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MONITORING OF LAND CONSUMPTION: AN ANALYSIS OF LOSS OF NATURAL AND AGRICULTURAL AREAS IN ITALY

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Abstract – This paper aims to describe land monitoring activities and to analyse land consumption status and trends in Italy. Two methods are developed for the estimation: land cover mapping and stratified sampling monitoring network. The former is used for the creation of an accurate map (10m spatial resolution raster for the years 2012 and 2015) of consumed land (i.e. artificial land cover); the latter allows to estimate very precisely the amount of consumed land. Several spatial analyses were produced integrating the map of consumed land with additional environmental spatial data, allowing for the calculation of several indicators, such as: consumed land inside a buffer of 150m from water bodies, the surface potentially impacted by consumed land inside buffers at several distances. The monitoring network allowed for the estimation of changes, also in terms of types of artificial areas. Estimates show that land consumption is increasing in Italy, with a pace of growth of about 35ha per day during the period 2013-2015, reaching about 21,100km^2 of consumed land (about 7% of Italian surface). These estimates can be useful for public administrations in monitoring urban sprawl and fostering policies preserving the ecosystem, as well as supporting land use planning policies.

Keywords: Land Cover, Imperviousness, Copernicus, Soil, Land Cover Change

Introduction

Soil has a fundamental role in the ecosystem, providing services in terms of food production, biodiversity, and sustainability (Lal, 2005). The Land System Science is a set of disciplines aiming to assess and explicate the complex relationship between land cover change, such as urban development, and the impacts thereof on the environment (Verburg et al., 2013).

The European Environment Agency (2017) defines soil sealing as the change of soil nature by human activities, which make soil to behave like an impermeable medium, or the covering of soil surface by impervious materials such as concrete, metal, glass, tarmac, and plastic. The continuous growing of buildings, roads, and infrastructures, often in low density urban areas, particularly at European level, has raised the attention toward this issue (European Commission, 2006; European Commission, 2011).

There are other definitions such as land cover, land take, and land consumption that are highly related to soil sealing (Huber, et al., 2008). Land cover is the physical material at the ground, which for instance is vegetation, bare soil, water, asphalt, etc. (Fisher and Unwin, 2005). Land take is sometimes referred to artificial land use at the expense of natural and semi-natural land use (European Environment Agency, 1997; European Environment Agency, 1999), therefore including unsealed soil in urban areas. Nevertheless, more recently, the European Commission (2012) explained that land take includes the conversion of land within an urban area (densification) and that land take means "sealing agricultural land and open spaces"

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(European Commission, 2016). In this sense, land take is the replacement of natural and agricultural areas with artificial land cover, mainly impervious surfaces like asphalt and concrete (i.e. soil sealing), therefore it is an indicator of loss of natural and rural soils that are permanently altered. In this paper we want to stress out the importance of referring to land take as the increase of artificial land cover independently from land use (e.g. unsealed soil in urban area is not consumed land, while sealed soil in natural areas is consumed land), preferring the term "land consumption". Land consumption encompasses impervious surfaces and other artificial surfaces altering the natural soil, such as dumps, quarries, and railways (Munafò et al., 2015).

The mapping of land consumption with traditional photointerpretation can be a constraint in monitoring large territories such as Italy, therefore alternative methods have been developed (Munafò, Salvati, and Zitti, 2013). For instance, the Corine Land Cover (CLC) maps are produced at the European level since the '90s and updated regularly (APAT, 2005). CLC has 25ha minimum mapping unit (i.e. smaller features are not mapped) and a classification system that is often related to land use, rather than land cover, making difficult the assessment of land cover changes (Feranec, et al., 2007).

Therefore, there is the need for the rapid and frequent monitoring of land consumption to keep pace with urban growth, and the mapping with an adequate spatial resolution to assess also urban sprawl and minor features.

Remote sensing has been used for several decades in monitoring the biosphere and soil changes (Committee on Remote Sensing for Agricultural Purposes, 1970). Land cover monitoring of urban and peri-urban areas through remote sensing is both affordable and efficient, allowing for the mapping of land cover changes (Brook & Davila, 2000; Chen et al., 2013). In particular, the European Union developed a specific product to monitor soil sealing (i.e. Degree of Imperviousness, a 20m resolution raster based on remote sensing images) in the frame of the Copernicus initiative (European Commission, 2014). Copernicus, that is the European Union Programme for the establishment of a European capacity for Earth Observation, aims at developing European information services based on satellite Earth Observation and in situ (non-space) data including the High Resolution Layers (HRLs) that are land cover raster maps referred to the year 2012 (new updated maps will be produced for the year 2015), for the environmental themes: Imperviousness, Forest, Grassland, Wetland, and Permanent Water Bodies.

The Italian Environmental Protection and Research Institute (ISPRA) and the National System for Environmental Protection (ARPA/APPA) develop several indicators for environmental monitoring that are presented in annual reports, representing a valuable tool for policy development in improving environmental quality. In particular, the annual report on land consumption aims to describe the status of built-up growth in Italy, reporting the results of the monitoring network and the land consumption map (ISPRA, 2016).

ISPRA developed a homogenous monitoring system of land consumption in Italy, that allowed the estimation from the 1950's to today, and that represents the official benchmark about national land consumption in the National Statistic Program 2014-2016. This monitoring system is based on the photo-interpretation of very high resolution images and topographical maps on a stratified sampling. The network is made of about 180,000 samples, with 12,000 belonging to the national monitoring network, 28,000 to the regional network, and the remaining samples to the municipal network. The monitoring network is very accurate in estimating land consumption. Nevertheless, a representation (i.e. map) can be very useful for spatial analyses aimed to localize the changes and relation to other environmental features.

The main objective of this study is the estimation of consumed land in Italy, related to the loss of natural soil, and the change thereof during the years 2012 and 2015. The resulting data and estimations, whose public access is freely provided by ISPRA, can be valuable information for land planning and decision making, especially for protecting and managing natural environment, highlighting areas where built-up increased.

In this study, we analyse the land consumption in Italy through the National High-Resolution Land Consumption (NHRLC) map developed by ISPRA using remote sensing images with semi-automatic classification techniques (the map is freely available at http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/il-consumo-di-suolo/i-dati-sul-consumo-di-suolo). This map is a binary classification (consumed/non-consumed) having 10m spatial resolution, allowing for the accurate estimation of land consumption at the local level and for the whole national territory. Several indicators were calculated from these data which aim to describe specific environmental aspects related to land consumption.

Materials and Methods

The NHRLC developed by ISPRA identifies built-up areas with a spatial resolution of 10m (see Figure 1 and the overviews of Turin, Milan, Rome, and Naples in Figure 2), with the legend illustrated in Table 1.

Table 1. Legend of the National High-Resolution Land Consumption.

Values	Description
0	Non-consumed land
1	Consumed land
2	Unclassified
3	Area outside the national boundary

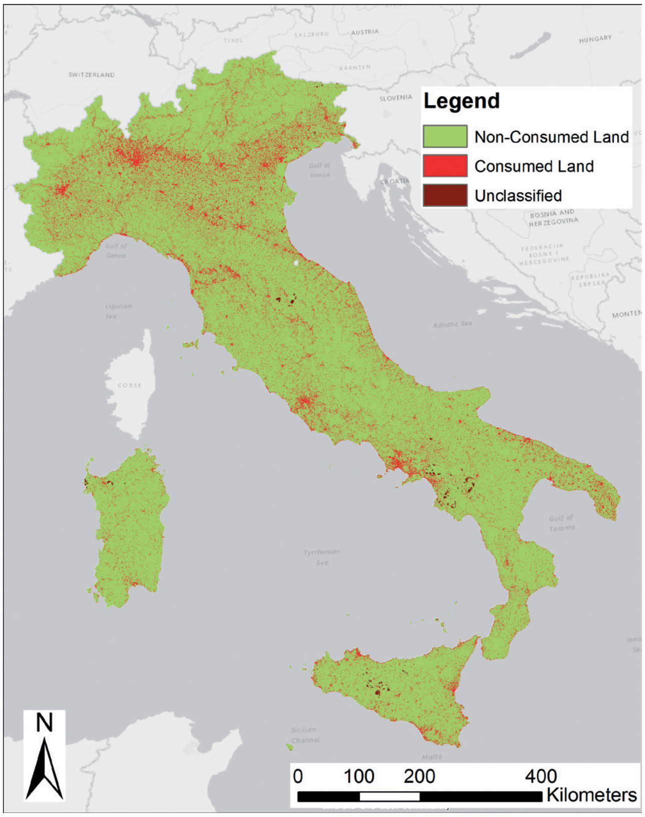

Figure 1. National High-Resolution Land Consumption 2015 by ISPRA.

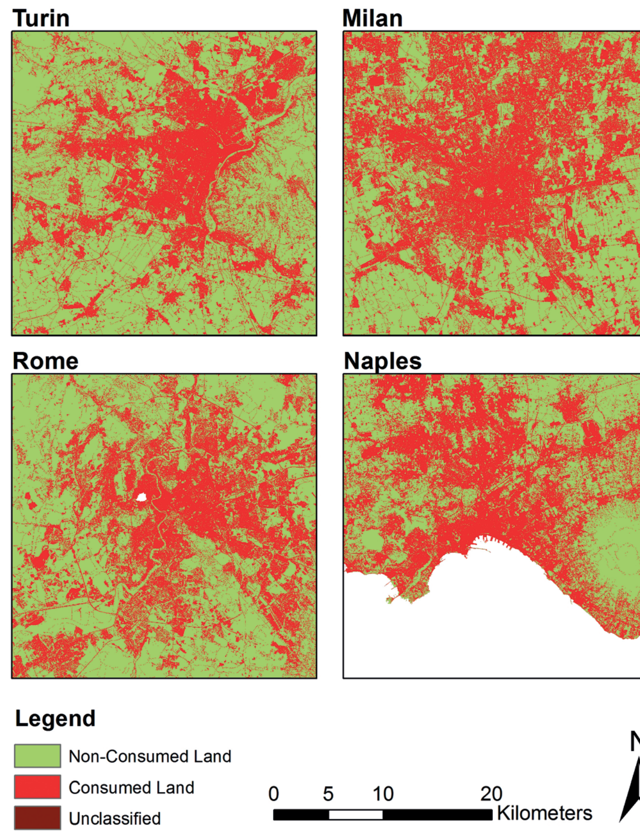

Figure 2. National High-Resolution Land Consumption 2015 by ISPRA, an overview of Turin, Milan, Rome, and Naples.

The following categories are comprised in the definition of consumed land:

- Buildings;
- Paved roads;
- Unpaved roads;
- Squares;
- Parking;
- Railway sites;
- Airports and ports (impervious surfaces);
- Impermeable areas in sports fields;
- Permanent greenhouses;
- Solar farms on land;
- Mining areas;
- Dump sites;
- Other impervious areas.

The classification was produced for the years 2012 and 2015. In particular, the 2012 classification was obtained from a previous classification made by ISPRA, based on semi-automatic classification of RapidEye imagery (5m spatial resolution), resampling the pixels to 10m resolution.

Prior to the 2015 classification, the 2012 map was aligned to Sentinel-2 images (Datum WGS84, UTM projection) provided for free in the frame of the Copernicus program. The free availability of Sentinel-2 images assures the sustainability of an annual monitoring of land consumption, reducing the cost of data. These images have 10m spatial resolution, providing multispectral images that have been used for semi-automatic classification and photointerpretation.

The classification process is based on the semi-automatic identification of artificial land cover exploiting the spatial and spectral resolutions of Sentinel-2 images; in addition, ancillary data, such as regional topographic databases, were used to improve the identification of artificial areas.

To enhance the classification of roads, the free and open data OpenStreetMap was used as ancillary information. These vector data are created by voluntaries and are frequently updated; the information on type of road is included, which is useful for estimating road width. After the conversion from vector to raster, these data were added to the NHRLC as consumed land, distinguishing between changes and omissions with the photointerpretation of remote sensing images.

It is worth mentioning the differences between the NHRLC and the Imperviousness HRL: the spatial resolution of NHRLC is 10m while the Imperviousness HRL is 20m; the classification system of the NHRLC includes railway sites, mining areas, and dump sites, which are excluded from the Imperviousness HRL (the inclusion of these features is still debated, although for ISPRA these should be considered as consumed land); the NHRLC is a binary classification that doesn't include information about the Imperviousness HRL. The following Figure 3 shows that NHRLC map outperforms the Imperviousness HRL, especially for roads and small buildings, because of the higher spatial resolution.

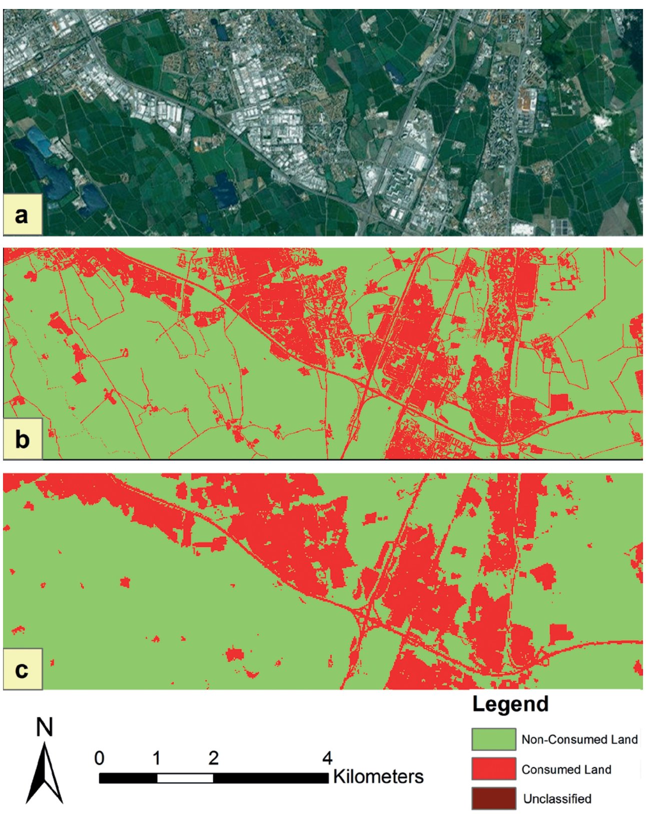

Figure 3. Comparison between the National High-Resolution Land Consumption 2012 by ISPRA (b), and the Imperviousness HRL 2012 (c), with a very high resolution image (a). Minor roads and small buildings are not classified in the Copernicus layer.

The accuracy of the resulting classification was assessed with a validation process that involved the subsampling of data and the comparison with ground truth. The result of the accuracy assessment is an error matrix where columns correspond to ground truth and rows correspond to map values (Congalton & Green, 2009). The major diagonal of the matrix contains correctly classified samples, the other elements represent classification errors. This error matrix allows for the calculation of several accuracy indices, such as the overall accuracy (Congalton & Green, 2009).

The NHRLC map was compared to the ISPRA monitoring network of land consumption to compute the error matrix and accuracy indices. In particular, at the National level the NHRLC map reached 95.6% of overall accuracy. Nevertheless, considering the spatial resolution of data, a shrink operation was applied to the NHRLC (i.e. a raster process that enlarged the consumed land patches by 1 pixel width) to eliminate errors due to the shift between data and very high resolution images used for validation. As described by ISPRA (2016), after the shrink the overall accuracy reached the 97.7%.

After the classification process, several analyses were produced with the reprojection of NHRLC map to an equal area projection (i.e. ETRS 1989 LAEA), to accurately estimate surfaces. These analyses aim to understand the relationship between land consumption and environmental aspects such as water bodies and protected areas. Moreover, the ISPRA monitoring network of land consumption (about 40,000 samples at the National and Regional level) was used for estimating changes of specific land cover classes.

First, the amount of land consumption in Italian Protected Areas (i.e. the official list EUAP), derived from a spatial intersection between the NHRLC map and the vector boundaries of protected areas. The impact of land consumption not only affects the artificial area, but also the surrounding areas because of the different effects on ecosystem and biodiversity (Scalenghe and Marsan, 2009).

The NHRLC map was compared to the Permanent Water Bodies layer (i.e. Copernicus High Resolution Layer 2012, with 20m spatial resolution), which is a raster mapping the national water surfaces such as lakes and rivers based on semi-automatic classification (European Environment Agency, 2013). A buffer area of 150m from every pixel of the Permanent Water Bodies layer was considered, allowing to estimate consumed land inside that buffer.

Estimations are the result of spatial processing between NHRLC map and the municipal boundaries by the Italian National Institute of Statistics. In addition, estimates were aggregated at the regional and national level.

Results

The NHRLC map of 2012 and 2015 allowed for the accurate estimation of land consumption and the change thereof during this period. In particular, land consumption estimates were calculated at the municipal level, as well as the regional level. The highest percentages of land consumption in 2015 at the municipal level are illustrated in the Table 2.

Table 2. Municipalities with the highest percentage of consumed land.

	Municipality	Province	Consumed land [%]
1.	Casavatore	Naples	85.4
2.	Arzano	Naples	78.9
3.	Melito di Napoli	Naples	76.0
4.	Cardito	Naples	67.9
5.	Frattaminore	Naples	66.9
6.	Torre Annunziata	Naples	65.2
7.	Lissone	Monza e Brianza	64.0
8.	Casoria	Naples	63.1
9.	Portici	Naples	62.3
10.	San Giorgio a Cremano	Naples	60.1
11.	Aversa	Caserta	60.0
12.	Mugnano di Napoli	Naples	59.1
13.	Lallio	Bergamo	59.1
14.	Frattamaggiore	Naples	59.1
15.	Curti	Caserta	59.0
16.	Sant'Antimo	Naples	58.1
17.	Fiera di Primiero	Trento	57.9
18.	Turin	Turin	57.6
19.	Naples	Naples	57.0
20.	Sesto San Giovanni	Milan	56.8

Table 3. Percentage of land consumption 2015 by region and increase in range 2012-2015.

Region	Consumed land 2015 [%]	Increase 2012-2015 [%]	Annual rate of change [%]
Piedmont	8.2	0.3	0.10
Aosta Valley	2.9	0.7	0.23
Lombardy	12.8	0.6	0.21
Trentino-Alto Adige	4.4	0.7	0.24
Veneto	12.2	0.6	0.21
Friuli-Venezia Giulia	8.8	0.7	0.22
Liguria	8.2	0.3	0.08
Emilia-Romagna	9.6	0.5	0.17
Tuscany	7.0	0.3	0.10
Umbria	5.4	1.0	0.35
Marche	7.0	0.9	0.31
Lazio	8.2	0.8	0.26
Abruzzo	4.8	0.8	0.27
Molise	3.8	0.7	0.25
Campania	10.7	0.6	0.21
Puglia	8.2	0.9	0.30
Basilicata	3.4	1.4	0.45
Calabria	4.9	0.9	0.31
Sicily	6.9	0.9	0.30
Sardinia	3.6	0.7	0.24
Italy	7.6	0.7	0.22

It is worth highlighting that consumed land is higher than 50% in several municipalities in the Province of Naples.
More than 57% of the area of Naples and Turin is consumed. These provincial capitals influence the urban development of several surrounding municipalities.
Regarding the capital Rome, about 30,000ha of land is consumed, which is the top value among Italian municipalities. However, other provincial capitals such as Milan, Turin, and Naples have values higher than 4,000ha.
The following table illustrates the percentage of land consumption in 2015 at the regional level, and the increase of the percentage from 2012 to 2015.

Lombardy, Veneto, and Campania are the Regions with the highest percentage of consumed land in 2015 (more than 10%). Basilicata had 1.4% increase of consumed land between 2012 and 2015. At the national level, about 7.6% is consumed land, with 0.7% increase during the period 2012-2015.
The percentage calculated from the NHRLC map was compared to the percentage obtained from the monitoring network of land consumption by ISPRA (Table 4). The former is a cartographic map with 10m spatial resolution, the latter is a network of about 40,000 samples for the national level allowing for accurate estimation of land consumption.

Table 4. Land consumption at the national level.

Year	Consumed land [%]	Consumed land [km^2]
‘50s	2.7	8,100
1989	5.1	15,300
1996	5.7	17,100
1998	5.8	17,600
2006	6.4	19,400
2008	6.6	19,800
2013	6.9	20,800
2015	7.0	21,100

Table 5. Consumed land inside a buffer of 150m from permanent water bodies in 2015 and increase from 2012.

Region	Percentage of consumed land inside 150m buffer	Percentage of consumed land increased from 2012 to 2015 inside 150m buffer	Area of consumed land increased from 2012 to 2015 inside 150m buffer
Piedmont	9.0	0.3	39
Aosta Valley	9.6	0.8	12
Lombardy	8.0	0.4	69
Trentino-Alto Adige	11.9	1.0	41
Veneto	9.3	0.3	55
Friuli-Venezia Giulia	6.8	0.6	26
Liguria	23.8	0.4	5
Emilia-Romagna	8.2	0.5	33
Tuscany	7.3	0.4	37
Umbria	4.5	1.5	39
Marche	6.7	1.3	25
Lazio	5.9	0.3	11
Abruzzo	5.6	0.7	5
Molise	3.4	3.3	7
Campania	7.4	0.6	8
Puglia	3.7	0.7	7
Basilicata	2.5	1.1	3
Calabria	4.6	0.5	3
Sicily	3.9	0.9	50
Sardinia	3.8	0.9	26
Italy	7.2	0.5	502

In the last 60 years, the percentage of consumed land in Italy increased from about 3% to 7% in 2015 (about 160% of increase during this period), covering an area of more than 21,000 km^2. As mentioned before, statistics were calculated also for Italian Protected Areas (i.e. the official list EUAP), estimating that about 34,000ha of land is consumed inside these areas (about 1.5% of total area is consumed).

As it regards the consumed land calculated inside the buffer area around the Permanent Water Bodies layer (i.e. Copernicus High Resolution Layer 2012), the Region Liguria has the maximum percentage of consumed land inside this buffer (i.e. 23.8%), and Trentino Alto Adige is the second with 12% (Table 5). This is mainly due to the orography and mountainous areas that foster urbanization along river valleys where the slope is lower.

It is also worth noticing the increase of percentage of land consumption for Trentino Alto Adige. This is particularly negative because it can be related to flooding phenomena. At the national level, over 500ha of land were consumed inside this 150m buffer.

In order to consider the surface interested by possible impacts related to land consumption, several buffer distances were considered (Table 6).

Table 6. Percentage of surface interested by possible impacts related to land consumption.

Region	2012 [%]			2015 [%]		
	60m	100m	200m	60m	100m	200m
Piedmont	42.8	56.8	76.2	42.8	56.8	76.2
Aosta Valley	19.0	25.3	36.7	19.0	25.3	36.8
Lombardy	48.1	60.8	77.7	48.2	60.8	77.8
Trentino-Alto Adige	32.2	42.4	57.0	32.3	42.5	57.0
Veneto	49.7	62.4	78.5	49.8	62.5	78.5
Friuli Venezia Giulia	42.4	54.4	70.1	42.4	54.4	70.1
Liguria	45.5	58.5	77.5	45.6	58.5	77.5
Emilia-Romagna	50.4	66.6	87.5	50.4	66.6	87.5
Toscana	43.4	58.3	80.4	43.4	58.3	80.4
Umbria	37.8	52.1	74.5	37.9	52.1	74.5
Marche	43.8	60.2	83.1	43.9	60.2	83.1
Lazio	44.2	57.0	75.3	44.3	57.1	75.3
Abruzzo	31.3	42.5	60.5	31.4	42.6	60.6
Molise	33.7	47.3	69.7	33.8	47.4	69.9
Campania	50.5	64.6	82.4	50.7	64.7	82.4
Puglia	52.3	68.7	87.5	52.5	68.8	87.6
Basilicata	30.3	43.0	64.7	30.4	43.2	65.0
Calabria	32.9	45.4	65.7	33.0	45.5	65.8
Sicily	44.5	60.5	82.6	44.6	60.6	82.7
Sardinia	29.9	42.7	65.0	30.0	42.8	65.1
Italy	42.1	55.9	75.4	42.2	56.0	75.5

About 42% of the national surface is potentially interested by impacts related to land consumption considering a 60m buffer; considering a 100m buffer this surface is 56% and reaches 75% considering a 200m buffer. At the regional level, Puglia and Emilia Romagna have the highest values, covering almost the 90% of the regional surface with the 200m buffer. If we considered a buffer distance of 1.000m, the interested area would cover almost the whole national surface.
In order to assess the relevance of particular types of artificial surfaces related to land consumption, the ISPRA monitoring network was used.

Table 7. Percentage of sealed surface by type in Italy for 2008 and 2013, and annual variation.

Type of artificial surface	2008 [%]	2013 [%]	Annual variation [km^2]
Buildings	2.0	2.1	48
Asphalt roads	1.6	1.6	38
Unpaved roads	1.1	1.1	-4
Parking and other unpaved areas	0.9	0.9	22
Permanent greenhouses	0.1	0.1	-

Considering the change from natural to artificial surface, the monitoring network allowed to assess the main types of natural cover that were lost from 2008 to 2013.

Table 8. Percentage of changes by type of natural cover over the total of changes from 2008 to 2013.

Type of natural surface	Changes by type over total changes from 2008 to 2013 [%]
Trees/shrubs in urban area	5
Other pervious surface in urban area	17
Trees/shrubs in rural areas	8
Crops	48
Other pervious surface in rural area	3
Trees/shrubs in natural areas	5
Meadows/grassland	5
Rocks	2
Other pervious surface in natural area	7

Between 2008 and 2013, almost 60% of new sealed surface was over rural areas (especially crops). About 22% of the changes were over urban areas, and 19% was over natural areas.

Discussion

The NHRLC map allowed for the estimation of land consumption at local level (i.e. municipalities) and at the national level. Moreover, several spatial analyses were produced for estimating the impact of land consumption on the environment.
Several regions of the North of Italy had a significant increase of consumed land area. The consumed land inside a buffer of 150m from permanent water bodies was calculated, demonstrating that several Regions of the North of Italy (especially Liguria having about a quarter of consumed land inside this buffer) are potentially impacted by flooding, with consequences on people safety.
The results of the surface interested by possible impacts related to land consumption show that a great portion of the nation is subject to possible environmental consequences, which could be assessed through ecosystem service modelling. This information could be relevant for urban planning to assess the relationship between spatial distribution of environmental components and artificial areas.
ISPRA monitoring network allowed the estimation changes from natural to artificial surfaces by type of land use/land cover. This survey, produced by the interpretation of very high resolution, integrated cartographic data (also in the Copernicus framework) to assure the coherence with spatial data. The main advantage of this monitoring network, compared to the NHRLC map, is that it is not affected by the limits of a minimum mapping unit, ensuring more accurate and reliable estimation of land consumption, including also sparse buildings for the assessment of even small changes. It is worth highlighting that estimations have a confidence interval of 95%, which depends on the area of Regions, the characteristics of monitoring network and the estimation error.
The percentage obtained from the NHRLC map (i.e. 7.6%) is very close to percentage of the monitoring network (i.e. 7.0%) for 2015 at the national level, which is a good result considering that NHRLC spatial resolution (i.e. 10m) limits the identification of small features such as narrow roads or small buildings.

Conclusions

This paper analysed land consumption in Italy, which is an anthropic phenomenon related to soil sealing and the urban sprawl process, which is the unplanned and discontinuous expansion of city limits with new buildings and infrastructures, impacting on the use of land and natural resources (European Environment Agency, 2006).

The European Union is monitoring the environment through several initiatives, especially the Copernicus program; Earth monitoring satellites were launched (i.e. Sentinel satellites) aiming to produced land cover maps that can be updated frequently with these data. The HRLs 2012 were produced with RapidEye imagery, using a semi-automatic classification approach, and validated/enhanced using ancillary data. In particular, the Imperviousness HRL is useful in monitoring land consumption at the European level. ISPRA developed a National High-Resolution Land Cover map for 2012 based on Copernicus High Resolution Layers, having 20m spatial resolution, which comprises the built-up class (Congedo, et al. 2016).

Nevertheless, the spatial resolution of HRLs is not sufficient for the assessment of land consumption at the local level. For this reason, ISPRA produced the NHRLC map for the years 2012 and 2015 with 10m spatial resolution, allowing for the estimation of land consumption and the change thereof during this period at the Municipal level.

The estimates of the NHRLC map are very similar to the ISPRA monitoring network, considering that the two methods (cartographic and point sampling) are different in terms of spatial resolution. In particular, the NHRLC map has a minimum mapping unit of $100m^2$, which can underestimate small built-up areas. These estimates confirm that land consumption is increasing in Italy, with a pace of growth that is slowing compared to the previous decades.

The estimation of the variation of land consumption are relevant for the analysis of changes in the Italian landscape, and the assessment of ecosystem services related to soil which are affected by land use and land consumption, such as carbon sequestration (Fu, et al., 2013). Built-up data can be used for assessing urban fragmentation and urban sprawl through spatial metrics (Jaeger, et al., 2010). Moreover, these data can motivate public administrations to reduce land consumption and urban sprawl, preserving the ecosystem (Millennium Ecosystem Assessment, 2005). ISPRA is committed to update the NHRLC map every year and provide the environmental indicators related to land consumption.

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