Land use inventory as framework for environmental accounting: an application in Italy

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Land use inventories are sound measures to provide information on the area occupied by different land use or land cover types and their changes, although less widespread than traditional mapping; as such, they are distinctively well-established tools for generating statistics on the state and the dynamics of land use in the European Union. Italy has recently set up a land use inventory system (IUTI) as a key instrument for accounting removals and emissions of greenhouse gases (GHG) associated to land use, land use change and forestry (LULUCF) activities elected by Italy under the Kyoto Protocol. IUTI adopts a statistical sampling procedure to estimate the area covered by LULUCF land use categories in Italy, and associated uncertainty estimates. Estimates of land use have been so far processed for the period 1990-2008 and highlight three interlinked land use change patterns in Italy: (i) increase in forest land for a total uptake of 1.7% of the Italian territory; forest cover estimates, with a standard error of 0.1%, indicate an annual increase of forestland higher over the period 1990-2000 (32 901 ha year^{-1}) than in 2000-2008 (22 857 ha year^{-1}); surprisingly, also a significant deforestation rate is observed (-7000 ha year^{-1}), due to forest land conversion mainly into artificial areas; (ii) consumption of arable land (-4.2% of the Italian territory) primarily due to land uptake by urban areas and to conversions to permanent crops (mainly orchards and vineyards); (iii) urban sprawl uptakes 1.6% of the Italian territory in this period, with a total coverage of settlements reaching 7.1% of total land surface in Italy in 2008. Overall, land use dynamic results in land uptake by forest land is of the same magnitude of land uptake by urban areas, but the effects of these processes on GHG removals (by forest sinks) and emissions (by urban areas) is expected to be significantly different. In a broader perspective, IUTI methodology, by providing reliable estimates and well-defined levels of statistical uncertainty for assessing stocks and flows of land use at national level, can be further implemented to frame other key questions for sustainable development policies, like the set up of environmental-economic accounting systems.

Keywords: Land Use Survey, Land Use Change, Statistical Sampling, Forest, Environmental Accounting

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Introduction

Land use inventories are sound measures to provide information on the area occupied by different land use or land cover types and their changes, although less widespread than traditional mapping. The use of formal statistical procedures allows land use inventory to straightforwardly provide area figures along with uncertainty estimates: this is an important advantage in comparison to other land-use area assessment methods, as the reliability of such figures can be quantitatively evaluated (Corona et al. 2007, Corona 2010).

Distinctively, land use inventories are well-established tools for generating statistics on the state and the dynamics of land use in the European Union: for instance, the Program Land Use/Cover Area frame statistical Survey (LUCAS, Decision N°1445/2000/EC of the European Parliament and the Council) provides harmonized data on land use/cover and their changes over time in the 27 EU countries based on direct observations gathered through ground survey in the framework of area-frame sampling scheme.

Italy is one of the first European countries that have adopted statistical systems to monitor land use changes earlier than the proliferation of mapping initiatives, thanks to the AGRIT project (http://www.itacon.it). More recently, the Italian Ministry of Environment, Land and Sea has implemented the land use inventory (Inventario dell'Uso delle Terre - IUTI) as a key instrument of the National Registry for forest carbon sinks. The Registry is part of the national system for the Italian greenhouse gas inventory, which includes all institutional, legal and procedural arrangements for accounting anthropogenic emissions by sources and removals by sinks of greenhouse gases (GHG) under the United Nation Framework Convention on Climate Change and its Kyoto Protocol (ISPRA 2011). Italy has elected forest management (Article 3.4) as activities eligible for the first commitment period, thus assigning to forest sector a leading role in the fulfilment of the Italian target under the Kyoto Protocol. Accordingly, the latest Italian National Forest Inventory (NFI) has been conceived as main data source for accounting removals/emissions of GHG in forest land (see http://www.infc.it), *e.g.*, by adopting the FAO FRA 2000 forest definition (FAO 2001) selected by Italy under the Kyoto Protocol (MATTM 2006, UNFCCC 2007).

The National Registry for carbon sinks integrates the NFI sample set within a bundle of integrated tools aimed at estimating greenhouse gases removals/emissions associated to activities under articles 3.3 (afforestation, reforestation and deforestation) and 3.4 (forest management) of the Kyoto Protocol, in accordance with the relevant decisions of the Meeting of Parties of the Kyoto Protocol and with the Good Practices Guidance for Land Use, Land Use Change and Forestry (GPG-LULUCF) of the Intergovernmental Panel on climate change (Penman et al. 2003). Notably, IUTI adopts statistical sampling procedures to estimate the area covered by GPG-LULUCF land use categories in Italy at three points in time (1990, 2008 and 2012).

The current paper is aimed at introducing IUTI methodological framework as a relevant example, and its current applications and future perspectives as a commentary discussion. Specific goals of the paper are: introducing the most relevant methodological features of IUTI inventory (see chapt. "IUTI methodological framework"); presenting IUTI land use estimates for the years 1990 and 2008, focusing on national and subnational trends in forest land use category (see Results); discussing how the IUTI inventory can be used to gain insights on the processes underpinning land use change in Italy, and future perspectives (see Discussion and final remarks).

IUTI methodological framework

IUTI estimates the coverage of the six land use categories identified in the GPG-LULUCF over the Italian territory. The methodology falls under approach 3 of the GPG-LULUCF ("geographically explicit land use data"), *i.e.*, sampling of geographically located points and classification of land use by visual interpretation of a time-series of digital aerial orthophotos (for further reference, see also Romano et al. 2011).

Sampling scheme

The localization of sampling points is carried out according to a tessellation stratified sampling design (also known as unaligned systematic sampling), preferable than simple random or systematic grid sampling (Barabesi & Franceschi 2011).

The set of sample points was extracted using a 0.5 km square grid, for a total of about 1 206 000 geo-referenced points randomly located in each square cell and fully covering the Italian territory (Fig. 1). The large sample size is due to the need of estimating land use changes occurred in a short time lag (2008-2012) with a suitable statistical accuracy. A subset of the IUTI sample is represented by the 301 300 first phase sample points of the NFI.

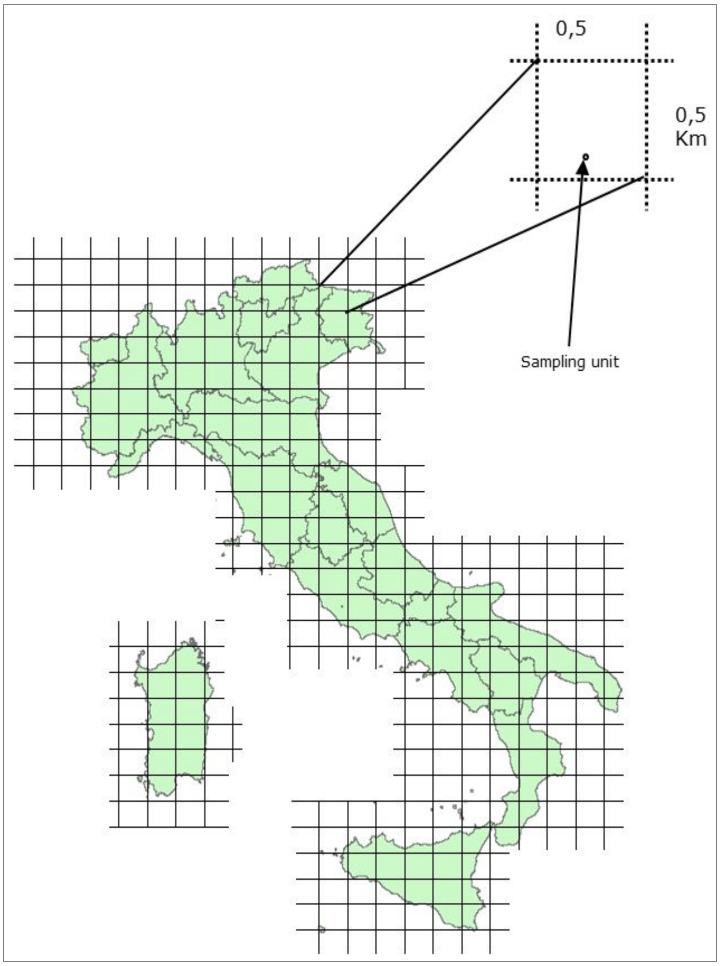

Fig. 1 - Exemplification of IUTI tessellation stratified sampling scheme.

Land classification method

The GPG-LULUCF identifies six broad categories for land-use classification: settlements, cropland, forest land, grassland, wetland, other lands. In IUTI the six categories are furtherly subdivided following a hierarchical approach (Tab. 1), so that to ensure comparability of classification with the NFI classification, where permanent crops in agricultural land, including forest plantations for wood production, are distinguished as separate classes. Marchetti et al. (2012) provides further details on the land classification of IUTI categories.

Each sample point is photo-interpreted in order to classify the sample into IUTI land use classes (Tab. 1) at different points in time (1990, 2008 and 2012). For sample points where land use change in the forest category is detected between 1990 and 2008, as result of afforestation/reforestation/deforestation activities, the land use classification is performed also in an intermediate point in time (2000), in order to estimate by interpolation the annual gain/loss of forest area in different time periods (1990-2000 and 2000-2008).

The classification of the sample set is currently completed for the years 1990, 2000 and 2008; photo-interpretation was based on the following set of multi-temporal orthophotos: (i) 1990, the black and white high resolution full national coverage aerial photography database of TerraItaly was used to produce orthophotos in scale 1:75.000, spatial resolution of 1 m (the aerial photos, taken on 1988/89, have the same image acquisition standard adopted by USGS-National High Altitude Program at that time: panchromatic film, 400 lines per millimeter); (ii) 2000, TerraItaly 2000 dataset, digital color aerial orthophotos with spatial resolution of 1 m; (iii) 2008, TerraItaly 2008 dataset, digital color aerial orthophotos with spatial resolution of 0.5 m. Furthermore, visual interpretation was supported by ancillary information from GOOGLE EARTH® and avai-

Tab. 1 - IUTI land use classification system.

GPG-LULUCF 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 land	Bare rock and sparsely vegetated areas		6

lable thematic forest and land use maps at regional and sub-regional scales.

Estimation

The estimate of the area of each land use class at national level and its breakdown by administrative districts was performed on the basis of the photo-interpretation results. The estimation procedures refer to the methodology proposed by Fattorini et al. (2004).

Let A be the extent of the national territory and A^* be the extent of the area formed by the N squares covering the national territory. The national territory is subdivided into L administrative districts (19 Regions and 2 autonomous Provinces) whose surfaces are $A_1, ..., A_L$. K land use classes (*e.g.*, 10 classes at the third classification level - see Tab. 1) are identified and the parameters to be estimated are the surfaces of each land use class in each district, say a_{lk} ($l = 1, ..., L; k = 1, …, K$), besides the surfaces of each land use class at the national level, say a_k ($k = 1, …, K$). Under the tessellation stratified sampling adopted by IUTI (eqn. 1):

$$\hat{a}_{lk} = A^* p_{lk}$$

($l = 1, ..., L; k = 1, …, K$) turns out to be an unbiased estimator of a_{lk}, where (eqn. 2):

$$p_{lk} = \frac{N_{lk}}{N}$$

($l = 1, ..., L; k = 1, …, K$) and N_{lk} is the number of sample points belonging to the class k within the district l.

Furthermore, the quantities (eqn. 3):

$$\hat{v}(\hat{a}_{lk}) = A^{*2} \frac{p_{lk}(1-p_{lk})}{N-1}$$

($l = 1, ..., L; k = 1, …, K$) and (eqn. 4):

$$\hat{c}(\hat{a}_{lk}, \hat{a}_{l'k'}) = A^{*2} \frac{p_{lk} p_{l'k'}}{N-1}$$

($l \neq l' = 1, ..., L; k \neq k' = 1, …, K$) constitute suitable estimators of the variance of a_{lk} and covariance of a_{lk}, and $a_{l'k'}$ respectively (Fattorini et al. 2004).

Since the sample points are selected on the area A^* that is wider than A, the sum of the resulting estimates, district by district, does not sum up exactly to the surface at national level. In order to obtain estimates whose summation provides exactly the area of the national territory, the following calibration has been carried out (eqn. 5):

$$\hat{a}_{lk}^{cal} = A_l p_{lk}^{cal}$$

($l = 1, ..., L; k = 1, …, K$) where (eqn. 6):

$$p_{lk}^{cal} = \frac{p_{lk}}{p_{l1} + \ldots + p_{lK}}$$

The calibrated estimators are approximately unbiased, with variances and covariances which can be estimated by (eqn. 7):

$$\hat{v}(\hat{a}_{lk}^{cal}) = \sum_{i=1}^{K} \sum_{j=1}^{K} d_{lki} d_{lkj} \hat{c}(\hat{a}_{li}, \hat{a}_{lj})$$

($l = 1, ..., L; k = 1, …, K$) and (eqn. 8):

$$\hat{c}(\hat{a}_{lk}^{cal}, \hat{a}_{l'k'}^{cal}) = \sum_{i=1}^{K} \sum_{j=1}^{K} d_{lki} d_{l'k'j} \hat{c}(\hat{a}_{li}, \hat{a}_{l'j})$$

where $l \neq l' = 1, ..., L$ and/or $k \neq k' = 1, …, K$, and (eqn. 9):

$$\hat{c}(\hat{a}_{li}, \hat{a}_{li}) = \hat{v}(\hat{a}_{li})$$

and where (eqn. 10):

$$d_{lki} = \begin{cases} 1 - p_{lk}^{cal} & \text{when } i = k \\ -p_{lk}^{cal} & \text{when } i \neq k \end{cases}$$

Finally, the calibrated estimates of the surfaces of the K land use classes over the national territory can be obtained by the sum (eqn. 11):

$$\hat{a}_k^{cal} = \sum_{l=1}^{L} \hat{a}_{lk}^{cal}$$

where $k = 1, …, K$, with estimated variances (eqn. 12):

$$\hat{v}(\hat{a}_k^{cal}) = \sum_{l=1}^{L} \sum_{l'=1}^{L} \hat{c}(\hat{a}_{lk}^{cal}, \hat{a}_{l'k}^{cal})$$

($k = 1, …, K$) where (eqn. 13):

$$\hat{c}(\hat{a}_{lk}^{cal}, \hat{a}_{lk}^{cal}) = \hat{v}(\hat{a}_{lk}^{cal})$$

Results

The land use estimates derived from IUTI database provide a statistically sound information basis to quantify land use changes in Italy over the period 1990-2008. Main results at national level are here presented, with a focus on the forest category at district level (19 Regions and 2 autonomous Provinces).

The allocation of different land use classes shows some key changes between 1990 and 2008 (Tab. 2). In 1990 the categories accounting for more than 5% of total land surface fall all in the rural domain (forest, other wooded land and agricultural areas); in 2008 land uptake by urban areas accounts for more than 7% of the Italian territory, at the expenses of a significant depletion of rural land.

On the whole, the most significant changes in the stocks of different land use categories expressed as percentage of Italian land surface are:

- consumption of arable land (-4.2%) and of grasslands (-1%);
- formation of forests (+1.7%), urban areas (+1.6%) and permanent crops (+1.4%).

The land use change matrix helps understanding the type of processes that have resulted in the observed land use changes (Tab. 3):

- consumption of arable land is primarily due to land uptake by urban areas and to conversion to permanent crops (mainly orchards and vineyards);
- consumption of grasslands is to a large extent associated to formation of other wooded land;
- forest formation is the outcome of other wooded land succession pathways, a transitional state to forest, or it is due to the creation of new forests in former arable land due to afforestation/reforestation activities or to natural forest expansion after withdrawal of farming.

Flows between forest land and other land uses result always in a positive balance (net formation of forest) except for the "other land" category and the settlements: the former mainly due to catastrophic events, mainly landslides, the latter caused by deforestation due to the creation of new mines, infrastructures and urban expansion (*e.g.*, in mountain areas, including ski trails).

Looking in more detail at the dynamics of the categories of forest interest, the most remarkable figure is the increase in forest land cover during 1990-2008, equal to 511 861 ha; forest cover estimates, characterized by a small standard error of 0.1%, indicate a coverage rising from 9 141 355 ha in 1990 up to 9 653 216 ha in 2008. Also other wooded land increased its area of about 124 000 ha

Tab. 2 - IUTI land use estimates for the years 1990 and 2008. (se%): percent standard error.

IUTI land use category / subcategory	1990		2008		Variation 1990-2008 (% of Italy land area)
	Area (ha)	se%	Area (ha)	se%	
Forest land	9 141 355	0.1	9 653 216	0.1	+1.70
Arable land	11 315 217	0.1	10 056 141	0.1	-4.18
Orchards, vineyards and nurseries	2 682 761	0.3	3 114 765	0.3	+1.43
Forest plantations	134 091	1.3	144 376	1.3	+0.03
Natural grassland and pastures	2 195 754	0.3	1 874 449	0.3	-1.07
Other wooded land	1 867 138	0.3	1 991 200	0.3	+0.41
Wetlands	510 061	0.7	518 586	0.7	+0.03
Settlements	1 644 010	0.4	2 140 903	0.3	+1.65
Other land	658 288	0.6	655 040	0.6	-0.01

Tab. 3 - Land use change matrix 1990-2008, values in hectares (see Tab. 1 for details on IUTI codes).

IUTI code		2008									
		1	**2.1**	**2.2.1**	**2.2.2**	**3.1**	**3.2**	**4**	**5**	**6**	**Total**
1990	**1**	9 014 117	30 192	13 573	975	13 446	37 213	9 497	21 118	1 225	9 141 355
	2.1	184 398	9 586 594	789 148	69 470	154 166	128 526	15 374	387 391	150	11 315 217
	2.2.1	35 547	272 931	2 269 752	775	21 650	16 571	575	64 962	0	2 682 761
	2.2.2	3 847	51 692	1 249	67 659	2 773	2 349	1 249	3 273	0	134 091
	3.1	138 121	60 692	22 573	4 224	1 662 343	276 904	5 349	24 998	550	2 195 754
	3.2	256 716	48 566	17 072	750	9 449	1 513 565	7 399	13 097	525	1 867 138
	4	14 696	1 225	425	400	2 999	11 224	476 768	1 500	825	510 061
	5	5 023	4 174	950	125	5 250	3 724	1 250	1 623 439	75	1 644 010
	6	750	75	25	0	2 373	1 125	1 125	1 125	651 691	658 288
	Total	9 653 216	10 056 141	3 114 765	144 376	1 874 449	1 991 200	518 586	2 140 903	655 040	30 148 676

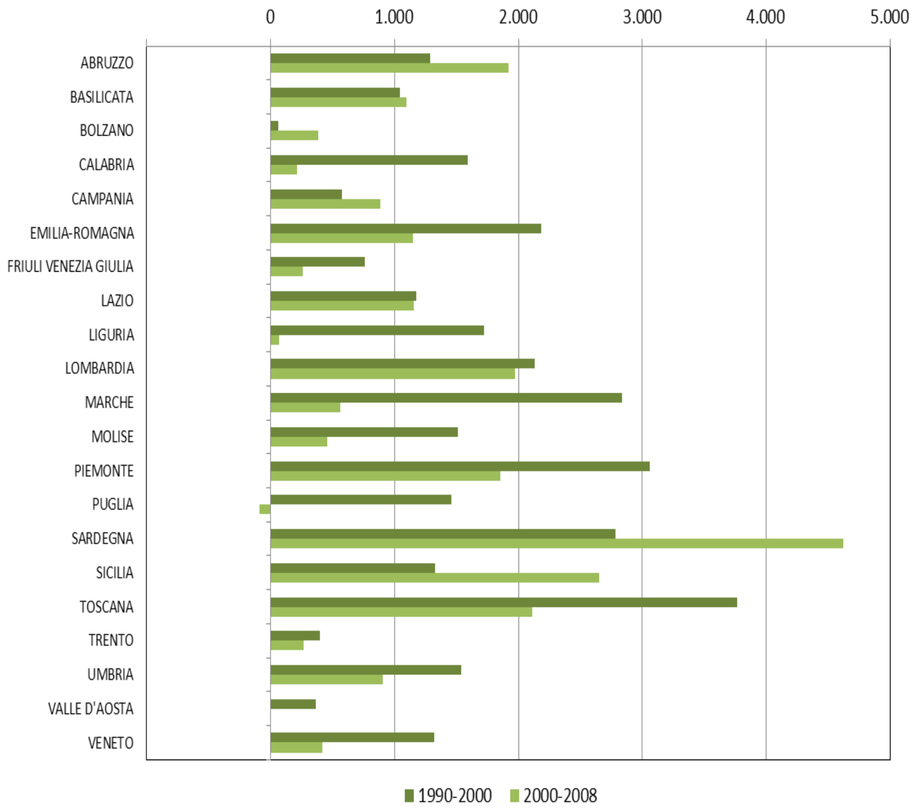

Fig. 2 - Annual variation of forest cover at district level in the periods 1990-2000 and 2000-2008.

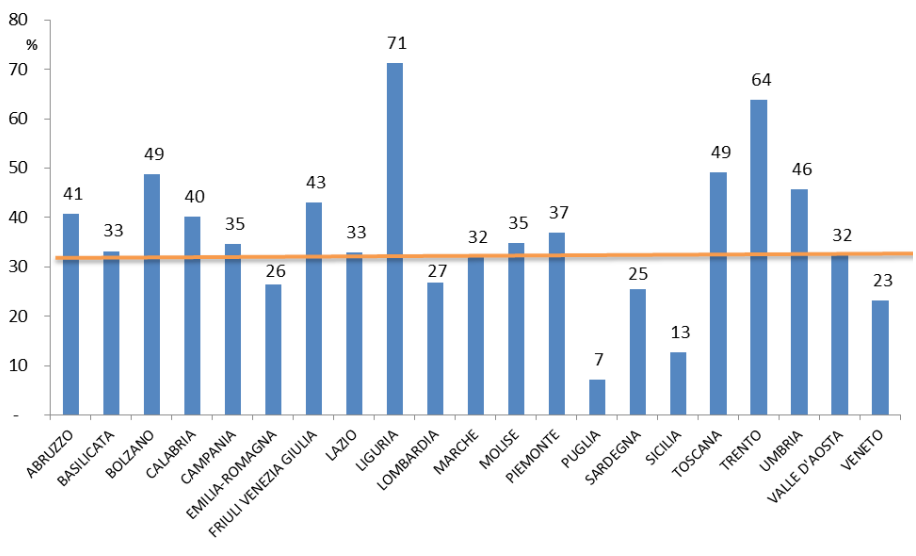

Fig. 3 - Distribution of forest cover at district level in 2008. Data are expressed as percentage of total district land area (the line shows the average national forest coverage value).

Tab. 4 - IUTI forest land estimates at district level for the years 1990, 2000 and 2008. (se%): standard error, in percentage.

Region /autonomous Province	1990		2000		2008	
	Area (ha)	se%	Area (ha)	se%	Area (ha)	se%
Abruzzo	412 009	0.6	424 890	0.6	440 267	0.6
Basilicata	312 493	0.7	322 917	0.7	331 667	0.7
Bolzano	357 365	0.6	358 015	0.6	361 115	0.6
Calabria	589 350	0.5	605 270	0.5	606 969	0.5
Campania	458 141	0.6	463 931	0.6	470 995	0.6
Emilia-Romagna	553 084	0.6	574 910	0.6	584 086	0.6
Friuli Venezia Giulia	327 880	0.7	335 476	0.6	337 575	0.6
Lazio	544 532	0.6	556 261	0.5	565 514	0.5
Liguria	368 511	0.5	385 703	0.4	386 253	0.4
Lombardia	601 129	0.6	622 457	0.5	638 216	0.5
Marche	277 506	0.8	305 869	0.7	310 367	0.7
Molise	135 630	1.1	150 739	1.0	154 417	1.0
Piemonte	894 270	0.4	924 895	0.4	939 733	0.4
Puglia	123 576	1.4	138 176	1.3	137 451	1.3
Sardegna	546 851	0.6	574 690	0.6	611 674	0.5
Sicilia	294 836	0.9	308 139	0.8	329 369	0.8
Toscana	1 079 282	0.3	1 116 936	0.3	1 133 810	0.3
Trento	389 612	0.5	393 582	0.5	395 704	0.5
Umbria	363 846	0.6	379 227	0.6	386 480	0.6
Valle d'Aosta	102 102	1.3	105 723	1.3	105 673	1.3
Veneto	409 351	0.7	422 555	0.7	425 881	0.7
Total	9 141 355	0.1	9 470 362	0.1	9 653 216	0.1

in the examined period.

Net formation of forest during 1990-2008 results from the balance between gains due to afforestation/reforestation and natural dynamics (639 099 ha, around 35 000 ha gained per year) and the losses due to deforestation (127 238 ha, around 7000 ha lost per year). The annual increase of forestland is higher over the period 1990-2000 (32 901 ha per year) than in 2000-2008 (228 57 ha per year). The slowdown in the annual value of forest expansion between the periods is a trend common to all districts (although with different magnitudes), except for islands (Sicilia and Sardegna) as well as for other regions as Abruzzo, Bolzano Province and Basilicata that show an opposite trend (Fig. 2). Two regions (Puglia and Valle d'Aosta) show a slightly negative variation of annual forest cover in 2000-2008 due to conversion into other land uses.

The highest ranked regions in term of forest cover in 2008 are Toscana, Piemonte and Lombardia; instead, Valle d'Aosta, Puglia and Molise show the lowest forest cover (Tab. 4). Looking at forest coverage share as percentage of total district land area, values higher than 60% are found in Liguria and Trento (Fig. 3). Puglia is the region with the lowest forest cover share (7%). The highest increment, in absolute values, of forest cover over the period 1990-2008 is found in Sardegna, followed by Toscana, Piemonte and Lombardia. Minor increments are registered in the mountain areas (Valle d'Aosta, Bolzano Province, Trento Province, Friuli Venezia Giulia) where the share between forest area and other land uses seems to have reached a certain degree of stability.

Discussion and final remarks

IUTI provides a statistically sound methodology for tracking changes in the land use assets in Italy; accordingly, it offers an analytical framework for addressing some key questions about sustainability of land use change, *e.g.*, accounting GHG removals/ emissions in areas under LULUCF activities.

The asset accounts for 1990-2008 highlight three interlinked land use change patterns in Italy, commented below.

(i) Increase of the stocks of forest and other wooded land reaching 11 644 416 ha in 2008, corresponding to 38.6% of the national territory. The same figure is reported by the last LUCAS survey campaign in 2009, confirming forest cover to be as high as 38% in Italy. On the other hand, these figures significantly differ from that by NFI: for a detailed discussion about possible causes of such discrepancies, see Marchetti et al. (2012). The IUTI estimate of forestland at the year 1990 is very similar to (and not significantly different from) the figure retrieved by Corona et al. (2007) by a two-phase survey involving Landsat imagery and aerial photos. Land uptake by forest and other wooded land between 1990 and 2008 has occurred mainly on arable land and grasslands; the key driver of land use change is confirmed to be the abandonment of farming activities on marginal areas, followed by natural vegetation encroachment of shrubs and trees (Corona et al. 2008). Conversely, deforestation processes are surprisingly relevant, with an annual rate of about 7000 ha of forest land converted in other land uses.

(ii) Decrease of the stocks of arable land, only partially counterbalanced by an increase in the stocks of permanent crops (orchards, vineyards, forest plantations for timber production). Distinctively, carbon sequestration potential by forest plantations and other wood formations like trees outside forest (Baffetta et al. 2011a, 2011b) is fairly significant. However, these crops are currently excluded from the Kyoto accounting system in Italy, as not classified as forest land: forest tree crops, including short rotation forestry, are indeed assigned to the cropland land use category, and they would enter in the accounting only if Italy decides to elect cropland management for the second commitment period.

(iii) While land use dynamics (i) and (ii) are contributing to increase the natural capital for delivering ecosystems services (carbon sequestration among others), urban sprawl is a fast driver of natural resource depletion and, implicitly, source of GHG emissions. IUTI estimates settlements coverage to be 7.1% of total land surface in 2008, in agreement with LUCAS 2009 (7.3% *vs.* an average of 4.3% in the EU). The average rate of increase of artificial lands within the period 1990-2008 is 1.6%, with an exponential growth over the examined period. Land uptakes affects mainly agricultural areas (lowland most fertile soils) and, to a lesser extent, forestland and marginal agricultural areas, in agreement with the general trend reported for Europe (EEA 2006a). Urban sprawl in Italy is localized not only in suburban areas of big cities, but also found under minor urban areas and related industrial and artisan areas (with the associated infrastructures). It results in unsettled clusters of residential suburbs and commercial areas, increasingly connected with main roads and big infrastructures. Urban sprawl phenomenon is by far one of the most challenging threats to sustainable development in Europe, due to its detrimental effects in term of soil consumption and sealing, loss and fragmentation of natural habitats, landscape degradation and environmental pollution (EEA 2006a, 2011a).

IUTI land use inventory is planned to be repeated at the end of 2012 for estimating forest and land use assets at the end of the first Kyoto commitment period. Overall, although land use dynamic results in land uptake by forest land of the same magnitude as land uptake by urban areas, the impacts of these changes on GHG removals (by forest sinks) and emissions (by urban areas) are expected to be significantly different.

In a broader perspective, IUTI methodology, by providing reliable estimates and well-defined levels of staistical uncertainty for assessing stocks and flows of land use at national level, can support also other kinds of environmental assessment. The future challenge for land use inventory lies in shifting the focus from a straightforward quantification of land use stocks and flows to targeting the analysis on key questions for sustainable development policies (EEA 2006b). Notably, the frontier is national environmental-economic accounting to frame policy action toward a greener growth (EEA 2011b). The purpose of environmental-economic accounting is to assess the sustainability of the economy-ecosystem interaction not only in terms of conventional indicators like gross domestic product (GDP), but taking into account the material or energy resource input (and waste generation) to produce one unit of GDP and associated impacts on depletion of natural capital and of related ecosystem services, like carbon sequestration, biodiversity conservation, water supply (EEA 2011b). In such a perspective, multi-temporal land use inventories are going to gain importance, as they provide the key information on land use stocks and flows (ha of land cover consumption and formation) required to develop accounting systems for measuring ecosystem capital degradation (*e.g.*, GHGs emissions, overexploitation of biological resources, waste disposal).

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