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Economic Downturns and Land-Use Change: A Spatial Analysis of Urban Transformations in Rome (Italy) Using a Geographically Weighted Principal Component Analysis

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Abstract: Globally, processes that drive urbanization have mostly evolved within economic downturns. Economic crises have been more severe and frequent, particularly in the Mediterranean region. However, studies on the recession effects on urbanization are limited. The present study explores possible differences in spatial direction and intensity of land-use change trajectories at two time intervals (2006–2012, 2012–2018) using high-resolution Copernicus Land Urban Atlas images in the Rome metropolitan area. To this aim, a landscape ecology classical approach based on land-use metric analysis combined with a multivariate spatial analysis has been carried out. Results have identified different land-use change patterns during expansion and recession. "Greening", defined as the conversion of urban marginal areas into croplands and forests, increased during the recession. At the same time, the rate of urban expansion into rural areas decreased, thus indicating a beneficial effect of economic downturns in reducing urban sprawl.

Keywords: economic crisis; land-use change; land-use trajectories; urban sprawl; geographically weighted principal component analysis; Italy

1. Introduction

Over the past decades, rapid demographic, economic, and urban expansions have pushed a massive movement of resources and people, especially in most developed countries [1–4]. This phenomenon has been widely investigated, demonstrating the strong relationship between urbanization processes and the economic conditions during expansion and recession periods [5–8]. In particular, metropolitan sustainability has been demonstrated to be associated with both wealth increase and public finances condition [9,10]. Economic conditions have been proven to also influence the effects of urban planning. Indeed, planning tools, such as urban growth boundaries, were more effective to promote urban development within the delimited area during economic expansion than during recession. The same result has been found for the efficiency of agricultural zoning in limiting urban expansion [11].

The scientific debate about this issue has recently grown in Europe [12,13], where there have been discussions on how, despite their intrinsic diversity, cities' growth trajectories are increasingly associated with many socioeconomic and environmental factors, whose impact varies with economic downturns [5,14–16]. In particular, urbanization dynamics changed drastically after the 2007 crisis in Mediterranean cities, shifting from an increase in urban sprawl to settlement densification close to the inner cities [17–19]. An example of these land-use change trajectories is reported by a recent study in the metropolitan area of Athens [19], where the authors suggest how the crisis may be considered as a chance to revisit urban expansion models, promoting sustainable and resilient urban areas [18,19].

Research about this topic has mostly used classic landscape analysis, analyzing land-use changes, and linking morphology with urban functions [20–25]. However, a step forward to better understand the multi-dimensionality of the urbanization processes and their association with societal, economic, and territorial domains can be done by also considering the spatial interactions among single patches of change. In this regard, a promising technique that can be used to complement traditional approaches is the geographically weighted (GW) principal component analysis (PCA). The GW–PCA, consisting of a series of localized PCAs, has the advantage of analyzing spatial data locally, accounting for their spatial heterogeneity, thus providing a better description at each target location and, at the same time, allowing for a local change identification in the multivariate data [26–28].

In this context, the present study aims to assess if recent land-use change trajectories differed between expansion and recession periods (2006–2012, 2012–2018) in a typical Mediterranean metropolitan area (Rome, Italy). Previous research has used these time spans as exemplary periods to study land-use dynamics during economic expansion and recession [19]. Therefore, due to the delayed and long-lasting impacts of the 2007 recession on land-use change, the 2012–2018 period was considered indicative of the association between land-use dynamics and the economic crisis [19]. This work employed high-resolution Copernicus Land Urban Atlas images to detect land-use change patterns during expansion and recession, applying a landscape ecology approach combined with a multivariate spatial analysis (GW–PCA). Results have identified diversified land-use change dynamics during expansion and recession, indicating that economic downturns had a beneficial effect on urban sprawl containment, while increasing the conversion of urban marginal areas into croplands and forests.

2. Materials and Methods

2.1. Study Area

The study area includes the statutory Rome metropolitan area (6169 km^2) which corresponds to the large urban zones (LUZ) of the Urban Audit program comprising the city core and its commuting zone. One hundred and twenty-two Nuts-3 municipalities are included in the Rome metropolitan area, among which, the Rome municipality (the largest in Europe) extends 1285 km^2. The study area is made up of approximately 30% lowlands (elevations below 100 m asl), 50% uplands (elevations between 100 and 500 m asl), and 20% mountains (elevations above 500 m asl). The climate is typical of the Mediterranean area, with mild winter temperatures, and rainfall concentrated mainly in autumn and spring [5,29].

Rome has been considered an example of the expansion paths typical of contemporary Mediterranean cities. Indeed, Rome represents a metropolitan area that has evolved from a nearly dense morphology to a fragmented and chaotic urban shape since the late 1980s [5,29].

2.2. Land-Use Data

Land-use data were derived from high-resolution maps (1:10,000) of the Copernicus Land Urban Atlas (UA) project (Figure 1). According to the theoretical framework proposed by Tomao et al. [19], seven trajectories were identified, referring to (i) "brownfield development", i.e., residential densification, sprawl, and industrial development on urban land-uses, (ii) "greenfield development", i.e., industrial development or compact and dispersed expansion of residential settlements on natural land-uses, and (iii) "greening", i.e., transitions from an "urban" land-use (such as dump sites, construction areas, land without current use) to cropland or forests. In particular, the main land-use trajectories in the study area have been classified as follows: 1 = residential densification on brownfields; 2 = residential extensification on brownfields; 3 = industrial development on brownfields; 4 = compact expansion of residential settlements on greenfields; 5 = sprawled expansion of residential settlements on greenfields; 6 = industrial development on greenfields; 7 = greening (for further details see Tomao et al. [19]).

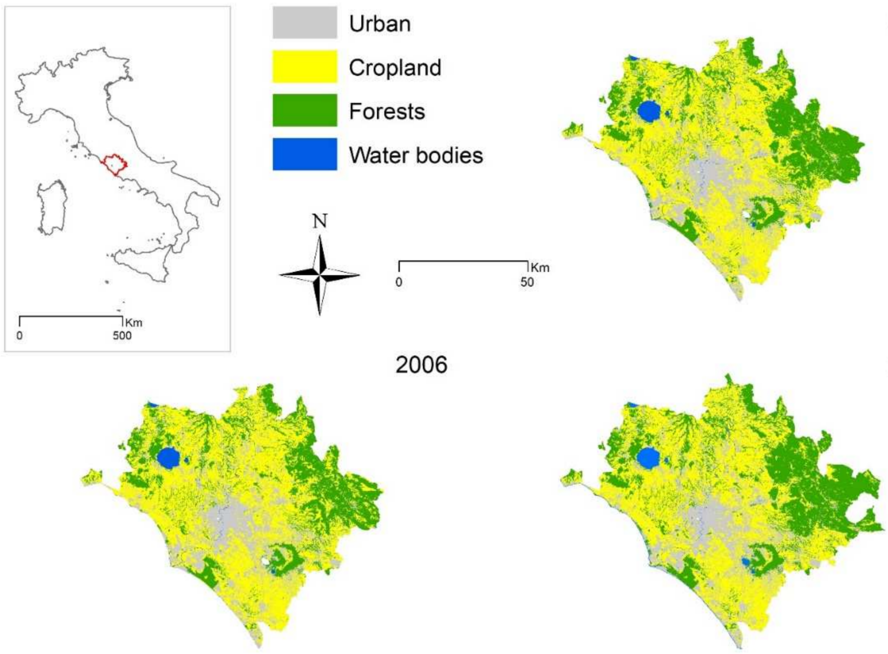

Figure 1. Main land-use categories at the years 2006, 2012, and 2018 for the study area. According to Tomao et al. [19], the displayed classes have been reclassified into urban, cropland, forests, and water bodies classes. Source: own elaboration from Copernicus Land Urban Atlas maps.

Five landscape/class metrics were calculated for each patch experiencing land-use change and each time interval: number of patches; mean patch size; class area in the landscape under transformation; perimeter-to-area (P/A) ratio; and mean distance from the center of Rome, i.e., "Piazza Barberini" (41°54′13″ N, 12°29′19″ E) [30,31].

2.3. Statistical Analysis

A spatially explicit GW–PCA was performed on a matrix of ten descriptors for each patch of change: three landscape metrics (patch size, P/A ratio, distance from downtown) and seven dummies (0–1 values) by individual patch, separately for each time interval [32,33]. The patch centroid spatial coordinates were used as the unit geo-referenced location [19]. GW–PCA allowed us to assess the spatial variation of the individual patches, as well as the influence of the variables on each spatially varying component [26–28]. Significant components were retained using 1 as the minimum eigenvalue threshold, according to the scree-plot criterion. Component loadings were used to identify the multivariate spatial relationship among the land-use trajectories and landscape metrics, thus evaluating patch spatial patterns and evidencing the highest influence of each variable on land-use change through time. All statistical analyses were performed using the "GWmodel" package of the R software [27,28].

3. Results

3.1. Urban Expansion

In the first time interval, the number of patches where a land-use change occurred was 7602, for a total area of 8532 ha (approximately 1.4% of the total LUZ) (Figure 2). In the second period, the number of land-use change patches decreased up to 2353, corresponding to a total area of 3480 ha (nearly 0.56% of the LUZ).

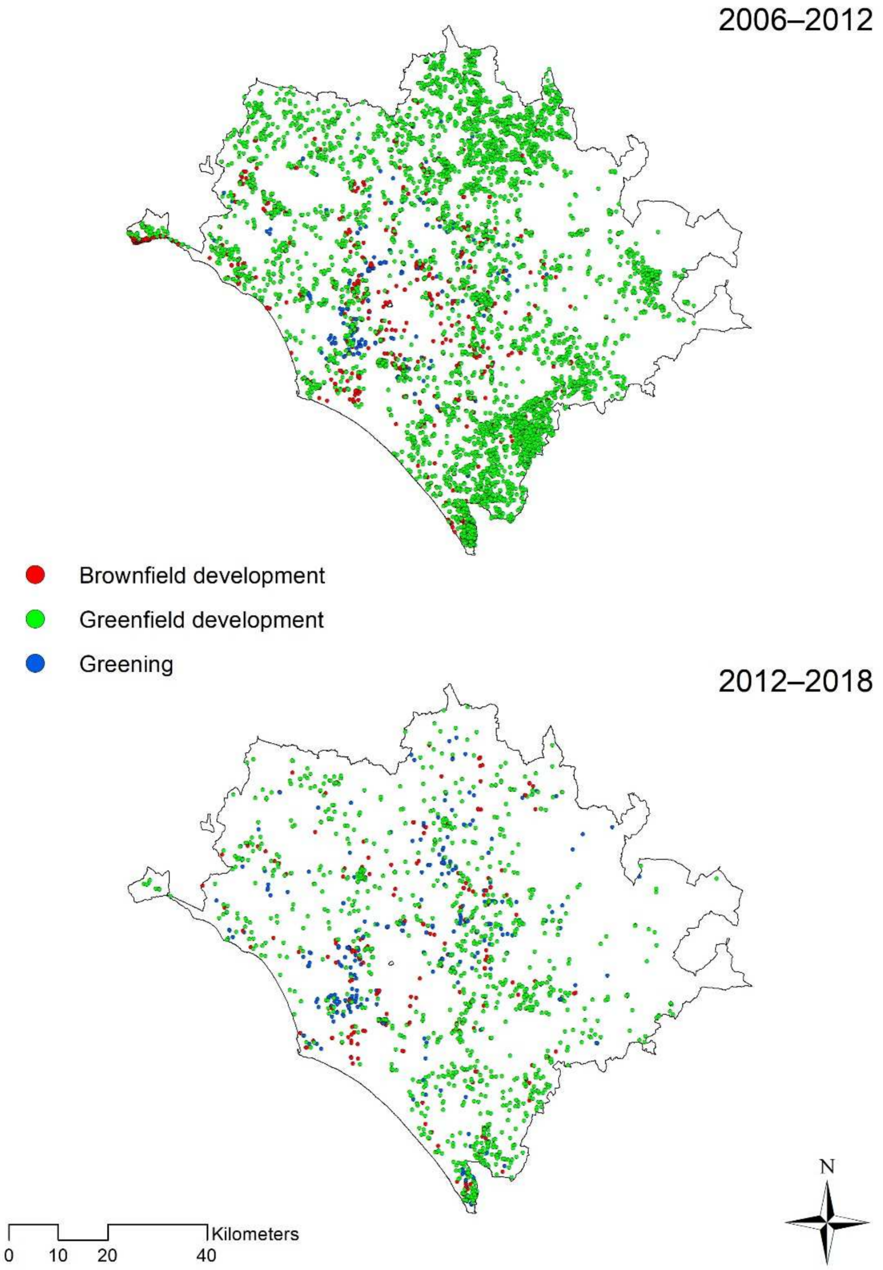

Figure 2. Spatial distribution of the patches experiencing land-use change in the two study periods according to the reclassification into the three land-use trajectories.

Focusing on the urban expansion, intended as the conversion into artificial uses of natural lands, such as croplands or forests (Figure 3), it has been found that these land-use changes account for around 65% and 40% of the total changes for the 2006–2012 and 2012–2018 periods, respectively.

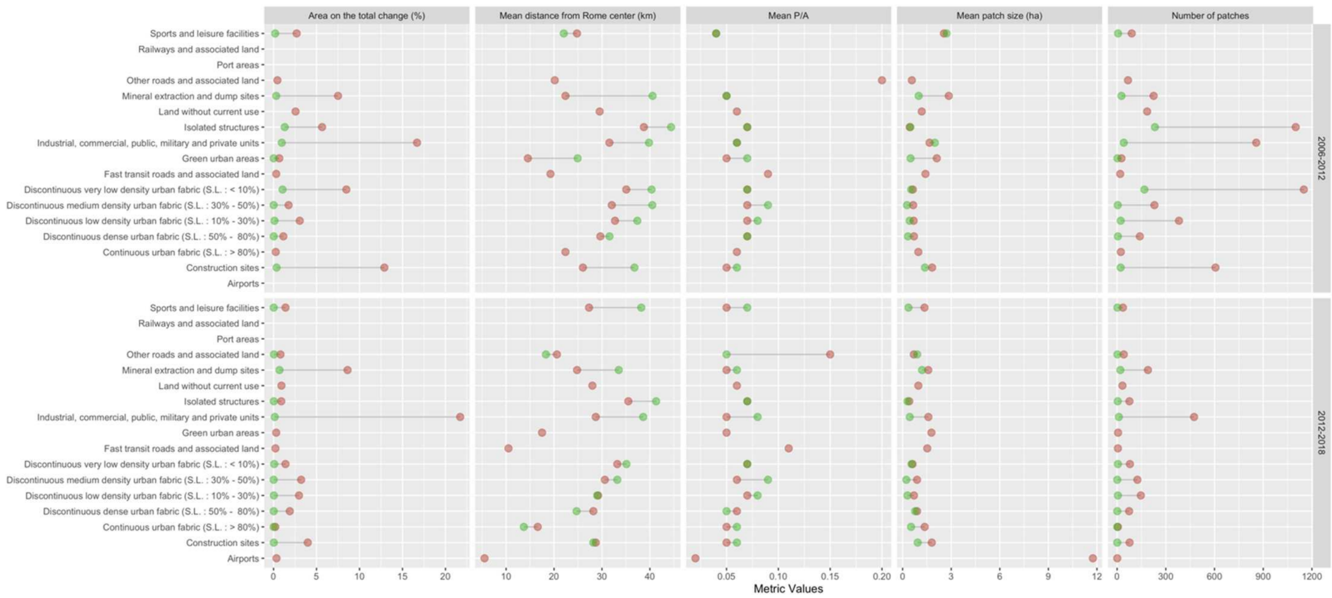

Figure 3. Urban land-use changes of cropland (**red dots**) and forest (**green dots**) patches in the Rome metropolitan area for each metric, by time interval.

Between 2006 and 2012, the dispersed urban fabrics expanded considerably into croplands, but not significantly into forests. Hence, a total of 3054 individual patches of greenfields were converted into landscapes hosting isolated structures or residential settlements with a density of sealed land lower than 30%. In this regard, the highest frequency of change was found for conversion into the "discontinuous very low-density urban fabric (with sealed land <10%)" class, primarily representing urban sprawl. The patches under change towards discontinuous urban fabric were characterized by a relatively modest average size (0.44–0.68 ha), but a moderately high P/A ratio, indicating patches with convoluted shapes. These changes represent more than 15% of the total changes throughout the entire period. The mean distance from the center of Rome of these patches ranged between 32 km and 44 km, showing that they are located in fringe areas further from Rome.

Industrial and commercial development was also a relevant conversion of greenfields, involving around 18% of the total area with changes. These changes involved medium-large patches (1.66–1.99 ha) at moderate distances from Rome (31–39 km). Conversion of rural areas (agricultural or forest) into construction sites or dump sites accounted for more than 20% of the total change. Similarly to the industrial development results, patches undergoing these conversions were characterized by large sizes (0.99–2.8 ha), but were located closer to the center of Rome, at least in the case of the conversion of agricultural areas (22–26 km).

In the 2012–2018 period, the rate of expansion into greenfields of low-density (<10% or between 10 and 30% of sealed land) residential settlements or isolated structures was lower than in the first period. Although very variable, the average distance from Rome decreased compared to the previous period.

Industrial development was the main land-use change that occurred in rural land, involving more than 20% of the total change (474 individual patches). These conversions comprised medium-large patches, especially in agricultural areas (1.59 ha), with a rather low P/A ratio. Change of rural areas (agricultural or forest) into dump sites or construction sites accounted for around 14% of the overall change. Moreover, similarly to the industrial development results, these patches were characterized by large sizes (0.9–1.8 ha), and situated at varying distances from Rome (17–28 km).

3.2. Comparing Trajectories of Land-Use Change

A comparison of land-use change trajectories over the two considered periods is reported in Table 1. Seven transformations impacting urban landscapes and rural territories have been considered, following the classes proposed in Table 1: urban changes (differentiating expansion on greenfields from brownfield development), and transition from urban to non-urban use (cropland or forest). Brownfield development rates varied across the two time spans, with 2006–2012 being more intense than the subsequent period. Figure 4 shows the trajectory variation percentage by landscape/class metrics between the two time periods. In the first period, residential densification and extensification of built-up areas on brownfields occurred in 568 and 328 patches, respectively (more than 11% of the study area undergoing change), whereas only 76 and 149 patches were involved in 2012–2018. Despite the number decrease in the second period, the average size of the patches increased (from 0.96–1.11 ha in 2006–2012 to 1.19–1.44 ha in 2012–2018) and the distance from downtown Rome decreased, especially for new dense settlements (from 31 to 21 km). The rate of industrial development on built-up areas did not change substantially between periods, but the distance from Rome greatly decreased (from 31 to 22 km).

Table 1. Summary of the land-use trajectories in the Rome metropolitan area, for each time interval.

Land-Use Trajectory	Number of Patches	Mean Patch Size (ha)	Area on the Total Land-Use Change (%)	Mean P/A Ratio (m^{-1})	Distance from Rome Center (km)
		2006–2012			
Brownfield development					
Residential densification	568	1.11	7.40	0.060	31.2
Residential extensification	328	0.96	3.70	0.061	27.6
Industrialization	19	0.56	0.13	0.072	31.5
Greenfield development					
Compact residential expansion	168	0.72	1.42	0.072	28.7
Residential sprawl	3288	0.56	21.39	0.069	36.8
Industrialization	984	1.60	18.41	0.067	30.9
Greening	229	2.28	6.13	0.053	17.5
Other trajectories	2018	1.75	41.43	0.058	23.4
Total	7602	1.12	100.0	0.065	30.9
		2012–2018			
Brownfield development					
Residential densification	76	1.44	3.14	0.051	20.93
Residential extensification	149	1.19	5.08	0.056	26.89
Industrialization	8	0.40	0.09	0.125	22.68
Greenfield development					
Compact residential expansion	81	0.91	2.12	0.064	27.30
Residential sprawl	441	0.68	8.62	0.069	31.61
Industrialization	534	1.52	23.27	0.062	28.07
Greening	262	2.56	19.24	0.050	22.97
Other trajectories	802	1.67	38.44	0.058	24.53
Total	2353	1.48	100.00	0.060	26.61

Regarding urban expansion into greenfields, the establishment of new compact settlements occurred in 168 patches in the first period (1.4% of the landscape under change). During 2012–2018, this land-use trajectory was less frequent (81 patches, 2.1% of the landscape), even with an increase in the average size (from 0.7 to 0.9 ha), as well as a minor reduction of the distance from downtown Rome (from 28 to 27 km). Concerning dispersed settlements, residential sprawl into rural landscapes was the most important land-use trajectory in 2006–2012 (3288 patches, 21% of the landscape). Despite a relevant decrease in the number of patches (441) during 2012–2018 period, this trajectory still accounts for 8.6% of the landscape under change, with a relevant reduction of the distance from Rome (from 36 km to 31 km). Industrial development on greenfields comprised around 1000 patches in the first period and 400 in the second. The average patch size (1.6 and 1.5 ha) remained nearly constant, and the average distance from Rome experienced a slight increment (28 and 31 km).

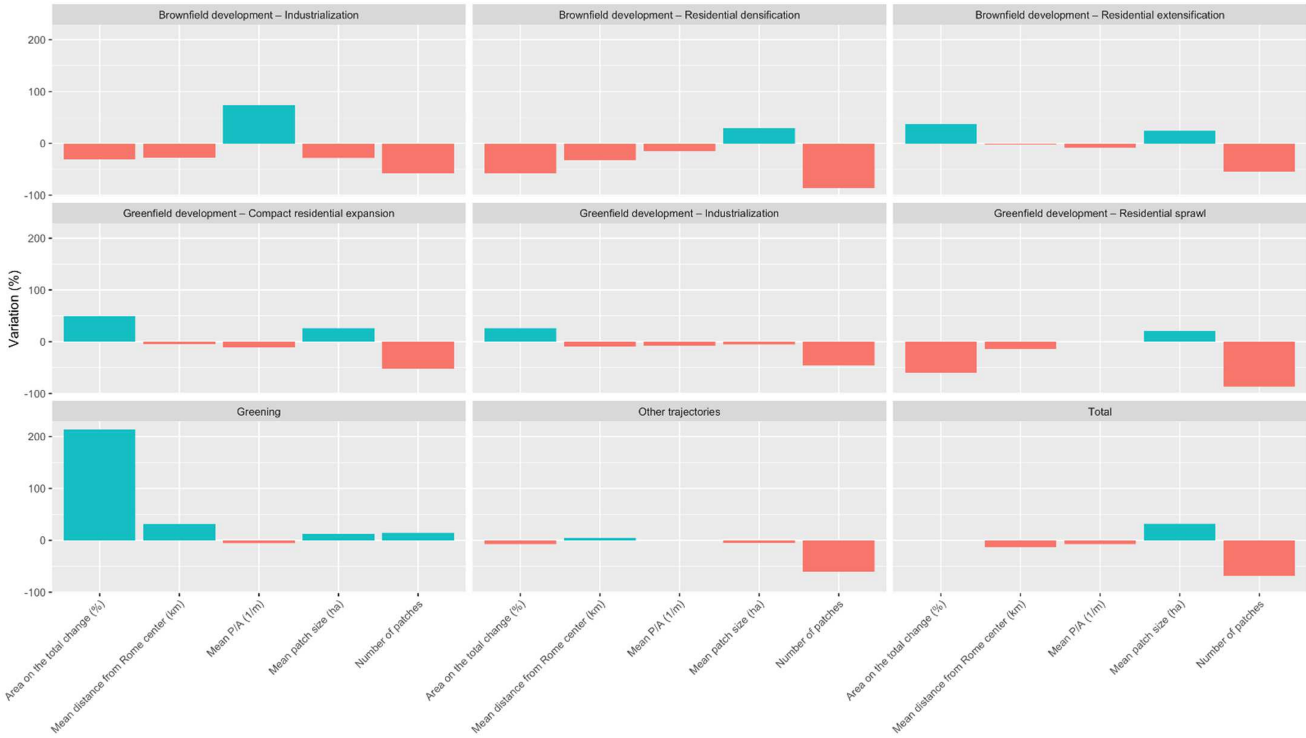

Figure 4. Change over time (trajectory variation percentage increase (blue), or decrease (red)) by landscape metric between 2006–2012 and 2012–2018.

Greening represented a relevant process in both periods. From 2006 to 2012, the conversion of marginal patches classified as "urban" into agricultural land or forests occurred on 229 patches, characterized by a relatively large area (2.3 ha) and a low P/A ratio (0.05). Greening patches were also, on average, those with a lower distance from Rome. In the second period, both the total number of patches (262) and mean size (2.5 ha) slightly increased. The relative importance over the selected land-use trajectories tripled, reaching 19% of the landscape under change. Distance from downtown Rome also greatly increased, reaching 23 km on average.

3.3. Spatial Analysis of Land-Use Trajectories

Table 2 reports the results of the GW–PCA analysis. Four significant axes were extracted in both time periods, accounting for 54.4% and 55.5% of the total variance, respectively. The structure of component loadings shows differences between periods. With economic expansion (2006–2012), Component 1 indicates an urban-rural gradient associated with residential sprawl in greenfields. Indeed, a higher distance from the city center characterizes patches facing a sprawled expansion of residential settlements in rural areas, whereas "industrialization on greenfields" occurred mostly closer to Rome. P/A ratio was negatively correlated with Component 2: lower P/A ratios characterize patches where conversion into rural land occurred. Component 3 groups larger patches characterized by industrial development on greenfields. Component 4 shows a gradient of residential land-use that differentiate between brownfield and greenfield residential densification.

Table 2. GW–PCA significant loadings (>|0.35|) for each land-use trajectory and time interval.

	2006–2012				2012–2018			
	Comp.1	**Comp.2**	**Comp.3**	**Comp.4**	**Comp.1**	**Comp.2**	**Comp.3**	**Comp.4**
Explained variance (%)	19.4	12.2	11.6	11.2	18 14.4	11.8	11.3	
Patch size			0.38		0.47			
P/A ratio		−0.36		−0.39	−0.47			
Distance from Rome center	−0.43				−0.37			
Brownfield development								
Residential densification			−0.63	0.59				
Residential extensification				−0.39			−0.46	0.70
Industrialization								−0.44
Greenfield development								
Compact residential expansion				−0.38				
Residential sprawl	−0.66				−0.48	0.42	0.39	
Industrialization	0.36	−0.63	0.44			−0.81		
Greening		0.53			0.40	0.35		−0.39

During the recession period, patch size (positive loadings) was opposed to P/A ratio and distance from Rome (negative loadings) along Component 1, thus separating patches sprawling on rural areas (negative loadings) from those where a greening process occurred. Component 2 groups patches characterized by sprawl on greenfields. Component 3 shows a gradient of residential extensification, which separately groups extensification on brownfields (negative loadings) and sprawl into greenfields (positive loadings). Conversely, Component 4 is positively associated with the establishment of low-dense settlements on brownfields.

The GW–PCA allowed us also to individuate the most influential variables on the selected components at each location of land-use change (Figures 5 and 6). During the first period, all the patches that experienced a land-use change were associated to sprawl for Component 1. Component 2 was associated to changes causing land consumption (i.e., industrial development on greenfields) in almost all the study area. On the other hand, during the second period, the results were less homogeneous from a spatial perspective. Indeed, greening emerged as a relevant variable not only far from the city center (Component 1), but also near Rome's downtown (Component 2).

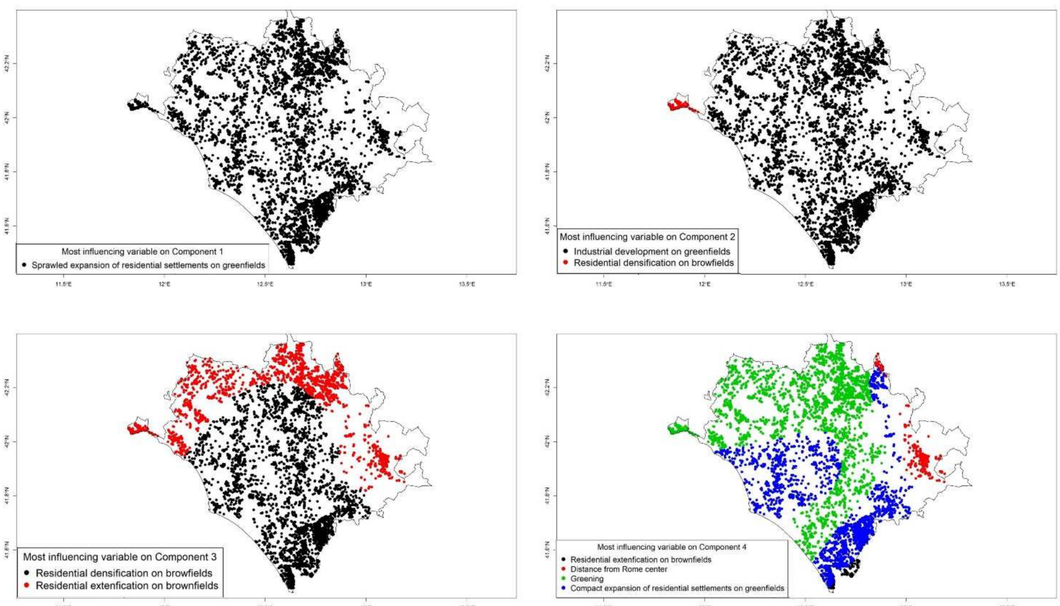

Figure 5. Most influential variables on components extracted by GW–PCA at each land-use change patch for the time interval 2006–2012.

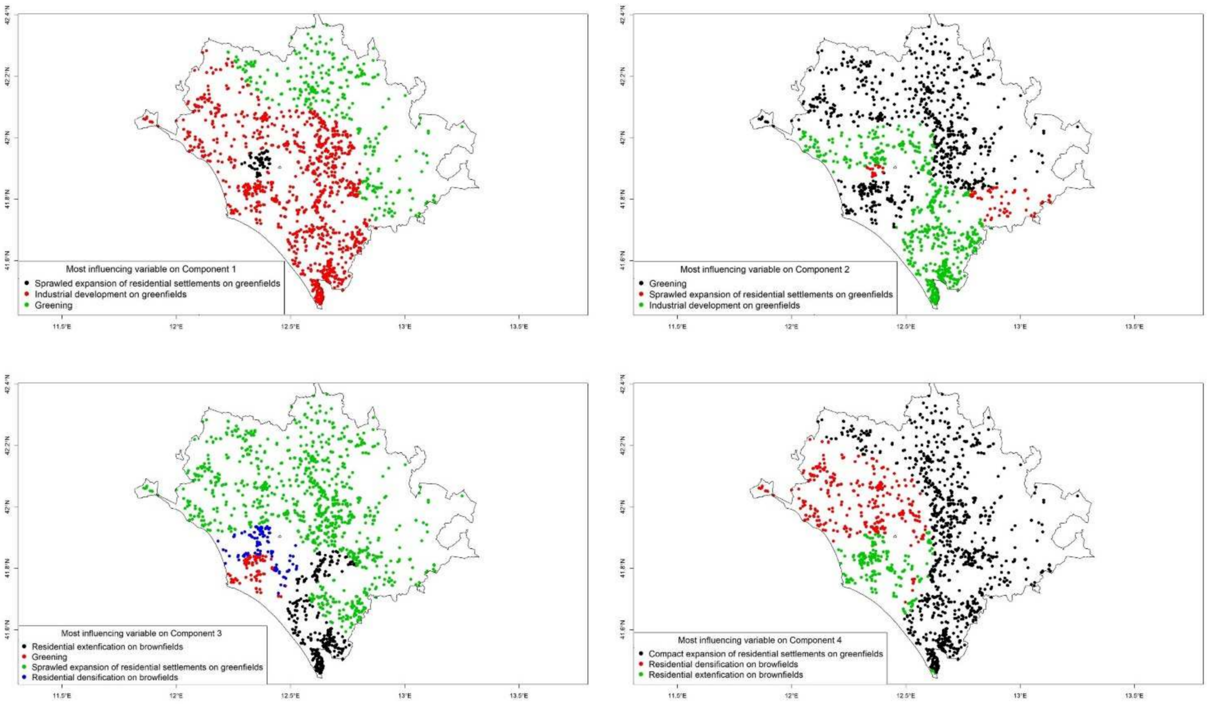

Figure 6. Most influential variables on components extracted by GW–PCA at each land-use change patch for the time interval 2012–2018.

4. Discussion

The present study, based on simplified landscape metrics and the application of the GW–PCA, has compared land-use dynamics in two subsequent periods between 2006 and 2018 in the Rome metropolitan region, with the main objective of assessing if specific land-use trajectories can be associated with the economic crisis. In this regard, the case study of a typical Mediterranean city, such as Rome, provides a unique opportunity to analyze the sensitivity in the short term of metropolitan areas to periods of economic expansion and recession. The underlying hypothesis that economic crises might contribute to a "land-saving urbanization" [34] has been confirmed by our results. Indeed, the land-use change analysis has clearly demonstrated that patterns of urban growth are different when comparing expansion and recession periods. Configuration (mean size), shape (P/A ratio), and position (distance from Rome center) of landscape patches experiencing land-use change differed from the first to the second period. Furthermore, the total number of patches under change was three times higher in 2006–2012 compared to the more recent period. These results are also in line with those of other recent studies in Europe, which have found a reduction of demographic dynamics and building activity during recession, resulting in slower land-use changes [18,19].

The analysis of land-use trajectories revealed that urbanization on greenfields, despite a decrease from 40% of all changes in 2006–2012 to 30% in 2012–2018, is still the main land-use change pattern in the study area, showing dynamics similar to other European metropolitan areas [21]. New built-up areas expanded primarily into agricultural areas (90% of changes during expansion, and more than 95% during recession). This evidence supports previous research identifying peri-urban cropland as the main land converted into new urban settlements [35–37]. Forests were rarely converted into urban land-uses, confirming, even in this case, the empirical results from earlier studies [38]. In the latter case, the low rate of change is probably due to the high level of protection of woodlands from land-use conversion by Italian normative and laws. The forest patches experiencing these changes are probably relict sites with low economic value in fringe areas linked to intensive use of private lands [39].

Despite the fact that natural land-uses were mainly converted into low-density residential settlements, a relevant rate of change of greenfields into industrial sites was also observed, especially during recession, when it became the main trajectory of change (23% of total landscape changes). Even if documented by previous studies for other Mediterranean cities [19,40], this phenomenon is still a somewhat surprising result. However, this can be explained by a latent trend of industrial development during the late 2000s in Rome and other Mediterranean cities that has been consolidated in the last decade, caused by advances in production efficiency [41], being therefore marginally affected by recession. Greening, here intended as the conversion of urban marginal areas into croplands and forests, is the only trajectory experiencing an increase from 2006–2012 to 2012–2018, both in absolute (229 to 262 landscape patches) and in relative terms (6% to nearly 20%). As shown by previous studies in several countries in the Mediterranean basin [42–44], this phenomenon is mainly due to the progressive abandonment of marginal areas with a lower income, and a location at a greater distance from the city center [45,46]. The increase in forest cover has multiple benefits since it can provide several ecosystem services, including connectivity among natural ecosystems in terms of green infrastructure [42,47]. However, most of the newly established forests or shrubland are fire-prone forest types [48]. Therefore, an unplanned expansion of these areas may cause an enhanced fire risk, especially in the wildland-urban interface [49–51]. In this regard, active management promoting interventions to reduce fuel and improve the functionality and quality of new forests is required [43,52].

The multivariate analysis results indicate significant changes in landscape configuration. Mean patch size and P/A ratio during expansion were significantly associated with compact expansion (both on brownfields and greenfields) and industrialization on greenfields. On the other hand, these indicators are associated only with residential sprawl into greenfields and greening during recession. Distance from the city center was associated with residential sprawl into greenfields, in both the first and second periods, when it also became significant to describe the emerging greening process. Indeed, all land-use change trajectories are progressively moving closer to the city center, demonstrating how the economic crisis is affecting the development of new brownfields or greenfields in the surrounding areas of the city center, increasing polarization between urban and rural areas.

The empirical results of our study suggest how periods of economic crisis may indirectly favor more sustainable urbanization. In this regard, it is worth noting that, assuming that urban containment is only a transitory effect of the crisis, future urban development can bring a new phase of residential sprawl [53]. Thus, despite the shift towards industrial development seeming to foster economic resilience in the metropolitan region in a time of crisis, this may not necessarily coincide with a sustainable and land-saving development model. Indeed, as shown by recent studies in Greece, industrial expansion, especially in rural areas, might be considered as a new form of urban sprawl [19,54]. Furthermore, even if the highlighted slight reduction of land-taking processes and of the urbanization scope in the urban region (e.g., an increase of settlement extensification on brownfields), comparing the two studied periods, settlement dynamics clearly show to be still affected by a trend toward further polarization focused on the urban core embodied by Rome, either in terms of economic activities or residential housing distribution. In the field of spatial planning strategies, this predicament—according to the wider EU proposed strategies [55]—calls to set up tools aimed to support polycentric settlement patterns [56,57] referring also to the city-region development paradigm [58]. Indeed, this kind of spatial paradigm seems suitable to offset (in normative terms [59]) interurban inequalities, either by supporting sustainable "city-region" model-based endogenous economies and coping with, and overcoming the limits of, the inherited Italian traditional municipal-based planning model. In this direction, the (bio)city-region spatial model as proposed by Snyder [60] or, more generally, the "Urban bioregion" as a cross-scale planning model proposed in the field of bioregional planning studies [61–64], can add a further contribution to address fairness and ecosystem integrity issues.

In this framework, the recently adopted strategic planning strategy on behalf of Rome Metropolitan City—although at its initial stage [65]—turns out to best fit with this prospect. Indeed, the mentioned strategic approach strongly draws on the vision based on an "inversion" strategy" aimed to reframe the Rome metro area city-countryside relationships according to the form of the "City Region" [66], mainly by protecting and enhancing (in socio-economic terms) the agroforestry matrix, along with the regional settlement middle-sized towns system as the counter-mold to reframe a balanced and sustainable region development and spatial framework. According to these goals, specific actions to contain urban sprawl on greenfields could include: (i) enhancing the protection level of marginal rural areas, including woodlots; (ii) increasing the quality of products and food safety, generating positive effects on the profitability of fringe agricultural productions; and (iii) encouraging brownfield development with appropriate incentives. Greenfield development should be limited only to high-density residential developments in agricultural contexts of low ecological value [67].

5. Conclusions

According to our study, economic downturns might have beneficial impacts on urban containment (i.e., reduction of the establishment of new settlements, and an increase of natural areas). However, these effects are not expected to modify the land-use structure, due to their transitory effect. Urban and regional planning should therefore capitalize on the "spontaneous" positive effects of recession, systematizing actions for urban containment by: (i) introducing a high level of protection of rural areas at the fringe; (ii) supporting the economic profitability of fringe cropland and peri-urban farms; (iii) managing new forests as a part of an organic green infrastructure; and (iv) encouraging development on brownfields and settlement/land rehabilitation.

Based on the concept of "crisis as an opportunity" [68], planning in Mediterranean Europe should consider post-crisis urbanity as an opportunity for sustainability. Urban planning should therefore seek to adapt urban forms to economic downturns, maximizing the beneficial transitory effects in each phase of expansion and recession. In this perspective, further advances of this study should include the application of the method (which combines traditional landscape metrics analysis with spatial multivariate procedures) to other contexts outside Mediterranean Europe. Furthermore, the effects of economic downturns should be examined not only in the short term, but also in the medium term, to understand how long the temporary effect on the reduction of land-taking processes may last in a specific area.

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