is given both at a 'detailed' level including nine classes and at a 'generalized' level consisting of five classes that correspond to the first level in the CLC nomenclature. In the latter case, class 1 corresponds to urban areas, class 2 to agricultural areas, class 3 to forest and semi-natural areas, class 4 to wetlands and class 5 to water bodies.

2.3. Analysis of LULC changes and identification of land-use trajectories

LULC changes were analysed with the help of the IDRISI Land Change Modeler (LCM) of IDRISI泰娜 (Eastman, 2009), comparing 1954 and 2008 datasets as well as intermediate time steps for specific analyses. The interpretation of LULC changes in terms of meaningful land-use trajectories with the help on LD processes was conducted in accordance with Hill et al. (2008) and the basis of a bibliographic analysis of the biophysical and socioeconomic forces behind the LULC changes in the area investigated.
### Land-Use Trajectories and ‘Syndromes’ of Land Degradation in Northern Italy

#### 2.4. Data analysis

The proportion of each class of land-use expressed at both the ‘detailed’ and the ‘generalized’ nomenclature level on the total investigated surface area as well as the percent annual change were tabulated by year in order to assess the main landscape transformations observed in Emilia Romagna. A mid-point in the 54-year time series (1976) was selected in order to analyse separately two horizons of a comparable length in time (1954–1976 and 1976–2008). This choice was made because the late 1970s were a period of changing demographic and settlement patterns in Emilia Romagna. After a considerable increase, the population began to decline in inner cities and to grow in peri-urban and rural areas, determining the expansion of low-density dispersed settlements with effects on land consumption and possible degradation. Also, in about the same period, marginal areas in the mountainous and hilly portions of the region started experiencing the abandonment of agricultural activities in favour of natural vegetation and forest recolonization.

#### 3. Results

##### 3.1. Trajectories of LULC change in Emilia-Romagna

Tab. 3 summarizes the areas and percentages of the nineteen LULC classes at the ‘detailed’ level of the nomenclature and for the five-year investigation, the percent difference between 1954 and 2008, and the intermediate time horizons. For the overall time sequence, the two classes with the highest increases were forest land (8.7%) and urban areas including urban fabric, commercial units, major roads and railways (4.0%), followed by industrial areas (2.2%). The classes with the highest decreases were arable land (-9.3%), crop mosaics (-4.3%) and scrubland (-4.3%).

It is interesting to observe the decline in crop mosaics decline which, as such, corresponds to a simplification of the agrarian landscape.

The results correspond to the trajectories of urban expansion and forest creation. As shown in Fig. 1, which indicates the contribution to the net changes for forest and urban expansion, the increase of forest land occurred at the expense of scrubland, crop mosaics, arable land, meadow, and only marginally of sparsely vegetated and bare rock areas. While in the latter case the change can be referred to afforestation and reforestation, the former transformations appear to be the result of land abandonment going through different re-cultivation processes. The re-colonization of forests and natural vegetation consists, in fact, of step transitions from arable land, to complex land mosaics and meadows, shrub land and, finally, to forest stands.

In the same figure, the contribution to the increase of urban areas illustrates the transformation of arable lands and other agricultural areas (complex, or mosaic cultivations and tree plantations), and only marginally forest and other natural areas, over the 54-year time horizon. A net increase in urban areas (870 km²) took place, reaching over 1,720 km² (8% of the total investigated area), if all categories of artificial land are considered (see class 1 at the ‘generalized’

---

**Table 3** LULC areas (in ha) and percentages by class and for the five time steps and 2008.1995. Difference

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1995</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1990</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1985</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1980</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1975</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1970</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1965</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1960</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1955</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1950</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

---

Source: Authors' own elaboration
Fig. 1 – Spatial distribution of the two investigated land-use trajectories

Legend
- Urban expansion (1954-1976)
- Urban expansion after 1976
- Agricultural abandonment in favour of forest and natural land expansion

Source: Author's own elaboration

Fig. 2 – Examples of urban expansion around urban centers and communication axes

Source: Author's own elaboration

Fig. 3 – Examples of transition to natural vegetation and forest land

Source: Author's own elaboration

classification level), Urban expansion occurred in different forms: densification around the pristine urban centres and along the coasts, and more recently, a sparse expansion along communication axes and in rural areas. Arable land is by far the most important net loser, with nearly 1,000 km² consumed by other uses in the time period considered.

3.2. LULC change over the two different time periods

LULC changes were also analysed according to the two different periods (1954-1976 and 1976-2008). Tab. 3 show the net changes for the two time horizons.

In the first phase, the net gains of the urban class were altogether modest. The net loss of arable land was weak and somewhat counterbalanced by the increase in vineyards, olive trees, and meadows, which can be regarded as indicators of a transformation in the agricultural system (although with a higher degree of capital and labour intensity).

Forest land was increasing, together with those planted with poplars. This process can be associated with both land abandonment and forestation. Indeed, until the 1960s, many new forest plantations consisting of poplars and rapid growth species (i.e. Short Rotation Forestry) were established in response to the needs of the pulp and paper industry. After that period, with the crisis of the paper industry, the interest in such tree plantations declined.
In the second phase (1976-2008), the net loss of arable land was substantial and no longer accompanied by internal conversions to more intensive land-uses. On the contrary, a reduction in the area planted with vineyards and meadows was recorded. The expansion of forest land and urban areas was also observed. In light of the above results we can assume that most forest land development after 1976 was actually the result of farmland abandonment.

3.3. Spatial patterns of LULC trajectories

Fig. 2 illustrates the spatial pattern of the land trajectories that occurred in the period 1976-2008. With regard to urban expansion, pre-existing (1954) urban settlements are shown in purple, while the expanding areas are in red. Apart from densification around the main urban poles, to be noted is that a similar process occurred around the road network (for instance the A1 'Del Brennero' motorway, the 'Via Emilia' and 'Pedemontana' highways, and roads towards the Apennines, oriented north-south, and the railways along the Adriatic coast). Finally, the urban development in the mountain areas of the Apennines (stretching from the western to the southern and the south-eastern parts of the region) due to winter sport tourism is less marked, but possibly with higher environmental impact. By contrast, the expansion of forest land (shown in green) mostly took place in the hilly and mountainous areas of Emilia-Romagna.

A more detailed spatial representation of the LULC changes confirms the nature of the trajectories examined. Fig. 3 shows an example of an area (A in Fig. 2) in the lower parts of the provinces of Reggio Emilia, Modena, and Bologna where the urbanization process took place between 1954 and 2008. Settlement growth around the pristine urban centers (in dark orange) and the sprawl along the major communication axes and in the rural areas are evident phenomena. Another area (B in Fig. 2) in the south-eastern part of the region is shown in Fig. 6 with an example of the transformation that occurred in the same period from agricultural land to naturally vegetated and forest land. As said, this can be mainly ascribed to the abandonment of cultivated areas in hilly and mountainous areas.

4. Discussion

The main LULC trajectories identified in Emilia-Romagna relate to urban expansion and agricultural land abandonment. In the case of urbanization, taking the form of both dense and dispersed expansion, the LULC processes most directly linked to this trajectory are land take and soil sealing. Apart from the physical consumption of land, which often threatens the most fertile agricultural areas in the Po valley, urbanization has the well-known effect of 'soil sealing'. This process exerts a negative effect on the environment by reducing the amount of rainfall that can be absorbed and stored by the soil, thus increasing run-off and, indirectly, soil erosion (Torrens; 2006; Shahid; et al., 2011; Villa, 2012). With soil sealing, topsoil is most often removed during building activities, which cause a significant loss of its organic carbon stock (Scalenghe et al., 2011). Reduction in evapotranspiration is, together with others, a significant factor contributing to the urban heat island effect. Pollution due to point contamination, which affects soil, water and air quality and the overall quality of life, can also be negatively affected by soil sealing. While these effects are clearly exerted on-site by dense urban growth, with the process of dispersed expansion, given the generally lower settlement density, the related processes are mainly, although not exclusively, occurring off-site (Salvati et al., 2013).

The case of forest expansion and the underlying farmland abandonment is characterized by the period from arable land and a complex mosaic of cultivation to protracted fallow meadows and natural grasslands, to transitional woodland-shrub and, eventually, to forest and woodland creation. In this case, the association with LUL processes is more controversial. In principle, a number of studies have recognized farmland abandonment in the region as leading to soil erosion, hydrological instability and indirectly, to wild fires (Nunes et al., 2010). However, a number of studies conducted in similar environments have indicated that 'new' forest land, if properly managed, can be the agent of a positive naturalization process, a valuable asset in both economic and biodiversity terms (Pellert; Sulli, 1999). The final result, i.e. whether the negative impact of LUL prevails over the positive effects of naturalization processes, depends on the region's climate, morphology and soil, as well as on the initial characteristics of farming (e.g. presence of terraces), conservation practices, and the type of forest succession. Land abandonment is likely to lead to land degradation in cases where vegetation cover remains altogether poor (Kosmas et al., 1999).

5. Conclusions

Emilia Romagna is an Italian region which over the past fifty years has been characterized by drastic transformations in both the primary and secondary sectors. These have been mirrored in land-use changes recorded by thematic cartography spanning the 1954-2008 time horizon. This is one of the few cases in Italy where detailed and comparable land-use datasets (in terms of both spatial resolution and classification hierarchy) are available for such a long time horizon. Analysis of LULC trajectories and associated LUL processes over 54 years in Emilia Romagna, showed that two 'syndromes' are of extreme importance in the region. The first is urbanization, which occurred extensively in the area investigated, thus reducing the agricultural production base as well as generating off-site negative effects especially in terms of run-off and soil erosion (Reckien et al., 2011). Land abandonment was also shown to be an important syndrome, while its net effects in terms of LUL are controversial and require more in-depth analysis using both secondary data and field observation (Garcia Rodriguez, Perez Gonzales, 2007).

A more detailed analysis of hotspots in the hilly and mountain areas of the region would help clarify the types and severity of the degradation processes associated with this syndrome. This analysis would have to consider factors such as climate, morphology, visible signs of actual soil degradation and soil conditions in general, as well as pristine farming types and conservation practices. From this perspective, interesting opportunities for in-situ data collection are
today provided by two distinctive but complementary options supplementing, or even replacing, traditional and very costly field surveys. On the one hand, proximal sensing and related platforms constitute a major technological advance in terms of sensors measuring soil properties, moisture and degradation, as well as other aspects. On the other hand, new forms of in-situ data collection, assisted by mobile devices for data geo-location and entry, can integrate traditional surveys. These are known as ‘citizen science’, volunteered geographic information, or ‘participatory mapping’, and in the near future they may provide information useful for quantitative environmental assessments. Combinations of the two may represent, in the future, a major breakthrough in terms of the generation of valuable in-situ information for planning and policies at all levels.

Whatever the net impact of the above-described syndromes, information on both their temporal and spatial dimensions and drivers is essential for devising focused land management options in the framework of sustainable regional planning. Previous studies (e.g. Mazzanti, Zoboli, 2013) have shown that economic instruments, in addition to urban and regional planning, are needed to shape and monitor environmental policies. The complementarity of land-use planning and economic instruments is considered a key driver of sustainability performances, and it corroborates the assumption that policy responses integrating economic, social and environmental targets are more effective than sectoral policies in the mitigation of Land Degradation (Briassoulis, 2011). The analysis proposed in this study can thus inform multi-target policy strategies against desertification in the Mediterranean basin.

Future research should consider the past trajectories in LULC together with trends in other relevant drivers of LD syndromes (e.g. aridity and climatic aggressiveness, water and soil erosion, soil salinization, soil compaction, industrial and agricultural soil pollution, urbanization and tourism driven forest fires) through quantitative indicators of land vulnerability and ‘narrative’ interpretations of a qualitative nature (Doysun, 2008). Climate forecasts, population projections and land-use modelling should be integrated with past LULC trajectories in order to develop future LD scenarios that link the traditional biophysical research perspectives with socioeconomic studies concentrating on drivers of land-use changes, urban form and the spatial organization of economic activities at the regional scale, among others. Regional planning should integrate these research themes more effectively in order to promote the sustainable management of rapidly-changing territories subject to increasing natural and anthropogenic pressures.

References


