An indicator of urban morphology for landscape planning in Lombardy (Italy)

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Abstract
Purpose – The spatial development of urban areas affects the characteristics of landscape as well as people's aesthetic perception of it. Specifically, sprawl results in an urban morphology which is diametrically opposed to the compact city model and which assumes several kinds of patterns: for example "striped", "ribbon" or "leapfrogged" urban development. Assessing urban morphology in spatial terms is crucial to urban policy, while landscape metrics are the key to a comprehensive understanding of different urban development patterns. The purpose of this paper to design and test an urban morphology indicator (UMI) for the Lombardy Regional Landscape Plan.
Design/methodology/approach – The paper describes an UMI that can be used to identify the heterogeneity of built-up patterns according to urban porosity, fragmentation and patch shape. This UMI is a result of Esri ArcGIS 10.3 "grouping analysis" which works by applying a spatial statistical metric for clustering geometries in a given geographical area.
Findings – Morphological analysis was used in regional urban development policies with a view to minimising impact on surrounding ecosystems and preserving the natural environment and landscape. It defines 28 different urban morphology patterns in the region, which are divided into systems, polarities and urbanised units.
Originality/value – The proposed methodology differs from those traditionally used in qualitative/descriptive landscape planning and supports the identification of morphological features with quantitative statistical and spatial data, allowing a fine-scale assessment of complex metrics.
Keywords Indicators, Landscape metrics, Landscape planning, Urban morphologies, Urban sprawl
Paper type Research paper

1. Introduction
The debate in Italy about appropriate policies to contrast land take and soil sealing has intensified in recent years. Parliamentary approval of a single national law is pending, and several regional laws have recently been adopted (Arcidiacono *et al.*, 2016) to achieve the European target of "no net land take" by 2050. Assessing human impact and its distribution at different levels of governance has become crucial for developing adequate land governance strategies (Antrop, 2004; Feranec *et al.*, 2000; Salvati *et al.*, 2012).

In this context, urban sprawl is universally seen as unsustainable due to its environmental, economic and social effects (Dupras *et al.*, 2016; Frumkin, 2002; Johnson *et al.*, 2005; Siedentop and Fina, 2010).

The European Environment Agency (2006) defines urban sprawl as "the physical pattern of low-density expansion of large urban areas under market conditions into the surrounding agricultural areas".

From an environmental perspective, urban growth of all kinds threatens ecosystem services (ES) by depleting crucial resources for long-term human well-being (Batista e Silva *et al.*, 2013), causing the fragmentation of natural habitats and loss of agricultural land. Urban sprawl is recognised as one of the biggest challenges on the way to sustainable land use, considering its high long-term costs and impacts on the environment and landscape (Artmann, 2016) and effects on private mobility (Artmann, 2014; Dupras *et al.*, 2016; Ursić *et al.*, 2016; Xi *et al.*, 2012).

Moreover, urban sprawl strongly affects the landscape in agricultural and rural areas (European Environment Agency, 2013) as it radically transforms the historical and traditional cultural heritage of the places affected by it.

Several indexes and spatial matrix approaches have been developed to evaluate the characteristics of land use composition and distribution at different scales through specific geographical interpretations of built-up areas (Inostroza *et al.*, 2016; Sanderson *et al.*, 2002; Zasada *et al.*, 2013). Nevertheless, a coherent framework which ties together the various indicators and descriptions of the phenomenon of sprawl has not yet been agreed upon in the academic debate.

The most common difficulties relate to measuring methodologies. Urban sprawl is often measured using an index that requires a multi-criteria analysis of built-up land which is typically based on the kind (characteristics) and the extent (quantity) of new settlements (Delattre *et al.*, 2015).

Urban sprawl indicators may integrate a variety of land use, social and economic variables (Vaz and Nijkamp, 2015), although it is generally agreed that sprawl is, by definition, a kind of development which tends to be "unplanned", "uncontrolled" or "disorderly".

This variety of definitions and approaches also includes a number of "extreme" cases, including ones based on theoretical physics and gravitational forces (Vaz and Nijkamp, 2015) which adopt a methodological perspective that confirms that sprawl affects geographical areas in a way which bears no relation to their "orographical condition".

Despite such radical interpretations, urban sprawl is traditionally defined by two basic features: low-density urban settlement (Adamiak, 2016; Jiao, 2015) and reduced land use diversity (Mosammam *et al.*, 2016).

According to the latter definition, sprawl is a system of low-density areas characterised by residential land use which heavily depend on individual mobility (Zolnik, 2012). This kind of urban development stands in contrast to the traditional centralised urban systems that have characterised Italy's historical centres with their dense, mixed land use development served by public transport, elegant public spaces, vitality and sense of historical heritage.

The Lombardy region's historical urban heritage is based on long-term cycles of urban and land development (Magnaghi, 2010, 2012). Recent development has mainly been in the peripheral areas of medium and small population centres. Our assessment and interpretation of their spatial distribution was facilitated by statistical census data and geospatial analysis.

Sprawl, however, is not exclusive to Lombardy, where the sprawl phenomenon is not a typical character of the Lombardy region, even if its physical distribution is peculiar and affected with different degrees many European cities and countryside.

The governance of the urban expansion for landscape conservation agrees with the Green Infrastructure Strategy launched by the European Commission to pursue "a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings" (Barbosa *et al.*, 2016; European Commission, 2016). Specifically, the EC strategy aims to support Target 2 of the EU biodiversity strategy to 2020 (Maes *et al.*, 2011) which establishes the following target: "By 2020, ecosystems and their services [must be] maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems".

Moreover, increased attention to preserving natural capital (Arcidiacono *et al.*, 2016; Crossman *et al.*, 2009; Häyhä and Franzese, 2014) has led in turn to a focus on "regeneration" as a paradigm of social and physical re-use of developed spaces which avoid the worst excesses of sprawl and consequent crises in the real estate market (Salata and Fior, 2016). Regeneration processes need to be implemented where urban sprawl has a high impact on the landscape. The harmful effects of urban sprawl are nowadays considered as one of the major threats for local government policies and a challenging issue of a large public debate. An accurate definition and assessment of the landscape patterns associated with urban sprawl phenomena is essential for the development of adequate land governance strategies through landscape planning policies and instruments.

In this study, a quantitative morphological analysis based on built-up characteristics was defined for monitoring and assessing the landscape consequences of urbanisation in the Lombardy region.

Lombardy is a typical example of a European region which is under severe threat from human activities (Sanesi *et al.*, 2017), which have altered the structure and distribution of its agricultural and natural areas, reducing them to small patches of land surrounded by cities and infrastructure.

Lombardy is characterised by a wide variety of landscape patterns (urban, mountainous, lacustrine, fluvial and agricultural) with a wide range of geomorphological features. Similarly, urban development has taken place heterogeneously, and includes dispersed, fragmented, leapfrog or sprawl patterns (Mazzocchi *et al.*, 2013).

Considering the specific nature of landscapes consisting of different types of land use/land cover (LULC) which occupy a fraction of a geographical space (Bogaert *et al.*, 2014), three morphological variables were combined into a final composite indicator which considers the characteristics of the region's built-up spaces and their distribution in natural, rural and densely urbanised landscapes.

The paper introduces the use of an urban morphology indicator (UMI) generated by a quantitative-based assessment of sprawl characteristics using a composite approach which draws on quantitative landscape ecology metrics (Ingegnoli, 1993; Inostroza *et al.*, 2013).

The complexity of the phenomenon of urban sprawl, given its impacts in several areas of urban life (such traffic congestion, long commutes, environmental quality and health), confirms the need for a system of indicators and a combination of measurements for its assessment (Mubareka *et al.*, 2011; Pozoukidou and Ntriankos, 2017).

The paper provides a detailed analysis of the composition of Lombardy's urban morphology with a view to orienting landscape policy. In addition, the work sheds light on the importance of landscape metrics in the effort to preserve the natural environment. With this in mind, the analytical framework of the landscape regional plan has been enhanced by means of a more detailed, analytical, computational GIS-based approach to describing the Lombardy region's urban morphology and providing support for local strategies to counter urban sprawl and land take.

2. Material and methods

2.1 Case study

Lombardy is one of Italy's most highly urbanised regions. Between 2008 and 2012, soil sealing in Lombardy increased by 12 per cent, the equivalent of more than 2,400 km^2 (Istituto Superiore per la Protezione e la Ricerca Ambientale, 2015). Since the Second World War, urbanisation has profoundly transformed the region's landscapes, with a significant impact in ecological terms as well as on the provision of important ES (Lv *et al.*, 2012) (Figure 1).

This has adversely affected the traditional features and quality of the region's landscape, which represent a cultural ES for citizens' identity (Gómez-Baggethun and Barton, 2012; Lafortezza *et al.*, 2013). This new urban development requires an innovative approach to planning and policy. While urban development after the war was concentrated around the region's traditional built-up centres, latterly day urbanisation (especially since 2000) has been characterised by a high degree of dispersion and fragmented distribution of settlements. The Lombardy Regional Landscape Plan (RLP), introduced in 2014, provides the institutional framework for new local government policies to counter land take and urban sprawl.

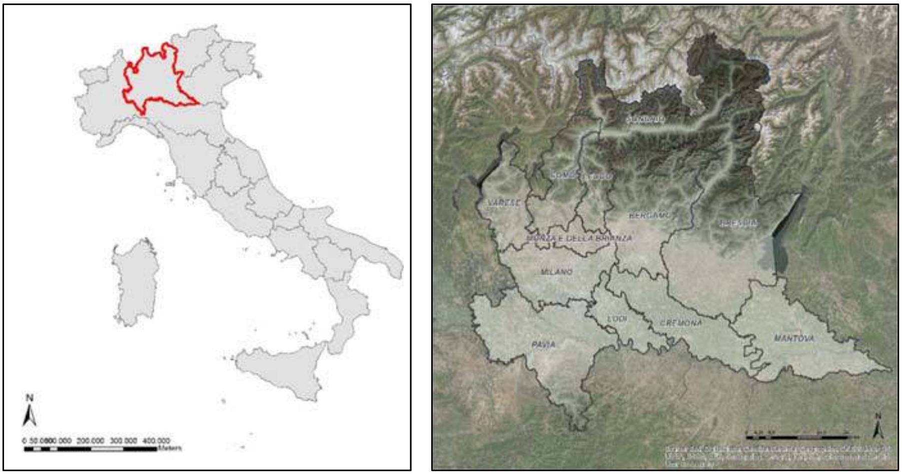


Figure 1.
Left: location of the Lombardy region, in North-west Italy.
Right: provinces of the Lombardy region

The RLP takes a multi-level approach, from the regional to the local authority level, with the direct involvement of sub-regional (provincial) authorities.

The new approach to regional landscape planning aims to provide landscape protection and conservation regulations according to the spatial distribution of the built-up environment. The methodology proposed in this paper provides an opportunity to analyse urban morphology at the regional level by considering different kinds of landscape pattern.

Moreover, the definition of Regional Green Infrastructure (RGI), a concept recently introduced by the European Commission (2013) and defined as a "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a broad range of ecosystem services", promotes actions for landscape regeneration by also taking built-up space and its cultural value into account. Urban morphology analysis is a crucial support in setting appropriate strategies for landscape restoration in accordance to the physical elements of the landscape.

As argued by Clifton *et al.* (2008), one approach to describing landscapes is to define their urban form by analysing and measuring their spatial pattern of land use distribution, including physical elements such as buildings and infrastructure systems.

The UMI constitutes an experimental composite indicator based on quantitative landscape ecology metrics (Ingegnoli, 1993; Inostroza *et al.*, 2013). The adoption of landscape metrics is a way of measuring the geometrical character of the built-up land and its distribution based on LULC. The UMI identifies the landscape patterns (mosaics) which constitute the structure of urban areas and provides information regarding the relationship between continuous or discontinuous built-up patterns by considering the distribution of statistics associated with features. Pattern analysis is a new method for describing and interpreting urban spatial dynamics as a key component of recent urban development. The variables that make up the indicator are based on the structural elements of urban morphology, considering the spatial relationships between different characteristics of the built-up system such as size, shape, number and type of urbanised polygons (each LULC entity is a polygon) (McGarigal and Marks, 1994). Urbanised polygons were analysed for the whole of Lombardy and the results were disaggregated at the municipal level to identify the kind of morphology. The indexes that comprise the UMI were selected in order to bring together the following elements: the relationship between permeable and impermeable surfaces of built-up areas by measuring their relation for each patch; the number and geometry of urban clusters to assess their degree of fragmentation and compactness. All the variables were subject to statistical analysis (see Section 3) to develop a composite indicator based on spatial.

3. Results

3.1 Urban porosity index

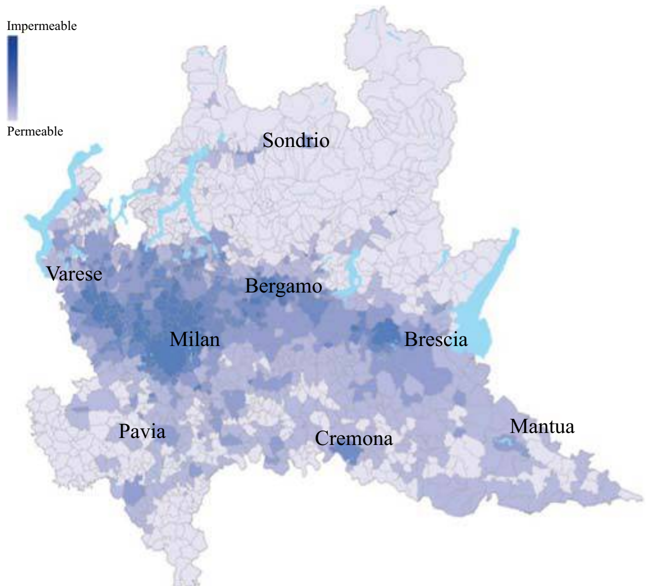
The urban porosity index (Figure 2) represents the degree of permeability of an urbanised patch. The index was calculated for each land use polygon and then distributed by aggregation at the municipal level (a total of 1,496 municipalities). It is the result of the percentage of permeable cover within an urbanised cluster. Two databases were used: the LULC data set for the Lombardy region built with the Corine Land Cover Legend (http://uls.eionet.europa.eu/CLC2006/CLC_Legeng.pdf), and the Degree of Imperviousness (Copernicus High Resolution Layer) with a raster resolution of 5×5 metres per cell provided by ISPRA (The Italian National Institute for Environmental Protection and Research) which represents the spatial distribution of sealed cells across the entire land area in question (Artmann, 2014, 2015; Vanderhaegen *et al.*, 2015; Xiao *et al.*, 2013). Artificial land cover (concrete, stone, asphalt) are impermeable surfaces and the degree of sealing for each land use is heterogeneous between different urban contexts. The calculation formula used is:

$$\text{Urban porosity index} = \frac{U_a - I_a}{U_a} \times 100$$

where U_a, urbanised areas; I_a, impermeable surfaces.

3.2 Fragmentation index

The fragmentation index (Figure 3) is calculated as the number of built-up clusters divided by the total number of urbanised areas. The term "fragmentation" refers to the land that has



Note: Level of detail: municipality

Figure 2. Lombardy region: porosity index for built-up areas

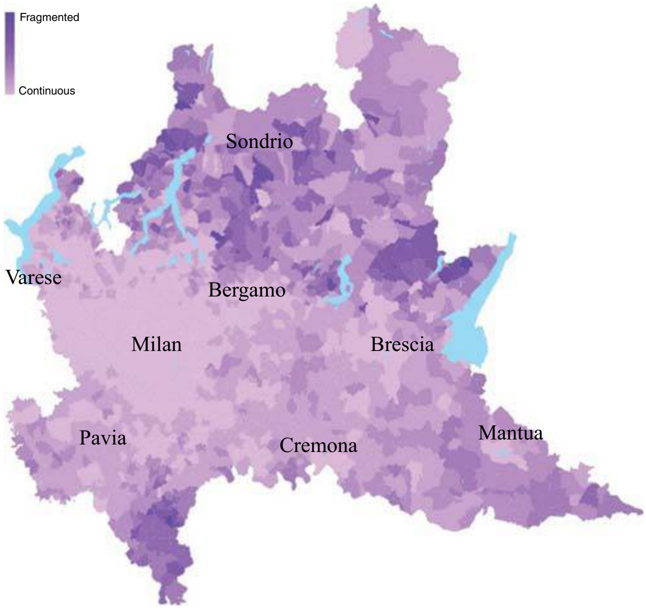


Figure 3.
Lombardy region: fragmentation index

Note: Level of detail: municipality

developed in either a patchy or scattered way, in which urban patches are often mixed with undeveloped areas (e.g. agricultural, natural or semi-natural and urban green areas) (Schneider and Woodcock, 2008).

The input layer was Class 1.1 – "Urban fabric" – from the LULC data set (Destinazione d'Uso dei Suoli Agricoli e Forestali (DUSAF)) available for the Lombardy region and built using the Corine Land Cover Legend (http://uls.eionet.europa.eu/CLC2006/CLC_Legeng.pdf).

The following calculation formula was used:

$$\text{Fragmentation index} = \frac{\text{nP}}{A} \times 100$$

where: nP, number of polygons in the input layer that make up the urbanised area; A, surface extension of the urbanised area (in hectares).

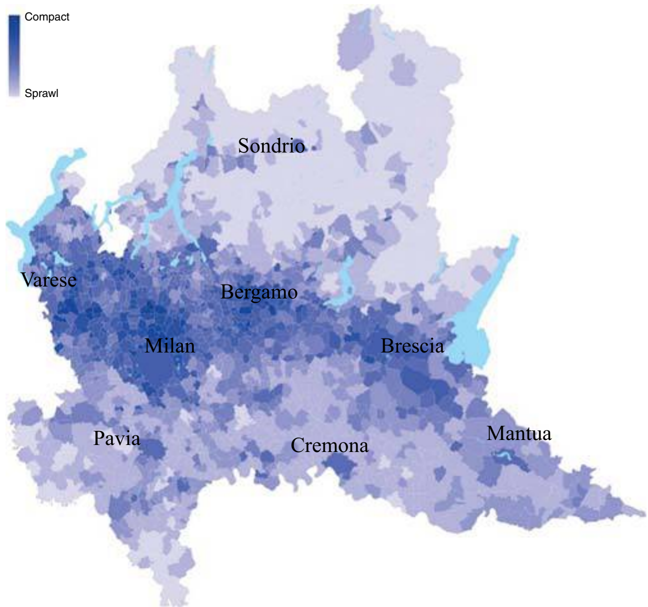
Based on the results, Lombardy's municipalities were divided into nine classes, ranging from municipalities in which the urban fabric is continuous to those in which it is highly fragmented.

As Figure 2 shows, the municipalities in the area surrounding Milan exhibit a lower degree of fragmentation, as they feature continuous urban areas and fewer green areas.

In contrast, fragmentation is greater in the municipalities close to mountain ranges (the Alps and Apennines) where natural and agricultural areas are characterised by fragmented built-up patches which exhibit a "dotted and scattered" distribution pattern.

3.3 Urban shape index

The final index is the urban shape index (Figure 4), in which the compactness of urban areas is measured as the extent to which they approximate an ideal circular built-up patch. The index measures the spread between the existing perimeter of each built-up patch against a hypothetical circular compactness. The more irregular (and thus non-circular) the perimeter of urban areas, the less the urban pattern is fractal, linear, stripped or ribbon. This index



Note: Level of detail: municipality

Figure 4.
Lombardy region: urban shape index

derives from Boyce and Clark's (1964) radial shape theory which posits a clear correspondence between the value of the index and the shape, as applied in geographical studies.

The urban shape index is calculated as follows:

$$\text{pe index} = \frac{\frac{2\pi\sqrt{A}}{\pi}}{P} \times 100$$

where: $P =$ perimeter of the urbanised area (in m^2); A, surface extension of the urbanised area (in m^2).

As Figure 4 shows, Lombardy's municipalities were divided into nine classes. The index is higher (i.e. with a greater proportion of circular shapes) in municipalities located in the Milan metropolitan area and "pivot" cities to the north of the region (Varese, Como and Lecco), and lower in suburban and rural areas where settlements are distributed along the main transport and infrastructure networks or in low-density urban areas in rural landscapes as opposed to in mountainous areas, due to their geomorphological characteristics.

3.4 UMI

The indexes described above cover different aspects of traditional morphological analysis: the relationship of buildings with open spaces, lots and streets (Moudon, 1997). The three indexes drawn up at the regional level were combined into a final composite indicator using Esri ArcGIS "grouping analysis" as a tool to apply the spatial statistics to the variable's distribution in the context of study.

The tool was used to clustering polygons with similar statistics using the combined indexes and their relative spatial distribution in order to classify urban zones into homogenous morphological groups. These are grouped by similar components of the built-up space in the Lombardy region. The groups display different kinds of morphologies with a mix of porosity, fragmentation and shape characteristics.

To ascertain the optimal number of groups in accordance with the Esri ArcGIS user guide (http://pro.arcgis.com), the Caliński-Harabasz pseudo F-statistic (Caliński and Harabasz, 2007) was used, which is a ratio reflecting within-group similarity and between-group difference.

The calculation formula used was:

$$\text{Grouping analysis} = \frac{\left(\frac{R^2}{nc-1}\right)}{\left(\frac{1-R^2}{n-nc}\right)}$$

where:

$$R^2 = \frac{SST-SSE}{SST}$$

$$SST = \sum_{i=1}^{nc}\sum_{j=1}^{ni}\sum_{k=1}^{nv}\left(V_{i_j}^{k} - \overline{V^k}\right)^2$$

$$SSE = \sum_{i=1}^{nc}\sum_{j=1}^{ni}\sum_{k=1}^{nv}\left(V_{i_j}^{k} - \overline{V_{i_j}^{k}}\right)^2$$

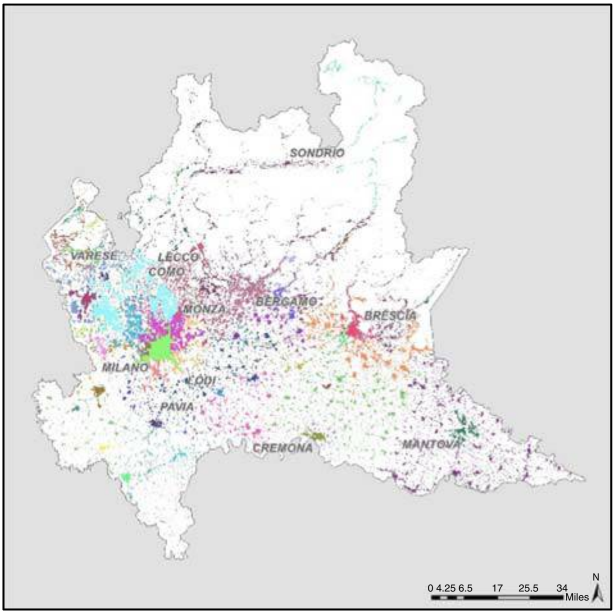
SST, reflection of between-group differences; SSE, reflection of within-group similarities; n, number of features; n_i, number of features in group i; n_c, number of classes (groups); n_v, number of variables used to group features; $V_{i_j}^{k}$, value of the kth variable of the jth feature in the ith group; $\overline{V^k}$, mean value of kth variable; $\overline{V_{i_j}^{k}}$, mean value of kth variable in group I; SST, surface extension of urbanised area (in m^2).

The grouping analysis input parameter was set with an output of 65 groups combining the three indexes previously mentioned. The number of groups was the result of an initial testing period where the output was verified against a document-based analysis and the field knowledge of the expert group. After several trial runs with a number of groups ranging between 40 and 70, a final value of 65 was chosen as giving the highest degree of feedback between the morphological groups and their distribution in the landscape. The output layer (Figures 5 and 6) is based on the feature attribute of the three indexes thus developed (the porosity index for built-up areas, the fragmentation index and urban shape index). The results show different urban agglomerations whose features were grouped according to statistical similarity.

For example, in the agricultural plain, the grouping analysis identifies those areas characterised by vine-growing in the province of Pavia, where the primary hills have influenced urban development, mainly consisting of single settlements which are functional to rural activities (in the Oltrepò area), in contrast with the Lodi and Cremona areas where the agricultural land use remains dominant yet recent infrastructure development (railways and roadways) has caused urbanisation to expand faster than the population growth.

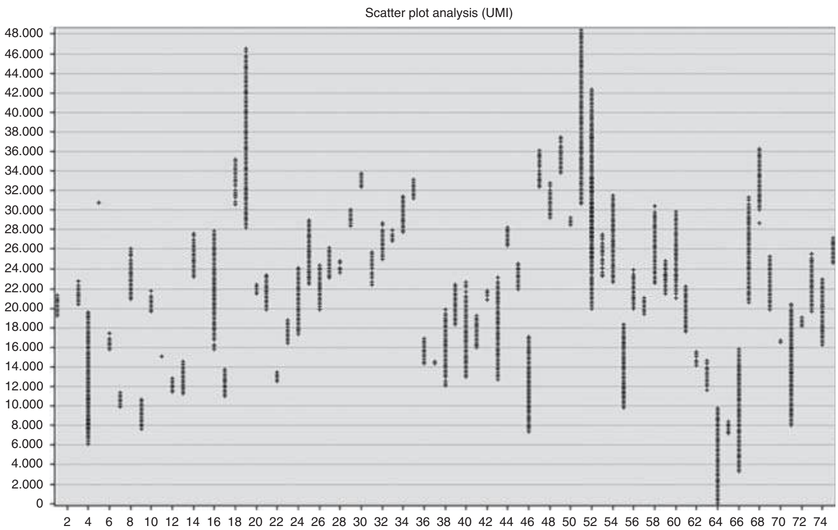
The output also shows a distinction between metropolitan areas which have maintained their original historical structure (such as the city centre of Milan, Bergamo or Brescia) and are characterised by limited urban green areas and high population density, and the more dispersed growth patterns in peripheral areas of cities.

Using the abovementioned configuration, the grouping analysis generates an output which highlights the differences between distinct morphological characteristics of the built-up environment in detail. Since heterogeneity is one of the main characteristics of settlement patterns in Lombardy, a straightforward methodology was required with



Note: Level of detail: regional

Figure 5. Lombardy region: grouping analysis output



Note: Level of detail: regional

Figure 6. Lombardy region: scatter plot distribution of grouping analysis output

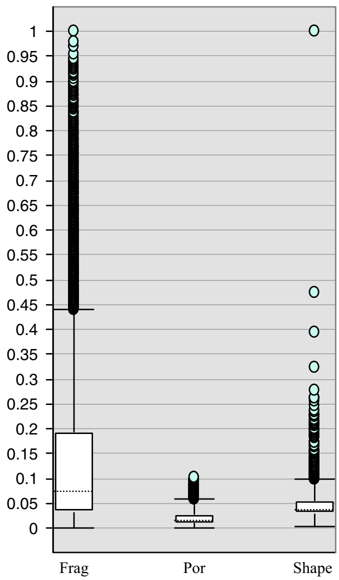
the following basic operations: define the most representative indicators for aggregation (e.g. porosity, fragmentation, shape); select the computational GIS procedure which allows an automatic grouping based on spatial statistics (e.g. ArcGis grouping analysis) and calibrate the model by setting the parameters until the result is sufficiently accurate (e.g. by testing the model with qualitative information, historical documents and additional data).

Figure 7 represents the box plot of the UMI, showing the distribution of the three variables of fragmentation (Frag), porosity (Por) and shape (Shape). The distribution was obtained by setting the range for all of the indicators from 0 to 1. Generally, over the entire region it is fragmentation which displays the greatest degree of variation, ranging from 0 to 0.45. In contrast, porosity shows a flatter cluster of values closer to 0 with low variability (0-0.06). Hence the characteristic of porosity is relatively homogenous across the entire region with a low degree of green areas in the urban context. Finally, the shape index ranges from 0 to 0.1, with a higher variation than porosity but much lower than fragmentation (although there are outliers as high as 0.5).

With regard to the spatial distribution of the indexes in Lombardy, Figure 8 shows the composition of the UMI and the independent character of its different patterns. An analysis of the box plot distribution of the three different morphologies generated by the grouping analysis (Milan and hinterland area, the Lomellina area and the linear lakes conurbation) provides significant statistical information:

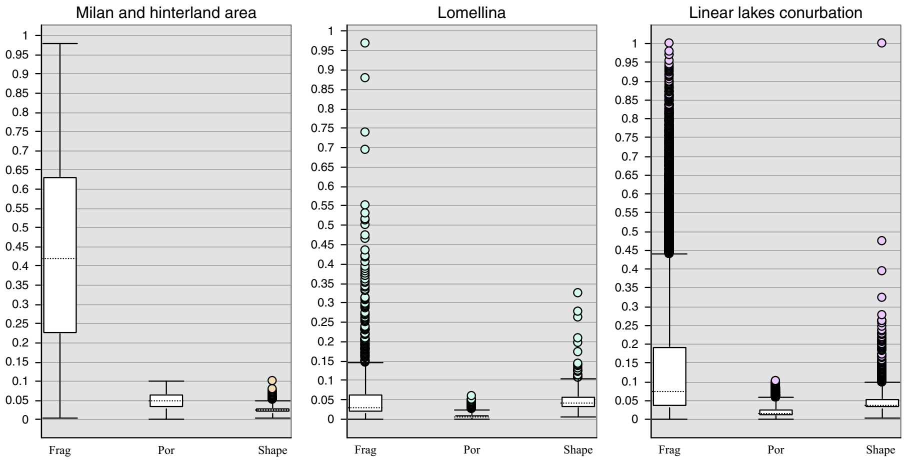
(1) The Milan and hinterland area, the region's dense metropolitan core, is characterised by a high degree (average of 0.4) and variability of fragmentation. Porosity, too, is higher than the average for the region while the shape index is flatter, with values close to 0. Milan and its hinterland are highly impacted by fragmentation of infrastructure, roads and parking areas which in turn affect the residual open space (thus the porosity index), even if the urban system is not exempted from ribbon development.

(2) The Lomellina area shows a low average fragmentation index with a narrow distribution of values around 0.1. The pattern of urban development in the



Note: Frag, fragmentation index; por, porosity index for built-up areas; shape, urban shape index

Figure 7.
Box plot of UMI composition and distribution of its variables



Notes: Frag, fragmentation index; por, porosity index for built-up areas; shape, urban shape index

Figure 8.
Box plot distribution of three indexes for selected area of Lombardy region

Lomellina area is widely recognised for its compactness, and its urban borders tend to have clearly defined edges. Porosity is much lower than the regional average, while shape is higher than for Milan and its hinterland. This combination of low porosity with a higher shape index value is the result of the presence of sprawl or sprinkling phenomena in the area.

(3) Like Lomellina, the linear lakes conurbation is characterised by a lower shape index value. Nevertheless, porosity is higher than in Lomellina (green urban areas characterise the built-up system along the linear coastal development of the lake), while fragmentation is much higher, making its morphology less continuous than it is in Lomellina.

The interplay of the statistical distribution between the three selected variables shows how grouping analysis can provide fundamental support to the statistical analysis of many regional patterns. The numerical and quantitative assessment obtained through the interpolation of variables was used as a framework for a subsequent document-based and qualitative validation of the patterns based on scientific literature in the field.

The grouping analysis output was then checked and adjusted slightly on the basis of detailed expert feedback in order to merge patterns and eliminate redundant classes. This refinement of the result was necessary to test the output against traditional urban planning studies of Lombardy's landscape morphology.

The results were also validated by comparing the output of the Fragmentation index to the Statistical Sprawl Index (SSI) for Lombardy drawn up in 2012 for a regional publication titled "Land cover changes in Lombardy over the last 50 years" (Pileri, 2012), in order to verify the correspondence between the two analyses. The SSI is defined as "the ratio between the growth rate of the urbanised area and the growth rate of the population in the same areas. A value greater than 1 is associable with urban sprawl. In fact the index measures one of the characteristics of sprawl (the ratio between the growth of the demographic determinant and the urbanised area) and on the basis of this characteristic it gives some interpretable answers" (Pileri, 2012):

$$SSI = \frac{GRurb}{GRpop}$$

where GRurb, growth rate of urban land cover (referring to the land cover classes indicated in the DUSAF data set, Classes 11, 12 and 13 were selected, while land cover class 14 need not be considered); GRpop, growth rate of the resident population.

In order to validate the UMI, a testing area was selected in order to compare its behaviour with that of a more traditional morphological indicator. The testing area selected was the irrigated plain of the region characterised by discontinuous urban patterns where fragmentation is evident and well documented in the scientific literature.

A comparison of the result of the fragmentation index with the SSI (Pileri, 2012) revealed similarities between the two indexes. A detailed analysis of the area around the city of Mantua shows how both indexes are characterised by a reticular network which increases low-density built-up patterns (Rectangle A), or the linear conurbation between the cities of Bergamo and Brescia as far as Lake Garda where sprawl conditions are identified (Rectangle B).

Any such linear correspondence between the two indexes is not evident when looking at the distribution of values in the metropolitan area of Milan. In this case, the SSI takes population into consideration (unlike the fragmentation index) and the result is influenced by this variable. In any case, a comparison of the SSI with the UMI suggests that the former has a high degree of statistical significance (Figure 9).

Once the consistency of the result achieved by grouping analysis had been verified through a validation process, it was possible to identify 28 different urban morphology patterns in the entire region, which were divided into systems, polarities and urbanised units (Figure 10). The patterns identified through the grouping analysis were typically given the established name in the existing literature on urban morphology.

This interpretation of the grouping analysis output is supported by urban geography studies conducted during the 1990s which identified areas of dense, continuous urban development or the discontinuous, scattered urban development in the Milan urban region and the low-density peripheral built-up system (Boeri *et al.*, 1994).

The analysis highlights two main patterns in the Milan metropolitan area, which are:

(1) A conurbation pattern characterised by a continuous urban area, which is in turn divided into 11 subcategories based on specific patterns (compact areas, continuous linear systems along infrastructure corridors and rivers, and peri-urban sprawl).

(2) A conurbation pattern characterised by a discontinuous urban area, which is in turn divided into six different patterns distributed between the peri-urban and rural system. It is composed mainly of minor agglomerations that have grown up around medium and small towns or along infrastructure corridors.

The following is a brief description of four patterns of dense, continuous urban areas and six patterns of non-dense, discontinuous urban fabric:

(1) compact, densely aggregated built-up areas made up of traditional dense urban shapes with varying degrees of porosity (Milan and the surrounding area);

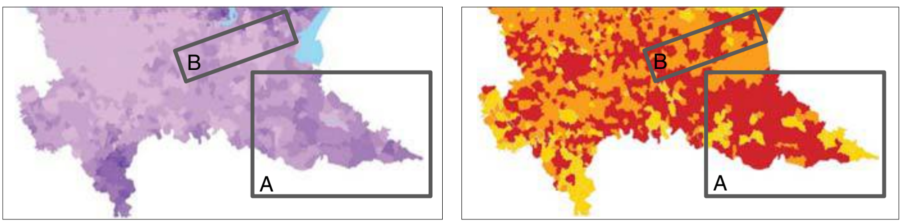


Figure 9.
Left: statistical urban sprawl indicator (1999-2007). Right: fragmentation index

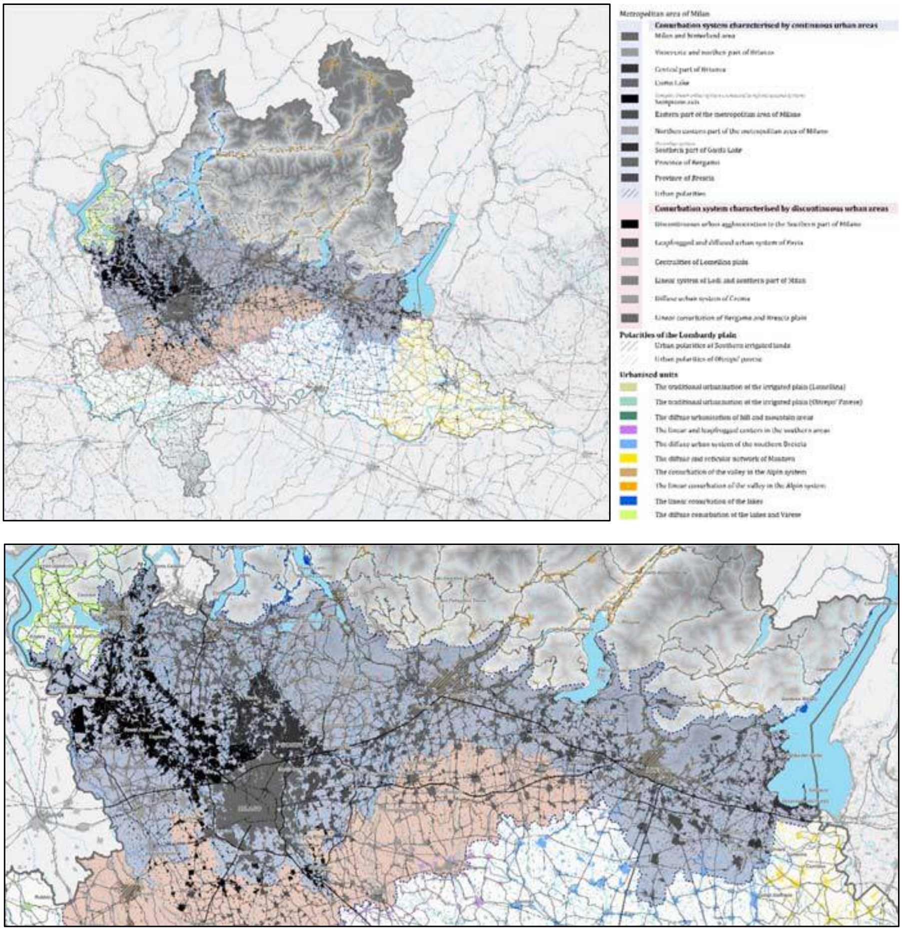


Figure 10.
Above: Lombardy region. Urban morphology indicator (UMI) based on grouping analysis. Below: details of the conurbation system characterised by continuous urban areas

(2) complex linear urban systems connected to primary infrastructure, comprised by the great metropolitan conurbations (The Sempione axes, east Milan area and north-west Milan area);

(3) peri-urban conurbations consisting of developing peripheral areas adjacent to dense urban centres which are the result of urban sprawl; and

(4) external urban polarities made up of traditional, self-contained urban centres of the metropolitan area.

The metropolitan area is also comprised by discontinuous urban patterns, and can be subdivided as follows:

(1) the discontinuous urban agglomeration of south Milan;

(2) the leapfrogged, low-density urban system of Pavia;

(3) the settlement centres of the Lomellina plain;

(4) the linear system of Lodi and the south-east of Milan;

(5) the low-density urban system of Crema; and

(6) the linear conurbation of Bergamo and the Brescia plain.

The discontinuous urban system is made up of the more traditional urban centres of the irrigated valley plain with a kind of urbanisation that is characterised by smaller, low-density additions in the peri-urban areas of medium-sized centres, as opposed to the historical development along infrastructural axes.

Beyond the Milan metropolitan area, an analysis based on the UMI enables another two types of system to be identified: the "polarities" of the Lombardy Plain and the low-density urban areas of the regional system.

Application of the UMI also identifies two "polarities" in agricultural areas. The term "polarity" is used in the sense proposed by Christaller (1966) as a concentration of functions, characteristics and services possessing relative rarity which acts as a core in gravitational areas.

Urban polarities in the Lombardy region are comprised by the outer urban centres of irrigated land to the south, and the outer polarities of the Oltrepò area, while its lower-density urban areas can be divided into subcategories.

The first polarity includes the provincial capitals of Cremona and Mantua, with their compact urban form, while the second is the urban area of Broni and Mortara near the Apennines (Oltrepò Pavese).

The final morphological pattern revealed by the UMI is that of the urbanised units beyond the Milan metropolitan area located in the agricultural plain, mountain regions (Alps and Apennines) and in proximity to the lake system. These units were grouped together because the spatial distribution of their urban settlement patterns and morphology was similar. They have the following characteristics:

(1) low-density urban development in the irrigated valley plain;

(2) low-density urban development in hilly and mountainous areas;

(3) the linear leapfrogged centres of the region's southern areas;

(4) the low-density urban system of southern Brescia;

(5) the low-density, reticular network of Mantua;

(6) the linear conurbation of the lower valley of the Prealpine and Alpine system;

(7) the linear conurbation along the shores of the region's lakes; and

(8) the low-density built-up system in the lake region and Varese.

4. Discussion

Urban expansion impacts landscape in both ecological and morphological terms. Often land use changes are understood as an imbalance between natural and man-made elements. The recent expansion of low-density, fragmented built-up areas has been caused by the construction of new infrastructure systems (such as roads and railways) which support the urbanisation process.

Sprawl, the most severe effect of land use changes, is a system of low-density areas characterised by mainly residential uses and which heavily depends on individual mobility (Zolnik, 2012).

In Europe, in the ten years from 1990 to 2000, the growth of urban areas associated with infrastructure development consumed more than 8,000 km^2 (a 5.4 per cent increase over the period) (European Environment Agency, 2006). Analogously, the same trend was found in Lombardy, where a recent analysis has estimated that more than 1,600 hectares of natural or agricultural land in the Milan metropolitan area were converted into road infrastructure (Ronchi and Salata, 2013).

As evidence of this, the discontinuous conurbation system of the Milan metropolitan area clearly shows how the development of infrastructure has affected urban spatial distribution, impacting upon the smaller rural pattern of the agricultural plain. Additionally, the development of infrastructure in the plain area has enforced the polarity system outside the compact city and created new, smaller gravitational centres around the main centres. The in-between peri-urban space of medium and small centres has been sparsely filled with new fragmented urban development.

Mention should also be made of the region's mountainous area, the morphological variety of which means that it cannot be considered a single, homogeneous morphological group.

These considerations furnish initial feedback regarding morphological variability as revealed by the UMI which distinguishes the morphology of the hills and mountain area, as a typical agglomeration of second home and leisure-based urban development, from the valley area, which is dominated by a pattern of strip development of mixed land use, with a high proportion of industrial and commercial land use. The application of the UMI to the Lombardy region has identified many patterns which are representative of the region's morphological variability in terms of landscape metrics. The statistical analysis provided by the UMI shows how the composition of indexes (fragmentation, porosity and shape) differs consistently among the identified morphological patterns. Such quantitative and statistical validation is confirmed by a qualitative/document-based validation which shows how the morphological patterns identified largely accord with traditional descriptions of the region's morphological patterns.

The main innovation introduced by the UMI is GIS statistics as a basis for mapping the distribution of phenomena over large areas. In the specific case of Lombardy, UMI values help to identify the areas in which built-up environments share similar characteristics or conversely where such characteristics change.

Statistical analysis shows that in the metropolitan area of Milan, which is represented as a transboundary urban region (Salata, 2017), the difference between continuous/discontinuous patterns is determined by a substantial change in the statistical distribution of UMI values; the discontinuous pattern is characterised by lower values of fragmentation and with lower porosity, while the shape index is higher. This means that the core character contradistinguishes the morphological conditions of the metropolitan areas is the density and the continuity of the urban system even if affected by fragmentation due to changes in urban function, infrastructure or open spaces. Porosity, in such continuous patterns, is high while the shape index is low meaning that feature borders are irregular, fractal and un-circular.

Within the UMI framework, the traditional morphological classification of built-up patterns defined by geographers and landscape architects has been reconsidered according to its similarity to those identified by the new indicator, which increases the level of detail regarding changes in character of the built-up system (Lanzani, 2011).

The main innovation introduced by the UMI framework is that it enhances and goes beyond the traditional approach based on direct surveys and typological descriptions of built-up areas by introducing a new computational approach which is faster, more reliable and more detailed. Such an approach makes it possible to highlight the morphological differences in low-density areas characterised by sprawl where land take and urban development have changed the character of the landscape in recent years. In such areas, traditional "academic" descriptions of morphologies which contrast modern urban development which the traditionally compact city are not sufficiently detailed or accurate for an understanding of the post-metropolitan urbanisation (Balducci, 2012; Brenner, 2002).

The UMI meets a need for traditional methodology based on qualitative urban morphology information to be integrated with quantitative descriptions and for monitoring systems at the regional scale and define landscape management scenarios. Moreover, the use of quantitative indicators of spatial distribution makes it possible to highlight politicians and decision makers that the contemporary city tends towards what Brenner (2002) defined "urban regionalism" which requires a shift from local to inter-municipal government of urban processes and dynamics. The proposed morphological classification is an asset in terms of landscape management. Considering the dynamics of certain types of urban morphology, political decision makers need to make provision for appropriate local and regional development strategies (such as planning tools and land use regulations) in order to regulate urban transformations.

The results of the UMI were considered in the RGI to identify the strategies for urban and landscape restoration at a local scale according to environmental value, characteristics of places and urban quality (Arcidiacono *et al.*, 2016). This approach accords with strategies at the European level, such as the Green Infrastructure Strategy for preserving ES and restoring degraded ecosystems.

The methodology proposed may be subject to certain limitations associated with the availability of data, especially the LULC layer, which strongly affects the results of the UMI indicator. Moreover, quantitative urban morphology analysis requires integration with the traditional qualitative/descriptive approach for a comprehensive interpretation of urban morphology characteristics. Finally, the three indicators used for the UMI do not provide an exhaustive description of urban morphology; therefore the selection could be made considering the territorial specificities of a study area.

5. Conclusions

Urban sprawl comprises a combination of multiple aspects, including form, density and land use patterns (Goerlich Gisbert *et al.*, 2017). It is therefore a complex phenomenon which requires a multiple combined indicator to measure and assess its characteristics.

The UMI captures differences between complex urban forms by adequately measuring morphological complexity and moving beyond the traditional landscape descriptions and interpretations.

Morphological classification is fundamental for landscape management and implementing appropriate governance measures as it considers the morphological features of an area to be an integral structural element of it. Its application to the Lombardy region could support the territorial governance promoting landscape conservation through urban regeneration.

Urban regeneration aims to achieve long-term economic, physical, social and environmental improvements (Comunian, 2011). Its implementation requires a detailed knowledge of the spatial and social characteristics of the contemporary city.

Areas in need of regeneration policies can be identified by the UMI indicator, as it provides information on the landscape structure and distinguishes between those areas historically subject to high pressure resulting from human activity from those where such pressure is currently growing.

The adopted methodology advances a pioneering approach which is different from those traditionally used in the quantitative landscape ecology, by introducing complex metrics for assessing urban morphology pattern into the broad instruments and tools for sustainable regional planning.

The UMI indicator and the related analysis for RGI were included in the RLP for the Lombardy region to support decision-making processes aimed at setting out the strategies for landscape regeneration projects.

The UMI indicator, therefore, is not merely a descriptive indicator of a spatial phenomenon but is aimed at providing legislative support for the "re-design" of landscape policies and tools at the regional scale. In a downscaling perspective, the UMI is designed with regional spatial metrics which should be subsequently re-designed and considered at the local scale for the fulfilment of landscape regeneration projects.

In-depth analysis of the morphological distribution of built-up settlements helps to draw up and implement appropriate strategies for regulating sprawl, including legislation to limit soil sealing, which compromises overall ecological and landscape quality.

Planning processes, especially when dealing with landscape quality, require a variety of actions, strategies and rules according to the specific characteristics of the context. The integration of the UMI indicator into the RLP has been necessary to provide and adopt suitable tools for reducing sprawl.

References

Adamiak, C. (2016), "Cottage sprawl: spatial development of second homes in Bory Tucholskie, Poland", *Landscape and Urban Planning*, Vol. 147, pp. 96-106.

Antrop, M. (2004), "Landscape change and the urbanization process in Europe", *Landscape and Urban Planning*, Vol. 67 Nos 1/4, pp. 9-26.

Arcidiacono, A., Ronchi, S. and Salata, S. (2016), "Managing multiple ecosystem services for landscape conservation: a green infrastructure in Lombardy region", *Procedia Engineering*, Vol. 161, pp. 2297-2303.

Artmann, M. (2014), "Institutional efficiency of urban soil sealing management – from raising awareness to better implementation of sustainable development in Germany", *Landscape and Urban Planning*, Vol. 131, pp. 83-95.

Artmann, M. (2015), "Managing urban soil sealing in Munich and Leipzig (Germany) – from a wicked problem to clumsy solutions", *Land Use Policy*, Vol. 46, pp. 21-37.

Artmann, M. (2016), "Urban gray vs urban green vs soil protection – development of a systemic solution to soil sealing management on the example of Germany", *Environmental Impact Assessment Review*, Vol. 59, pp. 27-42.

Balducci, A. (2012), "Planning the post-metropolis", *disP – The Planning Review*, Vol. 48 No. 1, pp. 4-5.

Barbosa, A., Vallecillo, S., Baranzelli, C., Jacobs-Crisioni, C., Batista e Silva, F., Perpiña-Castillo, C., Lavalle, C. and Maes, J. (2016), "Modelling built-up land take in Europe to 2020: an assessment of the resource efficiency roadmap measure on land", *Journal of Environmental Planning and Management*, Vol. 60 No. 8, available at: https://doi.org/10.1080/09640568.2016.1221801

Batista e Silva, F., Lavalle, C., Jacobs-Crisioni, C., Barranco, R., Zulian, G., Maes, J., Baranzelli, C., Perpiña-Castillo, C., Vandecasteele, I., Ustaoglu, E., Lopes Barbosa, A.L. and Mubareka, S. (2013), *Direct and Indirect Land Use Impacts of the EU Cohesion Policy Assessment with the Land Use Modelling Platform Contact Information*, Office of the European Union, Luxembourg, available at: https://doi.org/10.2788/60631

Bogaert, J., Vranken, I. and André, M. (2014), "Anthropogenic effects in landscapes: Historical context and spatial pattern", in Hong, S.K., Bogaert, J. and Min, Q. (Eds), *Biocultural Landscapes: Diversity, Functions and Values*, Springer, pp. 89-112, available at: https://doi.org/10.1007/978-94-017-8941-7_8

Boyce, R.R. and Clark, W.A.V. (1964), "The concept of shape in geography", *Geographical Review*, Vol. 54 No. 4, pp. 561-572.

Brenner, N. (2002), "Decoding the newest 'metropolitan regionalism' in the USA: a critical overview", *Cities*, Vol. 19 No. 1, pp. 3-21.

Caliński, T. and Harabasz, J. (2007), "A dendrite method for cluster analysis", *Communications in Statistics-Theory and Methods*, Vol. 3 No. 1, pp. 1-27.

Christaller, W. (1966), *Central Places in Southern Germany*, Prentice Hall, Englewood Cliffs, NJ.

Clifton, K., Ewing, R., Knaap, G. and Song, Y. (2008), "Quantitative analysis of urban form: a multidisciplinary review", *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, Vol. 1 No. 1, pp. 17-45.

Comunian, R. (2011), "Urban regeneration in the UK", Vol. 42 No. 4, Sage, London, pp. 674-676, available at: https://doi.org/10.1111/j.1468-2257.2011.00572.x

Crossman, N.D., Bryan, B.A. and King, D. (2009), "Integration of landscape-scale and site-scale metrics for prioritising investments in natural capital", *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*, pp. 2363-2369.

Delattre, L., Chanel, O., Livenais, C. and Napoléone, C. (2015), "Combining discourse analyses to enrich theory: the case of local land-use policies in South Eastern France", *Ecological Economics*, Vol. 113, pp. 60-75.

Dupras, J., Marull, J., Parcerisas, L., Coll, F., Gonzalez, A., Girard, M. and Tello, E. (2016), "The impacts of urban sprawl on ecological connectivity in the Montreal Metropolitan Region", *Environmental Science & Policy*, Vol. 58, pp. 61-73.

European Commission (2011), "Our life insurance, our natural capital: an EU biodiversity strategy to 2020", communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions, Our life insurance, our natural capital: an EU biodiversity strategy to 2020, Bruxelles.

European Commission (2013), "Building a green infrastructure for Europe", Publications Office of the European Union, Luxembourg, 24pp, available at: https://doi.org/10.2779/54125

European Environment Agency (2006), "Urban Sprawl in Europe – the ignored challenge", EEA Report, Vol. 10, Copenhagen, available at: https://doi.org/10.1080/02697451003740312

European Environment Agency (2013), "Land take", available at: eea.europa.eu/enquiries

Feranec, J., Šúri, M., Ot'ahel', J., Cebecauer, T., Kolář, J., Soukup, T., Zdeňková, D., Waszmuth, J., Vâjdea, V., Vîjdea, A.-M. and Nitica, C. (2000), "Inventory of major landscape changes in the Czech Republic, Hungary, Romania and Slovak Republic 1970s - 1990s", *International Journal of Applied Earth Observation and Geoinformation*, Vol. 2 No. 2, pp. 129-139, available at: https://doi.org/10.1016/S0303-2434(00)85006-0

Frumkin, H. (2002), "Urban sprawl and public health", *Public Health Reports*, Vol. 117 No. 3, pp. 201-217.

Goerlich Gisbert, F.J., Cantarino Martí, I. and Gielen, E. (2017), "Clustering cities through urban metrics analysis", *Journal of Urban Design*, Vol. 22 No. 5, pp. 689-708.

Gómez-Baggethun, E. and Barton, D.N. (2012), "Classifying and valuing ecosystem services for urban planning", *Ecological Economics*, Vol. 86, pp. 235-245.

Häyhä, T. and Franzese, P.P. (2014), "Ecosystem services assessment: a review under an ecological-economic and systems perspective", *Ecological Modelling*, Vol. 289, pp. 124-132.

Ingegnoli, V. (1993), *Fondamenti Di Ecologia Del Paesaggio*, Città studi (Ed.), Torino, Milan.

Inostroza, L., Baur, R. and Csaplovics, E. (2013), "Urban sprawl and fragmentation in Latin America: a dynamic quantification and characterization of spatial patterns", *Journal of Environmental Management*, Vol. 115, October, pp. 87-97.

Inostroza, L., Zasada, I. and König, H.J. (2016), "Last of the wild revisited: assessing spatial patterns of human impact on landscapes in Southern Patagonia, Chile", *Regional Environmental Change*, November, Vol. 16 No. 7, pp. 2071-2085.

Istituto Superiore per la Protezione e la Ricerca Ambientale (2015), *Il Consumo Di Suolo in Italia*, Vol. 218, Istituto Superiore per La Protezione E La Ricerca Ambientale, Rome, available at: https://doi.org/10.1017/CBO9781107415324.004

Jiao, L. (2015), "Urban land density function: a new method to characterize urban expansion", *Landscape and Urban Planning*, Vol. 139, pp. 26-39.

Johnson, A.E., Klemens, M.W. and Sterling, E.J. (2005), "The impacts of sprawl on biodiversity", *Nature in Fragments. The Legacy of Sprawl*, Vol. 10 No. 1, pp. 18-47.

Lafortezza, R., Davies, C., Sanesi, G. and Konijnendijk, C.C.C. (2013), "Green Infrastructure as a tool to support spatial planning in European urban regions", *iForest – Biogeosciences & Forestry*, Vol. 6 No. 3, pp. 102-108.

Lanzani, A. (2011), "Dinamiche dell'urbanizzazione nel sistema insediativo pedemontano e di pianura asciutta", in *L'uso Del Suolo in Lombardia Negli Ultimi 50 Anni*, Tarulli, pp. 77-94.

Lv, Z.-Q., Dai, F.-Q. and Sun, C. (2012), "Evaluation of urban sprawl and urban landscape pattern in a rapidly developing region.", *Environmental Monitoring and Assessment*, Vol. 184 No. 10, pp. 6437-6448.

McGarigal, K. and Marks, B.J. (1994), "FRAGSTATS: spatial pattern analysis program for quantifying landscapes structure", General Technical Report PNW-GTR-351, US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, Vol. 97331 No. 503, p. 134.

Maes, J., Zulian, G., Thijssen, M., Castell, C., Baró, F., Ferreira, A.M., Melo, J., Garrett, C.P., David, N., Alzetta, C., Geneletti, D., Cortinovis, C., Zwierzchowska, I., Louro Alves, F., Souto Cruz, C., Blasi, C., Alós Ortí, M.M., Attorre, F., Azzella, M.M., Capotorti, G., Copiz, R., Fusaro, L., Manes, F., Marando, F., Marchetti, M., Mollo, B., Salvatori, E., Zavattero, L., Zingari, P.C., Giarratano, M.C., Bianchi, E., Duprè, E., Barton, D., Stange, E., Perez-Soba, M., van Eupen, M., Verweij, P., de Vries, A., Kruse, H., Polce, C., Cugny-Seguin, M., Erhard, M., Nicolau, R., Fonseca, A., Fritz, M. and Teller, A. (2016), "Mapping and assessment of ecosystems and their services", Urban Ecosystems, Publications Office of the European Union, Luxembourg.

Magnaghi, A. (2010), *Il Progetto Locale. Verso La Coscienza Di Luogo*, Bollati Boringhieri, *Torino*.

Magnaghi, A. (2012), "Politiche e progetti di territorio per il ripopolamento rurale", in Bonora, P. (Ed.), *Visioni e politiche del territorio: Per una nuova alleanza tra urbano e rurale. Quaderni del Territorio. Collana di tesi e ricerche*, No. 2, pp. 109-142, available at: https://doi.org/10.1473/quadterr02

Mazzocchi, C., Sali, G. and Corsi, S. (2013), "Land use conversion in metropolitan areas and the permanence of agriculture: Sensitivity Index of Agricultural Land (SIAL), a tool for territorial analysis", *Land Use Policy*, Vol. 35, pp. 155-162.

Mosammam, H.M., Nia, J.T., Khani, H., Teymouri, A. and Kazemi, M. (2016), "Monitoring land use change and measuring urban sprawl based on its spatial forms: the case of Qom city", *The Egyptian Journal of Remote Sensing and Space Science*, Vol. 20 No. 1, pp. 103-116, available at: https://doi.org/10.1016/j.ejrs.2016.08.002

Moudon, A.V. (1997), "Urban morphology as an emerging interdisciplinary field", *Urban Morphology*, No. 1, pp 3-10.

Mubareka, S., Koomen, E., Estreguil, C. and Lavalle, C. (2011), "Development of a composite index of urban compactness for land use modelling applications", *Landscape and Urban Planning*, Vol. 103 Nos 3/4, pp. 303-317.

Pileri, P. (2012), "Learning and interpreting land cover and its changes", Land Cover Changes in Lombardy over the Last 50 Years, Regione Lombardia; ERSAF, Milan, pp. 185-204.

Pozoukidou, G. and Ntriankos, I. (2017), "Measuring and assessing urban sprawl: a proposed indicator system for the city of Thessaloniki, Greece", *Remote Sensing Applications: Society and Environment*, Vol. 8, October, pp. 30-40.

Ronchi, S. and Salata, S. (2013), "Il consumo di suolo per effetto delle nuove infrastrutture Lombarde", available at: http://consumosuolo.org/2013/12/il-consumo-di-suolo-per-effetto-delle-nuove-infrastrutture-lombarde/

Salata, S. (2017), "Land use change analysis in the urban region of Milan", *Management of Environmental Quality: An International Journal*, Vol. 28 No. 6, pp. 879-901.

Salata, S. and Fior, M. (2016), "Urban regeneration . The case study of PORU – Senigallia (Ancona, Italy)", *City Safety Energy*, No. 1, pp. 13-26.

Salvati, L., Munafo, M., Morelli, V.G. and Sabbi, A. (2012), "Low-density settlements and land use changes in a Mediterranean urban region", *Landscape and Urban Planning*, Vol. 105 No. 1/2, pp. 43-52.

Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V. and Woolmer, G. (2002), "The human footprint and the last of the Wild: The human footprint is a global map of human influence on the land surface, which suggests that human beings are stewards of nature, whether we like it or not", *BioScience*, Vol. 52 No. 10, pp. 891-904, available at: https://doi.org/10.1641/0006-3568(2002)052[0891:THFATL]2.0.CO;2

Sanesi, G., Colangelo, G., Lafortezza, R., Calvo, E. and Davies, C. (2017), "Urban green infrastructure and urban forests: a case study of the Metropolitan area of Milan", *Landscape Research*, Vol. 42 No. 2, pp. 164-175, available at: http://dx.doi.org/10.1080/01426397.2016.1173658

Schneider, A. and Woodcock, C.E. (2008), "Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information", *Urban Studies*, Vol. 45 No. 3, pp. 659-692.

Siedentop, S. and Fina, S. (2010), "Monitoring urban sprawl in Germany: towards a GIS-based measurement and assessment approach", *Journal of Land Use Science*, Vol. 5 No. 2, pp. 73-104.

Ursić, S., Mišetić, R. and Mišetić, A. (2016), "New perspectives on sustainable development of second homes in Croatia: strategic planning or proliferation of building?", *Procedia – Social and Behavioral Sciences*, Vol. 216 No. 1875, pp. 80-86.

Vanderhaegen, S., De Munter, K. and Canters, F. (2015), "High resolution modelling and forecasting of soil sealing density at the regional scale", *Landscape and Urban Planning*, Vol. 133, pp. 133-142.

Vaz, E. and Nijkamp, P. (2015), "Gravitational forces in the spatial impacts of urban sprawl: An investigation of the region of Veneto, Italy", *Habitat International*, Vol. 45 No. P2, pp. 99-105.

Xi, F., He, H.S., Clarke, K.C., Hu, Y., Wu, X., Liu, M., Shi, T., Geng, Y. and Gao, C. (2012), "The potential impacts of sprawl on farmland in Northeast China-Evaluating a new strategy for rural development", *Landscape and Urban Planning*, Vol. 104 No. 1, pp. 34-46.

Xiao, R., Su, S., Zhang, Z., Qi, J., Jiang, D. and Wu, J. (2013), "Dynamics of soil sealing and soil landscape patterns under rapid urbanization", *CATENA*, Vol. 109, pp. 1-12.

Zasada, I., Loibl, W., Köstl, M. and Piorr, A. (2013), "Agriculture under human influence: a spatial analysis of farming systems and land use in European rural-urban-regions", *European Countryside*, Vol. 5 No. 1, pp. 71-88.

Zolnik, E.J. (2012), "The costs of sprawl for private-vehicle commuters", *Journal of Transport Geography*, Vol. 20 No. 1, pp. 23-30.

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