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Modelling the impact of urban growth on agriculture and natural land in Italy to 2030

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ABSTRACT

The uncontrolled spread of towns and cities into their surrounding rural and natural land, and the consequent increasing demand for new natural resources are among the most important drivers of global climate and environmental change. This study investigated the loss of natural and agricultural land in Italy in the last decades, during which urban areas have undergone significant expansion. The study underlines the negative consequences of past uncoordinated urban and regional planning in Italy which often featured adaptive *ex-post* strategies favouring real estate market returns, rather than avoiding *ex-ante* the unsustainable threats. The aim is to show that only through a recalibration of priorities in planning, by adding policies that favour ecological conservation, it is possible to better foster sustainable land use practices. To this end, the research features a comparison of forecasts of land-use/cover changes (LUCC) corresponding to different policy-oriented scenarios, using a combination of multi criteria analysis and cellular automata modelling. In the planning literature there are many applications of land-use change modelling at the regional/local scale, however to the best of our knowledge, none does it at high resolution and at the full country scale. This sort of analysis is important for policy makers because it allows investigation of the combined relevance of local and global criteria in influencing urbanization for the future. Thus it couples locally relevant findings with a comprehensive vision of the phenomenon at a national scale. We conclude by discussing some critical socio-economic implications of the modelled scenarios in order to provide policy makers with useful tools and information to develop resilient and sustainable planning strategies.

1. Introduction

Urban areas worldwide have been steadily expanding, usually at the expense of natural and semi-natural land (Kourtit, Nijkamp, & Reid, 2014; Ramankutty, Amato, Monfreda, & Foley, 2008). Consequently, urbanites demand for new natural resource areas has increased, and is now among the most important drivers of environmental threats (Foley et al., 2005; Rockström et al., 2009). These contemporaneous phenomena contribute to global climate and environmental change in many parts of the world, and will dominate land changes in the 21st century.

In this regard, land taken for development and the consequent loss of natural and farm land are among the most evident consequences of urbanization (Cobbinah & Aboagye, 2017), and vegetated areas have been observed to be the land-use classes most prone to conversion for new urbanization (e.g. pasture, woodlands, shrubs, cropland etc.) (Seto, Güneralp, & Hutyra, 2012). One of the most evident effects of this juxtaposition is the paradoxical competition between land for housing and agricultural land for food (Ontario Federation of Agriculture, 2015; Amato, Maimone, Martellozzo, Nolè, & Murgante, 2016). Consequently, some regions are suffering the repercussions of this land-use conflict as a threat both to the environment and to food security (Lynch, Maconachie, Binns, Tengbe, & Bangura, 2013; Foley et al., 2011). For example, research has shown how high quality farmland is often threatened by urbanization in many parts of the world (Seto, Fragkias, Güneralp, & Reilly, 2011; Foley et al., 2011). Moreover, some countries have been responding to internal rapid urbanization through international land development, which has been identified as having negative consequences both on environment and society (Su, Jiang, Zhang, & Zhang, 2011; Messerli, Giger, Dwyer, Breu, & Eckert, 2014; Lambin & Meyfroidt, 2010). Land use science (Feranec, Jaffrain, Soukup, & Hazeu, 2010) and modelling (Basse, Omrani, Charif, Gerber, & Bódis, 2014) have made impressive progress in producing more accurate results, at larger scales (Haney & Cohen, 2015; Sohl et al., 2012), and

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with higher spatial-temporal resolution (Bhaskaran, Paramananda, & Ramnarayan, 2010; Tavares, Pato, & Magalhães, 2012; Soares Machado et al., 2014). However, the effectiveness of policies implemented to regulate land use change, and how and at which spatial scale these policies should be implemented for sustainability targets (He et al., 2013; Hewitt & Escobar, 2011) have only recently engaged scientific research and such questions have not been approached systematically with spatially explicit data (Stürck, Schulp, & Verburg, 2015).

The methodological framework adopted in this study features past trend data analysis coupled with modelled projections for Italy. The data used is a fusion of archived thematic maps (land use and topography), census and ancillary economic data, and LUCC forecasts obtained through cellular automata modelling using the SLEUTH model. The aims of this study are twofold. First, to provide an analysis of land use changes that occurred in Italy in the past, in relation to the dominant development criteria and policies. In particular, we offer a critical interpretation of the effects of planning policy in Italy, and we highlight the lack of effective plan implementation. In fact, these policies seem to have completely failed in regulating LUCC processes and in preventing an excessive level of urbanization (Amato, Martellozzo, Nolè, & Murgante, 2017), or at least their supposed limiting action was overruled by other interests (such as the economy) (Amato et al., 2016). This critical interpretation demonstrates the argument that in order to achieve or reduce the gap toward attaining the international Sustainable Development Goals (SDGs) regarding land use, future land planning instruments (Russo, 2013; Marinosci et al., 2013) should aim for more ambitious targets to counterbalance the influence of other competing factors that have changed the Italian National Bill under the influence of the market.

Secondly, this research includes an original modelling application to produce spatially explicit realistic forecasts of urbanization and LUCC that consider several criteria at the same time (i.e. socioeconomic, ecological, and landscape planning variables). Such modelling mimics the potential impact of a specific policy-oriented scenario on future landscape transformations. This builds upon two different simulations of urbanization and LUCC that respond to different policy-oriented scenarios. The first represents a continued prevalence of economic interests over ecological conservation criteria, thus – according to the opinion of an expert panel – mimicking what has happened in Italy in the last few decades (Romano & Zullo, 2014). Conversely, the second scenario aims at improving environmental conservation. This second scenario is useful to explore the possibility, the time, and the reciprocal weights of the different criteria needed to reduce the future ecological burden regarding land take (UNDESA, 2015).

The results feature a mapping of potential future LUCC and urban growth for the whole territory of the Italian peninsula and to our best knowledge is the first attempt to make an application of the chosen model (SLEUTH) at the country scale with detailed spatial resolution. In fact, usually LUCC analyses are performed at the local or regional scale because landscape transitions dealing with urban form are more evident at local scales, and mainly respond to local/regional dynamics (Pontius et al., 2008). In fact, the strategies aimed at controlling these dynamics are defined over a hierarchical set of scales (i.e. local, regional, country level, international etc.) (Las Casas et al., 2016; Lombardini et al., 2016; Tilman et al., 2001). Nevertheless, LUCC mapping and modelling requires a large amount of data and generous computational capabilities (Batty, 1997) that have prevented applications of this sort to date. Furthermore, besides the ability to finely map the effects and the consequences of LUCC dynamics for relatively small areas, the ability to grasp the magnitude of such dynamics for the large region (or a whole country) is extremely relevant.

Several LUCC modelling applications have tried to achieve this goal by investigating large areas, but at lower spatial and temporal resolution (Seto et al., 2012; Basse et al., 2014; Sudhira, Ramachandra, & Jagadish, 2004). However, there are now available both consistent time series of land cover/use data (e.g. Landsat imagery, Corine Land Cover, MODIS imagery, Moland etc.) and the computational capacity (e.g. super computing, cloud computing etc.) (Szul & Bednarz, 2014) to proceed. A spatially explicit investigational framework is extremely important for policy makers. On the one hand, it allows the investigation of the combined relevance of local and global criteria influencing LUCC dynamics and the evolution of landscape forms; on the other hand, it ensures both locally rigorous and country-scale homogenous results based on the same set of criteria.

The criteria used to characterize the two different scenarios were chosen from among the most important drivers of LUCC and urbanization known in the literature (Sudhira et al., 2004; Torrens & Alberti, 2000). The data used, although sometimes limited by availability, accuracy and completeness, includes a representative and significant subset of these criteria. The relevance and relative importance of the criteria used was mediated by the judgment of a panel of experts in Italian spatial planning. The variables were evaluated and merged through a multi-criteria decision making (MCDM) (Mahiny & Clarke, 2013) process in order to mimic a potential participatory planning situation resulting in two possible but contrasting policy scenarios. The two alternatives have been implemented separately in the CA modelling forecasts, to characterize independently a temporal series of LUCC prediction results, and then used to make a comparison between the two simulations.

A basic assumption is that by varying only the policy-oriented scenario in the model, and keeping all other parameters unchanged, the differences in the results must necessarily reflect differences between the two scenarios. The aim is to ground a comparative analysis of the consequences of different policy orientations with intelligible empirical data (Onsted & Clarke, 2012; Onsted & Clarke, 2011). The expert panel of 5 people was composed of: a professor of urban planning, whose main contribution was related to the analysis of the relationship between urban growth and landscape protection; two researchers in urban planning, who discussed the relations between the community protection rules of the Natura 2000 Network and the Italian national landscape policies; a professor of real estate, who discussed the relationship between the housing market and urban development, and a geographer, who analysed the spatial relationships between the distribution of the landscape components and human activities. The expert advisory panel supervised the definition of the scenarios and was also responsible for standardizing and weighting the criteria for the scenarios using the Analytical Hierarchical Process (AHP; SM2.1, SM2.2, and SM2.3).

2. Materials and methods

We linked data from the analysis of past trends to modelled projections based on a fusion of archived thematic maps, census and ancillary economic data, and land cover forecasts obtained using the cellular automata model SLEUTH. We chose this model for its ease of implementation and for its ability to input high resolution multi-temporal input data that was available at the country scale. The data used to investigate past LUCC are the same needed as input for the SLEUTH application. The SLEUTH model employs spatially explicit data describing the geographical distribution of topographic slope, land use, transportation, urban extent and exclusion factors. An important input to SLEUTH for correctly calibrating forecasts of future LUCC and urbanization is the way the model considers the intensity to which different areas resist changes or conversely are more prone to transition dynamics. This information is conveyed by an *exclusion* layer which was in this case created using a MCDM process informed by the AHP to establish the two different policy-oriented scenarios (Onsted & Clarke, 2012).

2.1. The SLEUTH urban expansion and LUC model and the analytic hierarchy process

SLEUTH is a CA model developed to deliver valid, statistically