http://www.press.ierek.com

ISSN (Print: 2357-0849, online: 2357-0857)

International Journal on:

Environmental Science and Sustainable Development

DOI: 10.21625/essd.v6i1.789

Land Consumption, Ecosystem Services and Urban Planning Policies: Preliminary Results of Research Undertaken in the Tuscany Region

Debora Agostini[1], Fabio Lucchesi[1], Francesco Monacci[1], Fabio Nardini[1], Massimo Rovai[2], Iacopo Zetti[1]

[1] *University of Florence - Department of Architecture*

[2] *University of Pisa - Department of Department of Civil and Industrial Engineering*

Abstract

In the contemporaneity, the issues of land or soil consumption and of the protection of areas that, within the urban areas, provide ecosystem services (ESs) is becoming increasingly important also in relation of the 2030 Sustainable Development Goals. The concept of "Ecosystem Service" appears, in this respect, a fruitful support to define the land consumption effects on the loss of functionality and of settlement quality. Following this considerations the paper presents the first results of a research developed in Tuscany and commissioned by the Regional Government. The research aims to measure the loss of ESs in connection with land use / land cover transformations, and to verify the contribution of soil consumption to these variations. The research use methodologies for elaborating of the geographical data required for territorial governance, LUCL 2010/2016 and Land Cover Flow (LCF) model and the theoretical model of the “Capacity matrix” to provide ecosystem services.

Keywords

Geographic information systems land cover change; urban development; ecosystem services, ecosystem assessment.

1. Introduction

This paper aims to inform the scientific community of preliminary developments and of some research methodologies that have been elaborated as part of an ongoinggg scientific project financed by the Urban Planning and Housing Policies Department of the Tuscany Region. The objective of this research is to test innovative methodologies for elaborating of the geographical data required for territorial governance. This paper will reflect on techniques for monitoring and evaluating transformations in land use/cover and how this information can be used to verify changes in the provision of Ecosystem Services.

1.1. The 2007-2016 LULC database and the description of settlement growth

In 2007, the Tuscany Region started developing a programme for acquiring and updating information on a three-year basis on the Land Use and Land Cover (LULC) throughout the entire region. The database provide multi-temporal readings of land use so it was relatively simple to use it to study the changes in land use that took place between 2007 and 2016. Among the many studies which have used this data to analyse changes in land use across the region, those

focusing on quantifying and analysing the dynamics of land consumption have been particularly important (Ciampi et al., 2015; Marson & Lucchesi, 2017).

1.2. The distribution of land use and the recent dynamics of territorial transformations (2010-2016)

The map LULC for 2016, at the first level of the classification, shows the distribution and the quantities of land-use in the region. In quantitative terms, land use in Tuscany in 2016, according to Corine Land Cover nomenclature, was subdivided as follows: artificial surfaces 8.6% (1,979 km²), agricultural areas 38.2% (8,782 km²), wooded and semi-natural areas 52.2%, (12,005 km²), wetlands 0.2% 49 km²) and water bodies 0.7% (172 km²).

Land use changes that took place throughout the region in the period 2010/2016 were evaluated using Land Cover Flow (LCF) methodology, a system for evaluating transformations in land use that was first developed for the European-level Corine Land Cover (CLC) project (Feranec et al., 2010) and subsequently applied to national and regional contexts using more detailed maps (Lucchesi et al., 2015).

The research described in this paper has focused on the transitions of land use towards urban uses, i.e. on ascertaining how much of agricultural and natural land in 2010 had been transformed into artificial surfaces for residential use (LCF2) or for productive and infrastructure use (LCF3) by 2016. In addition to measuring the land surfaces that in absolute terms now belonged to a different LULC category (either LCF2 or LCF3) a “settlement growth” index was created to relate the artificial surfaces that were registered for the first time in 2016 with those that were already in 2010.

The LULC database, using LCF classification (LCF 2 and LCF 3), shows that there was a total of 1,894.18 km² of artificial surfaces in Tuscany in 2010 (Tab. 1, Fig. 1). The 2016 data showed there had been a 42.52 km² increase in artificial surfaces since 2010, with an overall settlement growth rate of 2.24% over that time period. The rate of settlement growth was not homogeneous:

- artificial surfaces for residential use accounted for 931.92 km² in 2010 and a further 7.07 km² in 2016: a 0.76% increase;
- artificial surfaces for productive and infrastructure uses accounted for 962.25 km² in 2010 and a further 35.44 km² in 2016: a 3.68% increase.

Table 1. Increase in artificial surfaces in the years 2010-2016 divided between growth for residential use and growth for productive and infrastructure uses

	Artificial surfaces in 2010 (km²)	**Increase in artificial surfaces to 2016 (km²)**	**Increase (%)**
Development of residential areas (LCF2)	931.92	7.07	0.76%
Development of infrastructure, commercial and productive areas (LCF3)	962.25	35.44	3.68%

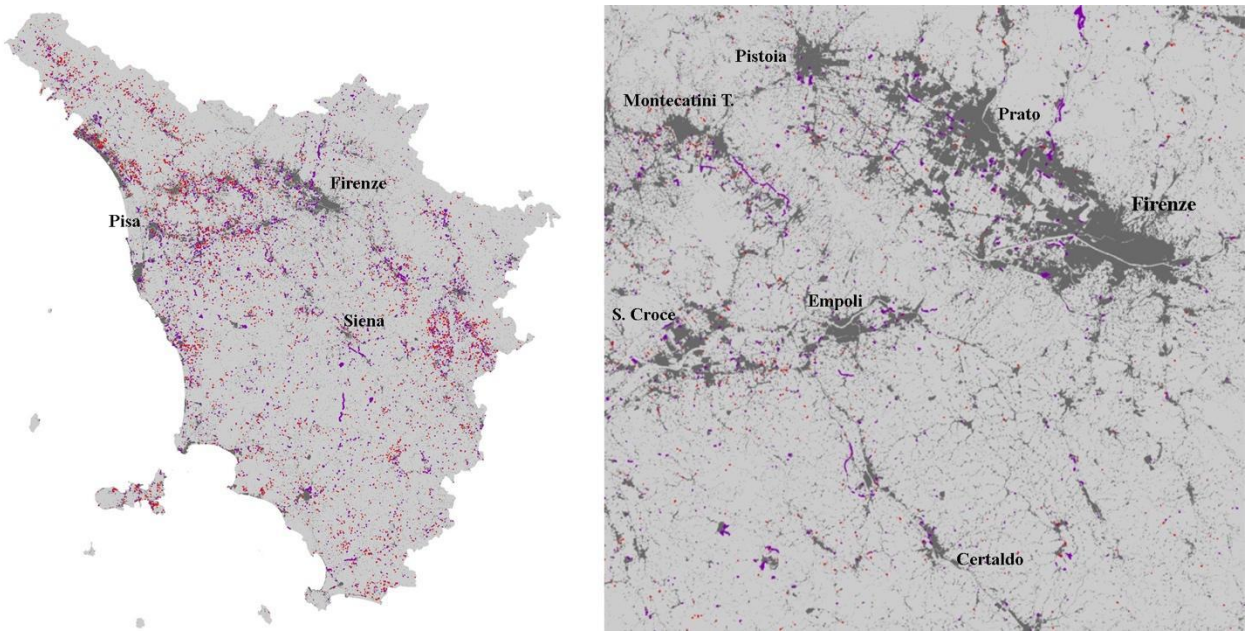

Figure 1. On the left: 2010-2016 LULC variations in Tuscany, using Land Cover Flow nomenclature. The LCF2 categories are colored red (Urban residential sprawl); the LCF3 categories are colored purple (Sprawl of economic sites and infrastructures); the artificial surface present in 2010 and also in 2016 are colored in dark grey. On the right: Details of the 2010-2016 LULC variations around Florence.

The ratio between the two growth indexes shows that the growth of production and infrastructure sites throughout Tuscany in the years 2010-2016 was almost five times greater than the growth of residential settlements. With this in view, the research sought to determine what consequences these transformations have had on the capacity to provide ecosystem services.

2. Mapping Ecosystem services on a local scale using Land Cover databases

Ecosystem services (ESs) are generally defined as the benefits, direct or indirect, that people can obtain from ecosystems (de Groot et al. 2002; Costanza, 1997).

In the last twenty years, and especially since 2005, the year in which the second Millennium Assessment study was carried out, research into the classification of ESs and their spatial mapping has greatly increased. In Europe, the process of spatial identification and ESs evaluation was significantly boosted following the definition of the European Biodiversity Strategy to 2020: the objective of Target number 2 was to maintain and improve ecosystems and related services by creating green infrastructure and restoring at least 15% of degraded ecosystems (Maes et al., 2016). Furthermore, in the context of Action n. 5 of this Strategy, Member States, supported by the MAES working group, undertook to map and evaluate the ecosystem services in their countries by 2014.

An interesting initiative to map ecosystem is attributable to the formulation of the Ecosystem Map of Italy (Blasi et al. 2017) and the monetary values assigned to some ESs contained in the Third Report on the State of Natural Capital in Italy. The Ecosystem Map of Italy identified ecosystems on a scale of 1:100,000 using a system whereby data from the Corine Land Cover project was connected with an archive of potential vegetation. More specifically, the map was developed with a methodology that used data from the Corine Land Cover project up until level 4 for classes 31x and 32x the data of the potential vegetation classes. This methodology made it possible to identify the typologies of ecosystems, but it did not push towards specific elaborations to identify ESs.

The second project used a completely different methodology which simplified the ecosystem macro-categories and pushed towards a spatial assessment of the monetary value of some ecosystem services at the 1:100,000 scale: recreational, crop pollination, water supply, flood risk regulation (La Notte et al. 2017).

A survey of the scientific literature reveals that in many studies the mapping of ESs has been carried out with *proxy* methods (Chan et al. 2006, Egoh, 2008, Naidoo et al., 2008; Eigenbrod, 2010), using data prepared in other contexts of research to compensate for the lack of primary data (Maes et al., 2012). While provisioning ESs can often be directly quantified with primary data, most regulating, supporting, and cultural services are less straightforward to be

put on maps and researchers must rely on proxies for their quantification. Land Use and Land Cover (LULC) map are the most common proxy data used, but also environmental indicators such as the evaluation of nitrogen concentration for the measurement of the ES of water purification (Grizzetti et al., 2008; Grizzetti et al., 2012), or the distribution of animal species for the evaluation of supporting ESs (Eigenbrod et al. 2010) are used.

In Italy a similar methodology has been adopted for the first time to test the role of protected areas to prevent loss of ES with land transformation (Scolozzi et al. 2012; Scolozzi et al.2014).

The availability of LULC themes, readily obtainable from satellite image processing, together with the possibility of quantifying changes in land use over time, has encouraged many researchers to develop ESs mapping methodologies which, over time, have evolved at national, regional and local levels (Eigenbrod et al. 2010).

Many of these studies avoid a monetary evaluation of ESs, adopting a comparative approach. In this latter case, for each land-use class are assigned scores in accordance with a predefined scale of values measuring the supply capacity of each ES. Scores are assigned on the base of ratings provided by experts from related disciplines regarding the different ES categories (or groups); the scores are then used to evaluate the evolution over time of the performance of an ES within a given geographical area (Burkhard et al. 2009; Burkhard et al. 2012).

3. Capacity matrix methodology applied to land in the Tuscan region

This paper presents the result of preliminary ESs mapping trials that were conducted on the Tuscany territory, using the methodology proposed by Burkhard in his studies on the landscape of central-eastern Germany (Burkhard et al. 2009; Burkhard et al. 2012) and used by many studies at European and international level (Campagne, 2020).

With the aim of evaluating the capacity of the different types of land cover to provide ecosystem services, Burkhard created a relation matrix with on the columns, the 44 types of land cover encoded by the Corine Land Classification Cover and on rows 29 ecosystem services: 7 ESs able to measure ecological integrity, 11 ESs aimed at measuring the provisioning services, 9 ESs for the regulating services, 2 ESs for cultural services.

In Burkard's work concerning ecological integrity service (corresponding to the support services as defined by MEA, 2005), reference was made to Muller, 2005, while, for the provisioning, regulating and cultural services reference to the works of de Groot, 2006; MEA, 2005; Costanza, 1997.

Therefore, each cell of the matrix reports a value (along a scale from 0 to 5 (0 = no relevant capacity of the land cover type to provide this particular ecosystem service, 1 = low relevant capacity, 2 = relevant capacity, 3 = medium relevant capacity, 4 = high relevant capacity and 5 = very high relevant capacity) which expresses the ability of each LULC class to provide a specific ecosystem service. In Burkhard's works, the method used for the attribution of scores is that of consulting with competent experts with respect to the different categories of ESs.

Once the capacity matrix has been built (Tab. 2), using GIS software, it is associated with the LULC database, for understanding the spatial distribution of service supply and for evaluating the dynamics on different time scales.

The twenty-nine indicators proposed by Burkhard have been grouped into four categories, according to TEEB, 2008: ecological integrity (supporting services), provisioning services, regulating services, cultural services. The score of the four main categories of ESs was obtained as the sum of the scores of each ES belonging to the specific category. Some values have been modified to adapt them to the LULC legend of Tuscany Region which have some difference from original CLC classification (Tab. 2). The total scores of the four ESs categories were subsequently normalized in the range from 0 to 1 so that the measurements of the four categories of ecosystem services would be comparable.

To calculate the ecosystem services capacity of the Tuscan territory, the research associated to each of the polygons in the database (for each of the four ESs categories) a score equal to the normalized value between 0 and 1 of the single LUCL class, multiplied by the area of the polygon.

The accuracy of the ESs supply is very dependent on the cartographic detail of the data used and its ability to recognize the presence of natural ecosystems that perform ecological functions. Small cartographic scales (eg. 1: 100.000) are more affected by the presence of polygons including too heterogeneous areas within them, failing to distinguish the presence of permeable areas and arboreal and shrubby vegetation. This capacity due to the greater detail are very

important especially in the areas surrounding the small Tuscan cities, often characterized by heterogeneity of use and by the permanence of agricultural cultivations.

The limits of the cartographic scale are particularly important in proxy methods (Eigenbrod, 2010); the availability of a medium-scale LULC cartography for the Tuscan territory considerably improves the evaluation of the distribution of ESs, partly improving the capability of this data to function as a proxy (Fig.2).

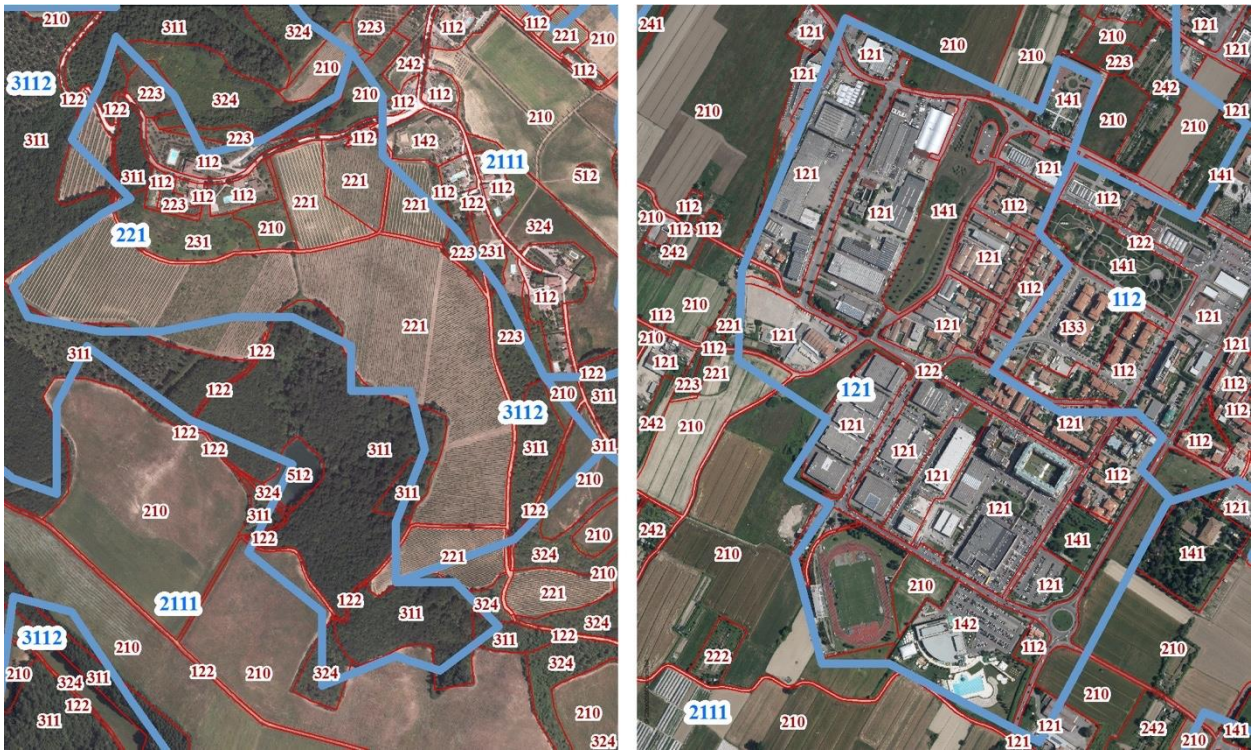

Figure 2. The two maps represent: in blue LULC database from EEA project (1:100.000), in red LULC database used as proxy to quantify ecosystem services (1:10.000). The greater cartographic detail of the LULC database at 1: 10,000 scale used by our research allows to map ESs provided by agricultural and forest areas and urban green areas not present in the 1: 100,000 scale dataset and to evaluate the effective contribution of artificial areas to the supply of ESs. The image on the left represents a portion of the countryside around San Gemignano (Siena); the one on the right, instead, a portion of peri-urban territory near Campi Bisenzio (Florence)

The analysis was carried out by choosing the Landscape Systems as the territorial unit (Rossi et al., 1994) (Fig.3). The Landscape System Map is a classification of the landscape of Tuscany created using digital data on altitude, geology and geomorphology, climate and land use. The method is similar to that used in other existing landscape classification maps (Amadei et al. 2003; Mucher et al. 2010). The Landscape System Map divides the region in 9 landscape system, within which a further 82 landscape sub-systems are articulated and is often used in environmental impact assessment, protection and management of natural resources and territorial planning policies.

Table 2 shows the capacity matrix used in our research. The assessment scale reaches from 0 / red = no relevant capacity of the land cover type to provide this particular ecosystem service, 1 / orange = low relevant capacity, 2 /yellow = relevant capacity, 3 / light green = medium relevant capacity, 4 / medium green = high relevant capacity and 5 / dark green = very high relevant capacity. Columns with gray headers give sums for the four ecosystem services groups.

The table differ from original one builted by Burkhard, 2009 in some codes of UCS: 1121 (land of relevance, scattered buildings), 1211 (urban wastewater), 1212 (photovoltaic system), 1221 (roads in forest areas), 1411 (cemetery), 210 (irrigated ed non irrigated arable land), 2101 (greenhouse), 2102 (plant nurseries), 2221 (agro-forestry areas), 3331 (firebreaks).

Classes 1121, 1211, 1212, 1221, 1411, 2221, 3331 were assigned the value of the class at the third level of classification; the UCS of the Tuscany Region does not contain, on the other hand, the items of UCS 211 (non-irrigated arable land) and 212 (permanently irrigated land): both these classes are grouped under an item called 210. Codes 2101 (greenhouses) have been attributed the value of class 121 while the codes 2102 (plant nurseries) have been given the same value used for the agro-forestry areas.

Table 2. Capacity Matrix

	Ecological Integrity	Abiotic heterogeneity	Biodiversity	Biotic waterflows	Metabolic Efficiency	Exergy capture	Reduction of nutrient loss	Storage capacity	Provisioning Services	Crops	Livestock	Fodder	Capture fisheries	Acquaculture	Wild foods	Timber	Wood fuel	Energy (biomass)	Biochemicals / Medicine	Freshwater	Regulating Services	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air quality regulation	Erosion regulation	Nutrient regulation	Water purification	Pollination	Cultural Services	Recreation & aesthetic values	Intrinsic value of biodiversity
111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112	7	1	1	1	1	1	1	1	3	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1121	7	1	1	1	1	1	1	1	3	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
121	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1211	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1212	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
122	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1221	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	1	1	0
124	7	1	1	1	1	1	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
131	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
132	8	2	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
133	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
141	18	3	3	2	1	4	3	2	2	0	0	0	0	0	1	0	1	0	0	0	11	2	1	0	2	1	2	1	1	1	3	3	0
1411	18	3	3	2	1	4	3	2	2	0	0	0	0	0	1	0	1	0	0	0	11	2	1	0	2	1	2	1	1	1	3	3	0
142	16	2	2	2	1	4	3	2	0	0	0	0	0	0	0	0	0	0	0	0	9	1	1	0	2	1	1	1	1	1	5	5	0
210	22	3	2	3	4	5	1	4	21	5	5	5	0	0	0	0	0	5	1	0	5	2	1	1	1	0	0	0	0	0	1	1	0
2101	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2102	21	4	3	4	2	3	2	3	13	5	0	0	0	0	0	4	4	0	0	0	19	2	2	2	2	2	2	1	1	5	5	5	0
213	20	3	2	5	1	5	1	3	7	5	0	2	0	0	0	0	0	0	0	0	4	2	0	0	2	0	0	0	0	0	1	1	0
221	14	3	2	3	1	3	0	2	5	4	0	0	0	0	1	0	0	0	0	0	3	1	1	0	1	0	0	0	0	0	5	5	0
222	21	4	3	4	2	3	2	3	13	5	0	0	0	0	0	4	4	0	0	0	19	2	2	2	2	2	2	1	1	5	5	5	0
2221	21	4	3	4	2	3	2	3	13	5	0	0	0	0	0	4	4	0	0	0	19	2	2	2	2	2	2	1	1	5	5	5	0
223	17	3	2	3	2	3	1	3	12	4	0	0	0	0	0	4	4	0	0	0	7	1	1	0	1	1	1	1	1	0	5	5	0
231	24	2	2	4	5	5	2	4	10	0	5	5	0	0	0	0	0	0	0	0	8	1	1	1	1	0	4	0	0	0	3	3	0
241	18	2	2	3	2	4	2	3	21	5	5	5	0	0	0	0	0	5	1	0	7	2	1	1	1	1	1	0	0	0	1	1	0
242	20	4	3	3	2	4	1	3	9	4	0	3	0	0	0	0	0	0	2	0	5	2	1	1	1	0	0	0	0	0	2	2	0
243	19	3	3	3	2	3	2	3	21	3	3	2	0	0	3	3	3	3	1	0	13	3	2	1	2	1	3	0	1	0	5	2	3
244	27	4	4	4	3	4	4	4	14	3	3	2	0	0	0	3	3	0	0	0	13	2	1	1	1	1	2	1	1	3	3	3	0
311	31	3	4	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
312	30	3	4	4	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
313	32	3	5	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
321	30	3	5	4	4	4	5	5	5	0	3	0	0	0	2	0	0	0	0	0	22	2	3	1	1	0	5	5	5	0	6	3	3
322	30	3	4	4	5	4	5	5	10	0	2	0	0	0	1	0	2	5	0	0	20	4	3	2	2	0	0	3	4	2	10	5	5
323	21	3	4	2	3	3	4	2	8	0	2	0	0	0	1	0	2	0	3	0	7	2	1	1	1	0	0	0	0	2	6	2	4
324	21	3	4	2	3	3	4	2	5	0	2	0	0	0	1	0	2	0	0	0	3	1	0	0	0	0	0	0	0	2	4	2	2
331	10	3	3	1	1	1	0	1	2	0	0	0	0	0	0	0	0	2	0	0	6	0	0	5	1	0	0	0	0	0	7	5	2
332	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	1	0	0	0	1	0	4	4	0
333	9	2	3	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	1	1	0	0	0	0	0	0	0	0
3331	9	2	3	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	1	1	0	0	0	0	0	0	0	0
334	6	2	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
410	25	3	2	4	4	4	3	5	7	0	2	5	0	0	0	0	0	0	0	0	14	2	2	4	2	0	0	4	0	0	0	0	0
411	25	3	2	4	4	4	3	5	7	0	2	5	0	0	0	0	0	0	0	0	14	2	2	4	2	0	0	4	0	0	0	0	0
420	23	2	3	4	3	3	3	5	2	0	2	0	0	0	0	0	0	0	0	0	8	1	0	5	0	0	0	2	0	0	3	3	0
421	23	2	3	4	3	3	3	5	2	0	2	0	0	0	0	0	0	0	0	0	8	1	0	5	0	0	0	2	0	0	3	3	0
422	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	2	2	0
423	13	2	3	0	2	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0	7	1	0	5	0	0	0	1	0	0	4	4	0
511	18	4	4	0	3	3	3	1	12	0	0	0	3	0	4	0	0	0	0	5	10	1	0	2	1	0	0	3	3	0	10	5	5
512	23	4	4	0	4	4	3	4	12	0	0	0	3	0	4	0	0	0	0	5	7	2	1	1	2	0	0	1	0	0	9	5	4
521	25	4	4	0	5	5	3	4	16	0	0	0	4	5	4	0	0	3	0	0	5	1	0	4	0	0	0	0	0	0	9	5	4
523	15	2	2	0	3	3	4	1	11	0	0	1	5	5	0	0	0	0	0	0	13	3	5	0	0	0	0	5	0	0	6	4	2

4. The ecosystem capacity of the Tuscany Region in 2016

In this paragraph we analyse the results of the methodology described above which made it possible to spatialize and quantify the ecosystem services provided by the territory of Tuscany in 2016.

The maps in Figure 4 show the normalized values (scale 0 - 1) of the ESs supply of each UCS polygon and refer to the 4 main categories (support, provisioning, regulating, cultural). Table 2 shows the contribution (as a percentage of the total) of each type of landscape to the supply of the 4 categories of ESs. This allows us to evaluate the contribution that each sub-region offers in the provision of services on a regional scale.

The Apennines (AP), the Anti-Apennine Reliefs (RA) and the Pliocene Hills (CP) are the areas that give the greatest contribution to the supply of the four ESs categories while the Alluvial Plain (PA) and the Coastal Plain (PC) which are the most urbanized areas, contribute in a more limited way.

It should be noted that if, on the one hand, the territorial surface of the different Landscape Systems shows values similar to those of the ESs offer, on the other hand, the most anthropized Landscape Systems (PA, PC and CP) show lower values of the ESs offer than to the surface and more rural and mountainous Landscape Systems (AP, RA, AA). Looking at the contributions of the different Landscape Systems to the four categories of ESs, the Apennines (PA), the Anti-Apennine Reliefs (RA) and the Apuan Alps (AA) highlight the highest values of regulating and cultural services offer while Pliocene Hils (CP), Alluvional Plains (PA) and Coastal Plains (PC) show higher values for the supply of provisioning services and ecological integrity.

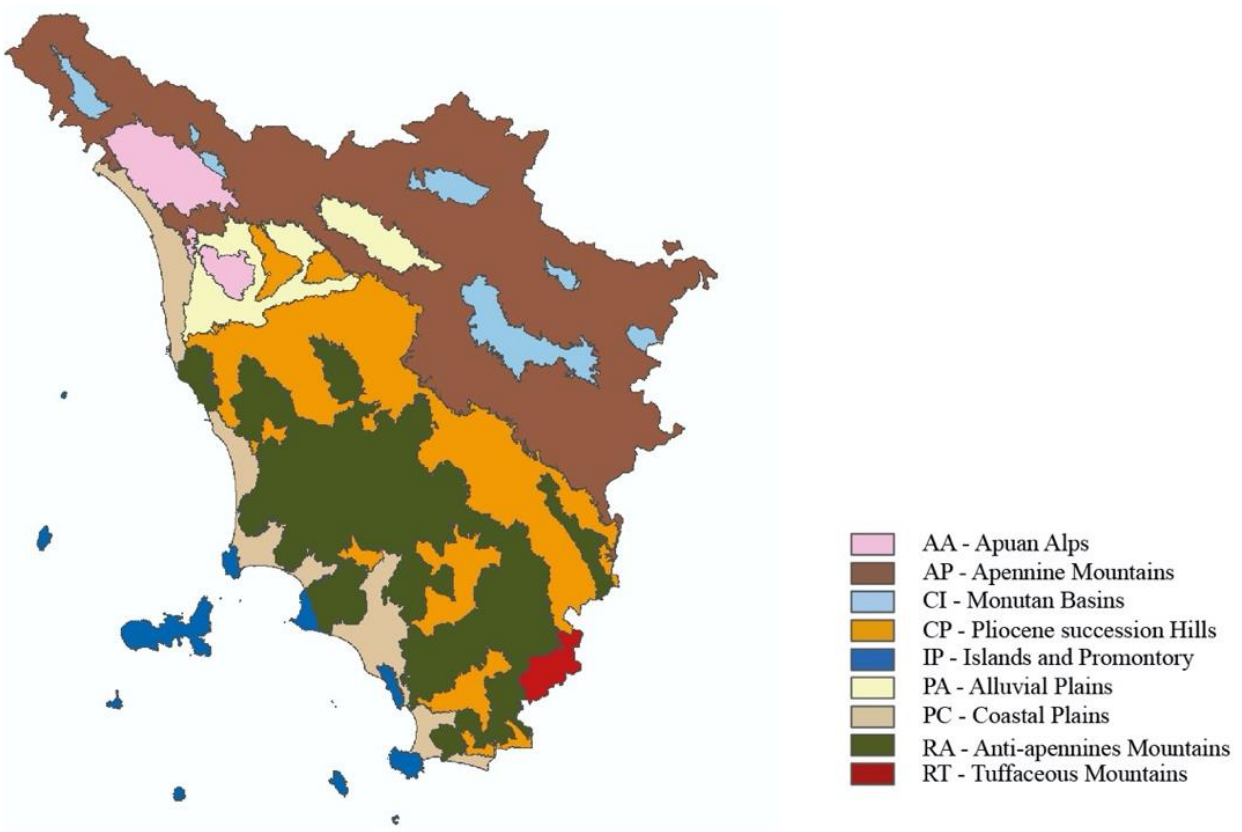

Figure 3. Landscape System according to Rossi et al. 1994 The division in Landscape System was used to calculate the supply capacity of ES of the different parts of the Tuscan territory

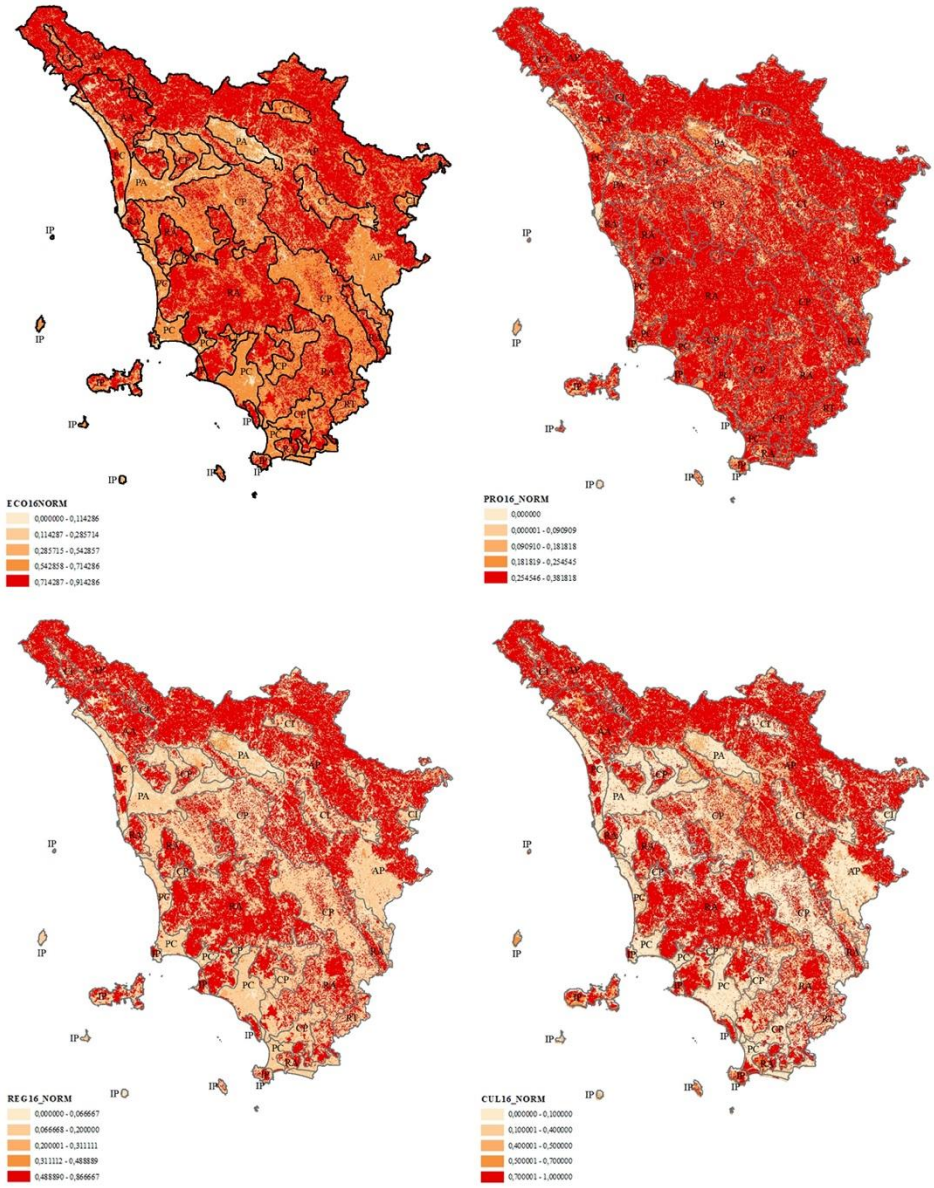

Figure 4. The measurement of ecosystem services in 2016 (normalized values). In the top left-hand corner: support service (ecological integrity); in the top right-hand corner: provisioning service; bottom left-hand corner: regulation service; bottom right-hand corner: cultural service.

Table 3. Contribution of different type of landscape systems to the provision of ecosystem services (support, provisioning, regulating, cultural-recreational).

Landscape System	Ecological Integrity (Support service)	Provisioning service	Regulating service	Cultural service	Landscape system area %
AA	4.02%	3.56%	4.99%	4.92%	3.22%
AP	38.87%	37.37%	46.62%	45.58%	33.37%
CI	3.67%	3.83%	2.78%	2.95%	3.51%
CP	16.48%	18.20%	10.09%	10.99%	18.31%
IP	1.97%	1.68%	2.00%	2.36%	2.55%
PA	3.37%	3.60%	1.29%	1.41%	4.42%
PC	4.92%	5.35%	2.48%	2.84%	6.38%
RA	25.79%	25.44%	29.01%	28.23%	27.23%
RT	0.90%	0.98%	0.73%	0.72%	1.00%
Total	100%	100%	100%	100%	100.00%

5. Assessment of changes in ecosystem service delivery 2010-2016

Many studies visualize and quantify changes over time and space of ESs supply (Carreno, 2012; Burgi, 2015; Ncube et. Al. 2018). Also in our research, having available the LULC 2007-2016 data of the Tuscany Region, we have produced maps of the evolution of the different ESs for the entire territory of Tuscany using the capacity matrix developed by Burkhard (Tab. 2). The comparison was made taking into consideration the years 2010 and 2016, because the first cartographic survey (2007) is more affected by photointerpretation errors than the others. The capacity matrix developed by Burkard (Tab. 2) was linked to the 2010 and 2016 land use and land cover classes contained in the 2010 and 2016 LULC database: Table 4 shows the absolute and percentage change in the supply capacity of ESs in the Tuscan territory in the period 2010/2016 for the four categories of ESs (support service; provisioning services; regulating service; cultural service). The data (Tab. 4) reveal a general reduction of the four ESs, with a higher value for the provisioning services and with lower values for the regulatory and cultural services. The quantities of the support services, on the other hand, remain substantially unchanged.

Table 4. Contribution of different type of landscape systems to the provision of ecosystem services (support, provisioning, regulating, cultural).

Δ Ecological Integrity (absolute value)	Δ Ecological Integrity (%)	Δ Provisioning Services (absolute value)	Δ Provisioning Services (%)	Δ Regulating Services (absolute value)	Δ Regulating Services (%)	Δ Cultural Services (absolute value)	Δ Cultural Services (%)
-2,530.39	-0.15%	-142,929.00	-1.41%	-176,558.00	-1.83%	-43,687.00	-1.30%

With the 2007/2016 UCS database linked to the capacity matrix, ESs losses or increases in the period 2010-2016 were determined, based on UCS transitions. Below are some summary tables related to changes in UCS at the first level of the Corine Land Cover classification. Table 5 shows the internal transitions at the same level (e.g. Code 141 in UCS 2010 which changes the LULC class to code 112 in UCS 2016), while Tables 5, 6, 7, 8 show the variations between the different UCS levels (e.g. code 311 in UCS 2010 which changes the LULC class to a code 223 in UCS 2016).The result of the query of the UCS 2007/2016 database, linked to the capacity matrix, allows to recognize the losses or increases of ESs in the period 2010-2016, according to the specific UCS transitions.

Table 5. Transition 2010-2016 of ecosystem services (support, provisioning, regulating, cultural-recreational): contributions of transitions within the same class classes at the first classification level

Transition type (CLC)	Balance ecological integrity 2010-2016 (absolute values)	Impact of the transition on the ecological integrity	Balance provisioning services 2010-2016 (absolute values)	Impact of the transition on the provisioning services	Balance regulating services 2010-2016 (absolute values)	Impact of the transition on the regulating services	Balance cultural services 2010-2016 (absolute values)	Impact of the transition on the cultural services
1-1	165.03	6.52%	6,261.00	4.38%	-1,116.00	-0.63%	-166.00	-0.38%
2-2	97.48	3.9%	17,633.00	12.34%	16,883.00	9.56%	-3,160.00	-7.23%
3-3	-1,117.95	-44.2%	-26,593.00	-18.61%	-43,730.00	-24.77%	-4,789.00	-10.96%
4-4	0.00	0.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%
5-5	0.73	0.02%	-5.00	0.00%	8.00	0.00%	-3.00	-0.01%

Table 6. Transition 2010-2016 of ecological integrity: contributions of transitions between different LULC classes at the first classification level.

Transition type (CLC)	(A) Balance ecological integrity 2010-2016 (absolute values)	Impact of the transition on the Ecological integrity	Transition type (CLC)	(B) Balance ecological integrity 2010-2016 (absolute values)	Impact of the transition on the Ecological integrity	Balance ecological integrity (A)+(B)	Impact of the pair of transition on the total balance
1-2	622.00	24.6%	2-1	-1,742.33	-68.9%	-1,120.34	-44.30%
1-3	172.31	6.80%	3-1	-495.21	-19.60%	-322.90	-12.80%
1-5	23.02	0.90%	5-1	-5.75	-0.20%	17.28	0.70%
2-3	-5.16	-0.20%	3-2	-194.26	-7.70%	-199.42	-7.90%
2-4	14.40	0.60%	4-2	-1.41	-0.10%	12.99	0.50%
2-5	-2.80	-0.10%	5-2	-1.41	-0.10%	-4.21	-0.20%
3-4	-0.03	0.00%	4-3	-2.26	-0.10%	-2.29	-0.10%
3-5	-29.48	-1.20%	5-3	-23.05	-0.90%	-52.53	-2.10%
4-1	-2.95	-0.10%	1-4			-2.95	-0.10%
4-5	-1.43	-0.10%	5-4	0.13	0.00%	-1.30	-0.10%
Tot.						-2,530.39	100,00%

Table 7. Transition 2010-2016 of provisioning: contributions of transitions between different LULC classes at the first classification level.

Transition type (CLC)	(A) Balance provisioning 2010-2016 (absolute values)	Impact of the transition on the provisioning	Transition type (CLC)	(B) Balance provisioning 2010-2016 (absolute values)	Impact of the transition on the provisioning services	Balance provisioning services (A)+(B)	Impact of the pair of transition on the total balance
1-2	28,154.00	19.70%	2-1	-134,491.00	-94.10%	-106,337.00	-74.40%
1-3	3,200.00	2.20%	3-1	-25,621.00	-17.90%	-22,421.00	-15.70%
1-5	1,154.00	0.80%	5-1	-635.00	-0.40%	519.00	0.40%
2-3	-15, 00	-11.10%	3-2	8,687.00	6.10%	-7,191.00	-5.00%
2-4	-256.00	-0.20%	4-2	90.00	0.10%	-166.00	-0.10%
2-5	-2,345.00	-1.60%	5-2	440.00	0.30%	-1,905.00	-1.30%
3-4	-14.00	0.00%	4-3	0.00	0.00%	-14.00	0.00%
3-5	1,887.00	1.30%	5-3	-4,609.00	-3.20%	-2,722.00	-1.90%
4-1	-24.00	0.00%	1-4	0.00	0.00%	-24.00	0.00%
4-5	46.00	0.00%	5-4	-10.00	0,00%	36.00	0.00%
Tot.						-142,929.00	100.00%

Table 8. Transition 2010-2016 of regulating: contributions of transitions between different LULC classes at the first classification level.

Transition type (CLC)	(A) Balance regulating services 2010-2016 (absolute values)	Impact of the transition on the regulating services	Transition type (CLC)	(B) Balance regulating services 2010-2016 (absolute values)	Impact of the transition on the regulating services	Balance regulating services (A)+(B)	Impact of the pair of transition on the total balance
1-2	9,777.00	5.54%	2-1	-46,992.00	-26.62%	-37,215.00	-21.10%
1-3	3,784.00	2.14%	3-1	-47,517.00	-26.91%	-43,733.00	-24.80%
1-5	744.00	0.42%	5-1	-408.00	-0.23%	336.00	0.20%
2-3	1,378.00	0.78%	3-2	-58,920.00	-33.37%	-57,542.00	-32.60%
2-4	172.00	0.10%	4-2	-49.00	-0.03%	123.00	0.10%
2-5	774.00	0.44%	5-2	-154.00	-0.09%	620.00	0.40%
3-4	-25.00	-0.01%	4-3	-4.00	0.00%	-29.00	0.00%
3-5	-9,569.00	-5.42%	5-3	-1,549.00	-0.88%	-11,118.00	-6.30%
4-1	-68.00	-0.04%	1-4		0.00%	-68.00	0.00%
4-5	9.00	0.01%	5-4	14.00	0.01%	23.00	0.00%
Tot.						-176,558.00	100.00%

Table 9. Transition 2010-2016 of cultural: contributions of transitions between different LULC classes at the first classification level.

Transition type (CLC)	(A) Balance cultural services 2010-2016 (absolute values)	Impact of the transition on the cultural services	Transition type (CLC)	(B) Balance cultural services 2010-2016 (absolute values)	Impact of the transition on the cultural services	Balance cultural services (A)+(B)	Impact of the pair of transition on the total balance
1-2	3,051.00	6.98%	2-1	-16,522,00	-37.82%	-13,471.00	-30.80%
1-3	2,624.00	6.01%	3-1	-14,295,00	-32.72%	-11,671.00	-26.70%
1-5	840.00	1.92%	5-1	-487,00	-1.11%	353.00	0.80%
2-3	4,140.00	9.48%	3-2	-17,926.00	-41.03%	-13,786.00	-31.60%
2-4	-34.00	-0.08%	4-2	11.00	0.03%	-23.00	-0.10%
2-5	2,697.00	6.17%	5-2	-758.00	-1.74%	1,939.00	4.40%
3-4	-10.00	-0.02%	4-3	8.00	0.02%	-2.00	0.00%
3-5	3,101.00	7.10%	5-3	-2,007.00	-4.59%	1,094.00	2.50%
4-1	-15.00	-0.03%	1-4		0.00%	-15.00	0.00%
4-5	31.00	0.07%	5-4	-18.00	-0.04%	13.00	0.00%
Tot.						-43,687.00	100.00%

Considering the four categories of ESs, in the period 2010-2016, the most significant reduction of ESs is given by the passage of some portions of the Tuscan territory from level 2 (agricultural areas) to level 1 (artificial areas). Compared to the total, the contribution of this transition to the loss of supply of ESs was, respectively: -68.9% for support services (ecological integrity) (Tab. 6); -94.1% for provisioning services (Tab. 7); -26.6% for regulatory services (Tab. 8) and -37.8% for cultural services (Tab. 9). This loss is partially compensated by a reverse transition from level 1 to level 2 (from artificial to agricultural surfaces); these transitions are mainly due to the presence of areas of relevance for construction for public and infrastructural works in 2010 (code 133) which, in 2016, return to arable land or, in any case, returned to agricultural use. These compensations, while decreasing the loss of ESs, nevertheless lead to an overall balance of these transformations very negative values equal to: -44.3% for ecological integrity services (Tab. 6), -74.4% for provisioning services (Tab. 7), -21.1% for regulatory services (Tab. 8) and -30.8% for cultural services (Tab. 9).

Considering all the transitions towards codes 1 as phenomena of land consumption, it can be said that the reduction of support and provisioning services is largely due to the processes of artificialization of the soil. With regard to regulating services and cultural services, both the phenomena of land consumption and the transitions from natural surfaces to agricultural surfaces play an important role in the loss of ESs with values equal to -32.6% and -31.6% (Tabs 8, 9). The analysis of the data also shows the contribution provided by the internal transitions to class 2 (agricultural land) to the reduction of the loss of supply capacity of ESs in the Tuscan territory (Tab. 5). This is evident, in particular, for provisioning (+ 12.34%) and regulating (+ 9.56%) services, while cultural services recorded a reduction (-7.23%). A contribution determined by the transition from permanent crops (especially olive groves and orchards) to arable land and / or meadows and pastures which, in fact, determine an increase in the ESs of provisioning and regulating, but reduce the supply of cultural services (probably linked to the aesthetic-perceptive of the landscape).

6. Conclusions

Burkard's methodology, applied at LULC data of the Tuscany Region, was used to develop easy-to-read maps, to identify macro-phenomena of erosion of ESs supply and to identify possible conflicts and limits to managing environmental resources with particular reference to land consumption. Thanks to the availability of homogeneous data for the Tuscany Region, the methodology is easy to use, quickly provides results, ensures the replicability of the process and allows to verify the correlation between the supply of ecosystem services and the incidence of anthropic activity described in the LULC archive.

However there are also some critical issues: one is related to the difficulties in correlating the delivery level of some ecosystem services to single LULC classes, another to the lack of descriptive detail for some LULC classes, both in natural and urban areas, which makes it difficult to adequate evaluation of the ecosystem services provided by these areas.

With regard to the first issue, there is a pressing need for further research to be undertaken on the opportunities offered by combining the use of the LULC data with other geographical data of the Tuscany Region in order to increase the reliability of the evaluation of the ecosystem services offer that are not closely correlated with the LULC data base.

The possibility of using the Tuscany Region LULC archive to undertake multi-temporal measurements (2007-2016), of the variation in ESs supply is a very promising area of research that could lead to the introduction of payment mechanisms for ecosystem services (PES) (Pagiola, 2007) between different territorial areas, especially in light of the opportunities provided by Law 22/2015 for promoting the green economy and limiting the excessive use of resources: in fact Art. 70 of this law envisages the establishment of systems of remuneration for ecosystem and environmental services (PSEA). The adoption of expeditious standardized methods such as the one proposed in this paper would make it possible to rapidly assess the effectiveness of urban, territorial and sectorial policies and to introduce, compensation mechanisms where required.

The introduction of PSEA between territories requires identifying both the places where the services are generated and where they are used, so that the environmental economic balance is oriented towards sustainability principles. In this approach the maps of ESs supply capacities elaborated according to the illustrated methodology and the

correlation of these with demographic data related to the population, can help to identify the spatial congruence or the disparities between supply, flow and demand of ESs (Santolini & Morri, 2010; Morri et al. 2014).

References

Amadei, M., Bagnaia, R., Lureti, L., Lugeri, F., Lugeri, N., Feoli, E., Dragan, M., Fernetti, M., & Oriolo, G. (2003). Il progetto CARTA DELLA NATURA alla scala 1: 250.000. Metodologia di realizzazione.

Blasi, C., Capotorti, G., Alós Ortí, M. M., Anzellotti, I., Attorre, F., Azzella, M. M., Carli, E., Copiz, R., Garfì, V., Manes, F., Marando, F., Marchetti, M., Mollo, B., & Zavattero, L. (2017). Ecosystem mapping for the implementation of the European Biodiversity Strategy at the national level: The case of Italy. *Environmental Science & Policy*, *78*, 173-184. https://doi.org/https://doi.org/10.1016/j.envsci.2017.09.002

Burkhard, B., Kroll, F., Müller, F., & Windhorst, W. (2009). Landscapes Capacities to Provide Ecosystem Services. A Concept for Land-Cover based assessments. *Landscape Online 15, 1-22.* *Landscape Online*, *15*, 1-22. https://doi.org/DOI:10.3097/LO.200915 OI:10.3097

Burkhard, B., Kroll, F., Nedkov, S., & Müller, F. (2012). Mapping ecosystem service supply, demand and budgets. *Ecological Indicators*, *21*, 17 - 29. https://doi.org/https://doi.org/10.1016/j.ecolind.2011.06.019

Bürgi, M., Silbernagel, J., Wu, J., & Kienast, F. (2015). Linking ecosystem services with landscape history. *Landscape Ecology*, *30*(1), 11-20. https://doi.org/10.1007/s10980-014-0102-3

Campagne, C. S., Roche, P., Müller, F., & Burkhard, B. (2020). Ten years of ecosystem services matrix: Review of a (r)evolution [10.3897/oneeco.5.e51103]. *One Ecosystem*, *5*, e51103.

Carreño, L., Frank, F. C., & Viglizzo, E. F. (2012). Tradeoffs between economic and ecosystem services in Argentina during 50 years of land-use change. *Agriculture, Ecosystems & Environment*, *154*, 68-77. https://doi.org/https://doi.org/10.1016/j.agee.2011.05.019

Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C., & Daily, G. C. (2006). Conservation Planning for Ecosystem Services [Article]. *PLoS Biology*, *4*(11), 2138-2152. https://doi.org/10.1371/journal.pbio.0040379

Ciampi, C., Bottai, L., Corongiu, M., Giusti, B., Lucchesi, F., & Sassoli, U. (2015). Tendenze recenti del cambiamento. La banca dati Uso e Copertura del Suolo di Regione Toscana (2007/2010/2013). Atti della XIX Conferenza Nazionale ASITA (Federazione Italiana delle Associazioni Scientifiche per le Informazioni Territoriali e Ambientali), Lecco - Polo di Lecco del Politecnico di Milano.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'neill, R. V., & Paruelo, J. (1997). The value of the world's ecosystem services and natural capital. *nature*, *387*(6630), 253-260.

De Groot, R. S., Wilson, M. A., & Boumans, R. M. J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, *41*(3), 393-408. https://doi.org/https://doi.org/10.1016/S0921-8009(02)00089-7

Egoh, B., Reyers, B., Rouget, M., Richardson, D. M., Le Maitre, D. C., & van Jaarsveld, A. S. (2008). Mapping ecosystem services for planning and management. *Agriculture, Ecosystems & Environment*, *127*(1), 135-140. https://doi.org/https://doi.org/10.1016/j.agee.2008.03.013

Eigenbrod, F., Armsworth, P. R., Anderson, B. J., Heinemeyer, A., Gillings, S., Roy, D. B., Thomas, C. D., & Gaston, K. J. (2010). The impact of proxy-based methods on mapping the distribution of ecosystem services. *Journal of Applied Ecology*, *47*(2), 377-385. https://doi.org/https://doi.org/10.1111/j.1365-2664.2010.01777.x

Feranec, J., Jaffrain, G., Soukup, T., & Hazeu, G. (2010). Determining changes and flows in European landscapes 1990–2000 using CORINE land cover data. *Applied Geography*, *30*(1), 19-35. https://doi.org/https://doi.org/10.1016/j.apgeog.2009.07.003

Foundations, T. (2008). *The economics of ecosystems & biodiversity : an interim report* (9789279089602 9279089609).

Grizzetti, B., Bouraoui, F., & Aloe, A. (2012). Changes of nitrogen and phosphorus loads to European seas. *Global Change Biology*, *18*(2), 769-782. https://doi.org/https://doi.org/10.1111/j.1365-2486.2011.02576.x

Grizzetti, B., Bouraoui, F., & De Marsily, G. (2008). Assessing nitrogen pressures on European surface water. *Global Biogeochemical Cycles*, *22*(4). https://doi.org/https://doi.org/10.1029/2007GB003085

Harrison, P. A., Vandewalle, M., Sykes, M. T., Berry, P. M., Bugter, R., de Bello, F., Feld, C. K., Grandin, U., Harrington, R., Haslett, J. R., Jongman, R. H. G., Luck, G. W., da Silva, P. M., Moora, M., Settele, J., Sousa, J. P., & Zobel, M. (2010). Identifying and prioritising services in European terrestrial and freshwater ecosystems. *Biodiversity and Conservation*, *19*(10), 2791-2821. https://doi.org/10.1007/s10531-010-9789-x

La Notte, A., Vallecillo, S., Polce, C., Zulian, G., & Maes, J. (2017). Implementing an EU system of accounting for ecosystems and their services. *Initial proposals for the implementation of ecosystem services accounts, EUR, 28681*, 1-124.

Lucchesi, F., Giusti, B., Bottai, L., Corongiu, M., & Sassoli, U. (2015). Grandezze e caratteri del cambiamento. Il contributo della banca dati uso e copertura del suolo di Regione Toscana. In I. S. p. l. P. e. l. R. A. (ISPRA) (Ed.), *Recuperiamo Terreno* (Vol. 2, pp. 79-91).

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., Grizzetti, B., Drakou, E. G., Notte, A. L., Zulian, G., Bouraoui, F., Luisa Paracchini, M., Braat, L., & Bidoglio, G. (2012). Mapping ecosystem services for policy support and decision making in the European Union. *Ecosystem Services*, *1*(1), 31-39. https://doi.org/https://doi.org/10.1016/j.ecoser.2012.06.004

Maes, J., Liquete, C., Teller, A., Erhard, M., Paracchini, M. L., Barredo, J. I., Grizzetti, B., Cardoso, A., Somma, F., Petersen, J.-E., Meiner, A., Gelabert, E. R., Zal, N., Kristensen, P., Bastrup-Birk, A., Biala, K., Piroddi, C., Egoh, B., Degeorges, P., Fiorina, C., Santos-Martín, F., Naruševičius, V., Verboven, J., Pereira, H. M., Bengtsson, J., Gocheva, K., Marta-Pedroso, C., Snäll, T., Estreguil, C., San-Miguel-Ayanz, J., Pérez-Soba, M., Grêt-Regamey, A., Lillebø, A. I., Malak, D. A., Condé, S., Moen, J., Czúcz, B., Drakou, E. G., Zulian, G., & Lavalle, C. (2016). An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020. *Ecosystem Services*, *17*, 14-23. https://doi.org/https://doi.org/10.1016/j.ecoser.2015.10.023

Marson, A., & Lucchesi, F. (2017). Consumo di suolo in Toscana: dinamiche recenti e impatto sul paesaggio. In M. Munafò (Ed.), *Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2017* (pp. 170-171). ISPRA (Istituto Superiore per la Ricerca e Protezione Ambientale).

Millennium Ecosystem, A. (2005). *Ecosystems and human well-being : synthesis : a report of the Millennium Ecosystem Assessment*. Island.

Morri, E., & Santolini, R. (2013). Valutare i servizi ecosistemici: un'opportunità per limitare i disturbi al paesaggio. In (pp. 178-182).

Mücher, C. A., Klijn, J. A., Wascher, D. M., & Schaminée, J. H. J. (2010). A new European Landscape Classification (LANMAP): A transparent, flexible and user-oriented methodology to distinguish landscapes. *Ecological Indicators*, *10*(1), 87-103. https://doi.org/https://doi.org/10.1016/j.ecolind.2009.03.018

Müller, F. (2005). Indicating ecosystem and landscape organisation. *Ecological Indicators*, *5*(4), 280-294. https://doi.org/https://doi.org/10.1016/j.ecolind.2005.03.017

Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R. E., Lehner, B., Malcolm, T. R., & Ricketts, T. H. (2008). Global mapping of ecosystem services and conservation priorities. *Proceedings of the National Academy of Sciences*, *105*(28), 9495. https://doi.org/10.1073/pnas.0707823105

Ncube, S., Spray, C., & Geddes, A. (2018). Assessment of changes in ecosystem service delivery – a historical perspective on catchment landscapes. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *14*(1), 145-163. https://doi.org/10.1080/21513732.2018.1489306

Pagiola, S., & Platais, G. (2006). Payments for environmental services: from theory to practice.

Rossi, R., Merendi, G. A., & Vinci, A. (1994). *I sistemi di paesaggio della Toscana*. Regione Toscana.

Santolini, R., & Morri, E. (2017). Criteri ecologici per l'introduzione di sistemi di valutazione e remunerazione dei Servizi Ecosistemici (SE) nella progettazione e pianificazione.

Scolozzi, R., & Geneletti, D. (2012). A multi-scale qualitative approach to assess the impact of urbanization on natural habitats and their connectivity. *Environmental Impact Assessment Review*, *36*, 9-22. https://doi.org/https://doi.org/10.1016/j.eiar.2012.03.001

Scolozzi, R., Morri, E., & Santolini, R. (2012). Delphi-based change assessment in ecosystem service values to support strategic spatial planning in Italian landscapes. *Ecological Indicators*, *21*, 134-144. https://doi.org/https://doi.org/10.1016/j.ecolind.2011.07.019

Scolozzi, R., Schirpke, U., Morri, E., D'Amato, D., & Santolini, R. (2014). Ecosystem services-based SWOT analysis of protected areas for conservation strategies. *Journal of Environmental Management*, *146*, 543-551. https://doi.org/https://doi.org/10.1016/j.jenvman.2014.05.040