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Technical note

Figuring the features of the Roman Campagna: recent landscape structural

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Abstract - This article evaluates the impact of urban expansion on landscape composition and structure of a landscape icon, the Roman Campagna, central Italy, during the last 30 years. Landscape attributes were assessed between 1974, when the distinguishing features of Roman Campagna are still widespread, and 2008, following decades of urban decentralization and urban sprawl. Changes in landscape structure were explored by spatial pattern analysis to detect how structural changes in landscape components can modify land structure and landscape profile. Non-parametric correlation statistics and factor analysis showed that the distinctive features of the Roman Campagna landscape are now blurred. A generalized landscape mix was generated by the juxtaposition of different land-use, reflected in a negative relationship between changes in surface area and patchiness found in natural and agricultural uses of land. Adaptation measures for preserving peri-urban agriculture in a changing landscape were finally discussed.

Keywords - landscape icon; Morphological Spatial Pattern Analysis (MSPA); fragmentation; peri-urban agriculture; Roman Campagna

Introduction

The low-lying landscape surrounding Rome (Latium, central Italy) has been shaped by humans for thousands of years, like other areas with ancient colonization in the northern Mediterranean basin. The area known as Roman Campagna was used for agriculture since Roman time and then abandoned during the Middle Ages, due to malaria and water shortage for farming needs. The Campagna became a famous landscape icon in Europe during the 18th and 19th centuries and an excursion into the Roman countryside was a must for travellers in the *Grand Tour* (Fig. 1).

The Campagna was reclaimed in the 19th and 20th centuries: efforts to make land more productive marked the beginning of its decline and the loss of agricultural land-use for a large part of the area. Starting with the 1950s, the Rome's expansion took over large parts of the Campagna, all around the city. However, until the 1970s the distinguishing features of Roman Campagna were still widespread: extensive arable land and pastures in lowlands, areas suitable for crops and sheep farming, and vineyards laid in a concentric semi-circle to the top of the Alban hills, where extensive cropping is spatially mixed with residential urban expansion.

Following a homogeneous path of urban decentralization and sprawl common to many European cities since the 1980s (Kasanko et al. 2006, Longhi and Musolesi 2007, Turok and Mykhnenko 2007, Schneider and Woodcock 2008, Munafò et al. 2013, Kazemzadeh-Zow et al. 2016), urban areas have greatly expanded in Rome's countryside (Fig. 2). The high rate of cropland conversion to urban uses is the most visible alteration of fringe landscapes,

Figure 1 - Cole Thomas, Roman Campagna, c. 1843, Wadsworth Athenaeum (photo in public domain).

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Figure 2 - 2012 Roman Campagna ©[Gasparella L.]

resulting in mixed land-use, the unwatched territory of the so called "edgelands" (Shoard 2002). Land-use spatial polarization, ecosystem deterioration, and loss in biodiversity are the main threats for the sustainability of rural landscape experiencing urban expansion (Cakir et al. 2008, Mavrakis et al. 2015; Colantoni et al. 2016, Salvati et al. 2017).

Paradoxical as it may sound, the ecological and functional-productive values of the countryside around towns in Europe are less recognized and appreciated by an urbanized society, than landscape amenities provided by a heterogeneous and complex agricultural land-use (Zasada 2011). In this framework, the alteration of the structure of the traditional agricultural landscape surrounding cities and, particularly, its interplay with the dynamics of urban development requires specific attention in a broader academic discourse on landscape transformations (Salvati et al. 2013, Ferrara et al. 2014, Serra et al. 2015, Smiraglia et al. 2015).

Based on these considerations, the present study aims at figuring out changes occurred in the landscape structure of Roman Campagna over an extended period of intense urban development (1974-2008). Other studies have approached this issue by landscape-level estimation of percolation and proximity indices (Metzger and Muller 1996; Metzger and Decamps 1997; Pili et al. 2017). We propose, instead, a novel application of the Morphological Spatial Pattern Analysis (Soille and Vogt 2009), which is conceived for the diagnosis of the spatial patterns of a given land cover class and the classification of their individual components. We apply MSPA to figure out to what extent observed land cover changes altered the inner structure of the Roman Campagna landscape.

The specific aims of this paper are therefore (i) to identify the most important landscape transformations during a period of rapid urbanization, (ii) to quantify changes in the structure of the rural landscape by using Morphological Spatial Pattern Analysis and, finally, (iii) to verify spatial segregation or association patterns between two (or more) land-use classes. Results may inform rural policies and spatial planning, with the aim to take account of specific peri-urban agriculture types when tailoring environmental and land management incentives.

Materials and Methods

Study area

The investigated area covers a regular, squared landscape scene of 3,000 km^2 in the Nuts-3 district of Rome that consists of 50% lowlands, 40% hills, and 10% mountains. This landscape scene includes the so-called Roman Campagna district (in Italian, "Campagna Romana"), corresponding to the territorial units of Sabatini Mountains (Rome province), Rome Countryside and parts of Tiber Valley and Rome Coastline, as illustrated in Fig. 3 using a

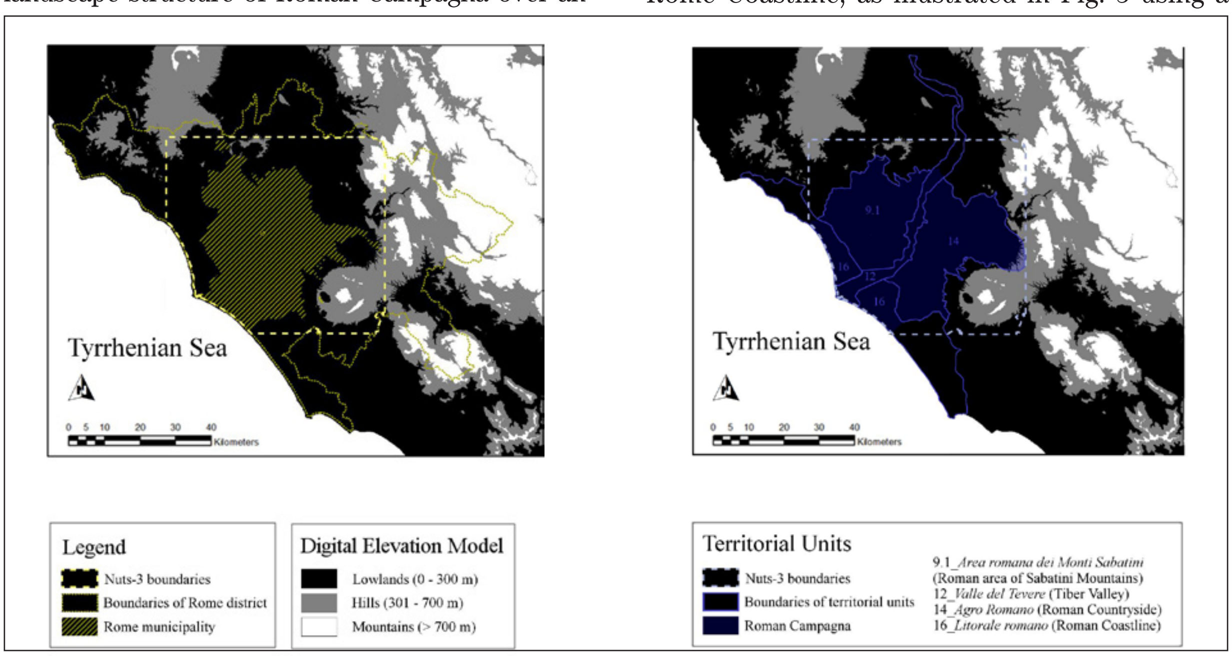

Figure 3 - The investigated area. Municipal boundaries (left) and territorial units (right).

specific district code (see also Savo et al. 2012 for a description of "Agro Romano"). Rome municipality occupies the 76% of Roman Campagna. Although nowadays urban areas cover a significant (and still increasing) almost 20% of the district land, the landscape matrix still consists of a mosaic of rural land-use. Rome is, namely, the most densely populated and the largest farming municipality of Italy at the same time (Salvati 2013). According to earlier studies (see Salvati et al. 2012 and references therein), compact growth occurred in Rome mainly between the early 1950s and the 1980s while peri-urban development was observed only in the following decades (Quatrini et al. 2015). In the 'compact growth' urban wave, population grew in the urban area at a higher rate compared to the peri-urban area (Munafò et al. 2010). The difference in population density between the two areas was high and the ratio between peri-urban and urban population increased slightly from 27% to 35% (Savo et al. 2012). During the 'dispersed growth' wave, population declined in the urban area while rose in peri-urban areas at a relatively high rate (1.5% per year).

Land cover maps

Two digital land cover maps (scale 1:25 000) were used as input data sources for this study: (i) the 'Agricultural and forest map of Rome region' produced by the district authority of Rome in 1974 (hereafter LCM74) and based on the elementary datasets developed by the Italian Geographical Military (IGM) and (ii) a land cover map derived from photo-interpretation of digital ortho-images released from the Italian National Geoportal (Italian Ministry for Environment, Land and Sea) with a 0.5 meters pixel related to 2008 (hereafter LCM08). The LCM74 map had a minimum mapping unit smaller (0.375 ha) than the LCM08 one (1.56 ha).

To harmonize spatial data for land cover change classification, the polygons of the LCM74 map with area smaller than the minimum mapping unit of the LCM08, were merged with the neighboring polygon with the largest area. Both maps were reclassified according to a land cover classification system based on 8 classes compatible with Corine Land Cover (EEA 2007). An additional class includes water bodies and other minor land-uses.

Landscape analysis

Mathematical morphology is a framework for analyzing the shape and form of objects (Soille 2003), that recently has been used in landscape ecology and environmental geography applications (Soille and Vogt 2009). The Morphological Spatial Pattern Analysis (MSPA) implements a series of image processing routines to identify features that are relevant to the diagnosis of the structural connectivity of land cover classes. The individual classes identified by MSPA are: (i) core areas, (ii) islets, (iii) perforations, (iv) edges, (v) loops, (vi) bridges, and (vii) branches. These categories cover a wide range of spatial elements mainly used, so far, to classify and map the structural connectivity of forest habitats (Elbakidze et al. 2011, Saura et al. 2011) and green infrastructures (Kuttner et al. 2013).

In order to identify and quantify variations in the spatial pattern of the Roman Campagna landscape between 1974 and 2008, we applied MSPA by means of the GUIDOS software (http://forest.jrc.ec.europa.eu/download/software/guidos/, Version 2.3, JRC, Ispra) to the 8 land-use classes mapped in the study area: (i) arable land, (ii) heterogeneous agricultural areas, (iii) vineyards, (iv) olive groves, (v) pastures, (vi) forests and semi-natural areas, (vii) continuous urban fabric, and (viii) discontinuous urban fabric.

Raster binary maps of each land-use class for the years 1974 and 2008 were processed to segment each given land use type into the mutually exclusive structural MSPA categories earlier described. MSPA classification routine starts by identifying core areas, based on user-defined rules for criteria linking connectivity and edge width (Soille and Vogt 2009). Connectivity was set for a node pixel to its adjacent neighboring pixels by considering 8 neighbors (a pixel border and a pixel corner in common). Edge width, that is the thickness of the pixels at the boundary of a core area, was set 100 m large. According to Vogt et al. (2009), this value for edge thickness is considered suitable for core-edge discrimination within a vast range of animal and plant species.

Statistical analysis

Variations in land-use and landscape structure observed between 1974 and 2008 in the study area were explored by parametric (Pearson) and non-parametric (Spearman) correlation coefficients testing for significance at $p < 0.05$. Pearson and Spearman correlation analysis were used with the aim to identify both linear and non-linear relationships among variables. Pair-wise correlations between the changes in the seven landscape structure categories observed between 1974 and 2008 for investigated classes were also carried out using Pearson and Spearman correlation tests testing for significance at $p < 0.05$.

To explore the evolution of landscape structure in Rome, a Multiway Factor Analysis (MFA) was applied to the matrix composed of the percentages of 7 GUIDOS landscape structure categories observed in Rome for the years under study (1974, 2008). The MFA is a generalization of the Principal

Table 1 - Variations in land use classes during 1974-2008 in Rome district.

1974	2008									
	Arable land	Heterogeneous agricultural areas	Vineyards	Olive groves	Pastures	Forests and semi-natural areas	Continuous urban fabric	Discontinuous urban fabric	Others land uses	Total
1 Arable land	**33.89**	0.60	0.31	0.48	2.87	2.30	3.33	4.09	1.29	49.15
2 Heterogeneous agricultural areas	1.25	**0.63**	0.16	0.63	0.38	0.27	0.62	0.78	0.23	4.95
3 Vineyards	1.01	0.32	**1.10**	0.22	0.16	0.07	0.23	0.54	0.17	3.81
4 Olive groves	0.36	0.07	0.04	**0.74**	0.06	0.10	0.04	0.09	0.05	1.56
5 Pastures	5.04	0.16	0.10	0.12	**3.32**	4.30	1.25	1.93	0.64	18.36
6 Forests and semi-natural areas	1.00	0.07	0.04	0.10	0.37	**4.20**	0.12	0.14	0.07	6.10
7 Continuous urban fabric	0.41	0.04	0.01	0.01	0.55	0.15	**9.03**	1.66	0.59	12.45
8 Discontinuous urban fabric	0.06	0.01	0.00	0.01	0.05	0.05	0.16	**1.00**	0.03	1.36
9 Others land uses	0.11	0.02	0.01	0.02	0.07	0.11	0.23	0.14	**1.54**	2.26
Total	43.13	1.91	1.77	2.33	7.82	11.55	15.79	11.09	4.61	**1.00**

Component Analysis (PCA) whose goal is to analyze variables collected on the same set of observations. The general objectives of MFA are (i) to analyze the relationship between the different data sets, (ii) to combine them into a common structure called 'compromise' which is then analysed via PCA to reveal the common structure between the observations and, finally, (iii) to project each of the original data sets into the compromise to analyse communalities and discrepancies (Lavit et al. 1994). Points placed close each other in the factorial plane, generated by the two main MFA axes (Coppi and Bolasco 1989), indicate spatial association, while points placed far each other indicate spatial segregation (Salvati et al. 2012).

Results

Land-use Changes in Rome (1974-2008)

To develop a comprehensive understanding of land use change dynamics in Roman Campagna district over nearly 35 years, we analysed land-use flows between urban and rural areas (Tab. 1). Looking at land-use classes transitions from 1974 to 2008 the most remarkable land-use dynamics are related to (i) land uptake by built up areas from arable lands, pastures and heterogeneous agricultural areas; discontinuous urban fabric consumed nearly 7.6% of the study area, formerly occupied by rural lands in 1974, while continuous urban fabric took nearly 5.6%; (ii) withdrawal of farming with woodland and semi-natural areas creation mainly on pastures and arable land (nearly 6% of the study area) and internal conversion in farmlands, notably conversion of heterogeneous agricultural lands into arable land occurring in more than 1% of the area. Some transition cases (e.g. urban fabric converted into pastures and forests and semi-natural areas), that could seem false detected cases, can be explained by the significant and rapid changes especially in productive areas that have resulted in underutilized land colonized by vegetation (Lafortezza et al. 2004).

Landscape structure dynamics

Changes in the spatial pattern of single land-use classes in the period from 1974 to 2008 are summarized in Tab. 2, which reports the change in landscape structure, as percentage of the study area, together with the observed surface variation for each land-use class. A pattern of change common to all land-use classes is the decrease in the presence of landscape components in the form of 'core areas' and the increase of land fragments in the form of 'islets'.

Arable land, heterogeneous agricultural land, pastures and vineyards have been significantly fragmented, loosing respectively 14.4%, 18.2%, 34.1%, 5.6% of the area occupied by 'core patches' in 1974.

Table 2 - Variations in land use and landscape structure during 1974-2008 in Rome district.

	% change (1974 - 2008)							
Land use	Total surface	Core	Islet	Perforatio n	Edge	Loop	Bridge	Branch
Arable land	-6.02	-14.44	2.42	-0.02	-3.04	1.38	11.42	2.29
Heterogeneous agricultural areas	-3.04	-18.20	53.41	0.00	-21.24	-0.62	-3.47	-9.88
Vineyards	-2.04	-34.12	27.70	-1.68	-14.57	0.32	20.13	2.21
Olive groves	0.77	-5.60	16.87	0.00	-11.99	-0.52	4.30	-3.06
Pastures	-10.54	-22.80	35.00	-0.12	-13.53	1.24	-0.55	0.75
Forests an semi-natural areas	5.45	2.29	0.65	0.14	-4.51	2.49	0.97	-2.30
Continuous urban fabric	3.34	-6.39	0.77	-1.21	-0.44	1.96	4.45	0.27
Discontinuous urban fabric	9.73	-12.60	15.06	0.10	-17.26	4.76	6.49	3.45
Pearson correlation test	-	0.55	-0.46	0.05	0.08	0.61	0.02	0.11
Spearman rank correlation test	-	0.67	-0.60	0.50	0.05	0.62	0.19	0.07

Also the increased area of olive groves occurred by addition of 'islets' (nearly 16.9%) and associated connectors structures (4.3%), while the area of core patches decreased by 5.6%. The increase of forest and semi-natural areas was mainly related to the closing of clearings with an increase of 'core areas' (nearly 2.3%) and connectors structures emanating from the same core connected component (nearly 2.5%) and, consequently, a reduction of 'edge' areas (nearly -4.5%). At the same time, urban development had a severe impact on landscape composition leading to (i) a remarkable land uptake by fragments of residential settlements in the class 'discontinuous urban fabric', amounting to nearly 15% of the study area, and (ii) an increase of linear infrastructure (loop and branches) connecting discontinuous urban fabric (11.3% of the study area) and continuous urban fabric (+6.4% of the study area).

Correlation between land-use changes and landscape structure

Even if significant correlations between percent surface area of each cover class and morphological spatial pattern classes percent area were not found at the landscape level, pair-wise correlations among structural classes (Tab. 3) indicate a negative non-parametric relationship among 'islet' surface area and 'core', 'edge', 'loop'. 'Bridge' showed a positive, linear correlation with 'perforation' but also with 'branch' surface area using both linear Pearson correlation and non-parametric Spearman correlation.

Summarizing landscape patterns by way of the MFA

The MFA extracted two axes explaining respectively 43.9% and 22.9% of the total variance for a total of 66.8% cumulated variance. Factor loadings are shown in Table 4 by year. The structural landscape classes mostly associated, during all the study period, to the MFA first axis were 'core', 'perforation', 'edge', 'loop', and 'bridge'. 'Islet' and 'branch', instead, were associated with axis 2 (Fig. 4). The first axis illustrates an urban-rural gradient discriminating different settlement forms (continuous vs discontinuous settlements). The second axis segregates urban land-use classes (positive values) from natural and semi-natural land use classes (negative values).

Table 3 - Pair-wise correlation between the changes in the seven landscape structure categories observed during 1974-2008 in Rome district (n = 8 land use classes); bold indicates significant correlation at $p < 0.05$.

Variable	Islet	Perforation	Edge	Loop	Bridge	Branch
			Pearson correlation coefficient			
Core	-0.61	0.51	0.52	0.30	-0.50	-0.20
Islet		0.03	-0.87	-0.52	-0.28	-0.56
Perforation			-0.16	0.19	**-0.64**	-0.30
Edge				0.21	0.15	0.36
Loop					0.04	0.61
Bridge						**0.65**
			Spearman rank correlation coefficient			
Core	**-0.74**	0.65	0.50	0.43	-0.17	-0.31
Islet		-0.28	**-0.76**	**-0.76**	-0.33	-0.21
Perforation			-0.19	0.32	-0.40	-0.20
Edge				0.36	0.24	0.05
Loop					0.31	0.60
Bridge						**0.74**

Table 4 - Loadings of the Multiway Factor Analysis by year and landscape structure category.

	1974		2008	
Variable	Axis 1	Axis 2	Axis 1	Axis 2
Core	-0.92	0.27	-0.79	-0.11
Islet	0.75	-0.45	0.94	-0.06
Perforation	-0.83	0.13	-0.73	-0.37
Edge	0.20	0.95	-0.67	0.53
Loop	0.08	-0.88	-0.25	-0.40
Bridge	-0.64	-0.59	-0.84	-0.07
Branch	0.93	-0.01	0.08	0.37
Explained variance	*43.93*		*22.88*	
Cumulated variance		*66.81*		

Different trends in morphological spatial pattern transformation for different land-use classes clearly stand out from point positions into the factorial plan that relate variables (i.e. structural landscape classes) and observations (i.e. land-use classes). The coordinates of structural classes points indicate a strong segregation between 'core' and 'bridge' for continuous urban fabric and 'core' and 'branch', 'islet' and 'perforation' for discontinuous urban fabric, while a spatial segregation between structural classes are not clearly recognizable for farmland (Fig. 5).

Discussion

The physical pattern of low-density expansion, typical of urban sprawl (EEA 2006), is clearly figured out, under the investigated case study. A remarkable growth of patchy and scattered areas was observed for all land-use classes (Tab. 2). Occlusion and shredding of portions of open land, interconnected in earlier time periods, highlights a trend towards fragmentation of the peri-urban agricultural land of the Roman Campagna. The processes of soil sealing that affected Rome's plain and the neighbouring areas in recent decades is certainly the main but not the only cause of the progressive patchiness. Urban development further away from the urban fringe was accelerated by the growth of linear infrastructures in response to needs of transportation and mobility. This is well captured by the increase of linear connectors in discontinuous urban fabric areas. This trend was observed in almost all other land-use classes determining a juxtaposition of different land uses and a generalized landscape mix (Zambon et al. 2015).

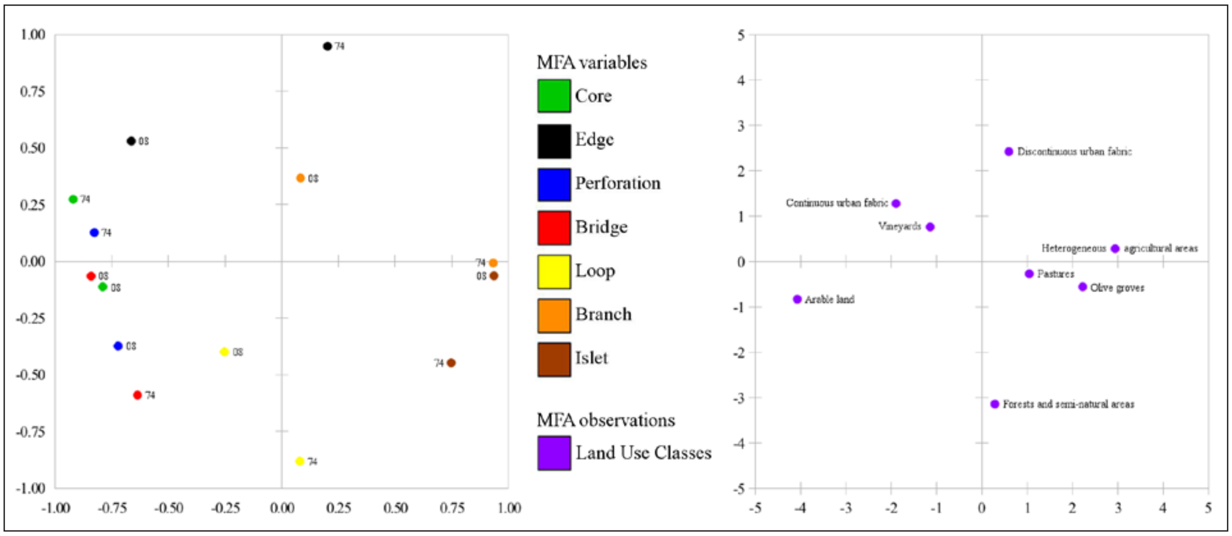

Figure 4 - MFA correlation map of variable (left) and MFA observation factor score plot (right).

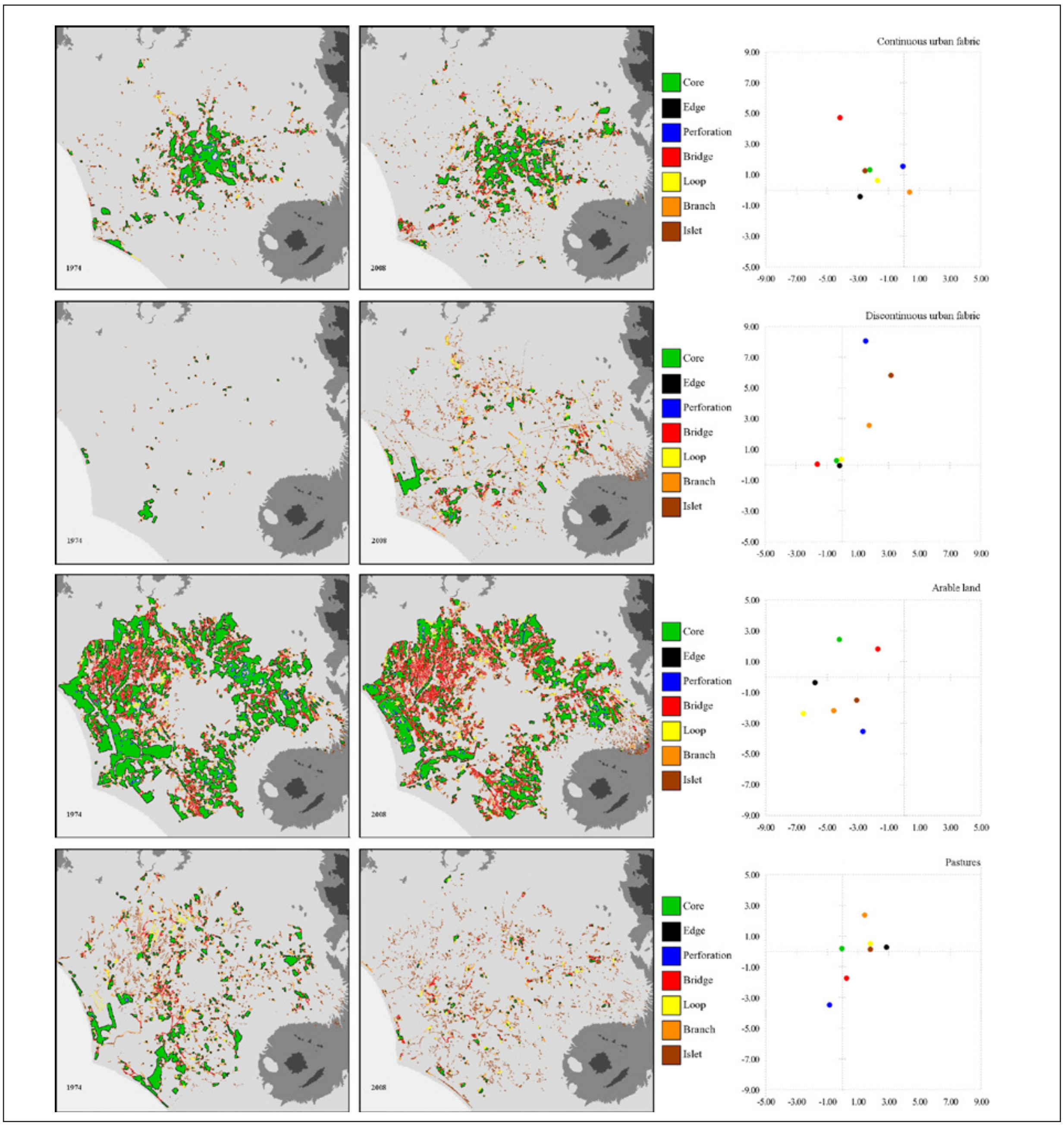

Figure 5 - MSPA pattern classes in 1974 and 2008 for continuous urban fabric, discontinuous urban fabric, arable land and pastures and the corresponding MFA factorial plan.

Landscape fragmentation of farmland, tracked by the decline in the surface of arable land, heterogeneous agricultural areas and pastures, and of core areas therein, is the combined effect of urbanization, agricultural intensification and land abandonment. This corroborates the data presented by Salvati et al. (2012). While arable land is still the main land-use, traditional farming (pastures and heterogeneous agricultural areas) decreased significantly throughout the study area. The significant increase of forest and semi-natural areas, typical of many landscapes in Italy (Corona et al. 2008, 2012), showed a peculiar spatial pattern (creation of 'islets' and 'core areas' with associated connectors) caused by the withdrawal of farming in arable land and heterogeneous agricultural areas (Barbati et al. 2013, Biasi et al. 2015, Ferrara et al. 2015). However, only absolute values of land-use classes gain or loss are not enough to explain landscape transformation. Each land-use class changes its morphological structure in different way, as shown by MFA analysis.

Continuous urban fabric landscape structure tends to the consolidation (spatial association for almost all MSPA classes into MFA factorial plan) while discontinuous urban fabric morphological pattern tends to expansion and spatial segregation between 'core' and 'islet' patches. Islet patches expands the wildland-urban interface, with the consequent significant increase of both wildfire risk and danger (Moreira et al. 2011). Arable land and pastures patterns of change are more complex. In the former case, a progressive erosion of cropland influenced negatively the expansion of connective fragments; in the latter case, a process of transformation of large patches into small patches was observed. Disappearance of connection patches is particularly relevant in processes of landscape fragmentation.

Conclusions

Land fragmentation is the most impressive change due to peri-urban development in Rome as well as in other Mediterranean cities (Chorianopoulos et al. 2010, Munafò et al. 2010). This kind of knowledge can be effectively used to steer socioeconomic policies towards sustainable urban growth (Salvati and Ferrara 2013, Smiraglia et al. 2014, Tombolini and Salvati 2014, Quatrini et al. 2015). Rome's municipality has made some efforts to protect peri-urban rural landscapes: the designation of protected areas has had positive effects for conservation and expansion of core forest areas (Barbati et al. 2013, Colantoni et al. 2015, Zitti et al. 2015). Rome is still surrounded by a large agricultural region, historically linked with the city. The present study shows that a multi-temporal MSPA can effectively highlight key changes in the landscape structure of a traditional and iconic rural landscape, like the Roman Campagna. This knowledge is a relevant base to inform integrated and co-operative spatial planning across the urban gradient, with the final objective to strengthen and modernize the role of farming activities in peri-urban areas, responding to pressures and opportunities derived from proximity to urban areas. Farming practices that promote conservation of heterogeneous and small-scale farming structure, punctuated with natural elements, are prioritized (Zasada 2011).

These "new" demands (i.e. conservation of cultural rural landscape and recreation in addition to food production) linked to peri-urban agriculture are not yet acknowledged by the city planning and land management tools. The General Rome City Plan, approved in March 2006, aims to support the peri-urban agriculture, but the lack of regional or national laws regulating by year and municipality the maximum surface of agricultural land which can be converted to space for housing or commercial development is a major bottleneck that negatively impacts on the surrounding landscape, as observed for other urban regions of the Mediterranean (Paul and Tonts 2005, Christopoulou et al. 2007, Jomaa et al. 2008, Cimini et al. 2013). Furthermore, policies of urban containment provide only a prerequisite for the preservation of open spaces in the Roman Campagna. Rural development programs (e.g. environmental and land management incentives) need to be locally tailored to face the gradual simplification and fragmentation of peri-urban landscapes. This approach can be applied to updated digital land cover maps, with the final aim to assess the impact of integrated planning measures.

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