Environmental Impact Assessment Review 54 (2015) 80–90

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Assessing land take by urban development and its impact on carbon storage: Findings from two case studies in Italy

L. Sallustio [a,*], V. Quatrini [b], D. Geneletti [c], P. Corona [d], M. Marchetti [a]

[a] Dipartimento di Bioscienze e Territorio (DiBT), Università del Molise, C. da Fonte Lappone, I-86090 Isernia, Italy
[b] Dipartimento per l'Innovazione nei sistemi Biologici, Agroalimentari e Forestali (DIBAF), Università della Tuscia, v. San Camillo de Lellis, I-01100 Viterbo, Italy
[c] Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, 38123 Trento, Italy
[d] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Forestry Research Centre (CRA-SEL), Viale S. Margherita 80, 52100 Arezzo, Italy

ARTICLE INFO

Article history:
Received 23 February 2015
Received in revised form 28 May 2015
Accepted 29 May 2015
Available online xxxx

Keywords:
Urbanization
Monitoring
Sampling approach
Ecosystem services
InVEST

ABSTRACT

Land take due to urbanization triggers a series of negative environmental impacts with direct effects on quality of life for people living in cities. Changes in ecosystem services are associated with land take, among which is the immediate C loss due to land use conversion. Land use change monitoring represents the first step in quantifying land take and its drivers and impacts. To this end, we propose an innovative methodology for monitoring land take and its effects on ecosystem services (in particular, C loss) under multi-scale contexts. The devised approach was tested in two areas with similar sizes, but different land take levels during the time-span 1990–2008 in Central Italy (the Province of Rome and the Molise Region). The estimates of total coverage of built up areas were calculated using point sampling. The area of the urban patches including each sampling point classified as built up areas in the year 1990 and/or in the year 2008 is used to estimate total abundance and average area of built up areas. Biophysical and economic values for carbon loss associated with land take were calculated using InVEST. Although land take was 7–8 times higher in the Province of Rome (from 15.1% in 1990 to 20.4% in 2008) than in Molise region, our findings show that its relative impact on C storage is higher in the latter, where the urban growth consistently affects not only croplands but also semi-natural land uses such as grasslands and other wooded lands. The total C loss due to land take has been estimated in 1.6 million Mg C, corresponding to almost 355 million €.

Finally, the paper discusses the main characteristics of urban growth and their ecological impact leading to risks and challenges for future urban planning and land use policies.

1. Introduction

Urbanization represents one of the main sources of disturbance and alteration of natural ecosystems (Churkina, 2008; Imhoff et al., 2004; Solomon et al., 2007), inducing the loss of several ecological functions (Foley et al., 2005). Land take, defined here as the area of land that is converted into settlements and artificial surfaces due to urban growth, alters environmental quality (Ellis and Ramankutty, 2008) and affects the provision of several ecosystem services, such as those related to climate and water regulation (Seto et al., 2012; Nelson et al., 2010). These environmental impacts produce direct and indirect effects on the quality of life of people living in cities (Chiesura, 2004; EEA, 2006; Escobedo et al., 2011; Elmqvist et al., 2013).

Urban areas emit a high proportion of the greenhouse gas carbon dioxide (Svirejeva-Hopkins et al., 2004) and contribute somewhere between 40 and 85% of total anthropogenic greenhouse-gas (GHG) emissions (Satterthwaite, 2008). The effects of urbanization on climate change are exacerbated by the loss of carbon (C) pools associated with the decreases in the vegetative cover caused by the land take associated with the expansion and intensification of urban areas (Hutyra et al., 2011a). Moreover, soils in urban areas have very low C densities (Pouyat et al., 2006), exacerbating the impact of urbanization on C sequestration. Land take by urban development yields both an initial loss in the carbon stock, as well as a permanent reduction in the carbon uptake potential by the land (Hutyra et al., 2011b). A few studies investigated this problem, by proposing methodologies to assess the carbon impact of growing urban regions. Seto et al. (2012) modeled the loss in aboveground biomass carbon from areas with high probability of urban expansion until 2030, and concluded that this loss is likely to be significant (equal to ~5% of emissions from tropical deforestation and land-use change). Raciti et al. (2012) focused on the effects of urbanization on soil carbon pools, by comparing the carbon content of open areas and impervious-covered soils. Their finding is that carbon content under impervious surfaces is 66% lower. Hutyra et al. (2011a) estimated

* Corresponding author.
E-mail addresses: davide.geneletti@unitn.it (D. Geneletti), piermaria.corona@entecra.it (P. Corona).

http://dx.doi.org/10.1016/j.eiar.2015.05.006

the carbon consequences associated with urban land take in the Seattle metropolitan region, and concluded that it represents a substantial term in the regional carbon balance.

Despite the findings of these studies suggesting that the loss of carbon stock (and future carbon uptake) due to land take by urban development is potentially significant, this effect is often overlooked during the assessment of the future impacts of urban growth. For example, the treatment of climate-related issues in Strategic Environmental Assessment (SEA) of spatial and urban planning is still quite weak and largely based on general recommendations, as opposite to analytical evaluations (Geneletti, 2015). There is a need for further development of methods to assess the impact of land take on carbon storage that can be transferred to practitioners and used to support the proposal of more sustainable urban plans and policies. Particularly, these methods need to address two issues: the analysis of land take dynamics and the modeling of carbon loss associated with them.

The objective of this paper is to contribute to filling this gap by proposing and testing a method to quantify land take dynamics associated with urban growth, and estimate their effects in terms of carbon stock loss. Land take dynamics were analyzed through the construction of transition matrices (Pontius et al., 2004; ONCS, 2009). Specifically, a method proposed by Baffetta et al. (2011) used for urban forest coverage assessment over Italy (Corona et al., 2012a) was implemented in order to estimate urban patch abundance and average size. The sampled urban patches were then used as input for the assessment of change in carbon loss, both in biophysical and economic terms.

The study areas are the Province of Rome and the Molise Region in Italy (see Fig. 1). These two areas represent different socio-economic contexts that lead to different population densities and urban growth patterns. In Rome, this produced a typical polycentric urban form, but in Molise very fragmented urban growth characterized by small patches surrounded by mostly rural lands. In Italy urban areas cover 7.1% of the land area, and grew by 500,000 ha from 1990 to 2008, at the expense of croplands in plains and low hills (Corona et al., 2012b; Marchetti et al., 2012a). However, few studies have addressed the impact of urban growth in Italy (Romano and Zullo, 2013), due to the lack of reliable data and the high costs of production. This lack highlights the need to improve land use monitoring systems and develop new methodologies aiming to increase their informative power while containing the costs of realization and updating.

2. Materials and methods

2.1. Study area and available data

Analyses were performed on two very different study areas in central Italy, one of the ancient human dominated areas within the Mediterranean Basin, which has been indicated by Myers et al. (2000) as one of the four most significantly altered hotspots on Earth (Fig. 1). In these areas natural capital has been altered by human population for thousands of years (Falcucci et al., 2007) and its pressure is still rising, especially along the coast (Salvati et al., 2012; Romano and Zullo, 2014). The Province of Rome is one of the most populated and urbanized areas in Italy. It covers about 5352 km^2 with a total population of 4,061,543 inhabitants (ISTAT, 2008). The territory mainly consists of hills (~50%), lowlands (~30%), and mountains (~20%). Like other Mediterranean cities, Rome went through a rapid transition from the historic compact model to a scattered and polycentric urban form, characterized by huge expansion around the urban area (Salvati, 2013).

However, the Molise region is among the least dense and urbanized areas in Italy, with a decreasing population during the past decades (ISPRA, 2014a; Sallustio et al., 2013). This region has an area of 4438 km^2 with 313,660 inhabitants (ISTAT, 2008) and a mountainous

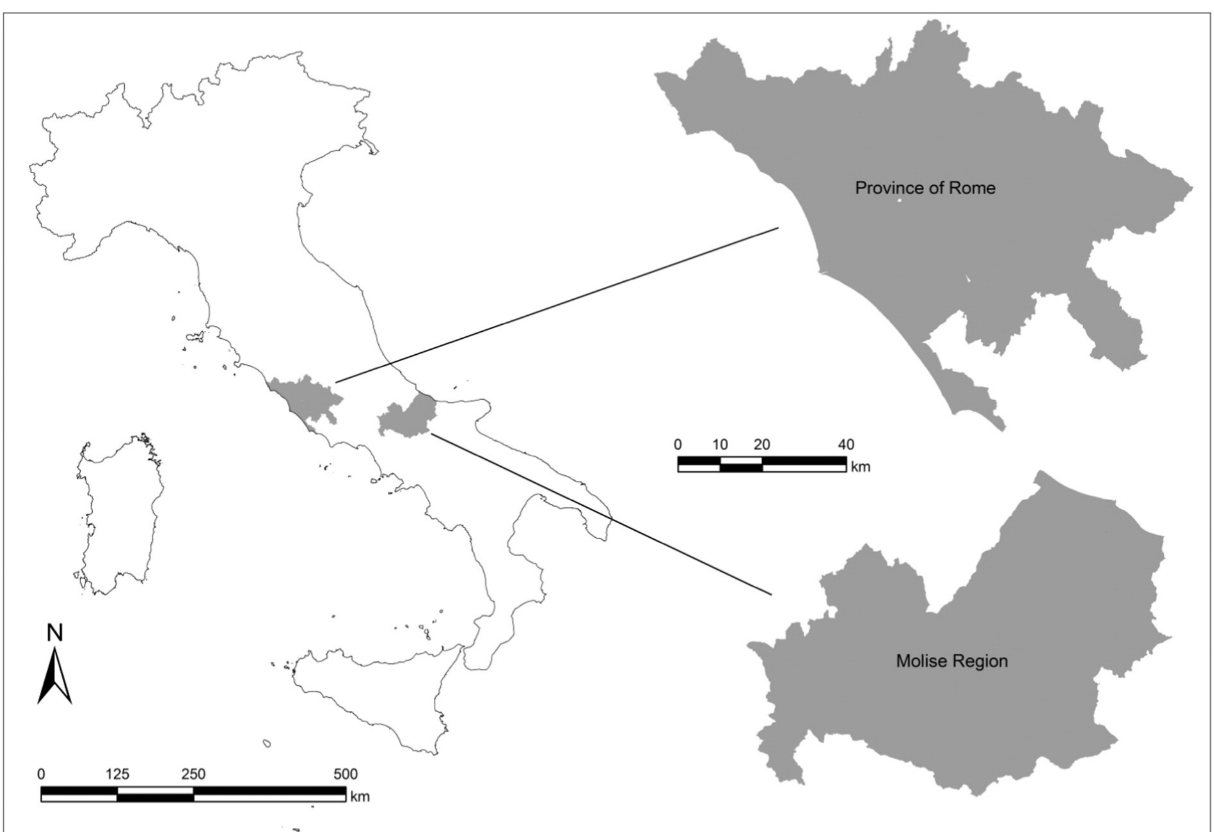


Fig. 1. Geographical location of the study areas.

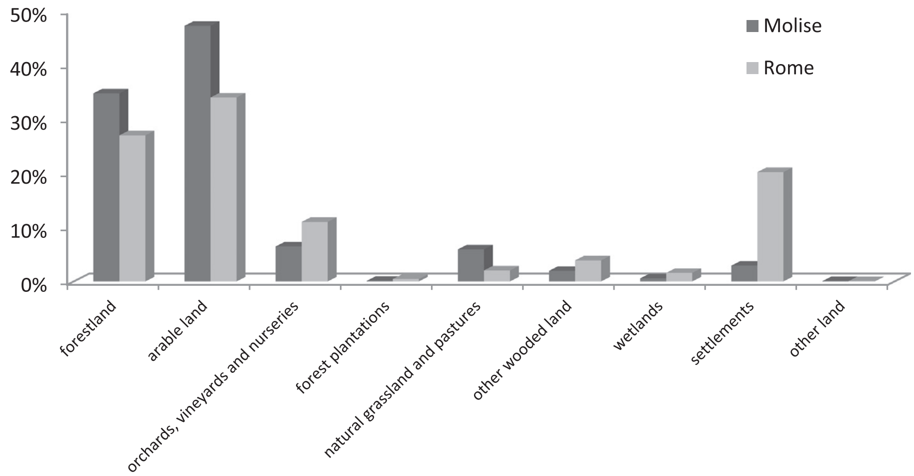


Fig. 2. Land use classes in the Molise Region and in the Province of Rome in the year 2008, according to IUTI classification (Table 1).

(55.3%) and hilly (44.7%) landscape. Fig. 2 shows land use of the two study areas in the year 2008.

Currently, various land use and land cover maps are available for both study areas. They are usually achieved through satellite imagery and a combination of supervised and unsupervised classification. The former is the case, for example, of Corine Land Cover (Maricchiolo et al., 2004) and land use maps produced by the regional administrations, obtained through the visual interpretation of high-resolution ortophotos or satellite images. The latter is the case of the high resolution layers made available by the GMES Copernicus program (EEA, 2013). Despite their recognized value, they are infrequently updated due to the high production costs, which represent significant barriers in using land use maps for monitoring land use and land cover change (LULCC) through time.

To overcome these limitations, several inventory approaches have been developed and applied as a reliable alternative for LULCC monitoring. In Italy, different projects are focused on LULCC using an inventory approach such as: the National Land Take Monitoring Network, performed by ISPRA (National Institute for Environmental Protection and Research) using a stratified sampling methodology, which combines orthophoto interpretation with high-resolution remote sensing data (ISPRA, 2014a); the AGRIT project, where sampling is based on an area frame from 1988 to 2000 and where a point frame (project POPOLUS) was introduced in 2001 (MIPAF, 2014); and the Land Use Inventory (IUTI), based on point sampling and implemented by the Italian Ministry of Environment, Land and Sea as an instrument of the National Registry for forest carbon sinks for the accounting of GHG emissions (Corona et al., 2012b).

2.2. Land take assessment

2.2.1. Classification method and urban patch delineation

The IUTI dataset was used in this study for its specific characteristics: large sample size, easy updates and uncertainty value estimate (Corona et al. 2007; Corona, 2010).The IUTI approach was used to estimate urban growth from 1990 to 2008, and furthermore was developed to estimate changes in urban patches abundance and their average area at the two inventory occasions.

Localization of sampling points was carried out according to a tessellation stratified sampling design (also known as unaligned systematic sampling; Barabesi and Franceschi, 2011). The set of sample points was extracted using a 0.5 km square grid, geo-referenced and randomly located in each square cell and fully covering the study area. A total of 21,412 sample points were extracted for the Province of Rome and 17,737 for the Molise Region.

Each sample point was photo-interpreted and classified according to the IUTI classification in Table 1 (for details, see Corona et al., 2012b). The minimum dimensional standards of reference are performed considering: a) surface or extension greater or equal to 5000 m^2; and b) width of the considered area greater or equal to 20 m. The visual interpretation and diachronic analysis were based on digital aerial orthophotos acquired in the years 1990 and 2008: 1990, TerraItaly 1988/1989, panchromatic aerial orthophotos, with spatial resolution of 1 m; 2008, TerraItaly 2008 dataset, digital color aerial orthophotos with spatial resolution of 0.5 m. For each sampling point classified as urban in the year 1990 and/or in the year 2008, the urban patches including the sample point were mapped for both inventory occasions.

An overlap analysis was performed in order to identify patches transformed from other land use classes to urban, during the considered time-span. The previous dominant land use class (in the year 1990) was also assigned according to the IUTI classification to each new urban patch in the year 2008. The outputs of this diachronic analysis were the land use classification for each sample point in the years 1990 and 2008, and the corresponding map of urban patches (Fig. 3) and their classification.

2.2.2. Estimation of coverage, abundance and average size of built up areas

The design-based estimation approach developed by Baffetta et al. (2011), already used for urban forest coverage assessment over Italy (Corona et al., 2012a), is here applied. It is worth noting that in a design-based estimation no assumptions are made about the population under study, in such a way that accuracy stems from the sampling strategy actually adopted to carry out estimates.

Let A, N and $\overline{a}$ be, respectively, the coverage, abundance and average size of the built up areas in each study case, and be Q the extent of the area formed by the n square grid cells completely covering the study area under the tessellation stratified sampling scheme adopted by

Table 1
IUTI land use classification (Corona et al., 2012b).

IUTI class	IUTI category/subcategory		IUTI code
Forest land	–		1
Cropland	Arable land		2.1
	Permanent crops	Orchards, vineyards and nurseries	2.2.1
		Forest plantations	2.2.2
Grassland	Natural grassland and pastures		3.1
	Other wooded land		3.2
Wetlands	–		4
Settlements	–		5
Other lands	Bare rock and sparsely vegetated areas		6

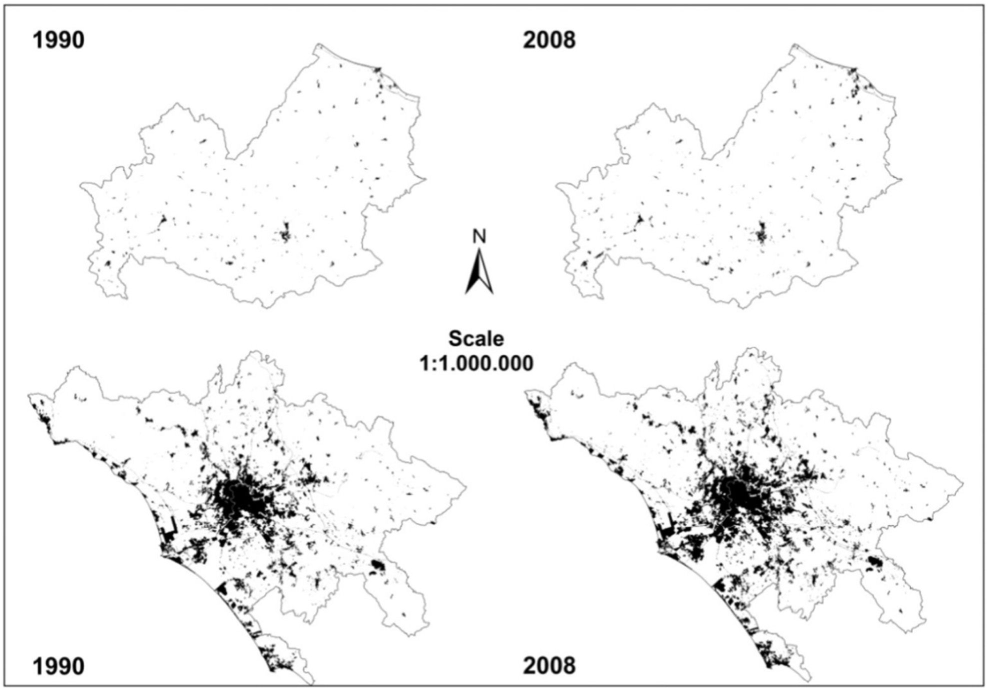


Fig. 3. Urban patches in the years 1990 and 2008 in Molise Region (top) and in the Province of Rome (bottom).

IUTI. The estimate of A is given by

$$\hat{A} = \hat{p}Q \quad (1)$$

where:

$$\hat{p} = \frac{n_u}{n} \quad (2)$$

n_u = number of sample points classified as built up areas.

The variance of $\hat{A}$ can be estimated as

$$\hat{\text{var}}\left(\hat{A}\right) = Q^2 \frac{n_u(n-n_u)}{n^2(n-1)}. \quad (3)$$

Let S and a_j be, respectively, the set of urban patches selected at least once by the n sampling points and the size of the jth urban patch. If the values of a_j are negligible with respect to Q, the estimate of N is given by

$$\hat{N} = \frac{Q}{n}\sum_{j \in S}\frac{1}{a_j} \quad (4)$$

with estimated variance equal to

$$\hat{\text{var}}\left(\hat{N}\right) = \frac{1}{n(n-1)}\left(Q^2\sum_{j \in S}\frac{1}{a_j^2} - n\hat{N}^2\right). \quad (5)$$

Accordingly, the estimate of $\overline{a}$ is given by $\hat{A}/\hat{N}$, i.e.

$$\overline{a} = \frac{n_u}{\sum_{j \in S}\frac{1}{a_j}} \quad (6)$$

with estimated variance equal to

$$\hat{\text{var}}\left(\hat{\overline{a}}\right) = \frac{Q^2}{\hat{N}^2 n(n-1)}\sum_{j \in S}\left(1 - \frac{\hat{\overline{a}}}{a_j}\right)^2. \quad (7)$$

2.3. Carbon loss assessment

Changes in C storage due to the urbanization are based on differences of C stock of different land use classes, and its loss or gain related to the transition from one class to another through time. Several ecosystem mapping and assessment tools with different aims and characteristics have been published in recent years, such as ARIES (Villa et al., 2014), InVEST (Nelson et al., 2013; Nelson and Daily, 2010) EcoAIM, ESR, ESvalue, NAIS, and EcoMetrix (Martínez-Harms and Balvanera, 2012; Waage et al., 2011). We decided to assess the changes of C stock both in biophysical and economic terms using the InVEST (Integrated Valuation of Environmental Services and Tradeoffs) Carbon Storage and Sequestration model developed by the Natural Capital Project (Daily et al., 2009; Tallis et al., 2013). The decision to use InVEST was for several reasons, among which: a) it is a free and open-source software; b) it is organized in different tiers of difficulty of use and input data availability; c) it is able to assess several ecosystem services; and d) it is based on the application of the production function approach, able to provide more accurate and policy-relevant results (Nelson and Daily, 2010). These characteristics enable its use in different contexts, and for mapping and assessment of other ecosystem services and their trade-offs. InVEST is a geospatial modeling framework and collection of tools that predict the provision and value of ecosystem services using land use/land cover maps and related biophysical, economic and institutional data. InVEST employs a simplified carbon cycle and evaluates the impact of LULCC on ecosystem services (Nelson et al., 2009; Polasky et al., 2011).

The model works by applying the estimates of carbon stored by each land use (LU) class to produce a map of carbon storage for the considered carbon pools. For each class, the model requires an estimate of the amount of carbon stored by each of four fundamental C pools.

All the data concerning carbon storage were determined using the Good Practices Guidance for Land Use, Land Use Change and Forestry (GPG-LULUCF) classification and definition: living biomass (above ground and below ground), dead organic matter (dead wood and litter) and soil (soil organic matter in the upper 30 cm) (Woomer et al., 2004; Gockowski and Sonwa, 2011; Adu-Bredu et al., 2011; Asase et al., 2011; Yao et al., 2010; Leh et al., 2013).

Values for each C pool and LU class were assigned using the IPCC methodology (IPCC, 2003, 2006) and data from a bibliographic review (Table 2). We assumed, based on the conservative approach proposed by the tier 1 of the Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), that settlements do not contribute to C storage. Moreover we did not take into account C stored in wetlands because land take did not occur at the expense of this LU class during the observed time-span.

For the C storage in the year 1990 we assumed carbon storage equilibrium (steady-state level) due to its long persistence in each grid cell. Therefore, this dataset was implemented in all the mapped patches to assess the net change in C stock due to land take in the period 1990–2008, assuming that change in carbon stocks is only due to LULCC.

Here we report the economic value of carbon storage as the Social Cost of Carbon (SCC). The SCC, also known as the marginal damage cost of carbon dioxide, is defined as the net present value of the incremental damage due to a small increase in carbon dioxide emissions. The choice of SCC is due to the fact that it would be equal to the Pigouvian tax that could be placed on C (Tol, 2009). Therefore, in our case, the final total SCC hypothetically represents the social cost related to the land take over time. The economic evaluation of Climate Change impact is a very complex issue resulting in a wide range of SCC values reported in the literature (e.g., van den Bergh and Botzen, 2015). In order to avoid the use of different SCC values, the price of $37 per Mg of CO_2 (about 109 € Mg^{-1} of elemental C) was adopted (OIRA, 2013), because this is one of the more frequently used values to estimate the potential costs of Climate Change. Furthermore, we assumed this value stable from 1990 to 2008. We used a discount rate of 7% per year, which is one of the typical values suggested for cost–benefit analysis of environmental projects (Stern, 2007). The discount rate has been used to refer all the economic values for a unique point in time, i.e. 2008. Moreover, this value falls within the range of 5–10% per annum suggested by several economic studies (e.g. Nordhaus, 2007), avoiding the misallocation of monetary resources and evaluate climate change mitigation activities similarly to all other policies. Thinking about urban policy and planning, this estimate could represent an attempt to internalize the externality and restore the market to an efficient solution. The results in terms of biophysical and economic benefits obtained for the sample patches were extended to the whole surface by statistical inference.

3. Results

3.1. Estimation of urban area

Table 3 shows the main results of the statistical survey carried out. Sampling point classification and polygon delineation in the years 1990 and 2008 highlight that urban areas in the Province of Rome covered about 81,037 ha (±1.7%) in 1990 and increased to 109,026 ha (±1.4%) in 2008. Urban areas in Molise increased from 9000 ha (±5.2%) in 1990 to 12,850 (±4.3%) in 2008 (Fig. 4). Land take by urban area expansion amounted to 28,000 ha and 3850 ha in Rome and Molise, respectively. The Province of Rome showed a smaller relative increase in total urban area compared to Molise, with a percentage increase of, respectively, 35% and 45% with respect to 1990.

Besides urban densification within the cities' cores, urban sprawl continues to affect the rural landscape under a contagion (sensu Ricotta et al., 2003) pattern, as demonstrated by the increase of the number of urban patches and the negligible variation of their size. This phenomenon has an important meaning on economic, social and environmental impact of urban growth. It is particularly evident in Molise, where the urban patch number increased by 41% in 2008 and the increase in the average urban patch size is less than 1%, significantly smaller in respect to the 3.4% of Rome.

The estimated average area of urban patches has remained stable from 1990 to 2008, with a slight increase in both territories. The average area of the urban patches is twice the size in Rome. The number of estimated urban patches is also higher in Rome, but the increase observed during the considered time-span is relatively lower compared to Molise (30 and 41% respectively).The Molise region shows higher standard errors for all the estimators compared to Rome.

Within the two study areas the land take occurred across different LU classes (Fig. 5). Although in both cases the majority occurred on croplands, which is particularly evident in Rome, which accounted for about 90% of its land take. This percentage is lower in Molise (about 61%), where land take is also remarkable on pastures and grasslands.

3.2. Carbon loss between the years 1990 and 2008

Average carbon densities in terrestrial LU decrease with increasing shift from natural to human-influenced LU classes. Through the literature review, we observed the highest C densities in forests (143.42 Mg C ha^{-1}), while the lowest in croplands (58.1 Mg C ha^{-1}). The smallest C density values were found in dead organic matter and below ground biomass, while largest in soil.

By statistical inference we estimated C losses for the whole area so that from 1990 to 2008 the Molise region had a total decrease of

Table 2
C stocks (Mg C ha^{-1}) in each terrestrial LU class and C pool and references used for the C pools' values.

IUTI class	Above ground (Mg C ha^{-1})	Below ground (Mg C ha^{-1})	Dead organic matter (Mg C ha^{-1})	Soil organic carbon (Mg C ha^{-1})	Total (Mg C ha^{-1})
Forestland	50.5 (Gasparini & Tabacchi, 2011)	11.525 (Est. ISPRA, 2014b)	5.295 (Gasparini and Tabacchi, 2011)	76.1 (Gasparini and Tabacchi, 2011)	143.42
Arable land	5 (ISPRA, 2014b)	/	/	53.1 (Chiti et al., 2012)	58.1
Orchards vineyards and nurseries	10 (ISPRA, 2014b)	/	/	52.1 (Chiti et al., 2012)	62.1
Forest plantations	28.55 (Gasparini and Tabacchi, 2011)	5.25 (Est. ISPRA, 2014b)	1.75 (Gasparini and Tabacchi, 2011)	63.9 (Gasparini and Tabacchi, 2011)	99.45
Natural grassland and pastures	/	/	/	78.9 (ISPRA, 2014b)	78.9
Other wooded land	3.05 (IPCC, 2003)	/	/	66.9 (ISPRA, 2014b; Alberti et al., 2011)	69.95
Settlements	*	*	*	*	*
Other lands	**	**	**	**	**

* According to the tier 1 proposed by IPCC (2006), the most conservative approach has been used, meaning that urbanization causes carbon stocks to be entirely depleted.
** Concerning other lands converted to settlements, change in carbon stocks has been not estimated, according to the GPG (IPCC, 2003), as no change in carbon stocks in the other land has been assumed.

Table 3
Estimates of number of urban patches ($\hat{N}$), urban coverage ($\hat{A}$) and urban patch average area ($\hat{\bar{a}}$), and their estimated relative standard errors (expressed in percent).

Study area	Year	$\hat{N}$	$se_{\hat{N}}$ (%)	$\hat{A}$ (ha)	$se_{\hat{A}}$ (%)	$\hat{\bar{a}}$ (ha)	$se_{\hat{\bar{a}}}$ (%)
Molise Region	1990	2449	10.1	9000	5.2	3.68	7.6
	2008	3455	8.5	12,850	4.3	3.72	6.2
Province of Rome	1990	10,763	4.9	81,037	1.7	7.53	4.4
	2008	13,989	4.2	109,026	1.4	7.79	3.8

252,335 Mg C (about 14,018 Mg C year^{-1}), corresponding to a total economic loss by 2008 equal to 54,619,258 € (about 3,034,403 € year^{-1}). The same estimates for Rome's territory provide a total loss of 1,390,234 Mg C (about 77,235 Mg C year^{-1}) and an economic loss by 2008 equal to 300,922,997 € (about 16,717,944 € year^{-1}). This provides evidence for C loss due to urbanization that occurred between 1990 and 2008 amounting to 59.7 and 65.5 Mg C ha^{1} in Rome and Molise, respectively. This corresponds to a mean economic loss of 12,920 € ha^{-1} in Rome and 14,186 € ha^{-1} in Molise.

These values represent the average SCC per hectare related to the urbanization. The higher values estimated in Molise (both in biophysical and economic terms) are related to the high percentage of land take that occurred in LU classes such as grasslands, which have a higher total C density than croplands.

4. Discussion

4.1. Ecological meaning of land take

The land take in the two different areas highlighted the higher severity of the urban growth issue in the Province of Rome as compared to the Molise Region. Indeed, in 2008 settlements covered about 19.6% of Rome's territory, gaining 4.9% with respect to 1990, while only increasing to 2.9%, gaining 0.9% in Molise in the same period.

This dramatic increase in settlements in both study areas led to a decrease in C stocks. Although the total C loss is higher in Rome, the unitary values of this loss are higher in Molise (+9.7%, corresponding to 5.8 Mg C ha^{-1}), due to the higher incidence of land take on semi-natural land uses which are characterized by relatively high values of C densities. In accordance with other studies, the ecological consequences of urban growth are strongly related to the previous land use (Jenerette et al., 2006; Pouyat et al., 2006; Pickett et al., 2008). We can conclude that there is a sort of anthropogenic gradient affecting the urbanization impact on C loss. Therefore, the higher the original naturalness of the territory, the higher the C loss. This is the case of forests,

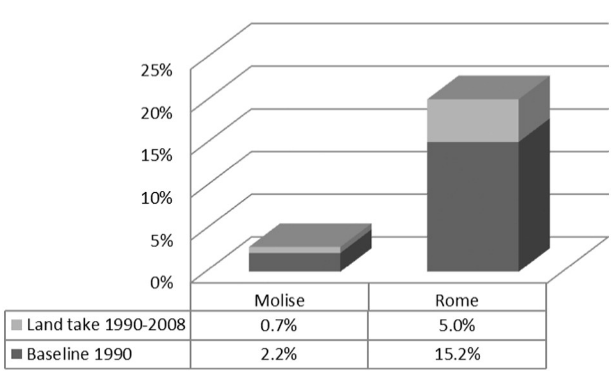


Fig. 4. Urban coverage in1990 and land take occurred between 1990 and 2008 in the study areas.

which, as demonstrated by Zhang et al. (2012), once converted are responsible for the highest unit values of C loss (Fig. 6).

To give a sense of the magnitude of the C loss associated with land take in the study areas, we compared it with the C stock and sink in the National Park of Abruzzo, Lazio and Molise (PNALM), one of the largest National Parks in Italy, which includes parts of the two study areas. The forest cover in the PNALM is about 37,962 ha, mainly dominated by beech forests. C stocked by forest aboveground biomass is about 3.3 M Mg C and the C sink is about 65,900 Mg C year^{-1} (Marchetti et al., 2012b). This means that the total C loss due to the urban growth occurred between 1990 and 2008 in Molise and Rome corresponds to about 49.5% of the C stocked by forests within the PNALM. Concerning the annual C loss, urbanization in the two study areas amounts to 91,253 Mg C year^{-1}, exceeding then the forest annual C sink of the PNALM for the 38.5%.

Yet, in order to increase the awareness of policy makers on the C footprint of urban growth, it could be interesting to simulate the implementation of project such as the realization and maintenance of urban green spaces as a mitigation strategy. Strohbach et al. (2012) estimated a C sequestration between 137 and 162 Mg CO_2 ha^{-1} (37.3 and 44.1 Mg C ha^{-1} respectively) for a 50 year urban green space project in Germany. In our case, this would correspond to the realization of 40,000 ha of urban green spaces to balance the C loss related to the total urban growth that occurred in both the study areas. This represents a topical figure that is almost coincident with the total amount of the urban forest coverage currently present in the whole Italian territory (43,000 ha; Corona et al., 2012a).

4.2. Risks and opportunities towards new paradigms for urban planning

LULCC is not always related to population growth, and other individual and social conditions must be taken into account (Lambin et al., 2001). This is particularly evident in our case studies, where the increase in the number of urban patches and the stability of their size, especially in the Molise Region, combined with the densification of urban industries within the cities, highlighted the duplicity of the urban growth patterns: compact but often under-used inside existing city boundaries (urban shrinkage), and more fragmented and scattered outside them (urban sprawl). With particular regard to the latter, as reported by Romano and Zullo (2012), in Italy during the past 50 years, the urban growth has been characterized by “a huge dispersion in diffused forms scarcely governed by interpretable rules, leading to the systematic reproduction of a city model lacking town planning.” Moreover, different urban forms and spatial structures may allow for different forms of land take containment, especially in terms of green infrastructure planning in the vulnerable areas such as the wildland–urban interface (WUI; Elia et al., 2014). The quantitative limits to the admissible increase in urbanized areas are not sufficient. Additional parameters should be considered, among which the shape of such areas, the territorial dispersion indices and the density and types of transport networks (Romano and Zullo, 2013).

On the other hand, analyzing demographic data provided by the National Institute of Statistics, between 1990 and 2008 the Province of Rome grew by about 110,000 inhabitants (+2.9% with respect to 1990), while the trend has been negative in Molise (−13,000 inhabitants, corresponding to about 4% of the population in 1990). In our case it is particularly evident that the urban growth is completely independent from housing demand related to the demographic trend. The consequent decrease in population within cities leads to the concept of shrinking cities (Haase et al., 2014), which is considered an important issue especially in Europe (Turok and Mykhnenko, 2007; Kabisch and Haase, 2011). Urban shrinkage involves at the same time new risks, challenges and opportunities for future land use policy and management. It implies dramatic impacts such as: under-utilization, densification and vacancy, demolition and resulting gray fields and brownfields in the compact areas (Schilling and Logan, 2008), new

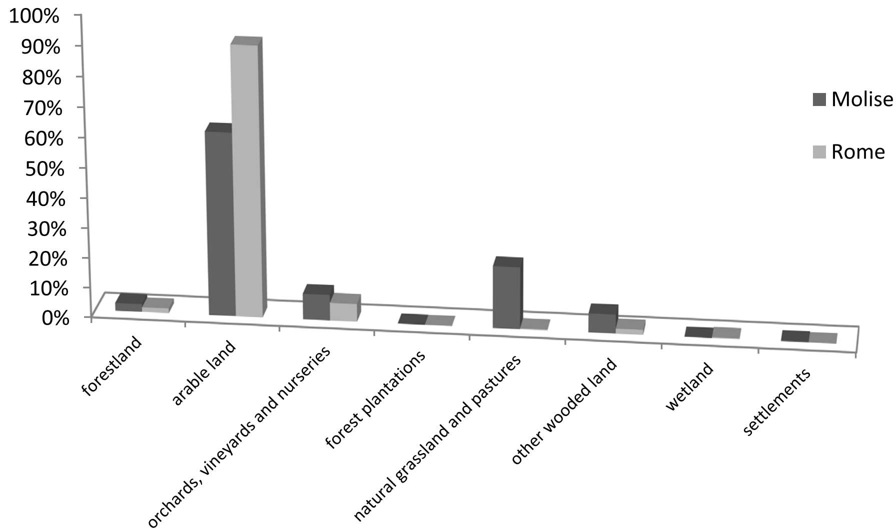


Fig. 5. LU classes affected by land take between 1990 and 2008 in the study areas. The y-axis represents the relative distribution of the urban growth among the different LU classes.

land take outside (Salvati et al., 2012) and other problems related to the policy and management strategies (Couch et al., 2012). Furthermore, as partially demonstrated in our study, the removal of vegetation, the addition of impervious surfaces and increases in local fossil fuel usage due to urban growth, are typically associated with significant carbon emissions (Hutyra, 2011a). However, the effect of urban shrinkage on urban spaces, especially those related to de-densification and vacancy, offers great potential to “re-create”, enhance and implement urban green space (Haase et al., 2014). The implementation of new green spaces and green infrastructure in urban and peri-urban areas may lead to the enhancement of several ecosystem services provision, including C storage and sequestration (Strohbach et al., 2012).

The assessment of biophysical and economic consequences of land use changes on ecosystem services may represent an important tool for public administrations (Cimini et al., 2013; Marchetti et al., 2014a, b), which can be applied during the SEA of their policies, plans and programs. For example, the SCC may be used to suggest suitable form of taxation on urban growth, as a way to compensate for its negative effects. This hypothetical Pigouvian tax may have a double effect: a) disincentive for land take, promoting the requalification of existing settlements; and b) offer the possibility for administrations to invest the income in urban green space projects to mitigate the negative effects of new urbanization. In this perspective, our estimates of 12,920 € ha^{-1} in the Province of Rome and 14,186 € ha^{-1} in Molise

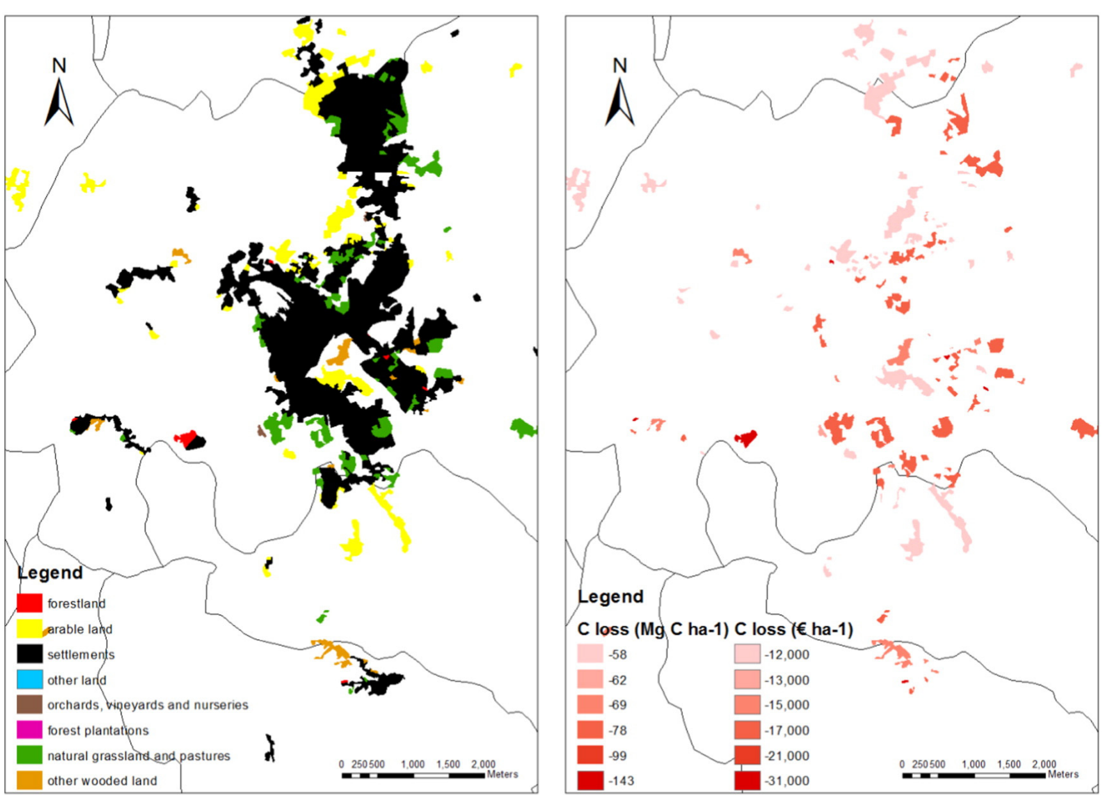


Fig. 6. Urban growth at the expense of different LU classes involves different impacts on C loss, both in biophysical and economic terms (detail of the Molise's study area).

region may represent a first attempt to define appropriate off-set measures for land take. However, it is important to remember that in our case these values refer only to carbon storage, ignoring all the other ecosystem services and their positive or negative trade-offs. An additional result of this economic tool, may relieve the pressure of urban growth on land uses with high ecosystem services value (e.g. forests), and set the value of the tax based on the previous land use. In our case, for example, this distinction would result to about 31,043 € ha^{-1} in the case of urbanization at the expense of forests or 12,576 € ha^{-1} in the case of urbanization at the expense of croplands (Fig. 6).

Considering that approximately 78% of the European population lives in urban areas (EEA, 2006), it is fundamental to include consideration of ecosystem services during impact assessment of urban policies and plans to promote urban sustainability and resilience. Ecosystem services assessment and valuation represent a potentially helpful support tool, especially for awareness raising, economic accounting, priority-setting, incentive design, alternative comparison and conflict resolution (TEEB, 2010; Barton et al., 2012; Gómez-Baggethun and Barton, 2013; Geneletti, 2013).

4.3. Limitations of the study

Although several studies demonstrate that urban areas are able to store reasonable quantities of C (Larondelle and Haase, 2013; Zhang et al., 2012) in green spaces and urban trees (e.g. Tao et al., 2014; Vaccari et al., 2013; Strohbach and Haase, 2012; Churkina et al., 2010; Tian et al., 2008; Pickett et al., 2008; Han et al., 2007) we decided to not consider these quantities. In accordance with the IPCC-tier 1 guidelines (2006), we opted for a more conservative approach, which gave us the opportunity to set up a carbon baseline related to urban growth. Despite this limit, mainly related to the underestimation of C stock in urban areas, such a conservative approach proves to be particularly useful in our study for different reasons, among which are: a) the absence of inventory data on C storage in urban green spaces (urban forests, garden, boulevard, etc.) applicable at regional scale; b) the huge variability of C stored by urban green spaces, which is heavily affected by the age of the stands, their design and management (Strohbach et al., 2012), suggesting to avoid the use of data from literature; and c) the conservative approach could be particularly suitable to increase the awareness of policy makers in context like the Italian one, where, despite the international commitment to reach the no (zero) net land uptake by 2050 (European Commission, 2011), the actual trend results far from this objective. Conditions in many countries are characterized by quite similar limitations, and this increases the relevance of the proposed conservative approach. Furthermore, this underestimation is partly balanced by the use of 0.5 ha and 20 m width as minimum thresholds for the identification of urban areas, thus excluding the isolated houses and the low density settlements, which are well represented especially in rural contexts, and their impact on C storage.

5. Conclusions

The fast growth of the urbanization, especially in sensitive areas represents a global issue. Monitoring urban growth is crucial, especially in Europe, where the target is to achieve the objective of no (zero) net land uptake by 2050 (European Commission, 2011).

In this paper we tested an innovative methodology for monitoring land take and its effects on ecosystem services (in particular C loss) widely applicable to other multi-scale contexts. Such a methodology could be particularly helpful in contexts where there is a lack of coordinated survey activities and LULCC monitoring. This is the case in Italy, where local and regional studies and monitoring programs use different methodologies usually based on wall to wall land use mapping with poor statistical accuracy. Differences in methodologies, time-span coverage and land use classification systems used among different territorial contexts, lead to difficulty in a) data standardization; b) their use to support SEA of land use policy and planning at larger scale; and c) the comparison across different territorial contexts. The latter, in particular, could be a helpful approach to control and verify the effect of different land management strategies promoting the implementation of best practices.

This study intended to present an approach easily applicable at different spatial scales even with a lack of available input data. Despite the low realization and updating costs, the integration of inventory and cartographic approach proves suitable for providing reliable estimates, enhancing their information potential. Moreover, the possibility to couple such estimates with a spatially explicit tool like InVEST allows the identification of C loss hotspots due to urban growth, thus providing useful information for land use planning.

The accounting of the economic value related to C loss could act as an additional tool to inform policy makers on urban growth impact on ecosystem services. Impacts on some ecosystem services are often neglected during SEA of land use planning because of their economic invisibility with respect to other issues, such as urban infrastructure and settlements. The assessment of impacts on ecosystem services, mainly in human dominated ecosystems, may help to reconcile the historical bias between nature and human improving and completing the costs–benefit analysis related to particular choices, policies, plans and projects (Jansson, 2013). Therefore, it will play an important role supporting future policies aimed to satisfy human needs but at a smaller cost on natural systems (Millennium Ecosystem Assessment, 2005).

Our results strongly encourage the joint use of monitoring approaches of land take with ecosystem services assessment and valuation to better understand the concept of sustainability in urban areas and its implications on other ecosystems. As suggested by Larondelle and Haase (2013), to use and maintain resources sustainably, land use decision-making processes have to incorporate ecological principles considering an urban–rural continuum.

Acknowledgments

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration, under grant agreement No 282887 (INTEGRAL) and was partially carried out under the research project “Sviluppo di modelli innovativi per il monitoraggio multiscala degli indicatori di servizi ecosistemici nelle foreste Mediterranee”, funded by the FIRB2012 program of the Italian Ministry of University and Research (project coordinator: F. Lombardi).

The authors also wish to acknowledge Martin Lacayo-Emery for contributing to the language review of the manuscript and the anonymous reviewers for useful comments and valuable feedback to a previous draft of this paper.

References

Adu-Bredu, S., Abekoe, M., Tachie-Obeng, E., Tschakert, P., 2011. Carbon stock under four land use systems in three varied ecological zones in Ghana. In: Bombelli, A., Valentini, R. (Eds.), Proceedings of the Open Science Conference on “Africa and Carbon Cycle: The CarboAfrica Project”. World Soil Resources Report No. 105. FAO, Rome, pp. 105–113.

Alberti, G., Leronni, V., Piazzi, M., Petrella, F., Mairota, P., Peressotti, A., Piussi, P., Valentini, R., Gristina, L., La Mantia, T., Novara, A., Rühl, J., 2011. Impact of woody encroachment on soil organic carbon and nitrogen in abandoned agricultural lands along a rainfall gradient in Italy. Regional Environmental Change 11, 917–924. http://dx.doi.org/10.1007/s10113-011-0229-6.

Asase, A., Wade, S., Ofori-Frimpong, K., Hadley, P., Norris, K., 2011. Carbon storage and the health of cocoa agroforestry ecosystems in south-eastern Ghana. In: Bombelli, A., Valentini, R. (Eds.), Proceedings of the Open Science Conference on “Africa and Carbon Cycle: The CarboAfrica Project”. World Soil Resources Report No. 105. FAO, Rome, pp. 131–143.

Baffetta, F., Fattorini, L., Corona, P., 2011. Estimation of woodlot and tree row attributes in large-scale forest inventories. Environmental and Ecological Statistics 18 (1), 147–167. http://dx.doi.org/10.1007/s10651-009-0125-0.

Barabesi, L., Franceschi, S., 2011. Sampling properties of spatial total estimators under tessellation stratified designs. Environmetrics 22 (3), 271–278. http://dx.doi.org/10.1002/env.1046.

Barton, D.N., Lindhjem, H., Magnussen, K., Holen, S., 2012. Valuation of ecosystem services from Nordic watersheds. From awareness rising to policy support? (VALUESHED). TemaNord. Nordic Council of Ministers, Copenhagen, p. 506.

Chiesura, A., 2004. The role of urban parks for the sustainable city. Landscape and Urban Planning 68 (1), 129–138. http://dx.doi.org/10.1016/j.landurbplan.2003.08.003.

Chiti, T., Gardin, L., Perugini, L., Quaratino, R., Vaccari, F.P., Miglietta, F.R., Valentini, R., 2012. Soil organic carbon stock assessment for the different cropland land uses in Italy. Biology and Fertility of Soils 48, 9–17. http://dx.doi.org/10.1007/s00374-011-0599-4.

Churkina, G., 2008. Modeling the carbon cycle of urban systems. Ecological Modeling 216, 107–113. http://dx.doi.org/10.1016/j.ecolmodel.2008.03.006.

Churkina, G., Brown, D.G., Keoleian, G., 2010. Carbon stored in human settlements: the conterminous United States. Global Change Biology 16, 135–143. http://dx.doi.org/10.1111/j.1365-2486.2009.02002.x.

Cimini, D., Tomao, A., Mattioli, W., Barbati, A., Corona, P., 2013. Assessing impact of forest cover change dynamics on high nature value farmland under Mediterranean mountain landscape. Annals of Silvicultural Research 37, 29–37. http://dx.doi.org/10.12899/ASR-771.

Corona, P., 2010. Integration of forest inventory and mapping to support forest management. IForest 3, 59–64. http://dx.doi.org/10.3832/ifor0531-003.

Corona, P., Fattorini, L., Chirici, G., Valentini, R., Marchetti, M., 2007. Estimating forest area at the year 1990 by two-phase sampling on historical remotely sensed imagery in Italy. Journal of Forest Research 1, 8–13. http://dx.doi.org/10.1007/s10310-006-0239-2.

Corona, P., Agrimi, M., Baffetta, F., Barbati, A., Chiriacò, M.V., Fattorini, L., Pompei, E., Valentini, R., Mattioli, W., 2012a. Extending large-scale forest inventories to assess urban forests. Environmental Monitoring and Assessment 184 (3), 1409–1422. http://dx.doi.org/10.1007/s10661-011-2050-6.

Corona, P., Barbati, A., Tomao, A., Bertani, R., Valentini, R., Marchetti, M., Perugini, L., 2012b. Land use inventory as framework for environmental accounting: an application in Italy. iForest-Biogeosciences and Forestry 5 (4), 204. http://dx.doi.org/10.3832/ifor0625-005.

Couch, C., Cocks, M., Bernt, M., Grossmann, K., Haase, A., Rink, D., 2012. Shrinking cities in Europe. Town & Country Planning 44, 264–270.

Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision making: time to deliver. Frontiers in Ecology and the Environment 7 (1), 21–28. http://dx.doi.org/10.1890/080025.

EEA, 2006. Urban Sprawl in Europe. The Ignored Challenge. Report 10. European Environment Agency, Copenhagen Retrieved from http://www.eea.europa.eu/publications/eea_report_2006_10.

EEA, 2013. GIO Land High Resolution Layers (HRLs) — summary of product specifications. Retrieved from http://land.copernicus.eu/user-corner/technical-library/gio-land-high-resolution-layers-hrls-2013-summary-of-product-specifications.

Elia, M., Lafortezza, R., Colangelo, G., Sanesi, G., 2014. A streamlined approach for the spatial allocation of fuel removals in wildland-urban interfaces. Landscape Ecology 29 (10), 1771–1784. http://dx.doi.org/10.1007/s10980-014-0070-7.

Ellis, C.E., Ramankutty, N., 2008. Putting people in the map: Anthropogenic biomes of the world. Frontier in Ecology and the Environment 6 (8), 439–447. http://dx.doi.org/10.1890/070062.

Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P.J., McDonald, R., Parnel, S., Schewenius, M., Sendstad, M., Karen, C.S., Wilkinson, C., 2013. Urbanization, biodiversity and ecosystem services: challenges and opportunities. Springer http://dx.doi.org/10.1007/978-94-007-7088-1_1.

Escobedo, F.J., Kroeger, T., Wagner, J.E., 2011. Urban forests and pollution mitigation: analyzing ecosystem services and disservices. Environmental Pollution 159 (8), 2078–2087. http://dx.doi.org/10.1016/j.envpol.2011.01.010.

European Commission, 2011. Roadmap to a Resource Efficient Europe Retrieved from http://ec.europa.eu/environment/resource_efficiency/about/roadmap/index_en.htm.

Falcucci, A., Maiorano, L., Boitani, L., 2007. Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. Landscape Ecology 22 (4), 617–631. http://dx.doi.org/10.1007/s10980-006-9056-4.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309 (5734), 570–574. http://dx.doi.org/10.1126/science.1111772.

Gasparini, P., Tabacchi, G., 2011. L'Inventario Nazionale delle Foreste e dei serbatoi forestali di Carbonio INFC 2005. Secondo inventario forestale nazionale italiano. Metodi e risultati. Ministero delle Politiche Agricole, Alimentari e Forestali; Corpo Forestale dello Stato. Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Unità di ricerca per il Monitoraggio e la Pianificazione Forestale. Edagricole-Il Sole 24 ore, Bologna 653 pp. (in Italian).

Geneletti, D., 2015. Research in strategic environmental assessment needs to better address analytical methods. Journal of Environmental Assessment Policy, and Management 17 (01), 1550014. http://dx.doi.org/10.1142/S1464333215500143.

Geneletti D. Assessing the impact of alternative land-use zoning policies on future ecosystem services. Environmental Impact Assessment Review 2013; 40: 25–25. doi:http://dx.doi.org/10.1016/j.eiar.2012.12.003.

Gockowski, J., Sonwa, D., 2011. Cocoa intensification scenarios and their predicted impact on CO_2 emissions, biodiversity conservation, and rural livelihoods in the Guinea rain forest of West Africa. Environmental Management 48 (2), 307–321. http://dx.doi.org/10.1007/s00267-010-9602-3.

Gòmez-Baggethun, E., Barton, D.N., 2013. Classifying and valuing ecosystem services for urban planning. Ecological Economics 86, 235–245. http://dx.doi.org/10.1016/j.ecolecon.2012.08.019.

Han, F.X., Plodinec, M.J., Su, Y., Monts, D.L., Li, Z., 2007. Terrestrial carbon pools in South and south-central United States. Climatic Change 84 (2), 191–202. http://dx.doi.org/10.1007/s10584-007-9244-5.

Haase, D., Haase, A., Rink, D., 2014. Conceptualizing the nexus between urban shrinkage and ecosystem services. Landscape and Urban Planning 132, 159–169. http://dx.doi.org/10.1016/j.landurbplan.2014.09.003.

Hutyra, L., Yoon, B., Alberti, M., 2011a. Terrestrial carbon stocks across a gradient of urbanization: a study of the Seattle. WA region. Global Change Biology 17 (2), 783–797. http://dx.doi.org/10.1111/j.1365-2486.2010.02238.x.

Hutyra, L.R., Yoon, B., Hepinstall-Cymerman, J., Alberti, M., 2011b. Carbon consequences of land cover change and expansion of urban lands: a case study in the Seattle metropolitan region. Landscape and Urban Planning 103 (1), 83–93. http://dx.doi.org/10.1016/j.landurbplan.2011.06.004.

Imhoff, M.L., Bounoua, L., Ricketts, T., Loucks, C., Harris, R., Lawrence, W.T., 2004. Global patterns in human consumption of net primary production. Nature 429 (6994), 870–873. http://dx.doi.org/10.1038/nature02619.

IPCC (International Panel on Climate Change), 2003. Good practice guidance for land use, land use change and forestry Retrieved from http://www.ipccnggip.iges.or.jp/public/gpglulucf/gpglulucf.html.

IPCC (International Panel on Climate Change), 2006. Guidelines for National Greenhouse Gas Inventories. AFOLU (Agriculture, Forestry and Other Land Use) Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

ISPRA, 2014a. Il consumo di suolo in Italia. Retrieved from http://www.isprambiente.gov.it/it/pubblicazioni/rapporti/il-consumo-di-suolo-in-italia (in Italian).

ISPRA, 2014b. Italian Greenhouse Gas Inventory 1990–2012. National Inventory Report 2014. ISPRA, Rapporti 198/14. ISBN 978-88-448-0654-5. Retrieved from http://www.isprambiente.gov.it/it/pubblicazioni/rapporti/italian-greenhouse-gas-inventory-1990-2012-national-inventory-report-2014 (in Italian).

ISTAT, 2008. Demographic statistics of the National Institute of Statistics of Italy. Retrieved from http://www.istat.it/it/lazio/datiq=gettableterr&dataset=DCIS_POPORESBIL1&dim=82,0,3,0&lang=2&tr=0&te=1 (in Italian).

Jansson, A., 2013. Reaching for a sustainable, resilient urban future using the lens of ecosystem services. Ecological Economics 86, 285–291. http://dx.doi.org/10.1016/j.ecolecon.2012.06.013.

Jenerette, G.D., Wu, J., Grimm, N.B., Hope, D., 2006. Points, patches, and regions: scaling soil biogeochemical patterns in an urbanized arid ecosystem. Global Change Biology 12 (8), 1532–1544. http://dx.doi.org/10.1111/j.1365-2486.2006.01182.x.

Kabisch, N., Haase, D., 2011. Diversifying European agglomerations: evidence of urban population trends for the 21st century. Population, Space and Place 17 (3), 236–253. http://dx.doi.org/10.1002/psp.600.

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomesf, O.T., Dirzog, R., Fischer, G., Folkei, C., Georgej, P.S., Homewoodk, K., Imbernonl, J., Leemansm, R., Lin, X., Morano, E.F., Mortimorep, M., Ramakrishnanq, P.S., Richardsr, J.F., Skanes, H., Steent, W., Stoneu, G.D., Svedinv, U., Veldkampw, T.A., Vogelx, C., Xuy, J., 2001. The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change 11 (4), 261–269. http://dx.doi.org/10.1016/S0959-3780(01)00007-3.

Larondelle, N., Haase, D., 2013. Urban ecosystem services assessment along a rural–urban gradient: a cross-analysis of European cities. Ecological Indicators 29, 179–190. http://dx.doi.org/10.1016/j.ecolind.2012.12.022.

Leh, M.D., Matlock, M.D., Cummings, E.C., Nalley, L.L., 2013. Quantifying and mapping multiple ecosystem services change in West Africa. Agriculture, Ecosystems & Environment 165, 6–18. http://dx.doi.org/10.1016/j.agee.2012.12.001.

Marchetti, M., Bertani, R., Corona, P., Valentini, R., 2012a. Changes of forest coverage and land uses as assessed by the inventory of land uses in Italy. Forest 9 (4), 170–184. http://dx.doi.org/10.3832/efor0696-009.

Marchetti, M., Sallustio, L., Ottaviano, M., Barbati, A., Corona, P., Tognetti, R., Zavattero, L., Capotorti, G., 2012b. Carbon sequestration by forests in the National Parks of Italy. Plant Biosystems. An International Journal Dealing with all Aspects of Plant Biology 146 (4), 1001–1011. http://dx.doi.org/10.1080/11263504.2012.738715.

Marchetti, M., Lasserre, B., Pazzagli, R., Sallustio, L., 2014a. Rural areas and urbanization: analysis of a change. Scienze del territorio 2, 239–258 Retrieved from http://www.fupress.net/index.php/SdT/article/view/14333/13324.

Marchetti M, Vizzarri M, Lasserre B, Sallustio L, Tavone A. Natural capital and bioeconomy: challenges and opportunities for forestry. Annals of Silvicultural Research 2014b; 38: 62–73. doi: 10.12899/asr-1013.

Maricchiolo C, Sambucini V, Pugliese A, Blasi C, Marchetti M, Chirici G, Corona P. La realizzazione in Italia del progetto europeo I&CLC2000: metodologie operative e risultati. In atti dell'8ª conferenza Nazionale ASITA, Rome; 2004. p. 14–17 (in Italian).

Martínez-Harms, M.J., Balvanera, P., 2012. Methods for mapping ecosystem service supply: a review. International Journal of Biodiversity Science, Ecosystem Services & Management 8 (1–2), 17–25. http://dx.doi.org/10.1080/21513732.2012.663792.

Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: synthesis. A report of the Millennium Ecosystem Assessment. Island Press, Washington.

MIPAF, 2014. The AGRIT project. Retrieved from http://www.sian.it/public/Agrit-Bollettini.html.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403 (6772), 853–858. http://dx.doi.org/10.1038/35002501.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K.M., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7 (1), 4–11. http://dx.doi.org/10.1890/080023.

Nelson EJ, Daily GC. Modelling ecosystem services in terrestrial systems. F1000 biology reports 2010; 2: 53. doi: http://dx.doi.org/10.3410/B2-53.

Nelson, E., Sander, H., Hawthorne, P., Conte, M., Ennaanay, D., Wolny, S., Manson, S., Polasky, S., 2010. Projecting global land-use change and its effect on ecosystem service provision and biodiversity with simple models. PloS One 5 (12). http://dx.doi.org/10.1371/journal.pone.0014327 e14327.

Nelson, E., Bhagabati, N., Ennaanay, D., Lonsdorf, E., Pennington, D., Sharma, M., 2013. Modeling Terrestrial Ecosystem Services. Chapter 427 in S. Levin, ed. Encyclopedia of Biodiversity, 2nd Edition. Elsevier, Amsterdam.

Nordhaus, W.D., 2007. Critical assumptions in the Stern review on climate change. Science 317, 201–202. http://dx.doi.org/10.1126/science.1137316.

Office of Information and Regulatory Affairs, 2013. Technical update of the social cost of carbon for regulatory impact analysis. Retrieved from http://www.whitehouse.gov/blog/2013/11/01/refining-estimates-social-cost-carbon.

ONCS. Primo rapporto dell'Osservatorio Nazionale sul Consumo di Suolo 2009. Pp. 128 (in Italian).

Pickett, S.T., Cadenasso, M.L., Grove, J.M., Groffman, P.M., Band, L.E., Boone, C.G., Burch, J.W.R., Grimmond, C.S.B., Hom, J., Jenkins, J.C., Law, N.L., Nilon, C.H., Pouyat, R.V., Szlavecz, K., Warren, P.S., Wilson, M.A., 2008. Beyond urban legends: an emerging framework of urban ecology as illustrated by the Baltimore Ecosystem Study. BioScience 58 (2), 139–150. http://dx.doi.org/10.1641/B580208.

Polasky, S., Nelson, E., Pennington, D., 2011. Johnson. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. Environmental and Resource Economics 48 (2), 219–242. http://dx.doi.org/10.1007/s10640-010-9407-0.

Pontius, R.G., Shusas, E., McEachern, M., 2004. Detecting important categorical land changes while accounting for persistence. Agriculture, Ecosystems & Environment 101 (2–3), 251–268. http://dx.doi.org/10.1016/j.agee.2003.09.008.

Pouyat, R.V., Yesilonis, I.D., Nowak, D.J., 2006. Carbon storage by urban soils in the United States. Journal of Environmental Quality 35 (4), 1566–1575. http://dx.doi.org/10.2134/jeq2005.0215.

Raciti, S.M., Hutyra, L.R., Finzi, A.C., 2012. Depleted soil carbon and nitrogen pools beneath impervious surfaces. Environmental Pollution 164, 248–251.

Ricotta, C., Corona, P., Marchetti, M., 2003. Beware of contagion! Landscape and Urban Planning 62 (3), 173–177. http://dx.doi.org/10.1016/S0169-2046(02)00146-9.

Romano, B., Zullo, F., 2012. Land urbanization in Central Italy: 50 years of evolution. Journal of Land Use Science 9 (2), 143–164. http://dx.doi.org/10.1080/1747423X.2012.754963.

Romano, B., Zullo, F., 2013. Models of urban land use in Europe: assessment tools and criticalities. International Journal of Agricultural and Environmental Information Systems (IJAEIS) 4 (3), 80–97. http://dx.doi.org/10.4018/ijaeis.2013070105.

Romano, B., Zullo, F., 2014. The urban transformation of Italy's Adriatic coastal strip: fifty years of unsustainability. Land Use Policy 38, 26–36. http://dx.doi.org/10.1016/j.landusepol.2013.10.001.

Sallustio, L., Vizzarri, M., Marchetti, M., 2013. Trasformazioni territoriali recenti ed effetti sugli ecosistemi e sul paesaggio italiano. Territori 18, 46–53 (in Italian).

Salvati, L., 2013. Urban containment in action? Long-term dynamics of self-contained urban growth in compact and dispersed regions of southern Europe. Land Use Policy 35, 213–225. http://dx.doi.org/10.1016/j.landusepol.2013.05.009.

Salvati, L., Munafo, M., Gargiulo Morelli, V., Sabbi, A., 2012. Low-density settlements and land use changes in a Mediterranean urban region. Landscape and Urban Planning 105 (1), 43–52. http://dx.doi.org/10.1016/j.landurbplan.2011.11.020.

Satterthwaite, D., 2008. Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions. Environment and Urbanization 20 (2), 539–549. http://dx.doi.org/10.1177/0956247808096127.

Seto, K.C., Güneralp, B., Hutyra, L.R., 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences 109 (40), 16083–16088. http://dx.doi.org/10.1073/pnas.1211658109.

Schilling, J., Logan, J., 2008. Greening the rust belt: a green infrastructure model for right sizing America's shrinking cities. Journal of the American Planning Association 74 (4), 451–466. http://dx.doi.org/10.1080/01944360802354956.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L., 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, p. 996.

Stern, N., 2007. The economics of climate change: the Stern review. Cambridge University Press, Cambridge, UK.

Strohbach, M.W., Arnold, E., Haase, D., 2012. The carbon footprint of urban green space—a life cycle approach. Landscape and Urban Planning 104 (2), 220–229. http://dx.doi.org/10.1016/j.landurbplan.2011.10.013.

Strohbach, M.W., Haase, D., 2012. Above-ground carbon storage by urban trees in Leipzig, Germany: analysis of patterns in a European city. Landscape and Urban Planning 104 (1), 95–104. http://dx.doi.org/10.1016/j.landurbplan.2011.10.001.

Svirejeva-Hopkins, A., Schellnhuber, H.J., Pomaz, V.L., 2004. Urbanised territories as a specific component of the global carbon cycle. Ecological Modelling 173, 295–312. http://dx.doi.org/10.1016/j.ecolmodel.2003.09.022.

Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Sharp, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M., Mandle, L., Griffin, R., Hamel, P., Chaplin-Kramer, R., 2013. InVEST 2.6.0 User's Guide. The Natural Capital Project, Stanford. Retrieved from http://data.naturalcapitalandresilienceplatform.org/invest-releases/documentation/2_6_0/.

Tao, Y., Li, F., Wang, R., Zhao, D., 2014. Effects of land use and cover change on terrestrial carbon stocks in urbanized areas: a study from Changzhou, China. Journal of Cleaner Production; http://dx.doi.org/10.1016/j.jclepro.2014.07.055.

TEEB, 2010. The economics of ecosystems and biodiversity: mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB. The Economics of Ecosystems and Biodiversity Retrieved from http://www.teebweb.org.

Tian, H., Xu, X., Zhang, C., Ren, W., Chen, G., Liu, M., Lu, D., Pan, S., 2008. Forecasting and assessing the large-scale and long-term impacts of global environmental change on terrestrial ecosystems in the United States and China using an Integrated Regional Modeling Approach, large-scale and long-term case studies and methods. In: Miao, S., Carstenn, S., Nungesser, M. (Eds.), Real World Ecology. New York, Springer, pp. 235–266.

Tol, R.S.J., 2009. The economic effects of climate change. Journal of Economic Perspectives 23, 29–51 Retrieved from http://www.jstor.org/stable/27740523.

Turok, I., Mykhnenko, V., 2007. The trajectories of European cities, 1960–2005. Cities 24 (3), 165–182. http://dx.doi.org/10.1016/j.cities.2007.01.007.

Vaccari, F.P., Gioli, B., Toscano, P., Perrone, C., 2013. Carbon dioxide balance assessment of the city of Florence (Italy), and implications for urban planning. Landscape and Urban Planning 120, 138–146. http://dx.doi.org/10.1016/j.landurbplan.2013.08.004.

Van den Bergh, J.C.J.M., Botzen, W.J.W., 2015. Monetary valuation of the social cost of CO_2 emissions: a critical survey. Ecological Economics 114, 33–46. http://dx.doi.org/10.1016/j.ecolecon.2015.03.015.

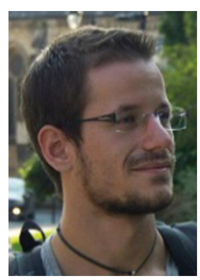
Villa, F., Bagstad, K.J., Voigt, B., Johnson, G.W., Portela, R., Honzak, M., Batker, D., 2014. A methodology for adaptable and robust ecosystem services assessment. PLoS one 9 (3). http://dx.doi.org/10.1371/journal.pone.0091001 e91001.

Waage, S., Armstrong, K., Hwang, L., Bagstad, K., 2011. New Business Decision-making Aids in an Era of Complexity, Scrutiny, and Uncertainty. Tools for Identifying, Assessing, and Valuing Ecosystem Services. BSR's Ecosystem Services, Tools & Markets Working Group Retrieved from http://www.bsr.org/reports/BSR_ESTM_WG_Comp_ES_Tools_Synthesis3.pdf.

Woomer, P.L., Touré, A., Sall, M., 2004. Carbon stocks in Senegal's Sahel transition zone. Journal of Arid Environments 59 (3), 499–510. http://dx.doi.org/10.1016/j.jaridenv.2004.03.027.

Yao, M.K., Angui, P.K.T., Konaté, S., Tondoh, J.E., Tano, Y., Abbadie, L., Benest, D., 2010. Effects of land use types on soil organic carbon and nitrogen dynamics in mid-west Côte d'Ivoire. European Journal of Scientific Research 40 (2), 211–222.

Zhang, C., Tian, H., Chen, G., Chappelka, A., Xu, X., Ren, W., Huib, D., Liub, M., Lub, C., Panb, S., Lockaby, G., 2012. Impacts of urbanization on carbon balance in terrestrial ecosystems of the Southern United States. Environmental Pollution 164, 89–101. http://dx.doi.org/10.1016/j.envpol.2012.01.020.



L. Sallustio is a postdoctoral researcher within the DiBT Forestry Labs at the University of Molise (, http://www.ecogeofor.unimol.it/index.php/it/). His research activity is mainly focused on the dynamics and fluxes of Land Use and Land Cover Change at different scales using inventory and mapping approaches, and the related effects on ecosystem services, primarily carbon sequestration and biodiversity conservation.

V. Quatrini is a consulting forester and PhD student with experience in Italy (Lazio region) in the fields of management of forest resources and monitoring of land take due to urbanization. Expertise in (i) sustainable forest management in Mediterranean environment, (ii) urban forest risk assessment, (iii) forest inventories, (iv) forest planning, and (v) Land Use Land Cover and forest cover change assessment.

D. Geneletti is an Associate Professor at the Department of Civil, Environmental and Mechanical Engineering of the University of Trento, and specializes in the fields of Strategic Environmental Assessment (SEA), spatial planning, ecosystem services and multicriteria analysis. He has been a Mid-Career Research Fellow at Harvard University's Sustainability Science Program, and a Visiting Scholar in European, North and Latin American and Asian universities. He consulted and performed project review and monitoring for public bodies internationally, including UNEP, UN-HABITAT, and the European Commission.

P. Corona is the Director of the Forestry Research Centre of the Italian Council for Agricultural Research and Economics (CRA), since 2013. Full Professor at the University of Tuscia, Italy (currently seconded at CRA). His main research field is forest resources monitoring and management, and geomatics for natural resources assessment. He is the author of over 400 scientific and technical publications, of which more than 90 on ISI journals, and 14 books.

M. Marchetti is Full Professor of Forest Management and of Forest Conservation at the University of Molise (Italy), currently Vice Rector. His main fields of work are multiresources inventory and forest mapping, forest management, land planning and biodiversity assessment. He authored around 400 scientific papers in these fields and acts in the editorial boards of national and international journals. He has been the leader of IUFRO's S4.02 “Forest Resources Inventory and Monitoring” (currently co-chair), former deputy of S8.07.01 “Key factors and ecological functions for forest biodiversity” and member of the Team of Specialists for the UN-FAO/ECE Forest Resources Assessment.