Land Quality and the City: Monitoring Urban Growth and Land Take in 76 Southern European Metropolitan Areas

ABSTRACT

Urban expansion causes socioeconomic and environmental changes with unpredictable impacts on peri-urban land, especially in ecologically-fragile areas. The present study assesses the impact of dense and, respectively, discontinuous urban expansion on high-quality land consumption in 76 metropolitan regions of Mediterranean Europe. Land quality indicators and land-use maps were considered together with the aim to analyze urban growth and land take processes in Portugal, Spain, southern France, Italy and Greece. Differences in the rate of selective land take (high quality *vs* low quality soils) were observed at the city scale depending on the size of metropolitan regions and the percentage of built-up areas and cropland in the total landscape. Dispersed settlements were more frequently developed on high-quality land in respect to dense settlements. Urban expansion consumed high-quality land especially in Spain and Greece. The approach presented in this paper may inform joint policies for urban containment and the preservation of high-quality soils in peri-urban areas.

Key words: Sprawl, Soil consumption, Comparative analysis, Multivariate statistics, Mediterranean.

1. INTRODUCTION

Land is a fundamental capital for the development of almost all economic activities. Especially high-quality soils have ensured the maintenance of a viable agriculture for millennia (Hubacek and van der Bergh, 2006). Land also supports ecosystem functions and shows ability to recover when experiencing biophysical and anthropogenic pressures (Montanarella, 2007). However, if pressure exceeds certain limits, land may no longer be able to perform some key functions, becoming sensitive to degradation (Lorent et al., 2008).

Urban sprawl is a key socio-environmental issue at the global scale and a serious concern to sustainable development in wealthier countries (Hasse and Lathrop, 2003; Couch et al., 2007; Longhi and Musolesi, 2007; Patacchini et al., 2009). Urbanization has played and is still playing a crucial role in land conversion (Alberti, 1999, 2010), mostly at the expenses of the best soils (Imhoff et al. 1999). The decoupling of urban growth from population growth in developed countries (resulting in expanding settlements with stable or declining population) has determined an increasing consumption of land at progressively larger distances from core cities (Aguilera et al., 2011; Arribas-Bel et al., 2011; Coisnon et al., 2014). A progressively larger proportion of rural areas has been converted to residential, commercial and industrial settlements producing socially polarized and economically unspecialized spaces (Portnov and Safriel, 2004; Richardson and Chang-Hee, 2004; Indovina, 2005; Oueslati et al., 2014). Changes in the use of land driven by historically-produced and place-specific social processes has also led to diverging environmental outcomes according to the socioeconomic context (Polyzos et al., 2008; Beniston et al., 2016; McCauley et al., 2015). For example, urban sprawl has determined an increased fragmentation of relict agricultural systems with the consequent loss of biodiversity, traditional agronomic practices and local culture (Biasi et al., 2015). Land-use changes have mainly threatened natural ecosystems in rapidly expanding metropolitan regions sensitive to climate changes (Vargo et al., 2013; Camacho-Valdez et al., 2014; Wu et al., 2015).

Dispersed urbanization has caused increasing pressures on ecologically-fragile landscapes (Aguilar et al., 2006) determining a drastic increase of sealed land in recent decades (Paul and Tonts, 2005; Kasanko et al., 2006; Turok and Mykhnenko, 2007; Schneider and Woodcock, 2008; Inostroza et al., 2013). Permanent soil sealing for housing, roads or other construction work is a process resulting in a significant loss of (high-quality) land resources (European Environment Agency, 2006). Soil sealing is considered a relevant threat for European environment, particularly in metropolitan regions (Salvati, 2013). For instances, Mediterranean European cities have recently undergone a shift from compact (and, possibly, land-saving) growth to a more discontinuous and dispersed spatial pattern based on the uneven expansion of low-density settlements (Salvati et al., 2014). Sprawl-driven consumption and fragmentation of rural land with fertile soils affects both the productive capacity of agro-ecosystems and the aesthetic value of agricultural landscapes (Zhang et al., 2015). Due to its negative impact on the cohesion and stability of local communities and the overall quality of natural landscapes (e.g. Alphan, 2003), in-depth evaluations are required to explore the linkage between soil sealing and local socio-environmental contexts in European countries (Salvati and Carlucci, 2013).

Soil resource depletion is a crucial issue in southern Europe owing to the intrinsic fragility of Mediterranean rural ecosystems (Zitti et al., 2015). Conversion of rural land to urban use is caused by multiple socioeconomic factors in turn promoting the degradation of the soil resource base. Based on a diachronic study examining land consumption trends over the last fifty years in Italy, Salvati (2013) has demonstrated that urbanization-driven land take affected soils with different economic values depending on the observed pattern of urban expansion (e.g. compact *vs* dispersed). In many urban areas, the expansion of compact settlements has primarily consumed low-quality soils and moderately degraded landscapes (pastures, abandoned fields and low-intensity agricultural areas) bordering large cities (Salvati et al., 2012). By contrast, an increasing consumption of high-quality rural land far away from core cities has been observed in recent decades as a result of dispersed urban expansion (Salvati et al., 2014). Sprawl-driven selective land take was reported by Salvati (2014) and Salvati and Ferrara (2013). Ceccarelli et al. (2014) identified land with high capability to agricultural production as the most threatened by dispersed urbanization in northern Italy. Ferrara et al. (2014) found that urban land take has determined a spatial mismatch between agricultural uses of land (e.g. intensive cropland) and high-quality soils. Taken together, these findings are in line with what was reported by Alphan (2003), Garcia (2010) and Serra et al. (2014).

Land consumption driven by dispersed urban expansion may become an issue of spatial justice when it alters the distribution of high-quality land along the urban gradient (Zitti et al., 2015) leading to destruction or privatization of valuable physical environments (Chatterton, 2010). The changing use of high-quality soils may have unpredictable, long-term consequences for the ecosystem stability of relict, fragile landscapes and socioeconomic implications for peri-urban areas (Briassoulis, 2011). This process may also consolidate disparities in the access to high-quality land among competing actors, such as urban dwellers, farmers, tourism operators and citizens using natural amenities for recreational purposes (de Groot, 2006).

Increasing concerns for urban sprawl justify a permanent monitoring of land-use changes at both continental and country scale (Portnov and Safriel, 2004; Salvati et al., 2012; Barbero-Sierra et al., 2013). Further investigation of the relationship between urban expansion, land consumption and physical depletion of high-quality soils at either regional or local scale (Salvati, 2013) is also required to support more effective strategies for the sustainable management of peri-urban land (e.g. Salvati et al., 2014). Indeed, urban sprawl, industrialization, tourism concentration and infrastructure development - intended as different forms of urbanization - are crucial drivers of land consumption (e.g. Lambin et al., 2001; Xiao et al., 2006; Wilson and Chakraborty, 2013).
Metropolitan regions in Southern Europe have been found rather homogenous in landscape structures and land-use composition, emerging as particularly compact and dense in respect to cities in other European regions (Salvati and Carlucci, 2015). The present study contributes to the debate on socioeconomic impacts of sprawl on environmentally-fragile metropolitan regions by investigating the relationship between land quality and recent processes of urban expansion in five countries of southern Europe (European Environment Agency, 2006; Couch et al., 2007; Coisnon et al., 2014). We evaluate the characteristics of recently developed soils distinguishing compact, dispersed and mixed urban expansion in 76 metropolitan areas based on high-resolution land-use maps. A 'holistic' assessment of land quality was proposed based on the Environmentally Sensitive Area (ESA) framework which integrates soil, climate and vegetation indicators with the aim to assess land resource depletion caused by urbanization (Salvati et al., 2014). The outcomes of this methodological framework can be integrated into a geographic information system supporting policies and planning decisions for a sustainable use of land.

2. Materials and methods

2.1. Study area

The Southern European region is characterized by undulated topography with distinct vegetation, soil and climatic zones that reflect place-specific factors shaping multiple socioeconomic contexts (Montanarella, 2007). We studied 76 metropolitan regions with a resident population > 100,000 resident inhabitants (see list published in the Appendix table and Figure 1) from five European countries (Portugal: 7 cities, Spain: 22, France: 6, Italy: 32 and Greece: 9). Metropolitan boundaries were defined according to the European Urban Areas statistical classification developed on the behalf of the urban audit programme (http://www.urbanaudit.org/) of the “Large Urban Zones” (LUZs). The LUZs are intended as metropolitan areas from which a significant share of the resident population commutes into the central city (Eurostat, 2004). LUZs include the core city and the surrounding peri-urban areas. The European classification mentioned above allowed collecting homogeneous data for cities with different socioeconomic and environmental characteristics, allowing for between- and within-countries comparisons. The related data sets have been used for in-depth analyses of the European urban landscape from the environmental points of view (e.g. Guerois et al., 2012).

2.2. Data and variables

The harmonized Urban Atlas nomenclature was used to classify the use of land in each metropolitan region considered in the present study (Salvati and Ferrara, 2013). The Urban Atlas (UA) program provides pan-European comparable land-use and land cover data referring to the late 2000s or the early 2010s for LUZs with a resident population > 100.000 inhabitants as defined by the Urban Audit program. The UA nomenclature is composed by 20 classes grouped in 9 basic uses of land for the purpose of this study: (i) dense urban fabric, (ii) mixed urban fabric, (iii) discontinuous urban fabric, (iv) service settlements, (v) transport infrastructure, (vi) open areas with urban uses (e.g. airports, construction sites, undeveloped land with no current use or waiting for urbanization), (vii) green urban spaces, wetland and waters, (viii) agriculture and (ix) forests (Table 1). The thresholds for distinguishing dense, mixed and discontinuous urban fabric had been fixed in, respectively, more than 50% incidence of sealed land, between 30% and 50% and less than 30% (Salvati and Ferrara, 2013). The other groups have been defined according to the function of the involved classes.

Land quality is regarded as a multidimensional concept representing the ability of a soil to sustain agricultural production and/or natural vegetation (Sposito and Zabel, 2003). Land quality is associated to soil degradation processes and intimately related with the socioeconomic local context. Assessing this relationship is a particularly hard task since soils are inherently variable over space and susceptible to multiple uses (Salvati, 2014). Based on these premises, the Environmentally Sensitive Area (ESA) framework was adopted in this study with the aim to provide a comparative and comprehensive assessment of land quality and sensitivity to soil degradation at the city scale in southern Europe (Salvati et al., 2014). The ESA framework integrates environmental indicators (Kosmas et al., 2003) derived from multiple data sources (Basso et al., 2000) that describe three biophysical dimensions (climate, soil, and vegetation) influencing the processes of soil degradation impacting the quality of a given land (Salvati et al., 2014). A score index assessing the level of land quality and sensitivity to degradation (SDI) was developed and validated on the field (Lavado Contador et al., 2009). A full description of the methodology is reported in European Environment Agency (2003). The SDI ranges between 1 (the highest land quality and the lowest sensitivity to degradation based on the local environmental context) and 2 (the lowest land quality reflecting the highest sensitivity to degradation).

The European Environment Agency (2003) prepared a raster map (1 km^2 grid) of the SDI covering homogeneously the entire area (Portugal, Spain, southern France, Italy and Greece) that was provided by after computation on 9 biophysical layers: 4 variables assessing soil quality (parental material, soil depth, texture, slope), one variable for climate quality (aridity index, i.e. the ratio of annual precipitation to annual reference evapotranspiration rate), and 4 variables assessing vegetation quality (protection from soil erosion, resistance to drought, plant cover, resistance to fire). Input layers were derived from official data sources referring to the late 1990s and covering homogeneously the Mediterranean European region at a fine spatial resolution (European Environment Agency, 2003). Values of each layer were ranked into the scale 1-2 and the SDI was calculated as the geometric mean of the score of all input layers (Salvati et al., 2014). Since the aim of this study is to investigate whether recent urbanization have occurred at the expenses of high quality soils, the SDI had not been calculated for already consolidated urban areas in the late 1990s.

Thus, the SDI raster map was overlaid to the UA land-use map to derive information on the biophysical conditions and land quality characterizing recently developed areas (late 1990s - late 2000s) or regions with stable (non-urban) use of land (e.g. cropland, forest). A total of 38 indicators (Table 2) were computed from the overlay of the two maps using ArcGIS 9.3 (ESRI Inc, Redwoods, USA) and from additional data sources including official statistics provided by Eurostat. Since information on land quality and land-use considered in this study respectively refer to the late 1990s and the late 2000s, the resulting overlay map reflects land take processes observed in the last decade at the metropolitan scale in southern Europe (see also Salvati and Ferrara, 2013 for technical details).

Median SDI scores were calculated for each land-use class producing 9 indicators (c1-c9). To assess landscape composition in every metropolitan region, percent class area in the total landscape was computed for each use of land (p1-p9). Four indicators were calculated as $[(SDI_j/SDI_y - 1)*100]$ score ratio between selected pairs (*j*-th, *y*-th) of land-use classes: (i) dense urban settlements *vs* mixed urban settlements (r1), (ii) mixed urban settlements *vs* discontinuous urban settlements (r2), (iii) dense urban settlements *vs* discontinuous urban settlements (r3) and (iv) agriculture *vs* forests (r4). These indicators assess the quality of land consumed by different forms of urban expansion or hosting a given non-urban use of land. Four environmental variables were also calculated: (i) the total surface area of each metropolitan region, (ii) the median SDI score at the metropolitan scale and (iii-iv) two indexes of landscape diversification computed on the percent class area of the 9 land-use types considered in this study (Shannon H' diversity and Pielou J evenness). Twelve contextual variables were finally calculated: (i) the ratio of the core city surface area to the LUZ surface area, (ii) a dummy variable indicating the capital city of each country, (iii) the distance of each city from the nearest LUZ (based on the geographic distance between LUZ centroids), (iv) a dummy variable indicating coastal or internal cities, (v) population density in early 2010s (resident inhabitants at the LUZ scale / km^2), (vi) the percent share of population residing in the core city to the population living in each LUZ in early 2010s, (vii-viii) the annual rate of population growth (%) respectively at the core city level and at the LUZ level in late 2000s, (ix-xii) four dummy variables identifying Greek, Italian, Spanish and Portuguese cities). The country dummy for France was not included in the analysis to avoid multi-collinearity. Contextual variables evaluate the importance of place-specific conditions or regional factors influencing land take across southern European countries.

2.3. Statistical analysis

A data mining strategy including (i) descriptive statistics, (ii) non-parametric inference based on the Analysis of Variance (ANOVA) and Spearman correlations, (iii) Hierarchical Clustering (HC) and (iv) Principal Component Analysis (PCA), was developed in the present study (see Table 2). An exploratory data analysis combining several variables is better suited to assess spatial linkages between urban expansion and land quality and to identify the latent relationship between land quality and different use of land possibly reflecting distinct patterns and processes of urbanization (Ferrara et al., 2014).

2.3.1. Non parametric inference

Differences in the spatial distribution of the SDI within the 9 land-use classes considered in our study were verified using non-parametric Kruskal–Wallis ANOVA. Tests for significance were run at $p < 0.05$ after Bonferroni's correction for multiple comparisons with the 76 metropolitan regions considered as the elementary units of analysis. Pair-wise Spearman non-parametric correlation tests were run to provide a preliminary overview of the relationship between the input variables. Significance was tested at $p < 0.05$ after Bonferroni's correction for multiple comparisons.

2.3.2. Hierarchical clustering

A three-step Hierarchical Clustering (HC) based on classification trees (Euclidean distance and Ward's agglomeration rule) was run with the objective to investigate similarity in the spatial distribution of the input variables (Salvati, 2013). A first HC was carried out to evaluate similarities in the spatial distribution of the median SDI score by land-use class. A second HC analyzed similarities in the spatial distribution of the percent class area of the 9 land-uses considered in this study. A third HC identified similarities in land-use patterns observed in the 76 metropolitan regions.

2.3.3. Principal Component Analysis

A Principal Component Analysis (PCA) was carried out to explore the dataset composed of (i) 9 indicators (c1-c9) estimating the median SDI score for each land-use class, (ii) 8 indicators (p1-p3 and p5-p9) that assess landscape composition by computation on the percent class area of each land-use type for each metropolitan region (service settlements (p4) were excluded from the analysis to avoid multicollinearity), (iii) 4 indicators (r1-r4) evaluating the percent ratio of SDI scores for selected pair-wise comparisons of relevant land-use classes, (iv) 4 environmental indicators (section 2.2) and (v) 8 contextual indicators (section 2.2). Significant components were selected according to the eigenvalue extracted by the PCA (Salvati et al., 2014). Due to the high number of variables elaborated in the PCA, components with eigenvalue > 3 were analyzed. Component loadings and scores were used to profile land take processes in the 76 metropolitan regions.

3. RESULTS

3.1. Descriptive statistics

We investigated 32 metropolitan regions from Italy, 22 from Spain, 9 from Greece, 7 from Portugal and 6 from France. Spanish and Italian metropolitan regions are the largest in southern Europe (respectively 1,374 km^2 and 815 km^2 on average). Landscape composition at the metropolitan scale was significantly different within the five European countries (Kruskal-Wallis H, $p < 0.05$). Considering together all the studied cities, cropland covered 60% of the metropolitan surface area, ranging between 54% in Portuguese cities and 79% in Greek cities (Table 3). On average, forests extended nearly 15% of the metropolitan area, ranging between 12% in Greek cities and 22% in Portuguese cities. Urban areas occupied around 25% of the metropolitan area, ranging between 9% in Greek and Spanish cities and 23% in French cities. The highest share of compact urban fabric in the total landscape was observed in Portuguese (7%) and French (5%) cities. The share of discontinuous urban fabric in the total landscape was higher in Italian and Portuguese cities than elsewhere in southern Europe. Landscape diversity was above the sample average in Portuguese and French cities and below the average in Greek cities.

The median SDI at the metropolitan scale was relatively high in Spain and Greece and rather low in France and Italy. This means that, on average, Spanish and Greek cities showed lower values of land quality than French and Italian cities - along with differentiated environmental conditions at the local scale. The comparative analysis of the median SDI score by land-use and country identified mixed spatial patterns of land quality depending on the final use of land. Open areas with mixed urban use were associated with high-quality soils (the lowest SDI score) in French and Spanish cities. Green urban spaces, transport networks and cropland were spatially associated with the highest level of soil quality respectively in Greek, Italian and Portuguese cities.

Compared with the median SDI observed at the metropolitan scale, dense urban settlements expanded on land with an above average level of soil quality in Greek, Spanish and Italian cities, and a lower soil quality in French cities. Discontinuous urban fabric expanded on lower quality soils (compared with the median SDI at the metropolitan scale) in France, Greece, and Italy. The reverse pattern was observed for mixed urban fabric since this class occupied lower quality soils (in respect to the median SDI at the metropolitan scale) in France and Greece, and slightly higher quality soils in Italy and Spain.

These results indicate that land take impacted high-quality soils more frequently in Spanish and, to a lesser extent, Italian cities, than elsewhere in southern Europe. On average, dense urban fabric covered soils with medium-low quality in respect to the overall landscape value. Discontinuous urban fabric was spatially associated with soils with a relatively high quality. Greek cities showed the highest ratio in the median SDI (i) between mixed and dense settlements and (ii) between discontinuous and dense settlements. This finding indicates that mixed urban fabric in Greek cities covered soils with lower quality compared with dense urban fabric. A high ratio of discontinuous-to-dense settlements median SDI was also observed for Spanish and Italian cities (respectively 0.72 and 0.54). The highest ratio of cropland-to-forests median SDI was observed for Greek and French cities and indicates that woodlands have covered soils with much higher quality than cropland. The reverse pattern was observed for Italian, Spanish and, to a lesser extent, Portuguese cities.

A city rank based on the intensity of land take (Table 4) indicates that dispersed urbanization consumed selectively high-quality land in 17 metropolitan regions irrespective of their size and country. These cities include intermediate and large-size metropolitan areas in the coastal regions of Greece (e.g. Athens and Salonika), Spain (e.g. Barcelona, Valencia and Alicante), France (Marseille and Montpellier), Italy (Palermo and Cagliari) and Portugal (Faro). All these cities were characterized by a low- or medium-low quality of undeveloped land at the metropolitan scale. Mixed compact-dispersed urbanization expanded into patches of land with higher quality compared with the average quality of the undeveloped land at the metropolitan scale in 13 southern European cities including Kalamata (Greece), Sevilla, Alicante and Valencia (Spain), Sassari (Italy) and Aveiro (Portugal). These cities have featured a low or intermediate level of land quality at the metropolitan scale.

3.2. Non-parametric correlations

The results of a Spearman non-parametric correlation analysis run pair-wise on the median SDI score and each environmental and contextual indicator pointed out that large metropolitan regions with a high share of cropland in the total landscape have low-quality land. The SDI increased significantly with the surface area of metropolitan regions ($r_s = 0.30$, $p < 0.01$, n = 76) and with the percentage of cropland in the total landscape ($r_s = 0.39$, $p < 0.01$, n = 76). Land quality increases with landscape diversity ($r_s = -0.43$, $p < 0.001$, n = 76). Pooling together all urban classes, the quality of land converted to urban uses increased with the respective percent class area ($r_s = -0.30$, $p < 0.01$, n = 76). Finally, the quality of land occupied by discontinuous settlements showed the reverse pattern ($r_s = -0.30$, $p < 0.01$, n = 76). On average, land quality at the metropolitan scale was systematically below the average in Spanish cities ($r_s = 0.41$, $p < 0.01$, n = 76) and above the average in Italian cities ($r_s = -0.36$, $p < 0.01$, n = 76).

3.3. Hierarchical clustering

Cluster analysis run on the data matrix composed of median SDI scores by land-use class (Figure 2) identifies two land-use groups with similar spatial pattern: (i) natural or semi-natural classes (cropland and forests), discontinuous residential settlements and mixed residential settlements and (ii) the remaining urban land-uses, namely residential dense and service (commerce, industry, infrastructure) settlements. Based on a 50% similarity threshold, hierarchical clustering classified the 76 southern European cities in four groups presenting different land quality at the metropolitan scale (Figure 3). Cities with the highest land quality clustered in the right side of the dendrogram.

3.4. Principal Component Analysis

The PCA carried out on the entire dataset extracted 3 components explaining 39.3% of the total matrix variance (Table 5). Component 1 (18.4%) identifies the urban-rural gradient in the studied cities (urban and agricultural land-uses associated respectively to positive and negative component loadings). The urban gradient was associated positively to landscape diversity and evenness, the dummy variable indicating Portuguese cities, The rural gradient was positively associated to the median SDI at the landscape scale, the ratio of the population residing in the core city to the population living in the LUZ and the total surface area of each metropolitan region. Component 2 (11.7%) discriminates high-quality land from low-quality land developed with compact or dispersed settlements in the last decade. High-quality rural land converted recently to dense residential settlements, service settlements and leisure green received positive loadings to component 2. High-quality rural land converted to discontinuous settlements or covered by cropland or forests received negative loadings to component 2. Metropolitan regions with the highest SDI have a higher proportion of rural land recently converted to dense settlements than cities with intermediate or low SDI scores. By contrast, the overall quality of rural land converted to discontinuous settlements or covered by cropland and forests displays a similar spatial pattern. These results suggest that the quality of rural land converted to discontinuous settlements was negatively correlated with the quality of rural land developed with dense settlements.

Component 3 (9.2%) finally indicates that the ratios of dense-to-mixed settlements' median SDI (positive loading) and of mixed-to-discontinuous settlements' median SDI (negative loading) were counter-correlated in the Mediterranean cities considered in this study. The ratio of dense-to-mixed settlements' median SDI scores and of mixed-to-discontinuous settlements' median SDI respectively increased and decreased with the size of metropolitan regions. Portuguese cities and metropolitan regions with a high ratio of city-to-LUZ surface area were negatively associated with component 3. This component identifies selective land take processes driven by dense and discontinuous urbanization in terms of different qualities of the developed soils.

The scores of component 1 and 2 classify Mediterranean cities according to the previously described geographical gradients (Figure 4). Greek (and, in part, Spanish) cities are associated with the negative side of component 1 and are distributed more heterogeneously along component 2. Greek cities are characterized by a marked urban-rural divide with metropolitan regions preserving relatively high proportions of cropland and forests. The quality of land covered by consolidated settlements is negatively correlated to that of (non-urban) fringe land including discontinuous settlements. In these cities compact and mixed settlements were developed on low or medium-low quality land, contrasting with what was observed for discontinuous settlements consuming higher quality land surrounding natural areas. French and Portuguese cities are primarily associated to the positive scores of component 1. Especially Portuguese cities showed a less marked urban gradient and a strong land-use divide as far as land quality is concerned. Italian cities are much more heterogeneous and present a dispersed distribution along both component 1 and 2. These findings outline the importance of place-specific factors in land take processes. Results from HC and PCA indicate that discontinuous settlements consumed the highest quality land in metropolitan areas with an overall level of land quality above the sample average.

4. Discussion

Scattered urban expansion in Mediterranean Europe has consumed a relevant proportion of high-quality rural and natural areas progressively far away from central cities (European Environment Agency, 2006). The present study demonstrates that different forms of urban expansion (dense, mixed, discontinuous) consumed land with different quality and sensitivity to soil degradation. Our approach integrates high-resolution land-use maps and multi-criteria indicators in a data mining strategy applied to a representative sample of southern European cities. Our results indicate that only in few cities dispersed settlements were developed on land with poor soil quality (Salvati et al., 2014). On the contrary, an in-depth assessment of land quality in areas undergoing dispersed urban expansion indicates a generalized loss of high-quality land. On average, discontinuous urban settlements consumed the best available land in most Greek and Spanish cities (Barbero Sierra et al., 2013). These results are in full agreement with previous evidences indicating Spain and Greece as the countries with the highest land sensitivity to degradation and the lowest land quality in southern Europe (e.g. Wilson and Juntti, 2005).

By contrast, dense residential and service settlements, infrastructures and green spaces covered land with lower quality than the average land quality at the metropolitan scale. Land-saving dense settlements proved to be a sustainable model of urban expansion in rapidly-growing Mediterranean cities since they usually consumes a lower proportion of high-quality land than mixed and discontinuous settlements (Chorianopoulos et al., 2010; Aguilera et al., 2011; Ceccarelli et al., 2014; Ferrara et al., 2014).

While country-specific socioeconomic factors have influenced urban expansion and land take patterns, local contexts may better discriminate metropolitan regions with high soil quality from those with low soil quality . Land quality increases with landscape diversity and decreases with the share of cropland in the total landscape area. Urban settlements in larger metropolitan regions expanded into rural land with a systematically lower soil quality compared with settlements developed in smaller metropolitan regions. Discontinuous settlements consumed selectively high-quality soils in regions where land quality is very low due to the joint action of different biophysical conditions such as poor soils and climate aridity (e.g. Greece, central/southern Spain and southern Italy). These results corroborate the evidences provided by Salvati et al. (2012) and Barbero Sierra et al. (2013) respectively for Italy and Spain, and indicates the key role of deregulated urban expansion and real estate speculation in the increased consumption rate of high-quality land (Portnov and Safriel, 2004).

The sprawl-driven selective consumption of high-quality land produced a spatial divide between forest and agricultural uses (mainly extending on low-quality land) and built-up areas progressively covering the most productive rural land, with important consequences for the economic viability of the primary sector (Ferrara et al., 2014), the conservation of natural environments (Aguilar et al., 2006) and the sustainable provision of basic ecosystem services to the surrounding regions (Paul and Tonts, 2005). Our results demonstrate that urban sprawl triggers a downward spiral of high-quality land take in ecologically fragile cities of the Mediterranean Europe, impacting negatively the relict peri-urban landscapes (Polyzos et al., 2008). Since land is a key natural capital contributing to local development (Hubacek and van der Bergh, 2006), urban sprawl may irreversibly alter the spatial distribution of high-quality land becoming a matter of spatial justice at the metropolitan scale (Richardson and Chang-Hee, 2004).

Urbanization-driven selective land take and high-quality land consumption should be more tightly considered in urban planning (Ceccarelli et al., 2014). In the light of sustainable management of peri-urban land, intermediate and low-quality rural land surrounding core cities can be partly 'sacrificed' to semi-compact urban expansion (Coisnon et al., 2014). The combined effect of soil degradation processes (e.g. soil sealing, contamination, compaction), micro-climate conditions (driven by urban heating), poor and fragmented vegetation cover and increasing human pressure contribute to deteriorate the environmental conditions of peri-urban areas (Camacho-Valdez et al., 2014) and to reduce their socioeconomic value (Salvati, 2013). Urban planning is increasingly required to identify derelict land and urban voids and to destine these areas to urban development (Paul and Tonts, 2005). Land-saving, semi-dense residential and service settlements intermixed with green urban spaces are demonstrated to form more sustainable urban morphologies preserving the quality of surrounding rural soils and the basic environmental services they provide (Portnov and Safriel, 2004). Based on these evidences, high-quality rural land should be more tightly preserved from urban expansion irrespective of the current use (e.g. agriculture, forest, pasture). Especially high-quality open areas close to peri-urban forests and mixed cropland, seen as potential sites for dense urban development required a dedicated conservation strategy (Chorianopoulos et al., 2010). Our study qualifies this land as particularly exposed to degradation of high-quality soils driven by urban sprawl.

5. Conclusions

Planning decisions oriented towards a sustainable use of land are difficult to apply to socioeconomic contexts with multiple agents determining (or influencing) urban expansion. The study illustrates an original methodology informing sustainable land management and urban containment strategies in different socio-environmental contexts of southern Europe. The multi-criteria land classification proposed here provides a comprehensive tool for assessing land take at local, regional and country scales. Understanding how different forms of urban expansion impact land quality is a relevant information base for the assessment of natural resource consumption caused by urbanization.

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Table 1. The land-use nomenclature system adopted in the present study (UA: Urban Atlas).

UA code	Description	Our code	Short description
1110	Continuous urban fabric (S.L.>80%)	1	Dense urban fabric (soil sealing > 50%)
1121	Discontinuous dense urban fabric (S.L. 50%-80%)	1	
1122	Discontinuous medium density urban fabric (S.L. 30%-50%)	2	Mixed urban fabric
1123	Discontinuous low density urban fabric (S.L. 10%-30%)	3	Discontinuous urban fabric (sealing < 30%)
1124	Discontinuous very low density urban fabric (S.L.<10%)	3	
1130	Isolated structures	3	
1210	Industrial, commercial, public, military and private units	4	Service settlements
1221	Fast transit roads and associated land	5	Transport infrastructure
1222	Other roads and associated land	5	
1223	Railways and associated land	5	
1230	Ports	6	Open areas with urban uses
1240	Airports	6	
1310	Mineral extraction and dump sites	6	
1330	Construction sites	6	
1340	Land without current use	6	
1410	Green urban areas	7	Green urban space, wetland, water bodies
1420	Sports and leisure facilities	7	
5000	Water bodies and wetlands	7	
2000	Agricultural areas	8	Agriculture
3000	Forests	9	Forests

Table 2. List of indicators used in the present study (acronyms in bracket) by type of statistical analysis.

Variable	Descriptive statistics	Spearman analysis	Indicator clustering	City clustering	Principal Component Analysis
# urban areas	●				
Median SDI by land-use class, score (c)					
Dense urban fabric (c1)	●	●	●	●	●
Mixed urban fabric (c2)	●	●	●	●	●
Discontinuous urban fabric (c3)	●	●	●	●	●
Service settlements (c4)	●	●	●	●	●
Transport infrastructure (c5)	●	●	●	●	●
Open areas with urban uses (c6)	●	●	●	●	●
Green urban space, wetland, water (c7)	●	●	●	●	●
Agriculture (c8)	●	●	●	●	●
Forests (c9)	●	●	●	●	●
Percent ratio of SDI scores (selected comparisons between land-use classes, r)					
Mixed urban / Dense urban (r1)	●	●			●
Discontinuous urban / Mixed urban (r2)	●	●			●
Discontinuous urban / Dense urban (r3)	●	●			●
Agriculture / Forests (r4)	●	●			●
Percent class area (p)					
Dense urban fabric (p1)	●	●	●	●	●
Mixed urban fabric (p2)	●	●	●	●	●
Discontinuous urban fabric (p3)	●	●	●	●	●
Service settlements (p4)	●	●	●	●	
Transport infrastructure (p5)	●	●	●	●	●
Open areas with urban uses (p6)	●	●	●	●	●
Green urban space, wetland, water (p7)	●	●	●	●	●
Agriculture (p8)	●	●	●	●	●
Forests (p9)	●	●	●	●	●
Environmental variables					
Total surface area, LUZ scale, km^2 (Area)	●	●		●	●
Median SDI, metropolitan scale, score (SDI)	●	●		●	●
Landscape Shannon diversity index (H')	●	●		●	●
Landscape Pielou evenness index (J)	●	●		●	●
Contextual variables					●
Ratio of core city to LUZ surface area, %					●
Country capital city (dummy)					●
Distance from the nearest LUZ, km					●
Mediterranean coastal city(dummy)					●
Population density, LUZ scale, inha./km^2					●
Ratio of core city to LUZ population, %					●
Pop. growth, core city scale, % per year					●
Pop. growth, LUZ scale, % per year					●
Greece (EL, dummy)		●			●
Italy (IT, dummy)		●			●
Portugal (PT, dummy)		●			●
Spain (SP, dummy)		●			●

Table 3. Descriptive statistics of selected indicators by country.

Variable	France	Greece	Italy	Portugal	Spain
# urban areas	6	9	33	7	22
Median SDI by land-use class					
Dense urban fabric	1.122	1.179	1.141	1.155	1.205
Mixed urban fabric	1.125	1.209	1.144	1.155	1.206
Discontinuous urban fabric	1.123	1.200	1.147	1.155	1.213
Service settlements	1.122	1.186	1.138	1.152	1.210
Transport infrastructure	1.125	1.181	1.143	1.156	1.210
Open areas with urban uses	1.114	1.186	1.141	1.156	1.188
Green urban space, wetland, water	1.124	1.176	1.145	1.153	1.213
Agriculture	1.122	1.195	1.143	1.151	1.208
Forests	1.115	1.183	1.153	1.158	1.210
Percent ratio of SDI scores (selected comparisons between land-use classes)					
Mixed urban / Dense urban	0.22	2.55	0.24	-0.03	0.09
Discontinuous urban / Mixed urban	-0.18	-0.80	0.30	-0.01	0.63
Discontinuous urban / Dense urban	0.04	1.73	0.54	-0.04	0.72
Agriculture / Forests	0.62	1.00	-0.90	-0.60	-0.16
Percent area by land-use class					
Dense urban fabric	5.3	1.2	1.3	7.3	0.5
Mixed urban fabric	2.5	0.7	1.1	3.0	0.6
Discontinuous urban fabric	1.6	0.8	3.2	2.8	1.9
Service settlements	3.2	1.3	2.7	4.7	1.5
Transport infrastructure	3.5	1.3	2.9	3.4	2.5
Open areas with urban uses	1.5	0.5	0.7	1.0	1.1
Green urban space, wetland, water	2.2	0.3	0.8	2.8	0.8
Agriculture	60.3	79.2	67.0	54.2	74.7
Forests	15.1	11.6	13.1	21.6	15.1
Environmental variables					
Average LUZ surface area (km^2)	386	587	815	414	1374
Median SDI, LUZ scale, score	1.121	1.181	1.146	1.155	1.213
Landscape Shannon diversity index (H')	1.36	0.79	0.98	1.37	0.92
Landscape Pielou evenness index (J)	0.62	0.36	0.44	0.62	0.42

Table 4. Southern European city ranking for the rate of SDI score of rural land taken by mixed or discontinuous settlements to the overall SDI score observed at the metropolitan scale; increasing values indicate consumption of higher quality land.

City (Country)	Mixed urban fabric	City (Country)	Discontinuous urban fabric
Palma di Mallorca (ES)	1.12	Alicante (ES)	2.39
Aveiro (PT)	1.02	Faro (PT)	2.25
Valencia (ES)	1.01	Setubal (PT)	1.99
Sassari (IT)	1.00	Aveiro (PT)	1.29
Santander (ES)	0.95	Marseille (FR)	1.01
Kalamata (EL)	0.86	Athens (GR)	0.96
Sevilla (ES)	0.84	Barcelona (ES)	0.88
Foggia (IT)	0.83	Montpellier (FR)	0.85
Badajoz (ES)	0.68	Salonika (GR)	0.83
Logrono (ES)	0.67	Logrono (ES)	0.76
Modena (IT)	0.63	Ioannina (EL)	0.72
Genova (IT)	0.63	Valencia (ES)	0.66
Alicante (ES)	0.50	Palermo (IT)	0.63
		Sevilla (ES)	0.63
		Volos (EL)	0.62
		Cagliari (IT)	0.61
		Nice (FR)	0.56

Table 5. Results of the PCA applied to the dataset composed of 37 input variables (bold indicates loadings > |0.4|).

Variable	PC 1	PC 2	PC 3
Variance (%)	18.4	11.7	9.2
Median SDI by land-use class (c)			
Dense urban fabric	0.17	**0.58**	0.35
Mixed urban fabric	-0.08	0.06	**-0.64**
Discontinuous urban fabric	-0.32	**-0.52**	0.38
Service settlements	0.17	**0.67**	-0.13
Transport infrastructure	0.18	0.27	0.37
Open areas with urban uses	0.15	-0.01	0.00
Green urban space, wetland, water	-0.01	**0.56**	0.01
Agriculture	-0.21	**-0.45**	0.02
Forests	-0.07	**-0.68**	-0.10
Ratio of SDI scores (selected comparisons between land-use classes, r)			
Dense urban / mixed urban f.	0.21	0.38	**0.69**
Mixed urban / Discontinuous urban f.	0.15	0.35	**-0.74**
Dense urban / Discontinuous urban f.	0.28	**0.77**	-0.07
Agriculture / Forests	-0.05	**0.44**	0.15
Percent area by land-use class (p)			
Dense urban fabric	**0.79**	0.02	-0.23
Mixed urban fabric	**0.80**	-0.05	-0.12
Discontinuous urban fabric	**0.49**	-0.19	0.14
Transport infrastructure	**0.74**	-0.09	0.26
Open areas with urban uses	0.38	0.21	0.00
Green urban space, wetland, water	**0.68**	0.10	-0.07
Agriculture	**-0.63**	0.24	-0.17
Forests	0.17	-0.24	0.18
Environmental variables			
Median SDI, metropolitan scale, score (SDI)	**-0.40**	**0.55**	-0.05
LUZ surface area (metropolitan scale)	**-0.45**	0.22	**0.52**
Landscape Shannon diversity index (H')	**0.92**	-0.16	-0.02
Landscape Pielou evenness index (J)	**0.92**	-0.16	-0.02
Contextual variables			
Ratio of core city to LUZ surface area, %	-0.11	-0.06	**-0.44**
Country capital city (dummy)	0.14	0.30	0.12
Distance from the nearest LUZ, km	-0.38	0.27	-0.07
Mediterranean coastal city(dummy)	0.29	0.16	-0.34
Population density, LUZ scale, inha./km^2	**0.60**	0.11	0.16
Ratio of core city to LUZ population, %	**-0.45**	-0.17	-0.33
Pop. growth, core city scale, % per year	0.10	-0.33	0.12
Pop. growth, LUZ scale, % per year	0.10	-0.06	0.27
Greece	-0.35	0.18	-0.32
Italy	0.11	-0.33	0.24
Portugal	**0.43**	0.07	**-0.44**
Spain	-0.27	0.22	0.33

Figure 1. Map of the northern Mediterranean basin with the 76 metropolitan areas considered in the present study.

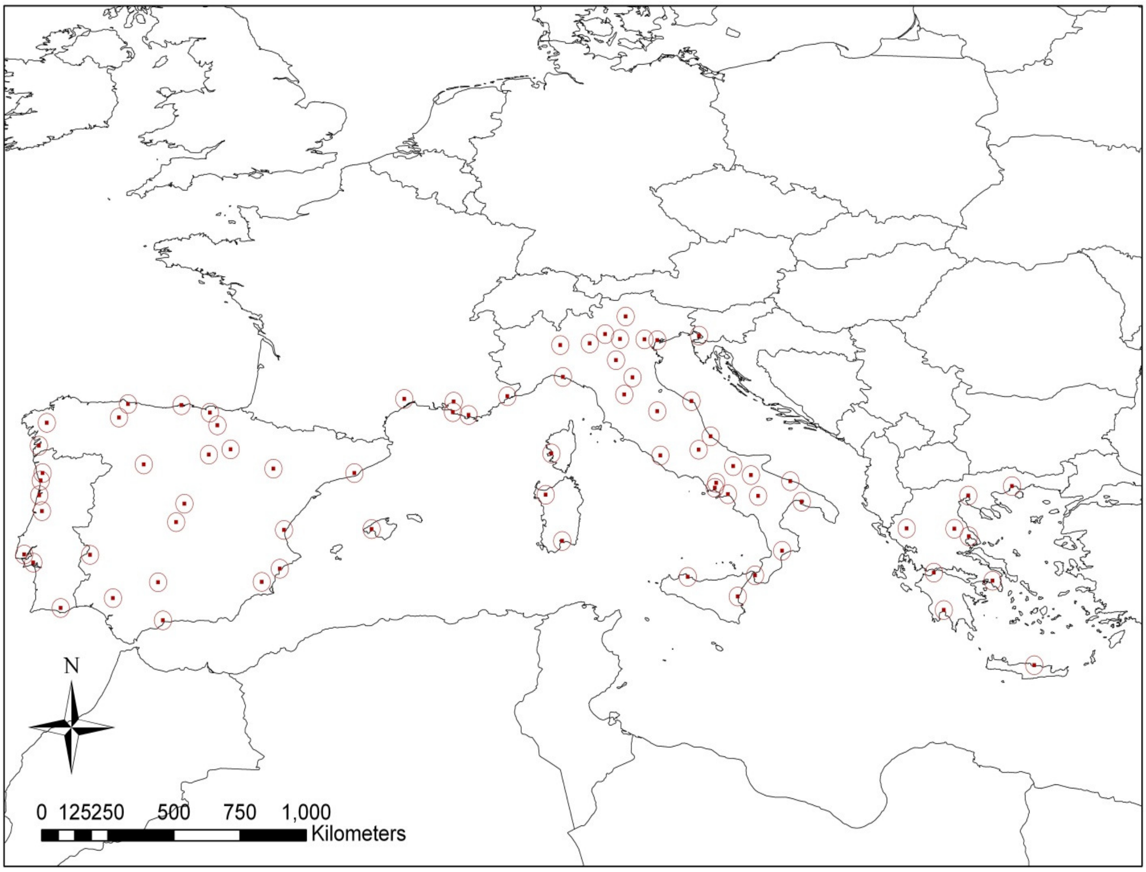


Figure 2. Hierarchical clustering of median SDI score (left) and percent area (right) of land-use classes considered in this study.

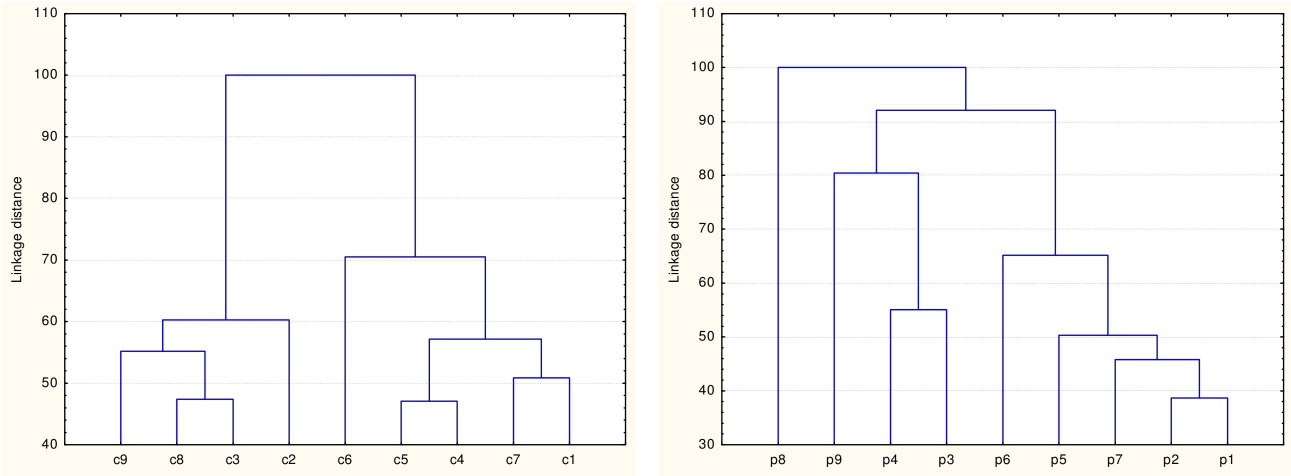


Figure 3. Hierarchical clustering of southern European metropolitan regions based on the median SDI score by land-use class.

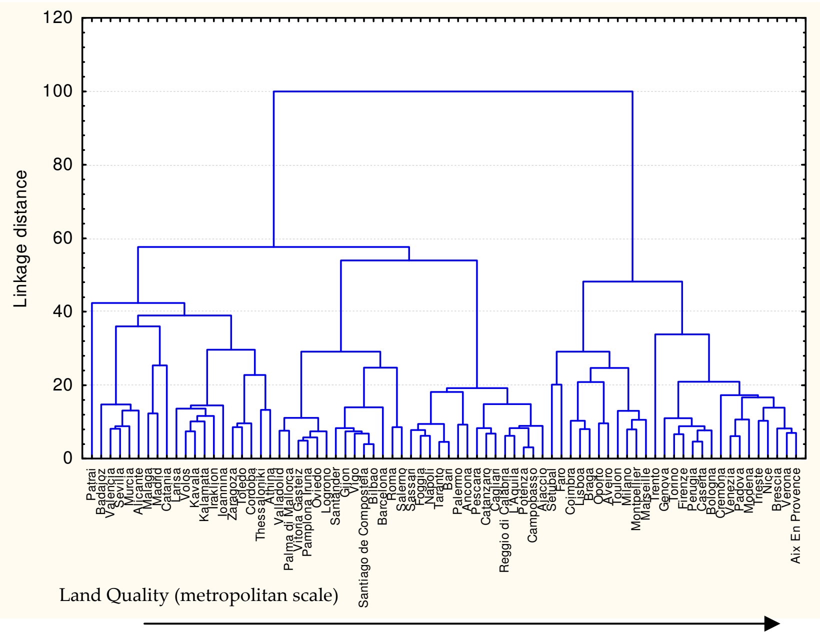
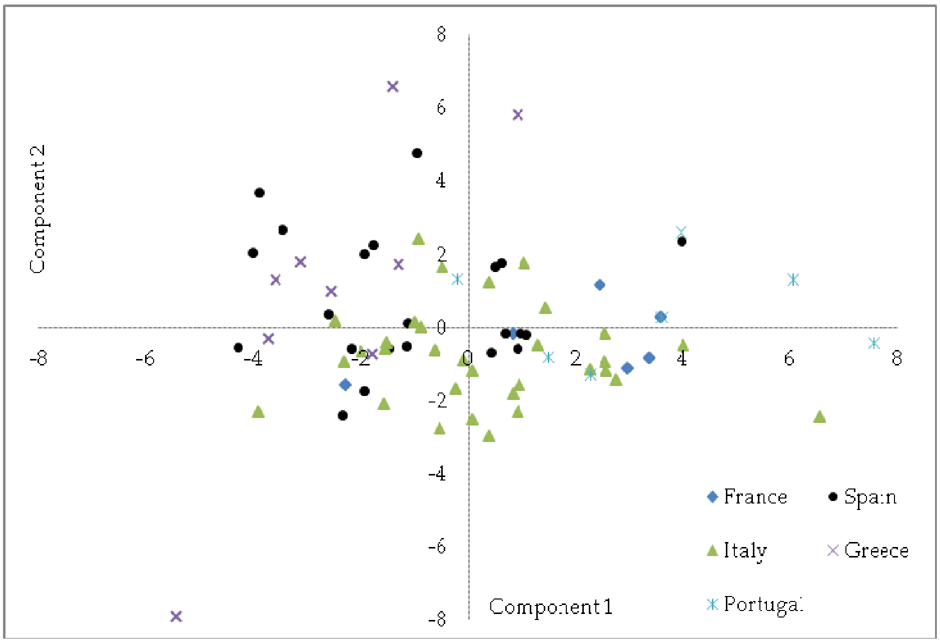


Figure 4. Indicator loadings on the first two principal components by country.



Appendix. List of metropolitan regions investigated in this study by country.

Country	Name	Country	Name
France	Aix En Provence	Greece	Athina
	Ajaccio		Ioannina
	Marseille		Iraklion
	Montpellier		Kalamata
	Nice		Kavala
	Toulon		Larisa
Italy	Ancona		Patrai
	Bari		Thessaloniki
	Bologna		Volos
	Brescia	Portugal	Aveiro
	Cagliari		Braga
	Campobasso		Coimbra
	Caserta		Faro
	Catania		Lisboa
	Catanzaro		Oporto
	Cremona		Setubal
	Firenze	Spain	Alicante
	Foggia		Badajoz
	Genova		Barcelona
	L'Aquila		Bilbao
	Milano		Cordoba
	Modena		Gijon
	Napoli		Logrono
	Padova		Madrid
	Palermo		Malaga
	Perugia		Murcia
	Pescara		Oviedo
	Potenza		Palma di Mallorca
	Reggio di Calabria		Pamplona Iruna
	Roma		Santander
	Salerno		Santiago de Compostela
	Sassari		Sevilla
	Taranto		Toledo
	Torino		Valencia
	Trento		Valladolid
	Trieste		Vigo
	Venezia		Vitoria Gasteiz
	Verona		Zaragoza