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Spatio-temporal analysis of the urban-rural gradient structure: an application in a Mediterranean mountainous landscape (Serra San Bruno, Italy)

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Abstract

The most recent and significant transformations of European landscapes have oc-
curred as a consequence of a series of diffused, varied and often connected phenom-
ena: urban growth and sprawl, agricultural intensification in the most suitable areas and
5 agricultural abandonment in marginal areas. These phenomena can affect dramatically
ecosystems' structure and functioning, since certain modifications cause landscape
fragmentation while others tend to increase homogeneity. Thus, a thorough compre-
hension of the evolution trends of landscapes, in particular those linked to urban-rural
relations, is crucial for a sustainable landscape planning.

10   In this framework, the main objectives of the present paper are: (a) to investigate
Land Use/Land Cover (LULC) transformations and dynamics occurred over the period
1955–2006 in the municipality of Serra San Bruno (Calabria, Italy), an area particularly
representative of the Mediterranean mountainous landscape; (b) to compare the settle-
ment growth with the urban planning tools in charge in the study area; (c) to examine
15 the relationship between urban-rural gradient, landscape metrics, demographic and
physical variables; (d) to investigate the evolution of urban-rural gradient composition
and configuration along significant axes of landscape changes.

    Data with a high level of detail (minimum mapping unit 0.2 ha) were obtained through
the digitisation of historical aerial photographs and digital orthophotos identifying LULC
20 classes according to the Corine Land Cover legend. The investigated period was di-
vided into four significant time intervals, which were specifically analysed to detect
LULC changes.

    Differently from previous studies, in the present research the spatio-temporal analy-
sis of urban-rural gradient was performed through three subsequent steps: (1) kernel
25 density analysis of settlements; (2) analysis of landscape structure by means of metrics
calculated using a moving window method; (3) analysis of composition and configura-
tion of the urban-rural gradient within three landscape profiles located along significant
axes of LULC change.

The use of thematic overlays and transition matrices enabled a precise identification of the LULC changes that had taken place over the examined period. As a result, a detailed description and mapping of the landscape dynamics were obtained. Furthermore, landscape profiling technique, using continuous data, allowed an innovative and valuable approach for analysing and interpreting urban-rural gradient structure over space and time.

1   Introduction

Over the last decades, the progressive world population growth has implied an increasingly exploitation of resources, with a growing demand for residential space and a corresponding increase in industrial activities and agricultural intensity. The consequent transformations of urban-rural systems are one of the most important types of Land Use/Land Cover (LULC) changes, since they are widespread all over the world and often determine negative effects on ecosystem functionality. Although most of the actions leading to LULC changes have a local origin, nevertheless their speed, extension and intensity bring about important global implications, in particular in carbon (Foley et al., 2005) and water cycles (Turner and Rusher, 1988). Moreover, LULC changes can dramatically affect the structure and functioning of ecosystems (Defries et al., 2004; Vitousek et al., 1997), since certain modifications cause landscape fragmentation while others tend to increase homogeneity (Forman, 1995; Farina, 1988). Their analysis is one of the main research topics of ecology (Braimoh, 2006) and landscape ecology (Wu and Hobbs, 2002). Therefore, the evaluation of LULC present status and trends of change can provide crucial ecological information for science-oriented resource management and policy-making, in relation to a wide range of human activities (Cihlar, 2000).

Urbanisation is a complex diffusion process that is dramatically spreading and variously affecting rural landscape at different spatial scales. The urbanisation process entails the transformation of landscapes, characterised by rural life styles, into urban

ones and determines functional and structural changes, thus creating new landscape patterns (Antrop, 2000). It can give rise to the most dramatic form of irreversible land modification (Luck and Wu, 2002) which poses threats on biodiversity and landscape integrity.

5   Urban sprawl is an inherently dynamic spatial phenomenon defined as a specific form of urban development with low density, dispersed spatial pattern and auto-dependent and environmentally and socially impacting characteristics (Hasse and Lathrop, 2003), which can be considered as one of the main challenges in spatial planning in the 21st century (Poelmans and Van Rompaey, 2009). The term "sprawl"

10 is often used to describe the awareness of an unsuitable development, of a disordered growth of urban areas (Sudhira et al., 2004). Taking into account its efficiency in terms of hectares of new development in relation to the number of people supported, sprawl can be considered as an "inefficient new urban growth" (Hasse and Lathrop, 2003). Thus, urban sprawl is the consequence of many individual decisions and some of its

15 causes are population growth, economic issues and proximity to resources and basic facilities (Hoffhine Wilson et al., 2003).

Especially in the Mediterranean area, the urbanisation process is still ongoing with significant effects in landscape fragmentation and in loss of ecosystem services (EEA, 2011). Historically, urban development and agriculture have acted as counterposed

20 activities in competition for the use of land: the expansion of cities has typically taken place on former agricultural lands (Hidding et al., 2000). Just to mention a few data, between 1990 and 2000, the amount of land consumed by urban areas and associated infrastructure throughout Europe was about $800\,km^2\,yr^{-1}$ (EEA, 2006). In Italy, in particular, an increase in urban pressure on the countryside can still be observed, owing

25 to land renting and displacement of certain typical urban functions outside the cities (Murgante and Danese, 2011). This trend is a reversal of the demographic and territorial dynamics occurred during the period immediately following the Second World War and has resulted in the progressive urbanisation of rural areas; in a general increase

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in the number of inhabitants in the periurban belts; and in a decrease in resident population in towns (Alberti et al., 1994).

The Mediterranean area is one of the most significantly altered hotspots on Earth (Myers, et al., 2000). Here, the widespread agricultural lands, evergreen woodlands and maquis shrublands are the result of anthropogenic disturbances occurred over centuries or even millennia (Blondel, 2006). The most recent and significant LULC changes have occurred as a consequence of a series of diffused, varied and often connected phenomena: urban sprawl; agricultural intensification in the most suitable areas and agricultural abandonment in marginal areas; more frequent and more intense summer forest fires; and rapid expansion of tourism activities and infrastructures, mainly along the coasts (Antrop, 2004; EEA, 2006, 2011).

Owing to these continuous anthropic pressures and according to the different physical and climate conditions, further research is needed to monitor and analyse, in quantitative and qualitative terms, ongoing LULC changes (EEA, 2006, 2011; Fichera et al., 2011) and trends of urban-rural gradients. Data on urban-rural transformations are a valuable source of information in understanding the methods and the effects of urban landscape changes and trends. As a consequence, they can influence the formulation of guidelines and policies to address future growth as well as to put into practice urban greenspace protection.

The gradient approach in landscape ecological analysis allows for a more realistic representation of landscape heterogeneity by not presupposing schematisations and discretisations of the natural and anthropic environment (McGarigal and Chusman, 2005). Urbanisation can be considered as a particular environmental gradient that produces modifications on the structures and functions of the ecological system (McDonnell and Hahs, 2008). Thus, also the traditional urban-rural dichotomy can be thought as a landscape gradient, whose representation mutates depending on the natural and anthropic variables taken into account and to the spatio-temporal scale adopted for the analysis.

The urban-rural gradient paradigm is commonly used to investigate how urbanisation is changing the ecological patterns and related processes across the landscape (Mc-Donnell and Pickett, 1990; Luck and Wu, 2002; Hahs and McDonnell, 2006; McDonnell and Hahs, 2008; Yang et al., 2010; Vizzari, 2011a).

One effective method for representing and analysing the urban-rural gradient and the urban sprawl is using Kernel Density Estimation (KDE) techniques applied on locations of buildings (Torrens and Alberti, 2000; Vizzari, 2011a). Density analysis takes measured quantities associated with point data and spreads them across the landscape to produce a continuous surface. Unlike simple density estimation, KDE produces smoother surfaces that are more representative of landscape gradients (Vizzari, 2011b). In KDE, a moving window is superimposed over a grid of locations and the density of events is estimated at each location using a distance-weighted function, with the degree of smoothing controlled by the kernel bandwidth (Gatrell et al., 1996). Since the first study on KDE proposed by Fix and Hodges (Silverman and Jones, 1989), many improvements of this smoothing technique have been developed by several authors, particularly within spatial analysis applications (see Danese et al., 2008 and references therein).

With the aim to explore the relationships between ecosystem processes and services and landscape patterns, a valuable source of information can be obtained from using landscape metrics. According to Botequilha Leitão et al. (2006), landscape is the optimal scale for sustainable land planning, considering that landscapes are usually large enough and intrinsically consistent with the scale of human perception, decision-making and physical management (Forman, 1995; Botequilha Leitão and Ahern, 2002). Landscape metrics are useful tools in mapping and quantifying spatial LULC characteristics and temporal variation (Cushman et al., 2008) as well as in understanding the process of urbanisation and its ecological effect at landscape level (Sudhira et al., 2004; Peng et al., 2010). Plenty of metrics can be efficiently calculated using specific software packages, such as FRAGSTATS (McGarigal et al., 2012), and, despite all their conceptual flaws, risks of improper use and well-known limitations (Cushman et

al., 2008; Li and Wu, 2004), they continue to be widely used in quantitative landscape ecology studies aimed at the analysis of landscape structure. Landscape metrics find a very effective application in the analysis of urban to rural gradient composition and configuration (e.g. Luck and Wu, 2002; Hahs and McDonnell, 2006; Weng, 2007; Yang et al., 2010).

In this framework, the objectives of this study can be summarised as follows: (a) to investigate LULC transformations, occurred in a fifty-year period in a Mediterranean forestry landscape, by means of different spatial techniques; (b) to compare the settlement growth with the urban planning tools in force in the study area; (c) to examine the relationship between urban-rural gradient, landscape metrics and demographic and physical variables; (d) to investigate the evolution of urban-rural gradient composition and configuration along significant axes of landscape changes.

Unlike previous studies (e.g. Luck and Wu, 2002; Hahs and McDonnell, 2006), in this research, the spatio-temporal analysis of urban-rural gradient was performed through three steps: (1) kernel density analysis of settlements; (2) analysis of landscape structure by means of metrics calculated using a moving window method; (3) analysis of the gradient composition and configuration within three landscape profiles located along significant axes of LULC change.

2 Materials and methods

2.1 Study area

The research was carried out in the territory of the municipality of Serra San Bruno (Fig. 1), located in *Serre Vibonesi*, a mountainous area of Calabria (a region of Southern Italy) presenting many heritage resources of great natural, historic and architectural interest. The municipality has an area of 4000 ha circa and a residential density of 174.5 inhab. km^{-2} and is situated at an average altitude of 980 m a.s.l. Century-old woods, characterised by the prevalence of chestnut (*Castanea sativa* Miller), beech

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(*Fagus sylvatica* L.) and silver fir (*Abies alba* Miller subsp. *apennina* Brullo, Scelsi and Spampinato) populations, highlight the intrinsic suitability of this land for forestry production. Starting from the 1950s, reforestation has been practised by planting first conifers, such as the European black pine (*Pinus laricio* Poiret) and fir-douglas (*Pseudotsuga menziesii* (Mirb.) Franco), and then broad-leaved trees, such as chestnut. For centuries, the forests were owned by the Charterhouse of Serra San Bruno, which was founded by St. Bruno of Cologne in the 11th century. They were managed efficiently and sensitively according to the methods of the Carthusian monks. Count Roger II gave St. Bruno of Cologne the territories of *Serre Vibonesi* plateau to build his hermitage, the Charterhouse of Santo Stefano del Bosco, second Carthusian monastery in Europe after the one in Grenoble (France). The high environmental value of this area motivated the institution of two National Natural Reserves (now SCIs – Sites of Community Importance – of Natura 2000 network, the centrepiece of EU nature and biodiversity policy) and of the Regional Natural Park of Serre in 2004. The local industrial archaeology heritage is also very significant. It is related to the utilisation of water and wood as energy sources and dates back to the time of the Bourbon rule in Calabria (XVIII–XIX centuries). Worth mentioning, in the same area, are the many historic monastic complexes, some of which are still inhabited by the original religious orders, either Catholic or Greek-Orthodox.

Over time, like the many mountain areas of the Mediterranean basin, Serra San Bruno district has developed an economy that strongly depends on local natural resources. After the Second World War, it suffered progressive depopulation and many traditional economic activities, such as charcoal production, became weak and went through periods of crisis. Recently, the development of forms of tourism, based on the valorisation of the rich cultural and natural resources, has been of some help in sustaining the local economy. Tourists search for high landscape quality, which should be improved through sensitive landscape planning based on accurate monitoring of the dynamics characterising land use. This is also needed for the maintenance of the environmental balance of these areas, which are particularly fragile since they are exposed

to relevant hydrogeologic risk (the last catastrophic flood occurred in 1935, causing death and destruction).

2.2 Data processing

For the aims of this research, observation covered a period of intense and radical transformation of the Italian economic, cultural and territorial assets, ranging from the end of Second World War to present years. The first step towards the detection of LULC changes was the acquisition of all the relevant LULC maps referred to the period under investigation.

LULC Changes were analysed using aerial photographs from the Italian Military Geography Institute (IGMI), for years 1955 and 1983, and digital georeferenced orthophotos from the National Geoportal (NG) of the Italian Ministry of the Environment, for years 1994 and 2006. All the aerial photographs were georeferenced by using 20–30 Ground Control Points (GCP) and orthorectified by using a Digital Elevation Model (DEM) with 10 m × 10 m of spatial resolution. Four datasets with a spatial resolution of 1.37 m and an RMSE (Root Mean Square Error) less than 6.5 m were produced. A set of 1998 orthophotos, a 1:10 000 numerical topographic map and the DEM were used as reference material (for further details see Di Fazio et al., 2011).

In order to produce settlement-strata to perform the urban gradient analysis for the period under investigation, the buildings in the study area were digitised according to all the time intervals defined. In addition, a Worldview-2 scene for year 2011 was processed (Updike and Comp, 2010) in view of extracting the settlement stratum. To this end, an RGB colour orthophoto was produced from the original multispectral image that had been georeferenced and orthorectified, using 30 GCP and the available DEM, and then pan-sharpened. A Subtractive Resolution Merge technique was used for the purpose.

2.3 Analysis of the landscape mosaic evolution

2.3.1 LULC mapping changes

LULC maps are commonly produced either by aerial visual interpretation or by classification of remotely sensed images. Definitely, photo-interpretation requires skilled analysts, is a time-consuming technique and is subjective, considering the high degree of operator control. Nevertheless, it is still widely used and considered as a useful source of information in studies focussing on landscape pattern analysis (Zhou et al., 2009) and landscape change (Ode et al., 2010), owing to the scarcity, if not lack, of historic satellite imagery related to years before the 70s. In this research, LULC mapping was conducted by visual photointerpretation, thanks to the availability of aerial photographs referred to the period investigated and characterised by good frequency and high spatial resolution.

Photointerpretation was conducted by the same operator for all the years investigated (1955, 1983, 1994 and 2006) at a fixed scale of 1:1000–1:1500 (minimum mapping unit 0.2 ha). The four LULC maps produced and their landscape composition according to the 9 LULC classes (Table 1) are shown in Figs. 2 and 3, respectively. The basic characteristics of an aerial photo used for visual interpretation are: shape, size, pattern, tone or hue, texture, shadows, geographic or topographic site and associations between features (Lillesand et al., 2003; Gomarasca, 2009). In order to reduce geometrical discordances, which could be interpreted as LULC changes, the other LULC maps were produced by updating the 2006 one and using it as reference map. In order to assess the thematic accuracy of this map, a stratified random sampling was used to carry out direct surveys in 100 sampling points, distributed among LULC classes according to their surface share in landscape mosaic. The overall classification accuracy was 95.85 % with a Kappa coefficient of 0.94. The reference legend was implemented starting from the CORINE legend. The original 44 LULC classes at III level of details were aggregated in 9 classes (Table 1) so as to interpret changes as *change types* (Di Fazio et al., 2011).

The spatial comparison of LULC vector maps was performed for the years 1955, 1983, 1994 and 2006 by means of a post-classification comparison technique that could provide a complete matrix of change directions (Lu et al., 2004). It is a type of change detection obtained through a cross-tabulation analysis which enables to high-
5 light the changes occurred in time both in qualitative terms, by showing them directly on the map, and in quantitative terms, by allowing to calculate the total areal extent of land use change occurred at different times. Relative and absolute changes for each of the 9 LULC types were calculated from 9x9 transition matrices (or cross-tabulation matrices). The transition matrices were built for the time interval t_1 to t_2, wherein rows
10 display the categories of time 1 and columns display the categories of time 2. While row vectors show the evolution of a land use type in the period t_1–t_2, column vectors show the land use type at time t_1, from which another land use type was generated at time t_2. The data of the main diagonal, shown in bold, indicate the area of LULC persistence. In this paper, changes detected in the period 1955–2006 are reported (Fig. 4). For further
15 information about the results of the intermediate time interval analysis (1955–1983, 1983–1994 and 1994–2006), please refer to Di Fazio et al. (2011).

2.3.2 Landscape metrics analysis at class and landscape levels

With the aim to better understand and describe the expanding footprints of residen-tial and urban areas, the landscape composition and configuration of the study region
20 was investigated by using landscape metrics. When applying spatial metrics, the spa-tial unit used is called patch, defined as a relatively homogeneous area that differs from its surroundings (Forman, 1995). The basis of the spatial metric calculation is a thematic map (either in vector or raster format) representing a landscape composed of spatial patches categorised in different patch classes. Landscape metrics can be
25 defined as quantitative and aggregate measurements based on a categorical, patch-based representation of a landscape showing spatial heterogeneity at a specific scale and resolution (Herold et al., 2003, 2005) and represent one of the key factors in land-scape ecological research (Uuemaa et al., 2009) and in landscape planning. According

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to several authors (e.g. Gustafson, 1998; Herold et al., 2003, 2005; Seto and Fragkias, 2005; Aguilera et al., 2011), the term *spatial metrics* relates to the characterisation of urban forms as such, while the term *landscape metrics* explicitly links to ecological functions. A major value of landscape metrics lies in their usefulness for comparing alternative landscape configurations, for example in evaluating the same landscape at different time periods (Gustafson, 1998).

For the purpose of this research and according to Cushman et al. (2008), a set of a limited number of landscape metrics with a valuable meaning in analysing landscape composition and configuration was selected, both at class and landscape level and for all the time intervals defined (Fig. 5 gives a short explanation for each of them). The land use datasets (1955, 1983, 1994 and 2006) were first converted into Grid format (pixel size 10 m × 10 m) in order to perform synoptic metric analyses and further analyses using the FRAGSTATS package v. 4.0 (McGarigal et al., 2012).

2.4 Analysis of urban planning tools

This subsequent step of the research activities was aimed to study the current urban planning tools of Serra San Bruno from their implementation until today and to assess their stages of development. The General Master Plan (GMP) was adopted as a municipal planning tool in 1997 and is now being updated so as to help direct new urbanisation processes towards areas that are not intended for agricultural and forest use. The analyses carried out were also aimed to analyse LULC maps focussing on built-up areas, in order to evaluate their importance and role in shaping the character of the town. The processing of the above-mentioned thematic maps was performed to examine urban planning effectiveness and to provide a base to suggest recommendations for future improvements and support management tasks.

In this framework, GIS tools were used by exploiting their capability to support spatial analysis and give suggestions to planners and policy makers. One of the major benefits of this approach is that highly visual and interactive modelling and analysis can be performed. The existing raster map, which represents the GMP of Serra San Bruno,

was transformed into vector format by means of semiautomatic editing. The new layer produced represents the zoning of the town according to the indication of the GMP and includes 16 different land use categories (Inner city, Completion, Expansion, Public area, Green areas, etc.) as shown in Fig. 6.

The land uses in the study area include all the categories usually found in plans conceived for typical small towns like Serra San Bruno. The goal of this analysis was to calculate the effectiveness of zoning: the degree of success of the 1997 GMP was evaluated by taking into account both its indications and built-up expansion in the last 15 yr. To this end, a geoprocessing approach was pursued through a GIS overlay of built-up evolution (1994, 2006 and 2011), zoning layer and LULC maps. In compliance with previous studies (e.g. Luck and Wu, 2002; Hahs and McDonnell, 2006), the integration of demographic and physical data, during this phase of the analysis, allowed a better comprehension of the urban-rural gradient evolution.

2.5 Urban-rural gradient analysis

In this particular application, urban-rural gradient analysis was performed through three consecutive steps: (1) landscape metrics calculation within FRAGSTAT software using a moving window analysis; (2) Settlement Density Index (SDI) calculation by means of Kernel Density Estimation (KDE); (3) Landscape gradients analysis along three significant axes of LULC changes.

2.5.1 Landscape metrics via moving window analysis

The window, whose size and shape have to be defined by the user, can be moved over every positively valued cell in the grid, calculating the selected metric within the window, returning that value to the focal (centre) cell and outputting a new continuous surface grid map for the selected metric in which the cell value represents the "local neighbourhood structure" (McGarigal et al., 2012). Several trials were conducted in order to test the impact of the window size on the metrics calculated as well as to improve

the smoothing effect on produced maps. According to previous studies, carried out for study areas comparable with the one presented in this paper for both extension and geometric data resolution, results with a 500 m radius window have proved to be more effective in revealing landscape metrics fluctuations (Kong and Nakagoshi, 2006; Kong et al., 2012). Furthermore, this window size is equal to the one adopted for the SDI implementation described below, so as to produce relevant landscape metrics spatially comparable with the SDI analysis. Considering that FRAGSTATS gives negative values for cells located close to the edge and not fully contained within the window of the input grid (McGarigal et al., 2012), a buffer area (or expansion strip, as it is referred to by Mc-Garigal et al., 2012), equal to the radius of the window size (500 m), was first defined along the outline of the input LULC raster grid in order to minimise the boundary effect. The maps obtained with this procedure show the spatial distribution of landscape structure based on the results of the selected metrics.

Several landscape metrics were tested across the study-area in order to better understand landscape change patterns and evolution trends. In this phase of the research, a set of three metrics with moving window analysis were selected, owing to their efficacy in supporting the analysis of urban-rural gradient: Agricultural percentage of landscape (A-PLAND), Natural percentage of landscape (N-PLAND) and Simpson's Diversity Index (SIDI, Simpson, 1949) (Fig. 7). The first two indices indicate, for every pixel, the proportion of the circular window (centred on the pixel itself) occupied by agricultural land uses (mostly sowable lands) and by natural land covers (grasslands, woodlands, etc.), respectively. Furthermore, in conjunction with SDI, they support the analysis of the main components influencing the urban-rural gradient composition. SIDI has an interpretation that is much more intuitive than Shannon's index (SHDI, Shannon and Weaver, 1949) and less sensitive to the presence of rare types (Nagendra, 2002; McGarigal et al., 2012). Like SHDI, also SIDI has been widely used in several studies for representing landscape diversity changing in space and time. Ranging from 0 (low complexity: only one patch dominates the scene) and 1 (high complexity: all patch types are evenly distributed), Simpson's index defines the probability that

two equal-sized and randomly selected sub-units of landscape belong to different class types. This diversity index combines evaluations of richness and evenness. It increases with the increase of the number of class types (richness) and/or when proportional distribution of area among class types becomes more equitable. In turn, since it reflects the patch abundance and heterogeneity in landscapes, the SIDI index can be used to assess landscape diversity. To this end, however, it is necessary to take into account evidence given by Nagendra (2002) on the need for caution when using SHDI and SDI in assessing landscape diversity.

2.5.2 Settlement density analysis using Kernel Density Estimation

The use of density analysis techniques, based on KDE, allowed to calculate a spatial index by measuring the density of buildings within the study area. The application of KDE requires the choice of the type of kernel function (e.g. Gaussian, triangular, quartic) and the definition of three key parameters: bandwidth, cell size and intensity. Bandwidth definition is the most problematic step, but also the most useful for exploratory purposes, since a wider radius smooths the spatial variation of the phenomenon and thus shows a more general trend over the study area, while a narrower radius highlights more localized effects, such as "peaks and troughs" in the distribution (Jones et al., 1996). Despite all these approaches, the examination of surfaces resulting from different values of bandwidth remains a common method for the definition of this parameter (Gatrell et al., 1996; Lloyd, 2007). In this study, after different tests (bandwidths of 100, 250, 500, 750, 1000 m), it was finally decided to adopt a bandwidth of 500 m in the analysis of buildings density at the working scale. Thus, KDE was performed within SAGA GIS (Böhner et al., 2006) using a quartic function, a cell size of 50 m and the area occupied by each building as intensity parameter. Considering the method of calculation, the calculated SDI expresses settlement concentration in a given area as the surface occupied by settlements over the territorial surface (Fig. 8). As a consequence, it gives a simplified but reliable representation of the gradient of urbanisation: it assumes maximum values in the central portions of more extensive urban areas and

progressively decreases when moving towards less urbanised areas. The same figures show the localisation of the landscape profiles described hereinafter.

2.5.3 Landscape gradients analysis through linear profiles

The overall analysis of the urban-rural gradient of the area was performed developing a landscape profiling technique: three different cross-sections (profiles) were located along the main urban development direction with their starting point in the most urbanised area (maximum SDI) (Fig. 8). Using GIS overlay technique, every section was intersected with the four indicator maps of SDI, A-PLAND, N-PLAND and SIDI. The tabular results of the intersection were plotted on different graphs showing the composition and the configuration of the urban-rural gradient along the three landscape cross-sections and its progressive transformations.

3 Results and discussions

3.1 Urban-rural transformations

During the period examined, all of the stages of land transformations (sensu Forman, 1995; Botequilla Leitão et al., 2006) occurred. Focusing on landscape metrics at landscape and class levels, and considering the results from Patch Density (PD) and Edge Density (ED) indices, the analysis also took into account the Number of Patches (NP) index, which is an index showing the ongoing fragmentation process (Fig. 9). NP increased from 76, in 1955, to 179, in 2006, while, in the same time interval, PD passed from 1.88 to 4.43. In all LULC classes, both indices grew, except for coniferous (Con-For) and mixed forestry areas (Mix-For), in which the attrition process in land transformation added up to the dissection process, as shown by the increasing ED values for these LULC classes. In the time interval analysed, the increase in the number of patches mainly concerns two LULC types characterised by two different land transformations. On the one hand, particularly referring to discontinuous urban areas, there are

two ongoing processes: attrition and perforation (at the expenses of former agricultural areas). On the other hand, in agricultural areas, it is possible to observe a dissection process in addition to perforation. These results are corroborated by the rising trends of PD and ED indices at class levels (Fig. 9).

The urban development of the study area extends along the Ancinale River and two roads, which start from the historical urban nucleus (Fig. 10), go through Serra San Bruno and connect it with the surrounding urban centres. Urbanisation has concerned and is still concerning almost flat and moderate slope areas (slope $\leq 10\%$). The urban fabric LULC class revealed complex and interesting dynamics throughout the period investigated. By 1955, the study area had a quite homogeneous structure, with two definitely prevailing LULC classes: Agric (41.19 %) and Mix-For (47.51 %). The urban fabric was almost completely continuous (Urb-Cont) and coincided with the historical nucleus (0.89 %). Over time, the urban fabric has been characterised by a dramatic growth, creating an extensive discontinuous built area (Urb-Disc) between the rural and the urban space, which, today, mostly occupies former agricultural lands. Urban areas passed from 4.48 ha, in 1955, to 80.56 ha, in 2006 (Di Fazio et al., 2011). As a result, the areas of greatest expansion of the Urb-Disc class are those next to the historic centre, where they form a continuously evolving outer urban belt. Moreover, the discontinuous urban fabric is still changing: since the 90s, it has been tending to be incorporated in the Urb-Cont class.

Agricultural areas (Agric) were the most concerned by the changes occurred in the period under investigation. They passed from 1663.18 ha, in 1955, to 847.29 ha, in 2006. In the time interval analysed (1955–2006) perforation process was dominant, resulting in a significant landscape change. In 2006, agricultural and forest areas as a whole occupied 94.32 % of the study area, even though they were differently distributed in comparison with the first period investigated: agricultural areas passed from 41.19 %, in 1955, to 20.98 %, in 2006; while forest areas passed from 54.25 %, in 1955, to 73.34 %, in 2006. In agricultural areas, both dissection and fragmentation processes characterised land transformations. In particular, fragmentation is leading today

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to attrition (gradual loss of remaining fragments), which is indicated as the third and final stage of land transformations (Botequilla Leitão et al., 2006). In terms of landscape composition (Fig. 3), the area occupied by the Agric class almost halved (41.19 % in 1955, 20.98 % in 2006) because of the intensification of silvicultural activities, of the still rising trend of agricultural abandonment and of the consequent shrub and herbaceous vegetation (Shrub) colonisation of these areas, which, from the point of view of ecological succession, is the initial phase of the process through which forest vegetation regains abandoned agricultural areas. In Calabria, this succession has often been accelerated by reforestation interventions. After the Second World War, they were carried out in large areas and mostly received financial support, first from national and regional public bodies and then from EU. Forestry areas have always been of crucial importance in the structural dynamics concerning the territory of Serra San Bruno. They are the formations that, in the period under investigation, replaced a considerable part of the area of the Agric class. Today, 705.48 ha (86.46 %) of the 815.94 ha of the Agric class, which have changed over the fifty years investigated, are forestry areas, 52.72 ha of which are the result of reforestation. In particular, the most significant increase was recorded for the Blv-For class, which passed from 217.44 ha, in 1955, to 725.27 ha, in 2006.

The dynamics described above are confirmed by the Agricultural Censuses conducted by the Italian National Institute of Statistics (ISTAT), for the years 1970, 1982, 1990, 2000 and 2010. The analysis of data shows that the number of farms has dropped dramatically, passing from 503, in 1970, to 89, in 2010 (−82.3 %). Correspondingly, Utilised Agricultural Area (UAA) has dropped, though less dramatically, from 1027.63 ha, in 1970, to 395.53 ha, in 2010 (−38.49 %), with a consequent doubling of the average area per farm (from 2.04 ha to 4.44 ha, +117.6 %). This was also due to public measures of financial assistance favouring specific interventions of land consolidation, the effects of which have already been highlighted in a previous work referring to the data of the 5th Agricultural Census (year 2000) (Di Fazio et al., 2011). On the basis of the currently available data from the 6th Agricultural Census (year 2010),

it can be observed that a similar trend (decreasing number of farms, decreasing UAA, decreasing fragmentation of land parcel) concerns the whole Italian territory.

3.2 Urban growth and general master plan effectiveness

The trend of the total number of buildings further confirms what has been stated above: 331 in 1955, 1011 in 1983, 1829 in 1994, 2057 in 2006 and, finally, 2251 in 2011. The same trend is obtained if the official number of dwellings, provided by ISTAT and shown in Fig. 11, is taken into account. Despite what similar studies in other areas have shown (e.g. Verburg et al., 2001; Bhatta, 2009, Fichera et al., 2012), the growth rate of urban fabric in the concerned study area is not related to population growth rate, which, in general, drives to the expansion of the built-up area. As matter of fact, a comparison of the number of buildings and of the demographic trend in the last decades, which decreased from 8517 inhabitants in 1961 to 6873 in 2011, shows that housing construction in the study area has not met residential needs but has rather answered the purpose of investing in the property market in a period of high monetary inflation (Di Fazio et al., 2011). As shown in Fig. 11 a significant number of houses are unoccupied and many of them are let during summer for the so-called "tourism of return" and, to a lesser extent, for exogenous tourism (Di Fazio et al., 2010). More in detail, the highest rate of housing construction was recorded between 1983 and 1994, when, owing to the temporary lack of effective planning regulations, many buildings were constructed in unsuitable areas. Between 1994 and 2006, a significant downturn in the construction of new buildings was recorded, which did not affect agricultural areas, as it had happened in the past, but rather open spaces in discontinuous urban areas (10.59 ha of the Urb-Disc class turned into Urb-cont).

Then, using the vector-based geoprocessing approach outlined in the previous paragraph, the GIS layers describing the built-up expansion (1994–2011), were juxtaposed on the map of the GMP zoning. At this stage of the analysis, the outputs of this processing were mapped as new GIS layers. It resulted that only very few buildings were built in locations which met GMP zoning definition and standards (Fig. 6). Afterwards, the

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dynamics within the study area was assessed comparing the amount of land occupied for built-up use with demographic data (e.g. Censuses), in order to analyse how the urban expansion was able to match the population requirements. These results high-light a trend similar to the one described above, corroborating the analysis based on the comparison between number of buildings and population growth. In this case, the comparison of built-up LULC expansion with ISTAT demographic data, during the last twenty-year period (1983–2011), showed a growth rate of the urbanised area higher than the population growth rate, as expected. Just to mention a few data, built-up areas increased by 26 % between 1983 and 1994 and by 9 % between 1994 and 2011. On the other hand, the population increased only by 6 % between 1981 and 1991 and by 2 % between 1991 and 2011.

3.3 Urban-rural gradient analysis

Landscape profile graphs effectively show the main characteristics of the urban-rural gradient using a 2-dimensional space that allow the simultaneous analysis of the four above-mentioned indices (Fig. 12). In all graphs, the x-axis represents the distance from the starting point of the profile; the left y-axis shows a percentage scale used for representing SDI and A-PLAND and N-PLAND curves; the right y-axis shows a probability scale used for representing SIDI curve.

In all the cases, the profile graphs indicate a similar landscape composition and configuration at the very initial part of the three profiles. In this particular context, the small extents of high urbanised areas determine a particular initial composition of the gradient that is not completely urban, since it is also characterised by agricultural and natural areas. Moving from the most urbanised area (the historical town centre) towards rural areas, SDI curves show a decreasing tendency, as expected, while A-PLAND and N-PLAND curves assume a different shape indicating different types of urban-rural gradients in the three directions under investigation.

The first profile shows a typical urban-agricultural-natural gradient characterised by two clear transitions from an urban-dominated landscape to an agriculture-dominated

landscape and from the latter to a natural landscape. As expected, landscape diversity is higher within these transitions, which are typical of periurban and agroforestry areas, where a more variegated landscape mosaic can be detected. On the contrary, SIDI assumes lower values within the areas dominated by agricultural lands and woodlands.

5 The second profile shows an initial smoother transition between the most urbanised area and the rural one, which is characterised by a growing incidence of natural areas (0–2.2 km). This part of the profile falls into a mixed landscape marked by high diversity and fragmentation. Along the other part of the profile, the two A-PLAND and N-PLAND curves assume a particular alternating behaviour indicating the relative incidence of

10 agricultural and natural areas and the position of the agricultural-forestry transitional areas, where SIDI increases as expected. The third profile illustrates another particular urban to rural gradient, with an initial steeper transition from the most urban to a natural-dominated agricultural landscape characterised by high values of diversity. The other section of the profile appears definitely occupied by natural areas.

15 The transformations of the urban-rural gradient were studied by means of a diachronic analysis of the four indices along the same landscape profiles (Fig. 13) and for all the time intervals defined. All the graphs indicate the variation of each index (positive or negative) occurred along the profile in a specific interval. SDI evolution was analysed on separate graphs taking into account the different magnitude of the tempo-

20 ral variations of this index, while A-PLAND, N-PLAND and SIDI variations were plotted, for each profile, using three different graphs corresponding to the three periods under investigation. This approach allowed an efficient spatio-temporal comparative analysis of the transformations of the urban-rural gradient composition and configuration in the study area.

25 As described above, the most relevant transformations of the landscape gradient took place in the 1955–1983 period. Thus, all the graphs referred to this period show an evident rise in SDI index, mostly in the first part of the profile, indicating a typical urbanisation process of the outer periurban agricultural areas. This process is confirmed by a related decrease in the A-PLAND index observed in the same period.

Another important transformation, highlighted by the outer section of the three profiles, is associated to the increase in areas mainly occupied by woodlands inside agricultural-dominated landscape. These modifications, which occurred mainly within urban-agricultural and agricultural-forestry fringes, produced a relevant increase in landscape diversity indicated by the double peaks of SIDI variation curves. The peaks are located exactly at the position of the transitions, which were identified by means of the previous landscape profile analysis. As a consequence, between 1955 and 1983, urban sprawl, on the one hand, and woodlands expansion, on the other, generated deep changes in the urban-rural gradient of the area. The two main processes described above continued, with diminishing magnitude, during the subsequent period 1983–1994, causing further erosion and fragmentation of agricultural landscapes. The variations of diversity along the urban-rural gradient directly reflect those transformations. During the last period, 1994–2006, minor transformations occurred, mainly entailing the urbanisation of small periurban areas and the further expansion of woodlands in steeper agricultural areas. As confirmed by SIDI variations, these modifications generated only small changes in landscape configuration, also due to the efficacy of the GMP as outlined in Sect. 3.2.

4 Conclusions

The research is part of a wider study and is aimed at quantifying and interpreting LULC changes in particularly significant areas of the Mediterranean landscape. Similarly to the results of previous researches, carried out in other Italian Mediterranean landscapes (Fichera et al., 2012), in the last sixty years, the urbanisation process has considerably modified the landscape of Serra San Bruno municipality, with significant land use conversions. This study has highlighted how understanding the evolution of landscape trends, particularly where the urban/rural dynamic relations play a significant role, is crucial to their sustainable planning. As argued by Botequilla Leitão et al. (2006), developing a basic understanding of landscape changes is fundamental to

weigh options and consequences associated with alternative planning options, besides being the best way to deal with them. To that end, in a first phase, the integration of spatial, historical (aerial photographs) and recent (orthophotos) data with socio-economic data, in a geodatabase at a detailed scale, proved to be of great importance to understand the relations between land-use, -cover and -functions (Verburg et al., 2009). The observation and temporal analysis of LULC changes is a procedure that allows to identify ongoing trends and to better understand landscape evolution. Therefore, it is fundamental to implement tools helping to envisage future scenarios. Furthermore, the analysis of LULC changes allows the temporal verification of the positive (e.g. reforestation of agricultural areas, land consolidation, etc.) or negative (lack of landscape planning tools, agricultural abandonment, etc.) effects of past territorial policies. Finally, these analyses can allow to implement landscape management tools and sustainable medium- and long-term landscape planning so as to direct future changes towards those which had positive effects and to contrast the past actions which had negative consequences on the landscape. This would have significant impacts not only at a local scale, which was the scope of this research, but also on regional-scale plans and programmes.

This research also offered an example of how GIS techniques and methodologies can be used to support land-use planning and decision making in urban growth management, by providing helpful tools to spatially analyse and study landscape patterns, spatial variations and their most significant correlations.

Landscape profiling technique for the analysis of the urban-rural gradient is an innovative and valuable approach for studying gradient characteristics over space and time. The landscape profile graphs allow a very effective diachronic analysis of the urban-rural gradient composition and configuration. The strength of the approach is in its relative simple applicability on every landscape context at the different scales of analysis and in the possibility to effectively compare more graphs referred to different areas under investigation. Certainly, the method needs further improvements, particularly in the selection of relevant metrics for better exploration and analysis of landscape

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configuration. Moreover, additional research is needed for deeper comprehension of the relations between graph shapes and landscape functions.

Future developments of this research will include the use of WorldView-2 imagery in order to compare automatic land cover classification using object-oriented analysis and automatic settlement extraction comparing different data sources.

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Table 1. Correspondence between CORINE legend nomenclature and LULC classes used for detecting LULC changes. In brackets, the symbols utilised in the text and in following figures.

	CORINE Land Cover legend	LULC Classes used for data analysis
1. Artificial surfaces	1.1.1 Continuous urban fabric	Continuous urban fabric (Urb-Cont)
	1.1.2 Discontinuous urban fabric 1.4.1 Green urban areas	Discontinuous urban fabric (Urb-Disc)
	1.2.1 Industrial or commercial units 1.2.2 Road and rail networks and associated land 1.3.1 Mineral extraction sites	Industrial, commercial and transport units (Ind)

2. Agricultural areas	2.1.1 Non-irrigated arable land
	2.3.1 Pastures
	2.4.1 Annual crops associated
	       with permanent crops
	2.4.2 Complex cultivation patterns
	2.4.3 Land principally occupied by
	       agriculture, with significant areas
	       of natural vegetation
	2.4.4 Agro-forestry areas
		Agricultural areas (Agric)

3. Forests and semi-natural areas	3.1.1 Broad-leaved forest	Broad-leaved forest (Blv-For)
	3.1.2 Coniferous forest	Coniferous forest (Con-For)
	3.1.3 Mixed forest	Mixed forest (Mix-For)
	3.2.4 Transitional woodland shrub 3.3. Open spaces with little or no vegetation	Shrub and/or herbaceous vegetation associations (Shrub)
5. Water bodies	5.1 Inland water	Waters bodies (Waters)

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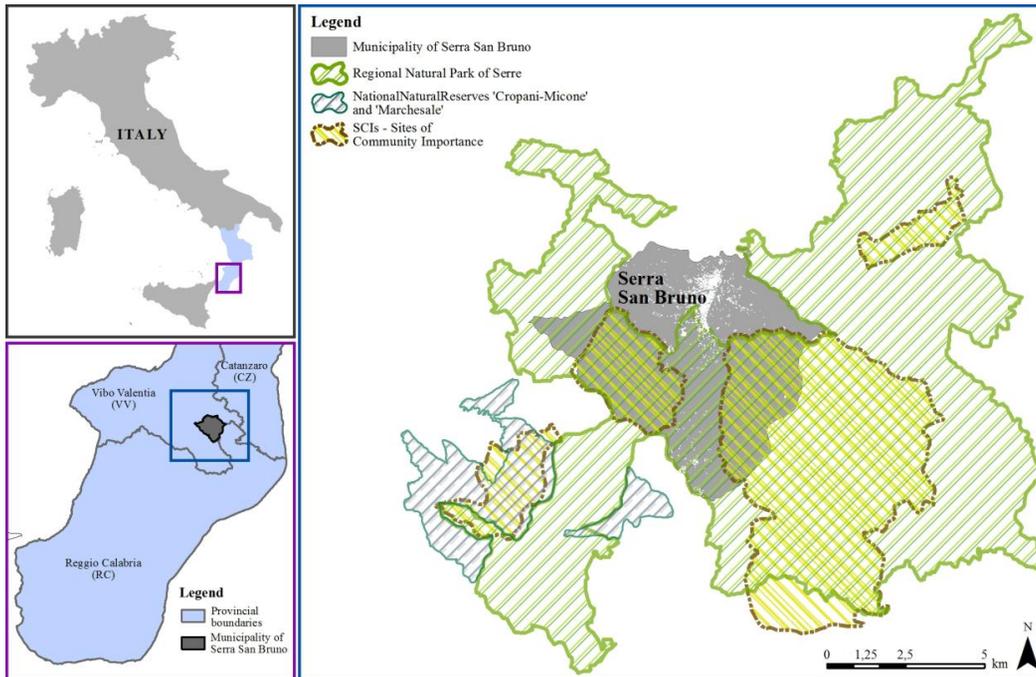
Fig. 1. Map showing the geographical location of the study area. In the blue box, the boundaries of protected areas falling in the territory of Serra San Bruno municipality are highlighted.
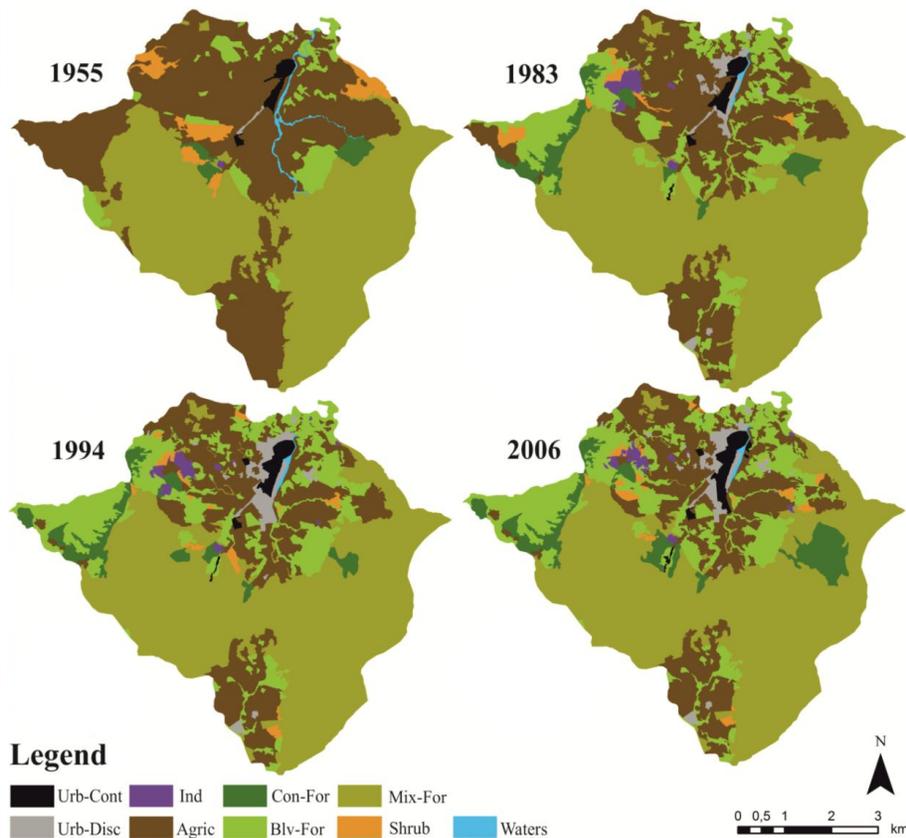
Fig. 2. LULC maps of the study area for all years under investigation and graphical representation according to the LULC class types composition.

LULC classes	1955 [ha]	[%]	[NP]	1983 [ha]	[%]	[NP]	1994 [ha]	[%]	[NP]	2006 [ha]	[%]	[NP]
Urb-Disc	31.34	0.78	2	38.40	0.95	3	45.96	1.14	4	59.65	1.48	6
Urb-Cont	4.48	0.11	2	53.31	1.32	8	89.37	2.21	12	80.56	2.00	14
Ind	1.97	0.05	1	36.13	0.89	10	34.34	0.85	19	30.55	0.76	10
Agric	1663.18	41.19	18	1079.36	26.73	25	890.92	22.07	42	847.29	20.98	50
Con-For	54.38	1.35	2	146.06	3.62	8	151.52	3.75	13	245.02	6.07	13
Blv-For	217.44	5.39	34	549.59	13.61	47	683.22	16.92	44	725.27	17.96	50
Mix-For	1918.27	47.51	6	2082.48	51.58	12	2087.68	51.71	17	1990.85	49.31	17
Shrub	121.91	3.02	5	46.06	1.14	8	47.71	1.18	15	51.53	1.28	18
Waters	24.64	0.61	6	6.21	0.15	1	6.89	0.17	1	6.89	0.17	1
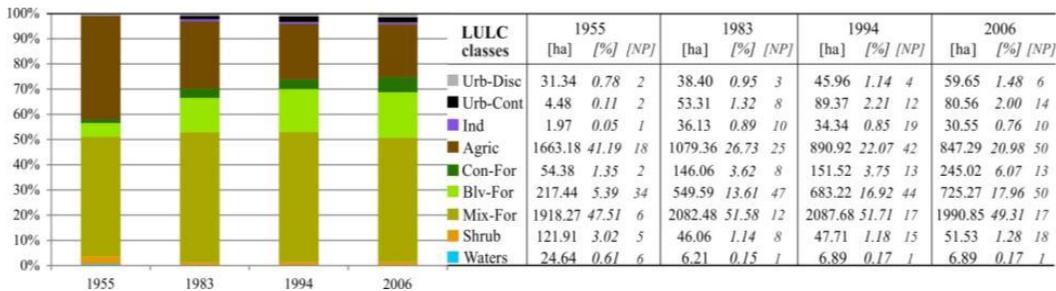
Fig. 3. Landscape composition of the study area in the four time intervals investigated, based on the 9 LULC class types. Data in [ha] and in [%]. In addition, for each LULC class the NP (Number of Patches) is shown.

1955 \ 2006	Urb-Cont	Urb-Disc	Ind	Agric	Con-For	Blv-For	Mix-For	Shrub	Waters	Sum 1955
Urb-Cont	**30.98**	-	-	-	-	-	-	-	0.36	*31.34*
Urb-Disc	-	**4.48**	-	-	-	-	-	-	-	*4.48*
Ind	-	-	**1.97**	-	-	-	-	-	-	*1.97*
Agric	24.68	72.21	27.39	**789.43**	87.51	484.82	133.14	41.07	2.92	*1663.18*
Con-For	-	-	-	-	**12.86**	0.36	39.90	1.20	-	*54.38*
Blv-For	-	0.74	-	29.28	1.02	**160.78**	25.29	0.33	-	*217.44*
Mix-For	0.27	-	0.75	8.82	138.18	18.10	**1749.21**	2.93	-	*1918.27*
Shrub	2.76	0.28	-	14.72	5.48	50.99	42.44	**5.25**	-	*121.91*
Waters	1.07	2.76	0.25	4.98	-	10.41	0.78	0.76	**3.61**	*24.64*
Sum 2006	*59.76*	*80.47*	*30.41*	*847.24*	*245.05*	*725.46*	*1990.77*	*51.55*	*6.89*	**4037.60**

Fig. 4. Transition matrix for the Time period 1955–2006.

Landscape metrics	Range	Units	Description	Years			
				1955	1983	1994	2006
Number of Patches (**NP**)	≥ 1, without limit	None	Equals the number of patches in the landscape.	76	122	167	179
Patch Density (**PD**)	≥ 0, constrained by cell size	Number per 100 hectares	Equals the number of patches of the corresponding patch type divided by total landscape area (m^2).	1.88	3.02	4.14	4.43
Edge Density (**ED**)	≥ 0, without limit	Meters per hectare	Equals the sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m^2).	34.43	54.46	58.37	66.27
Percentage of Like Adjacencies (**PLADJ**)	0 ÷ 100	Percent	Equals the number of like adjacencies involving the focal class, divided by the total number of cell adjacencies involving the focal class.	98.03	97.03	96.83	96.44
Interspersion and Juxtaposition Index (**IJI**)	0÷100	Percent	Equals minus the sum of the length (m) of each unique edge type divided by the total landscape edge (m), multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types times the number of patch types minus 1 divided by 2.	57.93	59.31	61.53	61.23
Shannon's Diversity Index (**SHDI**)	≥ 0, without limit	None	Equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion.	1.12	1.29	1.34	1.40
Simpson's Diversity Index (**SIDI**)	0÷1	None	Equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared.	0.60	0.64	0.65	0.68

Fig. 5. Description of landscape metrics (based on McGarigal et al., 2012) and their values obtained at landscape level for all time intervals under investigation.
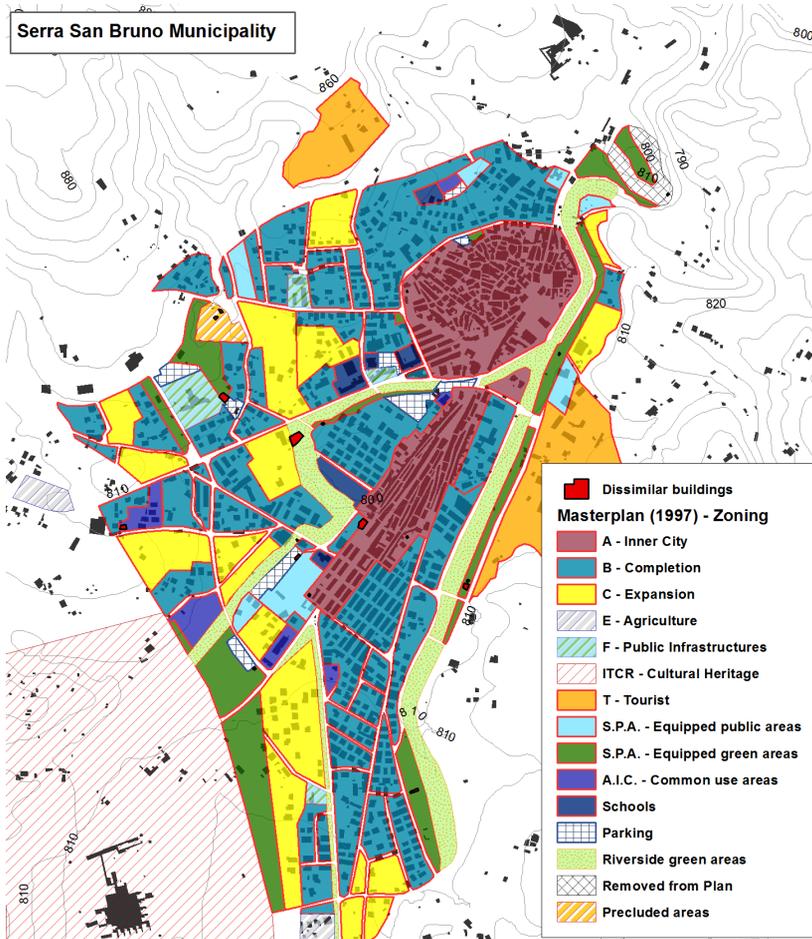
Fig. 6. Analysis of the General Master Plan adopted in 1997, in force until 2007 and currently being updated.

Legend:

Dissimilar buildings

Masterplan (1997) - Zoning
- A - Inner City
- B - Completion
- C - Expansion
- E - Agriculture
- F - Public Infrastructures
- ITCR - Cultural Heritage
- T - Tourist
- S.P.A. - Equipped public areas
- S.P.A. - Equipped green areas
- A.I.C. - Common use areas
- Schools
- Parking
- Riverside green areas
- Removed from Plan
- Precluded areas

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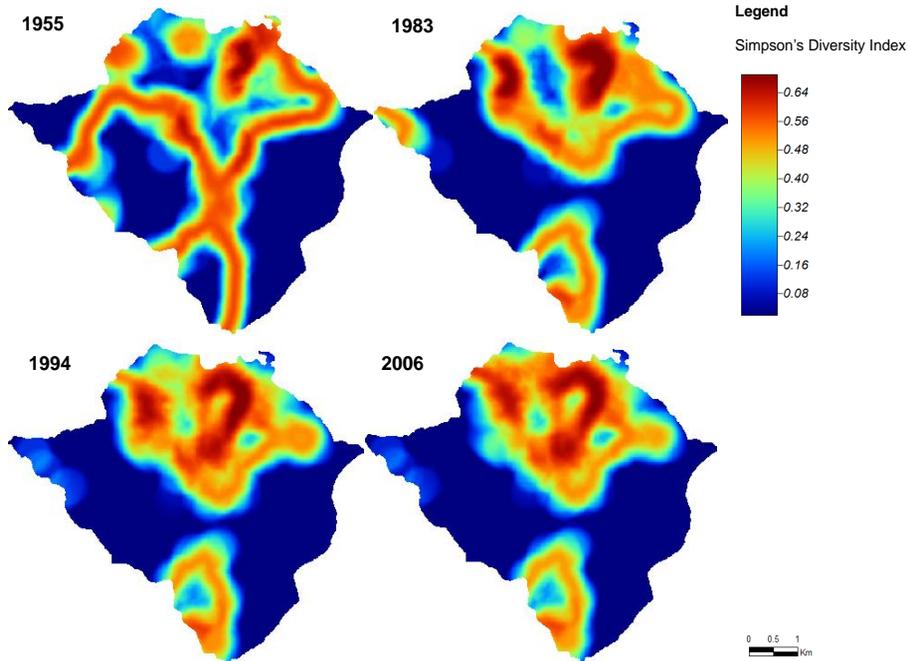
Fig. 7. Simpson's Diversity Index (SIDI) calculated in FRAGSTATS environment using the moving window method.

Fig. 8. Maps of the Settlement Density Index (SDI) calculated using Kernel Density Estimation (KDE) for all time intervals investigated. In each map, a localisation of the three defined profiles is shown (Profile 1: direction 251°, length 5 km – Profile 2: direction 186°, length 6 km – Profile 3: direction 118°, length 3.5 km).
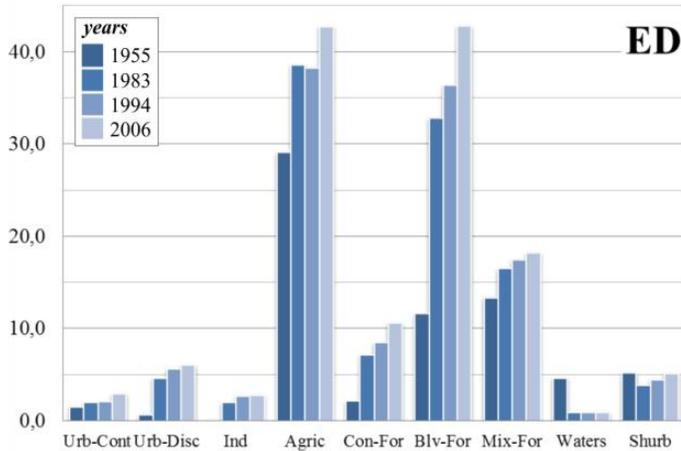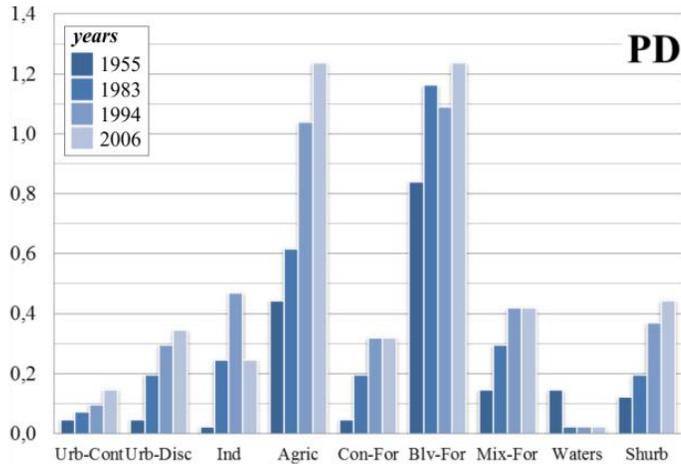
Fig. 9. Patch Density (PD) and Edge Density (ED) landscape metrics calculated at class level for all time intervals defined.

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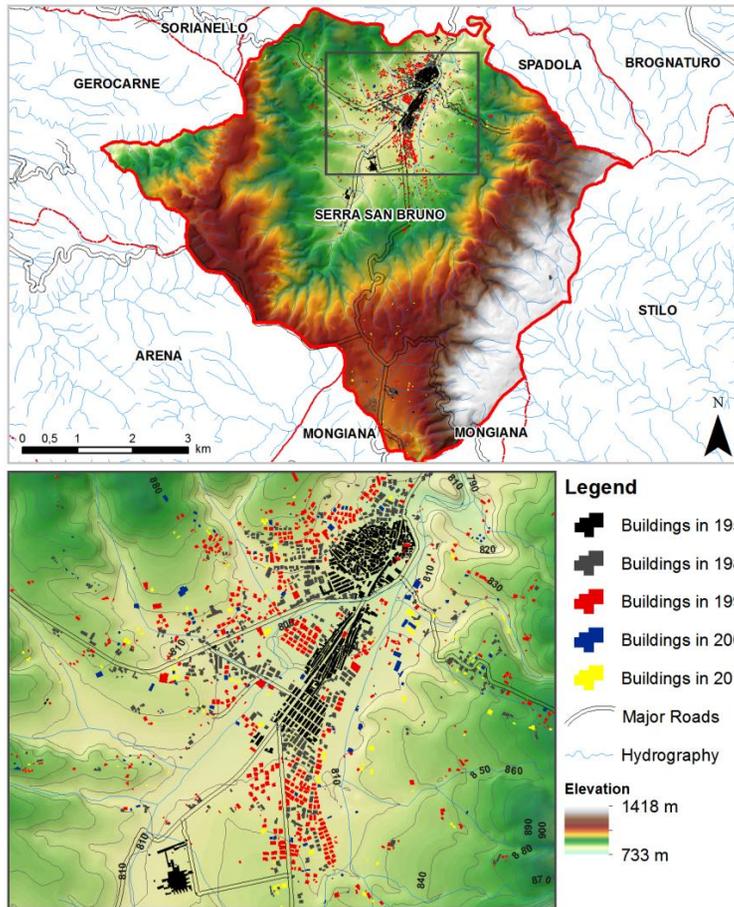
Fig. 10. Overview of the settlement expansion in the study area from 1955 to 2011 superimposed over the Digital Elevation Model (DEM).
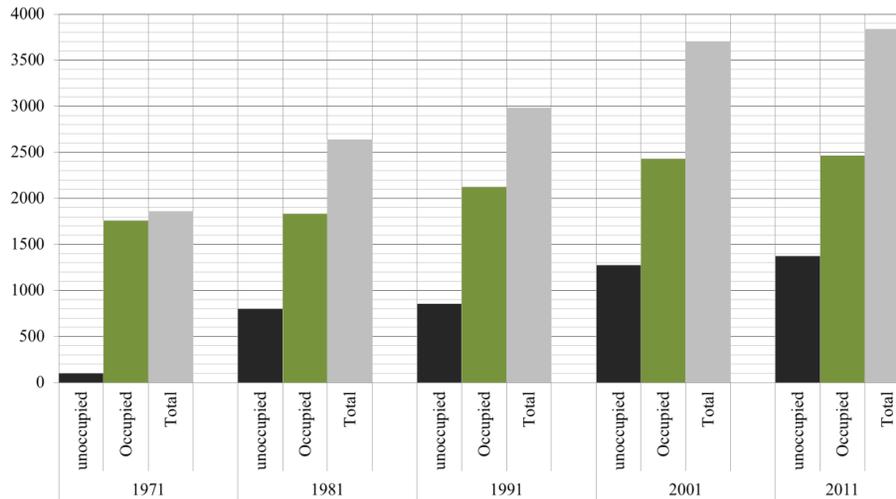
Fig. 11. Number of dwellings per type of occupation in Serra San Bruno municipality in 1971–2011 period (source: ISTAT, Italian National Institute of Statistics).
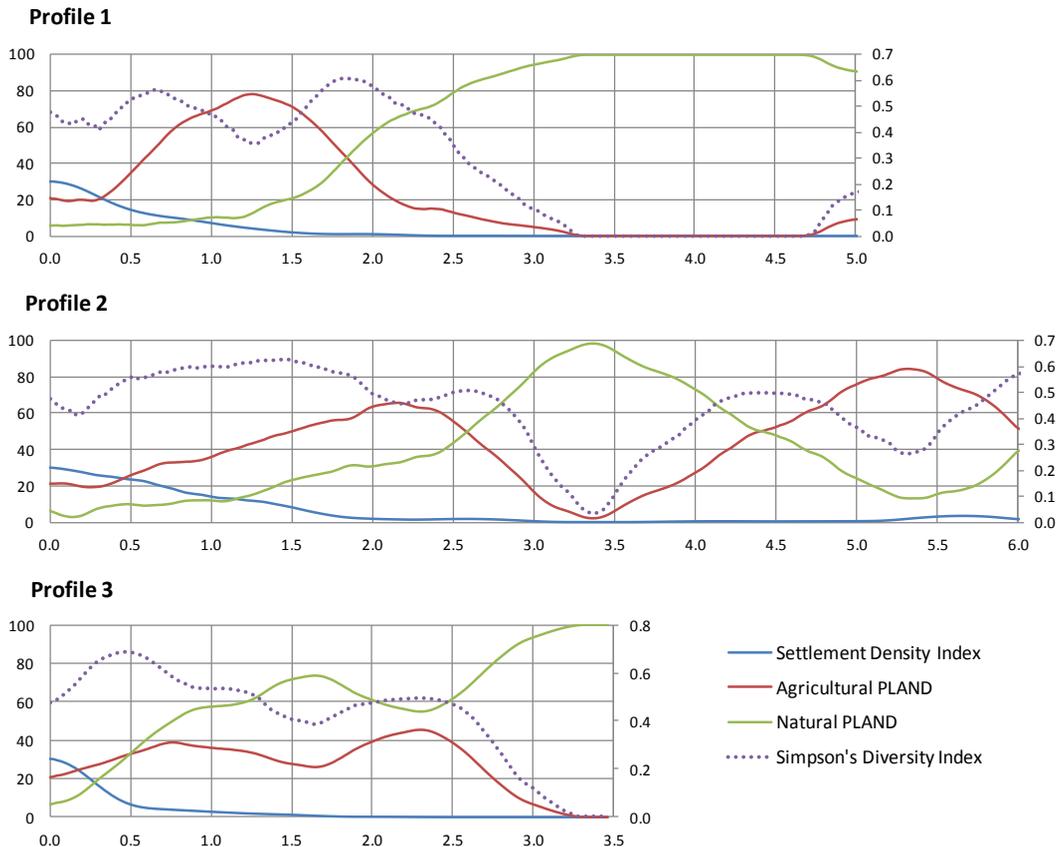
Fig. 12. Composition and diversity of the urban-rural gradient measured along the landscape profiles (year 2006). Settlement Density Index, agricultural and natural percentages of land-scape (PLAND), and Simpson's Diversity Index (SIDI). The latter is represented using the right graduation on the graphs.

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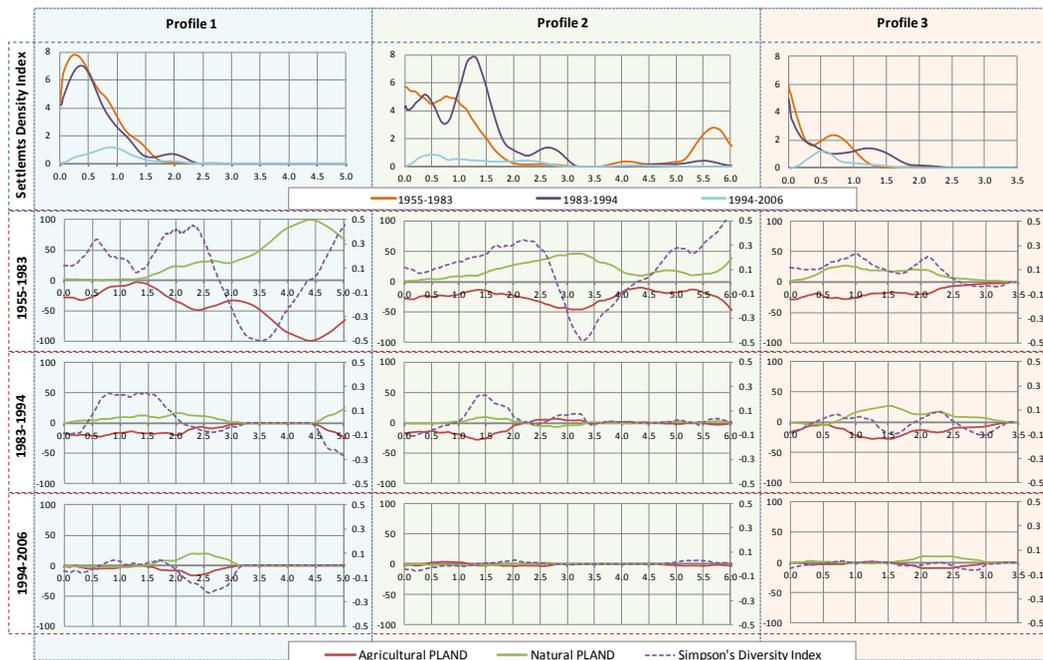
Fig. 13. Transformations of the urban-rural gradient measured along the landscape profiles (km are shown on the x-axis). Spatial and temporal variations of Settlement Density Index (SDI), of agricultural and natural percentages of landscape (A-PLAND and N-PLAND) and of Simpson's Diversity Index (SIDI). The latter is represented using the right graduation on the graphs.