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Integration of land use and land cover inventories for landscape management and planning in Italy

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Abstract There are both semantic and technical differences between land use (LU) and land cover (LC) measurements. In cartographic approaches, these differences are often neglected, giving rise to a hybrid classification. The aim of this paper is to provide a better understanding and characterization of the two classification schemes using a comparison that allows maximization of the informative power of both. The analysis was carried out in the Molise region (Central Italy) using sample information from the Italian Land Use Inventory (IUTI). The sampling points were classified with a visual interpretation of aerial photographs for both LU and LC in order to estimate surfaces and assess the changes that occurred between 2000 and 2012. The results underscore the polarization of land use and land cover changes resulting from the following: (a) recolonization of natural surfaces, (b) strong dynamisms between the LC classes in the natural and semi-natural domain and (c) urban sprawl on the lower hills and plains. Most of the observed transitions are attributable to decreases in croplands, natural grasslands and pastures, owing to agricultural abandonment. The results demonstrate that a comparison between LU and LC estimates and their changes provides an understanding of the causes of misalignment between the two criteria. Such information may be useful for planning policies in both natural and semi-natural contexts as well as in urban areas.

Keywords Double classification · Point sampling · Stratified allocation · Estimation · Monitoring

Introduction

During recent centuries, land use (LU) and land cover (LC) changes due to human activity have shaped terrestrial ecosystems (see e.g. Ellis et al. 2010), altering their

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resilience, biodiversity and capacity for providing goods and services for human well-being (Vizzarri et al. 2015). Furthermore, ecosystem alterations (Ellis and Ramankutty 2008; Sala 2000) and some LU and LC changes such as urbanization are now recognized as primary causes of political and social conflict (Plotkin 1987). As a consequence, the availability of data describing these processes is essential for environmental, landscape and land use planning and policy.

In cartography, soil is usually classified with respect to its use or its cover. In addition to its use in landscape planning, such information is used in predictive models of environmental protection (e.g. biodiversity, fragmentation of the habitats) and in economic planning. In cartography implementations, the choice between LU and LC is determined by the specific end use of the mapping product although hybrid classifications are adopted in most cases. Indeed, the confusion between the two concepts has existed in the literature for at least 30 years (Anderson et al. 1976). An example of the spread of "hybrid" classifications is given by Lund (2002), who found that 86 % of the 624 classes identified as "forest" can be referred to as having an LU and LC meaning. The undifferentiated use of LU and LC has become so widespread that it is now rare to find a "pure" classification (Di Gregorio and Jansen 2005). The lack of a universally recognized definition of LU and LC is surely the main cause of this confusion. The most common definitions of LU and LC are those adopted in the Land Cover Classification System by FAO (2000). They are reported below.

LU is the intended use for a specific land area by humans, that is, its socio-economic function.

LC is the biophysical cover observed on the Earth's surface, the type of superficial stratum of a specific area of land, including the vegetation, bare soil, open bodies of water and artificial surfaces that can be observed in the field and registered by orthophotos.

Both definitions are consistent with the Directive 2007/02/EC. Indeed, while the LC definition coincides with that of the Directive, in accordance with the LU definition, the classification of a territory should be based on the functional dimensions or the socio-economic intention and plan for the future, as stated by the Directive.

While biophysical evidence avoids subjective evaluations of LC, the attribution of LU classes is related to the interpretation of specific human activities. Therefore, LU attribution is inevitably conditioned by producers' needs. LU and LC are two very distinct aspects of the same informative context represented by a territory, and a twofold interpretation may be useful for a better understanding of transformation and/or persistence processes. Accordingly, the LU classification should not exclude the attribution of a LC class, even though the two characterizations are often confused with identical nomenclature.

LU and LC changes are dynamic processes that are closely connected to direct or indirect human activities. These changes are able, among other things, to influence the climate at a regional and global scale (Bonan 1997; Ramankutty and Foley 1998; Bounoua et al. 2002) and to impact the distribution of carbon sinks and sources (Brovkin et al. 1999). Knowledge of transitions between different categories of LU and LC is essential for addressing issues such as urban sprawl, loss of croplands and, more generally, all of the changes entailing the alteration of the balance and functionality of ecosystems. LC is indeed considered to be one of the essential climate variables in the framework of the Global Climate Observing System (GCOS 2003).

Land use is impossible to measure and classify with the direct use of remote sensing techniques. LU can only be classified through a cover interpretation based on ancillary information and operator skills. Finally, it should be mentioned that the main drawback of mapping methods, like the Corine Land Cover or Land Cover Classification System (Di Gregorio and Jansen 2005) is the presence of a minimum mapping unit (MMU). The MMU causes an underestimation of the extension of the most fragmented classes (like artificial and sealed areas) or linear classes (like road and railway infrastructure). Indeed, these classes are likely to attain patches with smaller sizes than the MMU and, as such, they frequently go undetected (Munafò and Tombolini 2014). Several attempts have been made to create more detailed maps by reducing the MMU. However, owing to technical and operational difficulties and budget limitations, the diffusion of these maps in Italy is usually restricted to a few small regions (Pulighe et al. 2013; Romano and Zullo 2013)

A possible solution to these issues may be the use of sample surveys based on point sampling schemes, usually referred to as inventories. Inventories can provide estimates of the LU, LC and their changes and, at the same time, provide estimates of the accuracy of the sampling strategy adopted to obtain these estimates. Consequently, inventories allow objective and scientifically sound comparisons of the estimates at different times. The possibility to assess the statistical accuracy, to frequently update and to substantially reduce the commission and omission errors suggests that the inventory approach is a valid and reliable alternative for LU, LC and LU/LC change assessments over time (Corona 2010; Corona et al. 2007).

The aim of this paper is to analyze LU change transitions in the Molise region (Central Italy) from 2000 to 2012 using the sample data obtained from the Italian Land Use Inventory (IUTI from the Italian acronym of *Inventario dell'Uso delle Terre d'Italia*). Molise represents an excellent case study, owing to its environmental and socio-economic characteristics, which render the area especially representative of the changes that have occurred at a national level. The analysis was performed as both a LU classification and through a new classification addressing LC. The results demonstrate that a comparison of the estimates from the two classifications may constitute a quick and effective instrument that is able to provide essential information to support land use planning, both for natural and semi-natural classes as well as for urban classes.

Methodology

Study area

The study area (Fig. 1) covers 446,051 ha. In accordance with the ISTAT (2013) classification scheme using altitude levels, the study area is almost equally partitioned between mountain areas (55 % of the territory) and hilly areas (44 %). The costal level, 40 km long, is partially urbanized. The presence of dunes and fragile ecosystems makes the Molise coast an important landscape and environmental resource. Moreover, the vast interface between the forest and agricultural systems renders the Molise area a representative example for analyzing transformations between natural and semi-natural classes. The two administrative provinces (Campobasso and Isernia) have different landscape characteristics and dynamics from both LU and LC perspectives. The province of Isernia lies partially within the Abruzzo, Lazio and Molise National Park, including mountainous areas such as the Matese and the Mainarde massif. The province of Campobasso is located along the Adriatic Sea. It is considerably more vulnerable to human impact, with a prevalence of intensive farming in the flattest area close to the coast and a high occurrence of natural grasslands and pastures in the inland. Even if human impacts may appear small in absolute terms, they are relevant in a socio-economic context, considering the negative demographic balance recorded in the last 20 years. The population size is of 312,686 inhabitants with a density of 70 ab/km^2, one of the lowest in Italy.

The IUTI sampling scheme

In order to implement a national greenhouse gas inventory, the Italian Ministry of Environment and Protection of Land and Sea promoted and realized the IUTI in the framework of the Extraordinary Plan of Environmental Remote Sensing. The Italian territory was covered by a network of 1,217,032 quadrats of 25 ha, in such a way that each quadrat contained at least a portion of this territory. Then, a point was randomly selected in each quadrat in accordance with the protocol of tessellation stratified sampling (TSS) (Fattorini 2014). Points that fell outside the Italian territory were classified in an additional class, referred to as "outside area". The large sample size adopted in the IUTI was due to the need for estimating LU and LU changes with adequate statistical accuracy, even estimating small changes that are likely to occur during brief temporal intervals (Corona et al. 2012). The results from the IUTI have been officially released for the years 1990, 2000 (partial) and 2008.

Land use and land cover classifications

A classification with a distinction between classes that is precise and univocal must necessarily be based on objective parameters. In most classification systems, a clear distinction between LU and LC is lacking. For example, in the case of the Corine Land Cover legend, LU and LC are often confused within non-homogeneous classes. This is the case with the LU class *artificial surfaces*, in which different LC classes coexist while remaining undetected due to the MMU. Among the current experiences of double classification, the Land Use/Cover Area frame statistical Survey (LUCAS) by Eurostat probably constitutes the most popular example (Martino and Fritz 2008). The aim is the production of both LU and LC statistics at a European scale. Similarly, in the present paper, a double classification is attempted as follows: the IUTI classification system is adopted for LU while the Italian National Institute for Environmental Protection and

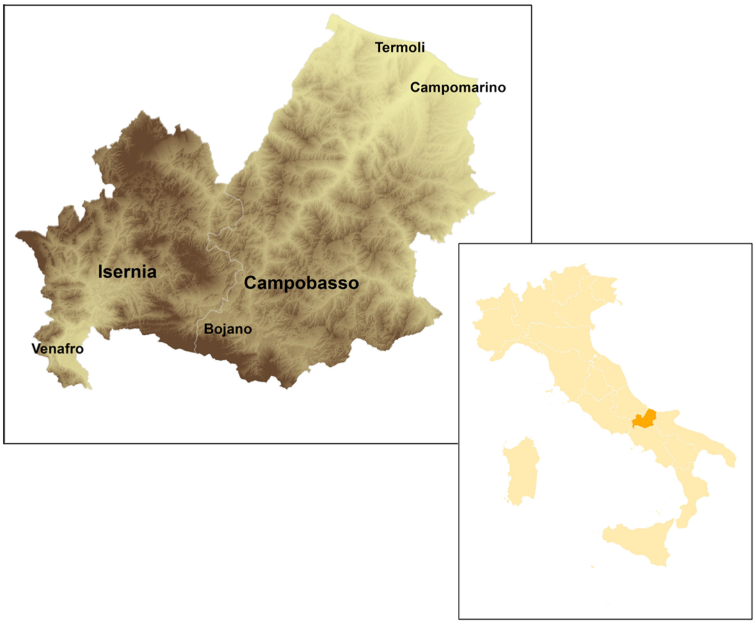

Fig. 1 The studied region of Molise

Research (ISPRA) system is adopted for LC. The discrimination between LU and LC classification systems is not easy, considering that sometimes a certain class can be attributed to both. Moreover, the LU classification is strictly dependent on the aim of the survey. This complication leads to a certain piece of land being classified relative to its "use" in multiple ways simultaneously (e.g. agricultural land used for recreational activities such as hunting or camping) or, alternately, during a specific time period (e.g. a reservoir used to provide water during the summer and to generate power during the winter) (Anderson et al. 1976). In our case, we used a methodological parameter to discriminate the LU and LC classification systems. In fact, the main difference attributable to the two selected inventories, as described in the following sections, is related to the portion of land and dimensional characteristics used by the operators during the photo-interpretation to classify the relative sample points. In the case of the LC classification, the area surrounding each sample point was not taken into account for its classification, as it can lead to underestimates of the more dispersed classes (Munafò et al. 2013). Moreover, LC could be seen as a component in the description of the landscape whereas LU could be seen as an attribute to characterize landscape units (Arnold et al. 2013). Conversely, a LU class was attributed to each sample point based on the characteristics of the surrounding area. Accordingly, the classification system refers to the characteristics of the sample points (without a physical dimension) in the case of LC and to the landscape pattern in which they are located in the case of LU. For example, given a sample point of a single building surrounded by forest, this would be classified as "building" by the LC classification and as forest by the LU one. In our case, the differences between LU and LC are further evidence of the classification misalignment demonstrated in Fig. 2.

IUTI land use classification

The IUTI LU classification system of the sampling points is based on the greenhouse reporting system introduced by the Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC 2003). The classification guidelines are codified by the Intergovernmental Panel on Climate Change (IPCC) with the aim of encouraging the construction of LU databases and harmonizing those that already exist.

The first level of classification adopts six LU categories: *forest land* (1), *cropland* (2), *grassland* (3), *wetland* (4), *settlements* (5) and *other lands* (6). The first level of classification is deepened, with hierarchical criteria, to second-level subcategories for forest land (1), cropland (2) and grassland (3) and to third-level ones for *permanent crops* (2.2) (see Table 1). Such a classification arises from the need to identify those portions of land that are of interest for the Kyoto Protocol reports as well as to integrate the results from the INFC, which defines

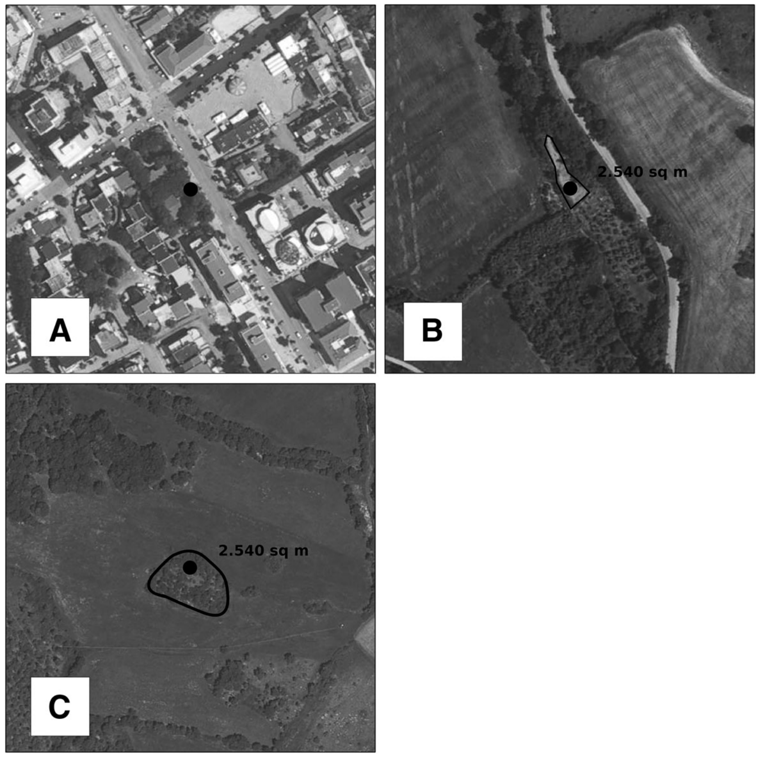

Fig. 2 Example showing the difference between LU and LC classifications, based on the use or the avoidance of a minimum mapping unit of 5000 m^2 (as described by the IUTI classification system). **a** LU class = settlement (5), LC class = trees in urban areas (31); **b** LU class = forest land (1.1), LC class = other permeable lands in natural areas (44); **c** LU class = cropland (2.1), LC class = trees in agricultural areas (32)

the macro categories of the inventory for woods and other woody areas on the basis of corresponding categories of FAO (2000).

In the original IUTI survey, the codification of sampling points has been carried out through photo-interpretation, identifying the homogeneous elements in which the points fall. Contextually, a verification of the minimum dimensional standards of reference is performed, considering the following criteria: (a) surface or extension greater or equal to 5000 m^2 and (b) width of the considered area greater or equal to 20 m. To distinguish between forests, other wooded lands and grasslands, the crown coverage of the vegetation layers is estimated (Marchetti et al. 2012), according to the FAO (2000) classification system. It should be noted that classes 4, 5 and 6 could be indiscriminately treated

Table 1 IUTI land use classification system

IPCC category Level I	IUTI category Level II	IUTI subcategory Level III	Code
1. Forest land	Woodland		1.1
	Wooded land temporarily unstocked		1.2
2. Cropland	Arable land and other herbaceous cultivations		2.1
	Permanent crops	Orchards, vineyards and nurseries	2.2.1
		Forest plantations	2.2.2
3. Grassland	Grassland, pastures and uncultivated herbaceous areas		3.1
	Other wooded lands		3.2
4. Wetlands	Marshlands and open waters		4
5. Settlements	Urban development		5
6. Other lands	Bare rock and sparsely vegetated areas		6

as LU or LC classes. The confusion and hybridization of the two classifications shows marked analogies with the system adopted by Anderson et al. (1976) for the interpretation of data collected through remote sensing at various scales and various resolutions, in which the authors underline the differences between LU and LC. In fact, in the present paper, the authors describe a classification system aimed at reducing the gap between "people-oriented" and "resource-oriented" classification systems, thus offering a basis to build a more exhaustive and flexible instrument for LU and LC monitoring. This system was based on different hierarchical classification levels aimed at investigating both LU and LC, depending on the purpose of the monitoring activities, but at the same time, allowing for aggregation of these data into upper and more generalized (and hybrid) levels of classifications.

ISPRA land cover classification

In this research, a new visual interpretation and classification was performed for LC based on a nomenclature previously used by ISPRA for the National Land Take Monitoring Network (Munafò et al. 2015). This classification is based on the definition of *land take*, which is defined as the transition from a non-artificial (unsealed) to an artificial (sealed) LC (see Table 2). The cover transformation occurs through sealing processes with waterproof material (soil sealing) or other degradation processes of the substratum (extraction activities, compaction, contamination, etc.) (Munafò and Tombolini 2014). In these cases, photo-interpretation does not require a size assessment of the surrounding area but just involves a visual interpretation of the sampling points, maintaining a constant scale of visualization. The advantage of this type of classification lies in the rapid process of photo-interpretation as well as the ability to capture artificial sampling points. For natural and semi-natural components, this classification can also be integrated, compared or validated using vegetation indexes, while for the impervious matrix, integration, comparison or validation can be performed by means of high-resolution layers made available by the GMES Copernicus Program (EEA 2013), in which the physical meaning of cover matches the definition of the sealed layers used in this legend.

The first level of the classification is based on the separation between *sealed/consumed* and *unsealed/non-consumed* classes, explicitly expressing the objective of the ISPRA monitoring network to evaluate land takes. The second level presents a close and specific examination of the sealed/consumed classes, with 11 subclasses of artificial cover, including point and linear elements, and of the unsealed/non-consumed classes, with 14 subclasses of natural and semi-natural covers. LC knowledge is an essential input for climactic and hydrological models but is not directly usable for most policy and planning objectives (both in urban and natural areas) where the LU is the most adequate system of classification (Comber 2007).

Estimation

In order to estimate the sizes of the LU and LC classes in the Molise region and the sizes of their changes from 2000 to 2012 and between classes, the IUTI sampling points have been classified in accordance with Tables 1 and 2 using photo-interpretation of the years 2000 and 2012. The classification for 2000 was performed from the TerraItaly 2000 digital colour aerial orthophotos with a spatial resolution of 1 m, whereas the classification for 2012 was performed from the AGEA 2012 digital colour aerial orthophotos with a spatial resolution of 0.5 m.

From the TSS protocol performed during the IUTI, Molise was covered by a network of $N = 18{,}341$ quadrats. Each quadrat contained at least a portion of the Molise territory. The total area of the network was $Q = 458{,}525$ ha, against the real area of the Molise region of $A = 446{,}051$ ha. The difference of 12,474 ha represents the outside area class, i.e. the portion of the coverage grid that was outside the administrative boundary of Molise. Out of the 18,341 points selected in each quadrat of the grid, 17,737 (96.7 %) fell within the administrative boundary of Molise and were adopted to estimate the extensions of LU and LC classes and their changes. The remaining 604 points (3.3 %) fell outside of the Molise boundary and were classified as outside area.

The size of any LU or LC class or of any transformed territory from one class to another is denoted by a. As customary in point sampling (Fattorini et al. 2004), a is estimated as follows:

$$\hat{a} = Qp \tag{1}$$

where p is the fraction of points falling within the class or within the transformed territory, i.e. $p = n/N$, whereas n denotes the number of sample points falling within the class or the transformed territory out of the N points

Table 2 ISPRA land cover classification system

IUTI land cover level I		IUTI land cover level II
Sealed/consumed	1	11. Buildings
		12. Paved roads
		13. Dirt roads
		17. Service areas and other dirt areas
		18. Greenhouses
		19. Airport and ports
		20. Impervious areas and sports fields
		21. Train station
		22. Other impervious surface
		23. Solar fields
		24. Mining areas, landfills and construction sites
Unsealed/non-consumed	0	31. Trees in urban areas
		32. Trees in agricultural areas
		33. Trees in natural areas
		34. Arable lands
		35. Grassland/pastures
		36. Water bodies
		37. River bed
		38. Wetlands (marshes and ponds)
		39. Rocks/beaches/dunes
		40. Ice or snow covered surfaces
		41. Permeable sports fields
		42. Other permeable lands in urban areas
		43. Other permeable lands in agricultural areas
		44. Other permeable lands in natural areas
N.V.		−998. Unclassified
		−999. Sea

selected within quadrats. Accordingly, p actually represents the estimated portion of the area covered by the class or by the transformed territory with respect to the network size Q, rather than with respect to the region size A.

It has been proven that under TSS, $\hat{a}$ is an unbiased and asymptotically (N large) normal estimator of the true size of a with a variance Var($\hat{a}$) that can be conservatively estimated as follows (Fattorini et al. 2004):

$$\hat{V} = Q^2 \frac{p(1-p)}{N-1} \quad (2)$$

Practically speaking, under TSS, $\hat{V}$ tends to overestimate the actual variance; i.e. it tends to provide a smaller accuracy than the true one, thus avoiding the dangerous occurrence of over-evaluating the accuracy. Obviously, from the variance estimator $\hat{V}$, it is possible to obtain the standard error estimator SE $= \hat{V}^{1/2}$ and the relative standard error estimator RSE $= SE/\hat{a}$. From Eqs. (1) and (2), the relative standard error estimator can be written as follows:

$$\text{RSE} = \sqrt{\frac{1-p}{p(N-1)}} \quad (3)$$

This shows that the relative standard error estimates turn out to be high when the portion estimate p is small.

Moreover, it has been shown that under TSS and with a sufficiently large N, Var($\hat{a}$) is a $K/N^{(1+\delta)}$ type, where K and δ are the unknown positive constants depending on the characteristics of the region under study (Barabesi and Franceschi 2011). Practically speaking, under TSS, the variance decreases at a power of N whereas it is a well-known result that if the points were allocated completely at random, the variance would be K/N; i.e. it would decrease slower with N. Accordingly, the estimators achieved by sampling one point at random per quadrat are super-efficient compared with those achieved by sampling the N points completely at random over the study area. This result provides a theoretical rationale for using TSS.

Because p in Eq. (1) is an estimate of the portion of the area covered by the class or by the transformed territory with respect to the network size Q, the sum of the size estimates for all of the possible classes does not give the size of the study area A (as it should be expected) but it gives $\hat{A} = Qp_A$, where p_A is the fraction of points falling within the study area outside of the N. In the same way, the sum of the portion estimates does not give 1 but it generates p_A. In order to achieve estimates summing to A, Fattorini et al. (2006) proposed to correct the original size estimates by the factor $\hat{A}/A$. This correction entails some methodological complexities. The corrected estimators are no longer unbiased (even if the bias is usually negligible), their variances are no longer known and can only be approximated, whereas their estimation becomes a cumbersome task from a computational point of view (see e.g. Corona et al. 2012). Moreover, from a practical point of view, $\hat{A}$ should be considered as usually very near to A, so that the factor $\hat{A}/A$ is usually very close to 1, thus providing negligible corrections to the original estimates. Practically speaking, the correction introduces a nuisance without providing relevant changes to the estimates. In the case of Molise, $p_A = 0.967$, from which $\hat{A} = Qp_A = 443,425$ ha. Thus, the correction factor $A/\hat{A}$ turns out to be 1.006, which would provide irrelevant changes to the estimates. In accordance with these considerations, corrections are avoided throughout this paper.

From Eq. (3), it is possible to achieve a condition where the relative standard error estimate is smaller than the maximum level of inaccuracy (r) allowed in the estimation. Solving the inequality RSE $\leq r$ with respect to p, it follows that

$$p \geq \frac{1}{r^2(N-1)+1}$$

As a rule of thumb, we determined that an acceptable level of precision for the size estimates should give a relative error smaller than $r = 0.20$. Thus, for the Molise estimation performed from $N = 18,341$ sampling points, the size estimates should be at least 0.14 % of the network surface, corresponding to approximately 625 ha. Moreover, because any point entails 25 ha of the size estimate, it follows that any size estimate should be based on at least 25 sampling points falling within the class in the transformed territory. Accordingly, throughout this paper, estimates smaller than 625 ha are considered unreliable.

Finally, if a_1 and $\hat{V}_1$ denote the size and variance estimates achieved for a given class in 2000 and a_2 and $\hat{V}_2$ represent those achieved in 2012, it is possible to assess whether a real variation in the true sizes occurs. Indeed, from the normality of the size estimator under TSS, if no real variation has occurred between the two years, the quantity

$$z = \frac{a_2 - a_1}{\left(\hat{V}_1 + \hat{V}_2\right)^{1/2}}$$

is approximately distributed as a standard normal variable. From the standard normality of z, the significance of the test turns out to be smaller than $2 - 2\Phi(|z|)$, where Φ denotes the standard normal distribution function. Small significances, usually smaller than 0.05, obviously cause a rejection of the hypothesis of no variation.

Results

Land use and land cover estimates

Tables 3 and 4 report the size estimates of LU and LC classes, respectively, achieved in the Molise territory in 2000 and 2012. The estimates of the relative standard errors are satisfactory, except for the small-sized classes. Regarding the LU classes, the RSEs vary from 0.78 to 27.73 % and only the classes *wooded land temporarily unstocked* (1.2), *forest plantations* (2.2.2) and other lands (6) are greater than 20 %. Regarding the LC classes, the estimated accuracy is less satisfactory due to the small size of most classes. The RSEs range from 0.84 to 100 % (for those classes containing a single sample point). For the classes 17, 19–23, 31, 38 and 41, the RSEs are greater than 20 %.

Regarding LU, the first level of classification of the Italian territory is mainly characterized by the presence of cropland (2), whose estimated sizes were 238,975 ha in 2000 (52.12 % of the network surface) and 225,375 ha in 2012 (49.16 %); forest land (1) had estimated sizes of 151,425 ha (33.04 %) in 2000 and 160,960 ha (35.1 %) in 2012, and grassland (3) had estimated sizes of 38,800 ha (8.46 %) in 2000 and 40,600 ha (8.85 %) in 2012. Regarding the second level of classification, *arable land and other herbaceous cultivations* (2.1) was the largest class, with estimated sizes of 215,425 ha (46.98 % of the network surface) in 2000 and 198,675 ha (43.33 %) in 2012, followed by *woodland* (1.1) with 151,100 ha (32.95 %) in 2000 and 160,050 ha (34.91 %) in 2012. All the temporal changes that occurred from 2000 to 2012 are highly significant, with the exceptions of forest plantations (2.2.2); *grassland, pastures and uncultivated herbaceous areas* (3.1); *wetlands* (4); and other lands (6). However, for the classes 3.1, 4 and 6, non-significance is probably due to the small changes that occurred between 2000 and 2012; for class 2.2.2, a non-negligible change occurred but was not sufficiently greater than that attributable to sampling variability.

Regarding the LC classes, the greatest class in the Molise region was *arable lands* (34), with estimate sizes of 199,775 ha (43.57 % of the network surface) in 2000 and 185,575 ha (40.47 %) in 2012, with a relevant loss of 14,200 ha (−7.1 %), which represents the greatest decrease among the LC classes. The change in arable lands (34) turns out to be highly significant, along with the changes in *trees in natural areas* (33) and *trees in agricultural*

Table 3 Size estimates of IUTI land use classes for the years 2000 and 2012 in the Molise region, their temporal changes and their corresponding statistical significance

IUTI land use category/subcategory	*p* (%) 2000	$\hat{a}$ (ha) 2000	RSE (%) 2000	*p* (%) 2012	$\hat{a}$ (ha) 2012	RSE (%) 2012	Difference (ha)	Significance
Woodland	32.95	151,100	1.05	34.91	160,050	1.01	8950	0.00007[a]
Wooded land temporarily unstocked	0.09	425	24.24	0.20	900	16.65	475	0.00900[a]
Arable land and other herbaceous cultivations	46.98	215,425	0.78	43.33	198,675	0.84	−16,750	0.00000[a]
Orchards, vineyards and nurseries	5.06	23,200	3.20	5.70	26,125	3.00	2925	0.00677[a]
Forest plantations	0.08	350	26.72	0.13	575	20.84	225	0.13878
Grassland, pastures and uncultivated herbaceous areas	6.26	28,700	2.86	5.89	27,025	2.95	−1675	0.14311
Other wooded lands	2.20	10, 100	4.92	2.96	13, 575	4.23	3475	0.00000[a]
Wetlands	0.51	2350	10.29	0.50	2300	10.40	−50	0.88312
Settlements	2.50	11,450	4.61	3.03	13,875	4.18	2425	0.00200[a]
Other lands: bare rock and sparsely vegetated areas	0.07	325	27.73	0.07	325	27.73	0	1.00000

[a] Significance smaller than 0.05

areas (32). All of the other changes in the LC classes were not significant, mostly because of the sampling variability, which deteriorates the accuracy of the estimates for small-sized classes. As will be subsequently shown in Tables 7 and 8, the decrease in arable lands (34) is mostly attributable to the transition towards trees in agricultural areas (32). The size estimates for this class vary from 24,825 ha (5.41 %) in 2000 to 27,025 ha (5.89 %) in 2012, with an estimated increase of 8.86 %. Another significant result is the increase in trees in natural areas (33), which constitutes the second greatest LC class. Its size estimates changed from 142,000 ha (30.97 %) in 2000 to 151,600 ha (33.06 %) in 2012, with an estimated increase of 9600 ha (+6.76 %).

Land use and land cover change analysis

The analysis of LU and LC changes is based on the construction of a transition matrix, also known as a cross-tabulation matrix (Pontius et al. 2004). It allows for straightforward analysis, in which the rows display the classes in the year 2000 and the columns display the classes in the year 2012 in such a way that the individual transitions that occurred between the two times can be easily identified. Tables 5 and 6 represent the transitions that occurred between the LU classes, whereas Tables 7 and 8 provide those that occurred between the LC classes. In these tables, estimated changes greater than 625 ha (0.14 % of the network surface), i.e. with RSEs smaller than 20 %, are highlighted in grey as reliable estimates, with respect to those based on less than 25 sampling points, which are affected by a sampling variability greater than 20 %.

Land use changes

The transition matrices of Tables 5 and 6 show that the greatest variation from 2000 to 2012 was the highly significant reduction estimated for arable land and other herbaceous cultivations (2.1). The decrease is mainly due to an increase of 5475 ha (1.19 % of the network surface) estimated for *orchards, vineyards and nurseries* (2.2.1) and an increase of 5350 ha (1.17 %) estimated for grassland, pastures and uncultivated herbaceous areas (3.1). These two variations are the greatest that occurred between LU classes. In turn, the grassland, pastures and uncultivated herbaceous areas (3.1) class was affected by the third greatest LU variation, with an

Table 4 Size estimates of ISPRA land cover classes for the years 2000 and 2012 in the Molise region, their temporal changes and their corresponding statistical significance

Land cover category	p (%) 2000	$\hat{a}$ (ha) 2000	RSE (%) 2000	p (%) 2012	$\hat{a}$ (ha) 2012	RSE (%) 2012	Difference (ha)	Significance
12. Paved roads	1.34	6125	6.35	1.4	6425	6.19	300	0.5897
13. Dirt roads	0.43	1975	11.23	0.44	2000	11.16	25	0.93665
17. Service areas and other dirt areas	0.13	575	20.84	0.17	775	17.95	200	0.27595
19. Airports and ports	0	0	–	0.01	25	100.00	25	0.31731
20. Impervious areas and sports fields	0.01	25	100	0.02	75	57.73	50	0.31729
21. Train stations	0.03	150	40.82	0.03	150	40.82	0	1
22. Other impervious surfaces	0.13	600	20.4	0.2	900	16.65	300	0.12103
23. Solar fields	0.01	25	100	0.03	125	44.72	100	0.10244
24. Mining areas, landfills and construction sites	0.26	1175	14.57	0.35	1625	12.38	450	0.08848
31. Trees in urban areas	0.03	150	40.82	0.03	125	44.72	−25	0.763
32. Trees in agricultural areas	5.41	24,825	3.09	5.89	27,025	2.95	2200	0.04665[a]
33. Trees in natural areas	30.97	142,000	1.1	33.06	151,600	1.05	9600	0.00002[a]
34. Arable lands	43.57	199,775	0.84	40.47	185,575	0.90	−14,200	0.00000[a]
35. Grassland/pastures	4.98	22,850	3.22	4.9	22,450	3.25	−400	0.69986
36. Water bodies	0.33	1500	12.89	0.34	1575	12.58	75	0.78643
37. River bed	0.27	1225	14.27	0.31	1425	13.23	200	0.43649
38. Wetlands (marshes and ponds)	0.03	150	40.82	0.03	125	44.72	−25	0.763
39. Rocks/beaches/dunes	0.26	1200	14.42	0.22	1025	15.60	−175	0.45755
41. Permeable sports fields	0.02	75	57.73	0.02	100	50.00	25	0.70544
42. Other permeable lands in urban areas	0.8	3675	8.21	0.92	4200	7.68	525	0.23471
43. Other permeable lands in agricultural areas	2.09	9575	5.06	2.19	10,050	4.93	475	0.49303
44. Other permeable lands in natural areas	4.67	21,425	3.34	4.61	21,125	3.36	−300	0.76581

[a] Significance smaller than 0.05

Table 5 Matrix of the size estimates of LU changes that occurred from 2000 to 2012 in the Molise region (values in hectares)

		2012										
		Woodland	Wooded land temporarily unstocked	Arable land and other herbaceous cultivations	Orchards, vineyards and nurseries	Forest plantations	Grassland, pastures and uncultivated herbaceous areas	Other wooded lands	Wetlands	Settlements	Other lands	Total
2000	Woodland	*149.325*	*900*	375	100	–	75	75	75	175	–	151.100
	Wooded land temporarily unstocked	425	–	–	–	–	–	–	–	–	–	425
	Arable land and other herbaceous cultivations	*3.575*	–	*196.125*	*5.475*	250	*5.350*	*2.500*	–	*2.150*	–	215.425
	Orchards, vineyards and nurseries	*700*	–	*1.575*	*20.525*	–	75	150	–	175	–	23.200
	Forest plantations	–	–	25	–	325	–	–	–	–	–	350
	Grassland, pastures and uncultivated herbaceous areas	*2.075*	–	250	25	–	*21.250*	*4.800*	25	275	–	28.700
	Other wooded lands	*3.875*	–	300	–	–	–	*5.850*	–	75	–	10.100
	Wetlands	–	–	25	–	–	25	125	*2.150*	25	–	2.350
	Settlements	75	–	–	–	–	250	75	50	*11.000*	–	11.450
	Other lands	–	–	–	–	–	–	–	–	–	325	325
	Total	160.050	900	198.675	26.125	575	27.025	13.575	2.300	13.875	325	443.425

Values in italics refer to change estimates greater than 625 ha, with an estimated standard error smaller than 20 %

Table 6 Matrix of size estimates of LU changes that occurred from 2000 to 2012 in the Molise region (values as percentages of the network surface)

		2012										
		Woodland	Wooded land temporarily unstocked	Arable land and other herbaceous cultivations	Orchards, vineyards and nurseries	Forest plantations	Grassland, pastures and uncultivated herbaceous areas	Other wooded lands	Wetlands	Settlements	Other lands	Total
2000	Woodland	*32.57*	*0.20*	0.08	0.02	–	0.02	0.02	0.02	0.04	–	32.95
	Wooded land temporarily unstocked	0.09	–	–	–	–	–	–	–	–	–	0.09
	Arable land and other herbaceous cultivations	*0.78*	–	*42.77*	*1.19*	0.05	*1.17*	*0.55*	–	*0.47*	–	46.98
	Orchards, vineyards and nurseries	*0.15*	–	*0.34*	*4.48*	–	0.02	0.03	–	0.04	–	5.06
	Forest plantations	–	–	0.01	–	0.07	–	–	–	–	–	0.08
	Grassland, pastures and uncultivated herbaceous areas	*0.45*	–	0.05	0.01	–	*4.63*	*1.05*	0.01	0.06	–	6.26
	Other wooded lands	*0.85*	–	0.07	–	–	–	*1.28*	–	0.02	–	2.20
	Wetlands	–	–	0.01	–	–	0.01	0.03	*0.47*	0.01	–	0.51
	Settlements	0.02	–	–	–	–	0.05	0.02	0.01	*2.40*	–	2.50
	Other lands	–	–	–	–	–	–	–	–	–	0.07	0.07
	Total	34.91	0.20	43.33	5.70	0.13	5.89	2.96	0.50	3.03	0.07	96.71

Values in italics refer to change estimates greater than 0.14 %, with an estimated standard error smaller than 20 %

Table 7 Matrix of size estimates of LC changes that occurred from 2000 to 2012 in the Molise region (values in hectares)

		2012	
		artificial domain	natural and semi-natural domain
2000	artificial domain	300 ha 0.07% RSE 28.9%	400 ha 0.09% RSE 25.0%
	natural and semi-natural domain	2,425 ha 0.53% RSE 10.1%	33,625 ha 7.33% RSE 2.6%

The highlighted cells in grey refer to change estimates greater than 625 ha, with an estimated standard error smaller than 20 %

estimated loss of 4800 ha (1.08 %) transitioned into *other wooded lands* (3.2). The second greatest variation from 2000 to 2012 was the highly significant increase estimated for woodland (1.1), which turns out to be the most dynamic class. The increase was mainly due to the reduction of 3575 ha (0.78 %) in arable land and other herbaceous cultivations (2.1); the reduction of 2075 ha (0.45 %) in grassland, pastures and uncultivated herbaceous areas (3.1); and the reduction of 3875 ha (0.85 %) in other wooded lands (3.2).

Table 8 Matrix of size estimates of LC changes that occurred from 2000 to 2012 in the Molise region (values as percentages of the network surface)

	LU classes	LC classes	LU (%)	LC (%)	LU (ha)	LC (ha)	absolute differences (%)	absolute differences (ha)	significance
Forest lands and forest plantations	1.1- 1.2- 2.2.2	33	35.23	33.06	161,525	151,600	2.16	9,925	0.00001(*)
Arable lands	2.1	34- 43	43.33	42.66	198,675	195,625	0.67	3,050	0.19821
Orchards, vineyards and nurseries	2.2.1	32	5.82	5.89	26,700	27,025	0.07	325	0.77257
Grasslands and other wooded lands	3.1- 3.2	35- 44	8.85	9.50	40,600	43,575	0.65	2,975	0.03140(*)
Wetlands	4	36- 37- 38	0.50	0.68	2,300	3,125	0.18	825	0.02464(*)
Settlements and artificial lands	5	From 11 to 24	3.03	3.71	13,875	17,025	0.69	3,150	0.00027(*)
Other lands	6	39- 40- 41- 42	0.07	1.16	325	5,325	1.09	5,000	0.00000(*)

The cells highlighted in grey refer to change estimates greater than 0.14 %, with an estimated standard error smaller than 20 %

Land cover changes

In the first level of LC classification, the size estimate of sealed/consumed classes (11–24) was 17,025 ha (3.71 % of the network surface) in 2012, against an estimate of 15,000 ha (3.27 %) in 2000. The increase of 2025 ha (0.44 %) occurred mostly (70 %) in arable lands (34). From the size estimates of the second-level LC classes, a non-negligible increase, even if not significant, occurred in the size estimates of *buildings* (11), which varied from 4350 ha (0.95 %) in 2000 to 4925 ha (1.07 %) in 2012, reaching 29 % of the size estimate of the sealed/consumed surface. Overall, the size estimate of changes that occurred for LC classes from 2000 to 2012, i.e. the total estimate minus the estimates of the unchanged surfaces (diagonal of the matrix in Table 7), was 36,725 ha (8.01 % of the network surface).

By partitioning the matrices of Tables 7 and 8 into four submatrices, the upper-left submatrix (denoted by I) represents transitions between the sealed/consumed classes (11–24), i.e. transitions within the artificial domain, whereas the lower-right submatrix (denoted by III) represents transitions between the unsealed/non-consumed classes (31–44), i.e. within the natural and semi-natural domain. Obviously, the remaining upper-right submatrix (denoted by II) represents the transition from the artificial domain to the natural and semi-natural domain and the reverse is true for the lower-left submatrix (denoted by IV). Table 9 presents a 2 × 2 matrix containing the estimates of size and the corresponding proportions with respect to the network surface of the total changes that occurred within and between the two domains. From the estimates in Table 9, it is apparent that the changes were more relevant within the natural and semi-natural domain. Indeed, the first nine greatest changes estimated from 2000 to 2012 belong to submatrix III. The greatest estimated change was the transition from *other permeable lands in natural areas* (44) to trees in natural areas (33), which turns out to be 7350 ha (1.60 %).

Table 9 Matrix of the size estimates of LC changes that occurred from 2000 to 2012 within and between artificial, natural and semi-natural domains in the Molise region (values in hectares and as percentages of the network surface)

		2012	
		Artificial domain	Natural and semi-natural domain
2000	Artificial domain	300 ha 0.07 % RSE 28.9 %	400 ha 0.09 % RSE 25.0 %
	Natural and semi-natural domain	2425 ha 0.53 % RSE 10.1 %	33,625 ha 7.33 % RSE 2.6 %

Interpreting the transition phenomena is facilitated by an analysis of the LC transitions. For example, as shown in Fig. 3, the decreased estimate for arable lands (34) was mostly due to an estimated increase in trees in agricultural areas (32) and *grassland/pastures* (35), whereas only a small loss was due to land take. Indeed, from Table 9, the land take increase from 2000 to 2012 is estimated as 2425 ha (0.53 %), which is far smaller than the transitions observed towards natural and semi-natural classes, which are estimated to be 33,650 ha (7.33 %).

In order to further explore the transitions within the natural and semi-natural domain, two subsets of classes were considered in this domain: subset 3A, comprised of the classes *trees in urban areas* (31), trees in agricultural areas (32), trees in natural areas (33), arable lands (34) and grassland/pastures (35), which may be viewed as the classes referring to deforestation and cultivation abandonment, and subset 3B, comprised of the classes *permeable sports fields* (41), *other permeable lands in urban areas* (42), *other permeable lands in agricultural areas* (43) and other permeable lands in natural areas (44), which may be viewed as the classes referring to reforestation and new land reclamation and arboriculture on rural and natural lands. Transitions from 3A to 3B and vice versa identify the phenomena of reforestation and deforestation, i.e. the trends of LC changes between planted and non-planted areas. However, such terminology is more correctly referred to as a LU rather than LC classification. The analysis of permanencies and changes within these two subsets reveals a strong dynamic of change in the woody areas, agricultural fields and grasslands.

Combining and comparing the LU and LC data

In order to compare LU and LC classifications, Table 10 reports a first attempt at aggregation, carried out at the second level of the LU and LC classes for the year 2012. The aggregation indicates good correspondence between the LU and LC estimates only for arable lands and orchards, vineyards and nurseries, whose

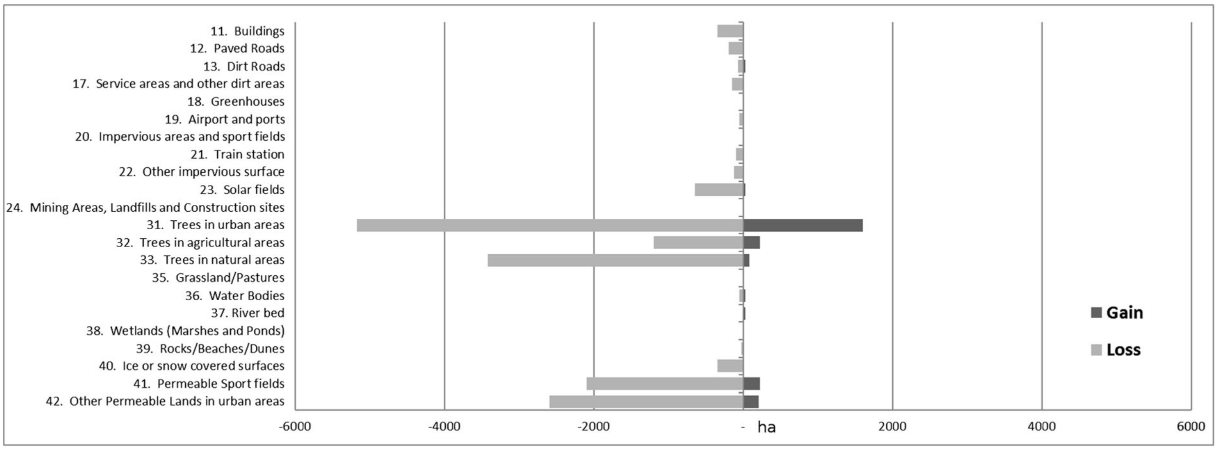

Fig. 3 Estimates of transitions from and to the land cover class arable lands between 2000 and 2012

differences are not significant; i.e. they may be attributable to the sampling variability of the adopted estimators rather than to actual differences in the LU and LC surfaces. In the other cases, differences between the LU and LC estimates are highly significant, mainly for *forest lands and forest plantations*, *settlements and artificial lands* and other lands. In the case of forest lands and forest plantations, the significant difference between LU and LC classifications is 2.16 % and is mainly due to the LU parameters of classification for forest land (1), such as the height of mature trees, the crown coverage, the extension and the minimum width of the woods, which are not considered in the LC classification. In the case of *grasslands and other wooded lands*, the significant difference is probably due to the LU class other wooded lands (3.2), which is difficult to compare as its LU definition is impossible to connect with the LC classification. Indeed, the 82 % of points falling in class 3.2 are classified in the LC class other permeable lands in natural areas (44), which may be considered as a transitional class between natural and artificial stages in which it is difficult to capture the tree vegetation because of the low density or small dimension of the crowns.

Furthermore, through a combination of LU and LC data, it is possible to better characterize and deeply understand the processes and dynamics occurring within the study area. For example, from the repartitioning of the sampling points classified in 2012 as settlements (5) among the LC classes of Table 2, 31.9 % fall in *unsealed/non-consumed classes* (31–44) and most of them (approximately 86 %) fall into other permeable lands in urban areas (42) (Fig. 4). This result provides insight into the density and the actual imperviousness of urban areas. The greater the urban extension classified as unsealed/non-consumed, the greater is its degree of permeability, due to a lesser density of buildings and infrastructures. The consequent increase of greater open spaces and surfaces surely provides important ecosystem services.

Discussion

The results underscore the polarization of LU and LC changes that are attributable mainly to the following: (a) natural surface recolonization in high hilly and mountainous areas, woods and other wooded lands, according to vegetation stages; (b) a strong dynamism between the different LC classes attributable to the natural and semi-natural domain; (c) the urban sprawl in lower hills and plains, mainly close to the largest urban and productive centres of the region; and (d) transitions that are mostly due to decreased croplands, natural grassland and pastures, although for a different reason and in a different manner (Marchetti et al. 2013). Despite the low percentage of the involved classes (though the relative change is comparable to the one for natural and semi-natural classes), the results confirm the phenomena of urban sprawl as one of the three main causes of LU change, which acts directly on the urban fringe and indirectly on the rural landscape, fragmenting arable lands and forests (Salvati et al. 2012).

In sum, the Molise region proves to be quite resistant to LU and LC changes, with 8.01 % of the network surface affected by LC changes and 7.97 % by LU

Table 10 Comparison of the estimates achieved for LU and LC aggregated categories in 2012, their differences and their corresponding significance

	LU classes	LC classes	LU (%)	LC (%)	LU (ha)	LC (ha)	Absolute differences (%)	Absolute differences (ha)	Significance
Forest lands and forest plantations	1.1 and 1.2–2.2.2	33	35.23	33.06	161,525	151,600	2.16	9925	0.00001[a]
Arable lands	2.1	34–43	43.33	42.66	198,675	195,625	0.67	3050	0.19821
Orchards, vineyards and nurseries	2.2.1	32	5.82	5.89	26,700	27,025	0.07	325	0.77257
Grasslands and other wooded lands	3.1 and 3.2	35–44	8.85	9.50	40,600	43,575	0.65	2975	0.03140[a]
Wetlands	4	36–38	0.50	0.68	2300	3125	0.18	825	0.02464[a]
Settlements and artificial lands	5	11–24	3.03	3.71	13,875	17,025	0.69	3150	0.00027[a]
Other lands	6	39–42	0.07	1.16	325	5325	1.09	5000	0.00000[a]

[a] Significance smaller than 0.05

changes. It is worth noting that while at a national level, the urban area in 2008 is estimated as 7.6 % of the national territory and the estimate in 2012 in the Molise region turns out to be 3.03 % of the network surface in terms of the *settlement* (5) LU class and 3.72 % of the sealed/consumed LC classes. These results are consistent with those achieved in other LU/LC inventories, such as LUCAS (2.54 % in 2012, based on 312 sampling points) and ISPRA (3.6–4.1 % in 2012, based on 1996 sampling points). From 2000 to 2012, soil sealing in the Molise region is estimated to be equal to 2025 ha (+0.44 %). Most of the soil sealing was due to the decrease in agricultural lands (34 and 43 LC classes), and a smaller portion was due to the decrease in woodlands, grasslands and pastures (classes 33 and 35). These estimates are consistent with those achieved by IUTI and other sample surveys performed at a national level (Munafò et al. 2013). Furthermore, while urban growth of 0.53 % of the network surface and 21.18 % with respect to the 2000 estimate were consistent with the Italian trend (Marchetti et al. 2013), it turns out to be anomalous with respect to the negative demographic balance observed from 2000 to 2012 in the Molise region (Sallustio et al. 2013).

The comparison between the LU and LC estimates indicates that, among the proposed seven matching classes, they significantly differed in five classes. Particularly, the differences were more significant for comparative classes showing a large difference between the LU and LC concepts (e.g. forest lands and forest plantations and grasslands and other wooded lands), whether they were less consistent for those classes alternatively considered LU or LC classes (e.g. arable lands). In particular, the artificial and agricultural surfaces can surely be considered as LC classes owing to the physiognomic attributes of the landscape objects (shape, size, colour, texture) and their reciprocal relationships. However, from a similar logical process, they can also be considered as LU classes (Feranec et al. 2007). Indeed, the size estimates from the LU and LC class aggregation regarding arable lands indicate a small, non-significant disagreement. The LU classification shows an estimate slightly greater than that achieved from the LC classification, with a non-significant difference of 3050 ha (0.67 % of the network surface). A similar difference of 3150 ha (0.69 %) was found between the estimates of the LU and LC classes attributable to settlements and artificial lands, even if, in this case, these classes are much smaller than agricultural

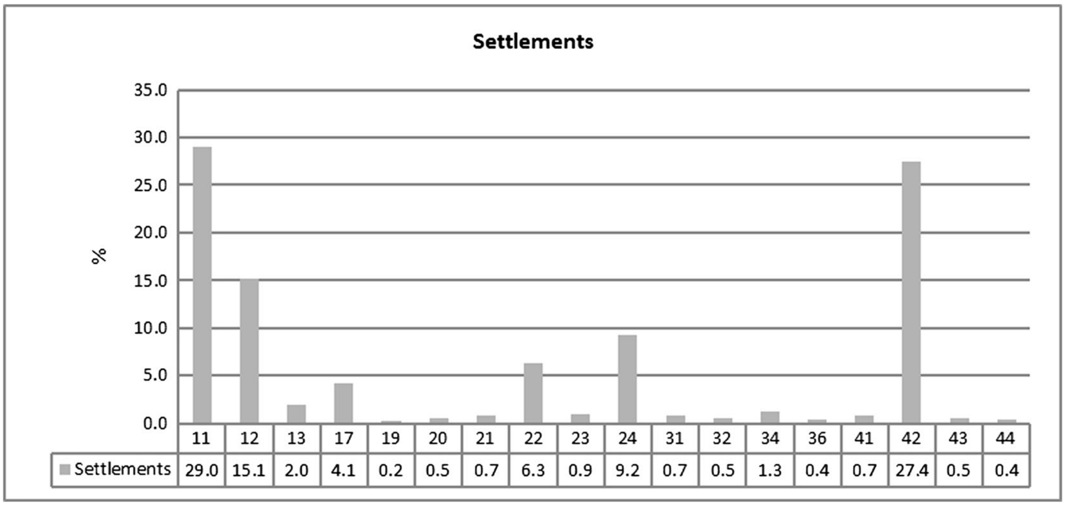

Fig. 4 Repartitioning of the size estimate of the land use class settlements into land cover class estimates (values as percentages of the size estimate of settlements)

surfaces, such that the difference turns out to be highly significant.

Even though LU and LC represent two distinct aspects, they are closely interconnected, influencing each other. Relations between LU and LC can be determined by means of a joint analysis. MMU is a typical parameter for LU classifications, and it affects the estimates of phenomena such as soil sealing due to the fragmentation and pulverization of the new urban fabric, which constitutes a widespread trend in Molise as well as in other Italian regions (Romano and Zullo 2013). This is at once apparent from the size estimate achieved for the LU class settlements (5), which turns out to be of 13,875 ha (3.03 % of the network surface) and is lower than the total estimate of the LC classes sealed/consumed (11–24), which turns out to be of 17,025 ha (3.72 % of the network surface). Despite the inclusion of unsealed urban areas with recreational functions (e.g. sports fields and urban parks) in the settlements (5) LU class, this comparison shows how the LC classification is more suitable for identifying those artificial surfaces that, although not considered urban in terms of the LU, surely have a similar role from an ecological and functional point of view (e.g. soil sealing).

Regarding the combined use and interpretation of the LU and LC estimates, with specific regard to the expansion of urban areas, is helpful for deeper analysis of the urbanization processes. Indeed, compact settlements correspond to high values of artificial LC (sealed) and to low values of artificial LU. In a similar way, highly scattered and fragmented settlements correspond to low values of artificial LC and to high values of artificial LU. The estimates of settlement density will play a key role in future urban planning, particularly in the context of urban shrinkage (Haase et al. 2014), which is considered as an important issue especially in Europe (Turok and Mykhnenko 2007; Kabisch and Haase 2011). In fact, the availability of unsealed spaces in urban (*terrain vague*) and peri-urban areas (*vacant lands/derelict lands*) offers a great potential to "re-create", enhance and implement urban green spaces (Haase et al. 2014). The implementation of new green spaces and green infrastructure leads to the enhancement of several ecosystem services, among which are C storage and sequestration (Strohbach et al. 2012), flood mitigation (Kubal et al. 2009) and biodiversity (Strohbach et al. 2009). These findings can be conveniently expanded to other LU/LC typologies such as forests (Coulston et al. 2013) to increase the understanding of the overall ecological meaning of LU and LC changes.

Conclusions

From the above considerations, we conclude that the combined use of LU and LC classifications provides new opportunities for understanding their dynamics by increasing the informative power of inventories in the framework of landscape analysis. Considering the availability and frequent updating of satellite images as well as the low costs compared to traditional mapping, double classification seems suitable for applications across the whole Italian territory. While inventories are convenient in terms of costs and allow objective estimates of the reached accuracy, they do not allow spatialization of estimates. This fact constitutes a relevant drawback, if one considers that many spatially explicit models such as those adopted for mapping and assessing ecosystem services (InVEST, ARIES, etc.) require spatial estimates. In spite of this limitation, enhancing the awareness of past dynamics, their drivers and impacts, these estimates provide powerful instruments supporting land use planning, mainly facilitating the construction of alternative LU/LC future scenarios (e.g. Schirpke et al. 2012).

The different characteristics of LC and LU classifications are suitable for assessing LC transformations in urban and peri-urban areas as well as LU transformations in agricultural and forest areas. In urban planning, artificial linear and point elements (e.g. paved roads, dirt roads, squares) are very important. Although they represent most of the sealed surface (54 % in 2012), they are almost solely detected by the LC classification, owing to difficulties in reaching the minimal dimensional parameters for the LU classification (extent and width). The use of a classification system able to identify these objects is helpful for territorial planning, especially in those territories that are heavily marked by infrastructural transport networks, as is customary in Italy. While LU offers a suitable estimation of built-up areas, LC may be used instead to assess the impact of urbanization processes on ecosystem services (i.e. soil retention), thereby providing a better understanding of ecosystem functioning. In the Molise region, it has been estimated that 32 % of the urban area (*sensu* LU) is unsealed. This finding offers important insights into the need for increasing the porosity of urban areas or at least avoiding further soil sealing. Improving monitoring systems will facilitate the assessment and valuation of ecosystem services. The implementation of concepts such as the ecology *of* and ecology *in* cities and using the lens of ecosystem services (Jansson 2013) will enhance the sustainably of urban areas, thereby promoting the reconnection of human needs with the capacity of the biosphere (Millennium Ecosystem Assessment 2005; Folke et al. 2011). From this perspective, the availability of accurate estimates of LU and LC change, jointly with the ability to distinguish or integrate use and cover concepts, represents a primary need for land use policies addressing ecosystem services issues.

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