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Keynote Article

Long-term land cover changes and ecosystem services variation: have the anthropogenic transformations degraded human well-being in Italy?

Davide Marino, Margherita Palmieri, Angelo Marucci, Silvia Pili

University of Molise, Italy

Abstract. Landscape composition has a crucial role in determining ecosystem functioning and human well-being. Human activities (e.g. urban expansion or agricultural intensification) have strongly modified the natural environment and ecosystem integrity. This paper presents an exemplary application of the ecosystem service (ES) concept to the whole Italian territory. A GIS-based analysis of the long-term dynamics (1960-2018) between land cover changes and landscapes' capacities to provide ecosystem services was conducted in order to achieve a qualitative and quantitative assessment of the supply and demand of ES. The applied methodology considers a matrix linking spatially explicit biophysical landscape units to ecosystem services supply, which was united in a GIS framework. We set the analysis considering national scales and 3 time periods (1960-1990, 1990-2018, 1960-2018). As main results we found a great impact of intensification and urbanization on the decline of ES supply, while forest expansion and forest permanence determined the most important increases. The analysis detected several variations of ES supply that have direct impact on humans and can provide information about the importance of preserving the environment and the benefits we derive from nature.

Keywords: ecosystem services, land cover changes, national scale assessment, GIS analysis.
JEL codes: Q57.

1. INTRODUCTION

1.1. Background

Ecological systems are relevant in the supply of many goods and services essential for human survival, health and economic well-being (Costanza *et al.*, 1997; Müller and Burkhard, 2007). These benefits are defined as Ecosystem Services (ES) generally classified into support, supply, regulation and cultural services (Millenium Ecosystem Services, 2005; Costanza *et al.*, 2011). The continuous natural capital degradation by anthropogenic activities compromises the ecosystem services flow, determining an impact on the socio-economic well-being of present and future generations (IPBES, 2019). Therefore, the responsibility of researchers is to provide tools to public decision makers for monitoring the conservation status of ecological systems. The need to quantify and assess ES and include them in decision-making policies is also highlighted in the Biodiversity Strategy for 2030 and the "EU Guide on Integrating Ecosystems and Their Services in Decision Making" (SWD (2019) 305 final) (Marino *et al.*, 2021).

The supply of ES is linked to the various land cover (LC) classes (Costanza *et al.*, 1997): for example, wooded areas are essential for air purification, whereas meadows and pastures for forage supply (Marino *et al.*, 2021). LC changes (LCC) modify the functions and structure of ecosystems (Wu *et al.*, 2019; Salvati, Colantoni, 2015) and consequently their ability to produce goods and services (Blumstein, Thompson, 2015). Also, population growth and urbanization affect the ability of ecosystems to provide goods and services (Lawler *et al.*, 2014; Li *et al.*, 2010; Obeng, Aguilar, 2018; Ridding *et al.*, 2018). Rapid development of the economy and urbanization has increased ES demand. This has led to soil conversion to agricultural and urban land and severe habitat loss (Wang *et al.*, 2019). Globally, natural ecosystems conversion into agricultural land, and grasslands into urban areas, have caused a loss of biodiversity and a reduction in the supply of ecosystem goods and services (Balvanera *et al.*, 2006; de Groot *et al.*, 2002; Díaz *et al.*, 2006; Mendoza-González *et al.*, 2016).

1.2. Land Cover Changes and methods to evaluate Ecosystem Services

Over the past 20 years, the number of publications studying future changes in land use and impacts on ES has increased. According to the analysis conducted by Gomes *et al.* (2021), these studies are mainly located in Asia (55.7%) and Europe (17.7%). Recently Schirpke *et al.* (2021) studied the ES response to LCC in Europe in the period between 2000 and 2018. The study highlighted a loss in the value of the provisioning ES due to (i) urban expansion, (ii) the conversion of grasslands into arable land and (iii) an increase in the regulation and cultural ES due to the presence of protected areas. In Italy, the main drivers of LCC are depopulation of remote areas (inland and mountain rural areas) and urbanization processes with effects on the ES supply (Munafò, 2021). In the period between 1960 and 2012, the LCC in Italy affected an area of 13 million hectares, approximately 42 percent of the national surface (Marino *et al.*, 2016). While the abandonment of inland mountain areas (Falcucci *et al.*, 2007) causes a loss in the ES supply, the population increase in urban areas causes an increase in the demand for ES, creating a strong imbalance between supply and demand (Marino *et al.*, 2021). Understanding the impacts of LCC on the ES supply is essential to mitigate the consequences of the interactions between human activities and natural capital and to identify a correct management strategy.

In the international context, there is no common methodology for quantifying ES supply (Wei *et al.,* 2017). Usually based on data availability, biophysical methods are used (Vihervaara *et al.*, 2017). To map ES, remote sensing data (Richard *et al.*, 2015) and GIS (Geographic Information System) software are the tools mainly used, which allow the spatial and temporal distribution of ES to be analyzed (Grêt-Regamey *et al.*, 2012) and understand how their supply varies in relation to territorial dynamics (Rodríguez *et al.*, 2006). Some authors (Talukdar *et al.*, 2020; Sharma *et al.*, 2019; Arowolo *et al.*, 2018) have associated land cover classes with the 16 biomes identified by a model of ESV (Costanza *et al.*, 1997). These studies analyzed the net variation rate of ES values with respect to Land Use and Land Cover (LULC) using the two coefficients of Costanza (Costanza *et al.*, 1997; Costanza *et al.*, 2019). To evaluate the variation of ES supply, Assefa (2012) used the transition matrix model (Gashaw *et al.*, 2017; Berihun *et al.*, 2019) and the coefficient of Kindu *et al.* (2016) for ESV analysis. The transition matrices have also been used by Tang *et al.* (2020), Lin *et al.* (2021) and Chen *et al.* (2020) to study landscape change and ESV. The GIS and the integrated Valuation of Ecosystem Services and Tradeoffs Tool (InVEST) model were used to estimate the economic value of some ES. For example, Rimal *et al.* (2021) used Landsat and InVEST satellite images to estimate ES trade-offs. Other authors used InVEST to estimate the ES response to LCC (Daneshi *et al.*, 2021; Berta Aneseyee *et al.*, 2020; Fadaei *et al.*, 2020; Liang *et al.*, 2017). Furthermore, on the international scene there are also qualitative methods based on ES matrices to estimate the supply and response of ES to LCC dynamics. The ES matrix method is a generally used approach for a synthetic assessment of ES and is based on the LCC. The ES matrices are constructed by associating a single class of land use, habitat or ecosystem with a score related to the ES supply and demand potential. For example (Madrigal-Martínez and Miralles i García, 2020; Madrigal-Martínez and Miralles i García, 2019), developed a matrix to estimate the ability of different land use classes to provide SE. According to Campagne *et al.* (2014), the Burkhard matrix approach (Burkhard *et al.*, 2009) and related updates (Burkhard *et al.*, 2012; Burkhard *et al.*, 2014) is among the methods most used by researchers (Marino *et al.*, 2014) as it can be adapted to map and evaluate ES at a local (Nedkov, Burkhard, 2012), national (Depellegrin *et al.*, 2016) and continental (Stoll *et al.*, 2015) scale. The Burkhard matrix links the units of the physical landscape (ecological integrity) to the supply and demand of ES. Some authors (García-Llamas *et al.*, 2019; Wu *et al.*, 2019; Li *et al.*, 2016) have adapted the Burkhard (Burkhard *et al.*, 2012) matrix scores with expert team judgements to evaluate the ES in their study areas.

1.3. Objective of paper

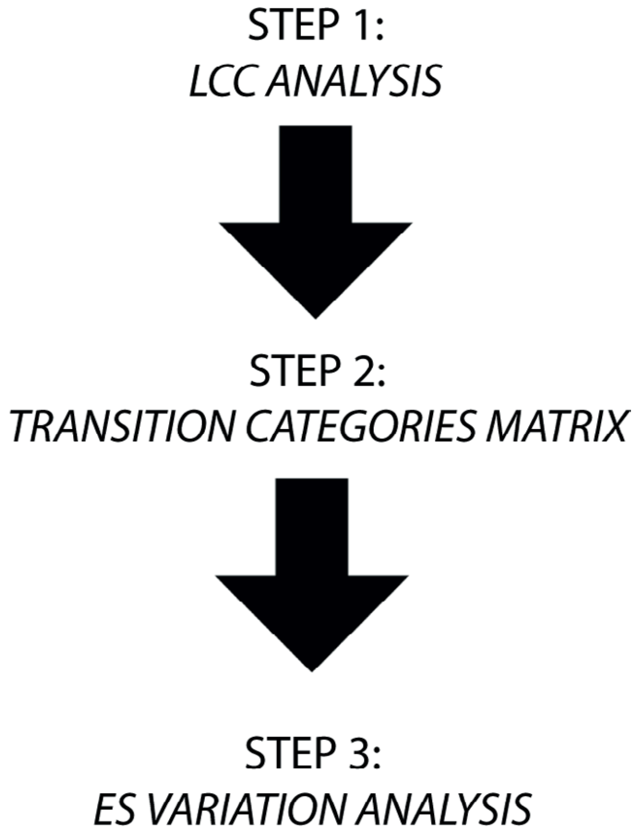
Our research is different from other studies because we used an innovative method to analyze LCC and relative variations to ES supply. This method is based on transition categories and describes LULC permanencies and LCC due to intensification, extensification, urbanization, renaturation process (Tab. 1). According to these categories of transitions we evaluated the ES supply response variation. Through a diachronic analysis (1960-2018), we analyzed the qualitative variation in ES supply in Italy, using the ES matrix approach. We also mapped the total ES variation as a function of transition processes. This allowed us to analyze synergies and trade-offs between different ES at spatial and temporal scales. The transition analysis between different categories and variation in ES supply can support decision making in defining strategies and land planning tools.

2. MATERIALS AND METHODS

2.1. Study area

The national territory is the area we selected to improve current studies on ES variation appling our innovative approach. The spatial extension of this paper consists of 301.670 km^2 and corresponds to the whole Italian territory, which is mainly represented by agricultural areas (51%) and forests (41%). Administratively, Italy comprises 7,904 administrative municipalities in 20 regions. The population has increased from 50.6 million to 59,8 million from 1960 to 2018, with an average population density of 183/km^2. Italy is characterized by a Mediterranean climate with rainy winters and a notable drought during summer months. As Frigerio and De Amicis (2016) report, it is one of the European countries that are most strongly exposed to a wide range of natural hazards. In the context of climate change and increasing frequency of extreme natural events, which represent only some of the current threats along with, for example, increasing air and water pollution, the analysis of the variations of the benefits nature provides to humans over time seems to be a crucial issue to face potential socioeconomic impacts.

Fig. 1. Methodological framework of the ES variation analysis.



2.2. Methodological Framework

Our study was based on a methodological framework divided into three steps (Fig. 1). In the first step we analyzed the land use changes in Italy between 1960 and 2018. In the second step we applied a GIS-based methodology that allows a thematic in-depth analysis of diachronic LCC. Finally, in the third step, we analyzed the qualitative assessment of potential ES supply on the basis of the transition matrix.

2.2.1. Step 1 - Land Cover Change analysis

In our study we studied land use change over the whole period 1960-2018 and also for two sub-periods 1960-1990, 1990-2018 to observe different trends in land use and ES supply fluctuations. We considered these two periods of circa 30 years as they were affected by different socio-economic dynamics that influenced the environmental and spatial context. We considered the interval 1960-2018 to assess the long-term effects of land use on the supply of ecosystem services. We used GIS software to generate LCC maps. The vectorial geographic dataset consists of two data sources: (i) Land Use Map 1960 that was edited by the National Research Council of Italy (CNR) and published by Touring Club Italiano (TCI) and (ii) CORINE Land Cover (CLC) (used for 1990 and 2018). In order to ensure the comparison between CNR and Corine map legends, previous works (Marino *et al.*, 2021; Marino *et al.*, 2016) achieved the equivalence of codes. For more details concerning legend conversion see Tab. A.1. in the Appendix). Since there are no alternative cartographic resources for the time period considered (1960-2018), we performed the analysis with the available data. While equivalence of code methodology presents some limitations due to the differences between the maps used, it represents the first original contribution on long-term analysis of the SE variations linked to changes in uses and land cover occurring in Italy.

2.2.2. Step 2 - Transition categories matrix

The LCC map, at the basis of the Transition Categories approach, has been generated intersecting TCI 1960 vector data with CLC 2018 data. This new approach takes into account the Corine Land Cover legend at the III hierarchical level (artificial areas = 1xx, agricultural lands = 2xx, forests = 3xx, etc.). At each change from one to another use (e.g. wood to urban) a concatenation code was assigned creating the first new column in the attribute table of the shapefile. For instance, in the case of a wood-to-urban conversion, the concatenation code is 3xx1xx (for example 300100). Each code has been linked, in turn, to a "text" qualitative attribute described by a new column in the shapefile (e.g. 300100= "urbanization"). These categories, from here onwards defined as *Transition Categories,* indicate a specific land use process of change or rather transformations (urbanization, agricultural intensification or extensivization, evolution to complex agricultural areas, natural forest expansion) or permanences (Tab. 1).

2.2.3 Step 3 - ES Variation analysis.

The qualitative assessment of potential ES supply was made on the basis of the transition categories. In fact the transition categories approach allows not only land use permanences and transformations but also ES supply variation analysis.

This paper provides continuity to the ES matrix approach (Burkhard *et al.*, 2009; Burkhard *et al.*, 2012, Burkhard *et al.*, 2014) that links land cover types to ES supply capacities. We used a new original matrix, that links ES variation with Transition Categories as defined by Marino *et al.* (2016). As the literature highlighted, each land use correlates with a specific ES potential supply, each LCC has been linked to a specific ES variation. We used the classification developed in the LIFE + MGN project based on 8 provisioning ES (P), 9 regulation ES (R) and 3 cultural ES (C) (Schirpke *et al.*, 2013): crops (P1), forage production (P2), huntable species and fish (P3), raw materials (e.g. wood, fibres) (P4), edible plants and mushrooms (P5), medicinal plants (P6), genetic resources (P7), drinking water (P8); carbon sequestration (R1), local climate regulation and air purification (R2), groundwater recharge (R3), water purification (R4), protection from erosion and geological instability (landslides, slope instability) (R5), protection from hydrological disasters (floods) (R6), pollination (R7), biological control (pests) (R8), habitats for biodiversity (R9), aesthetic value (C1), recreational value

Tab. 1. Transition categories description.

Permanences	All areas in which there is a permanence of land use and cover are included (artificial areas, arable land and pastures, permanent crops,...)
Urbanization	Conversion of agricultural and forest are land cover and use in artificial areas.
Agricultural intensification	The category includes all the transitions that, starting from agrarian or rural land uses, evolve in the sense of an increase in anthropogenic pressure (exept urbanization). This is the case of the evolution of pastures into agricultural land uses, of less intensive into more intensive cultivation, as well as of forest into agricultural cultivation.
Agricultural extensification	The category includes all the transitions that, starting from permanent crops ends in arable and pastures.
Evolution to complex systems	The category represents the transition to heterogeneous agricultural areas starting from arable and pastures and permanent crops
Forest extension	The category includes all the transitions that correspond to secondary ecological succession.

(ecotourism, outdoor activities) (C2), inspiration for culture, arts, educational and spiritual values, sense of identity (C3).

For the qualitative evaluation of ES variation, we have i) assigned to each LULC class a relevance class on a scale from 0 to 3 (3 - very important, 2 moderate importance, 1- low relevance, 0 - no relevance), (ii) assigned a quantitative change score of the ES for each transition category of the intended use change, iii) weighted the ES variation score on the percentage (TCA*100/A) of surface area occupied by each plot of land to reflect the spatial extent of the analysis.

$$\Delta \mathrm{ES} = QV \times \left(\frac{TCA \times 100}{A}\right) \quad (1)$$

Where:
ΔES is the Variation Score of ES;
QV is the qualitative value of ES;
TCA is Transition Category Area (ha);
A is the overall area of the study (ha).

3. RESULTS

3.1. Land Cover Change and transition categories

The first step of our analysis highlighted the quali-quantitative distribution of LCC as shown in the table and map below. The figure (Fig. 2) represents the macro classes of LULC (artificial, agriculture, forests and water bodies) and their distribution in 1960 (left), 1990 (centre) and 2018 (right).

The pivot table shows that the highest level of permanence occurred mainly in the following land use and cover classes: 300 and 211, which arewoodland and non-irrigated arable lands, respectively (Tab. A.2. in Appendix). This observation is valid in all the considered time periods and is corroborated by the matrix below.

At national level, between 1960 and 2018, transition categories analysis finds a consistent permanence of forests (89,345 km^2), arable lands (54,655 km^2), heterogeneous agricultural areas (12,151 km^2) and permanent crops (12,104 km^2) (Fig. 3). Concerning transformation, agricultural intensification represents the most important process of LCC that occurred in Italy in the considered time period: a total of 168,257 km^2 was transformed mainly from (i) natural to agricultural, (ii) heterogene-

Fig. 2. LULC in Italy represented through 4 macroclasses.

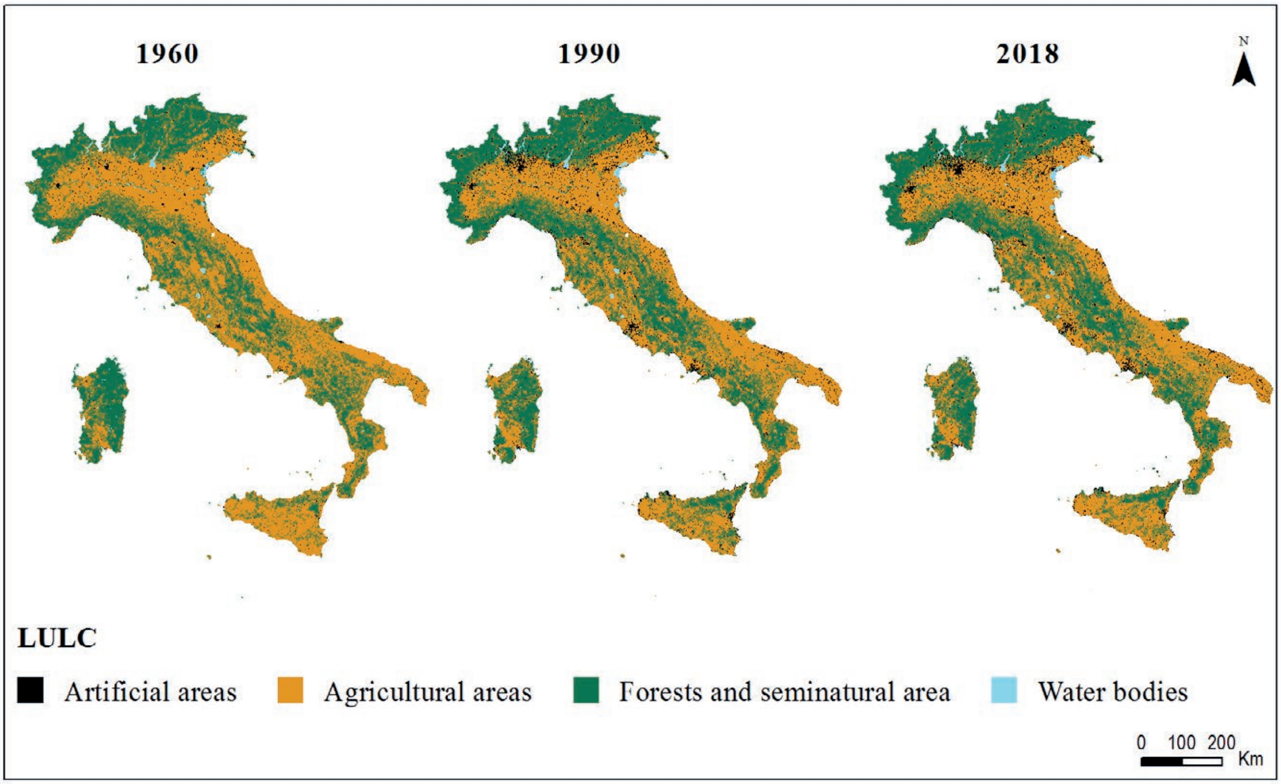
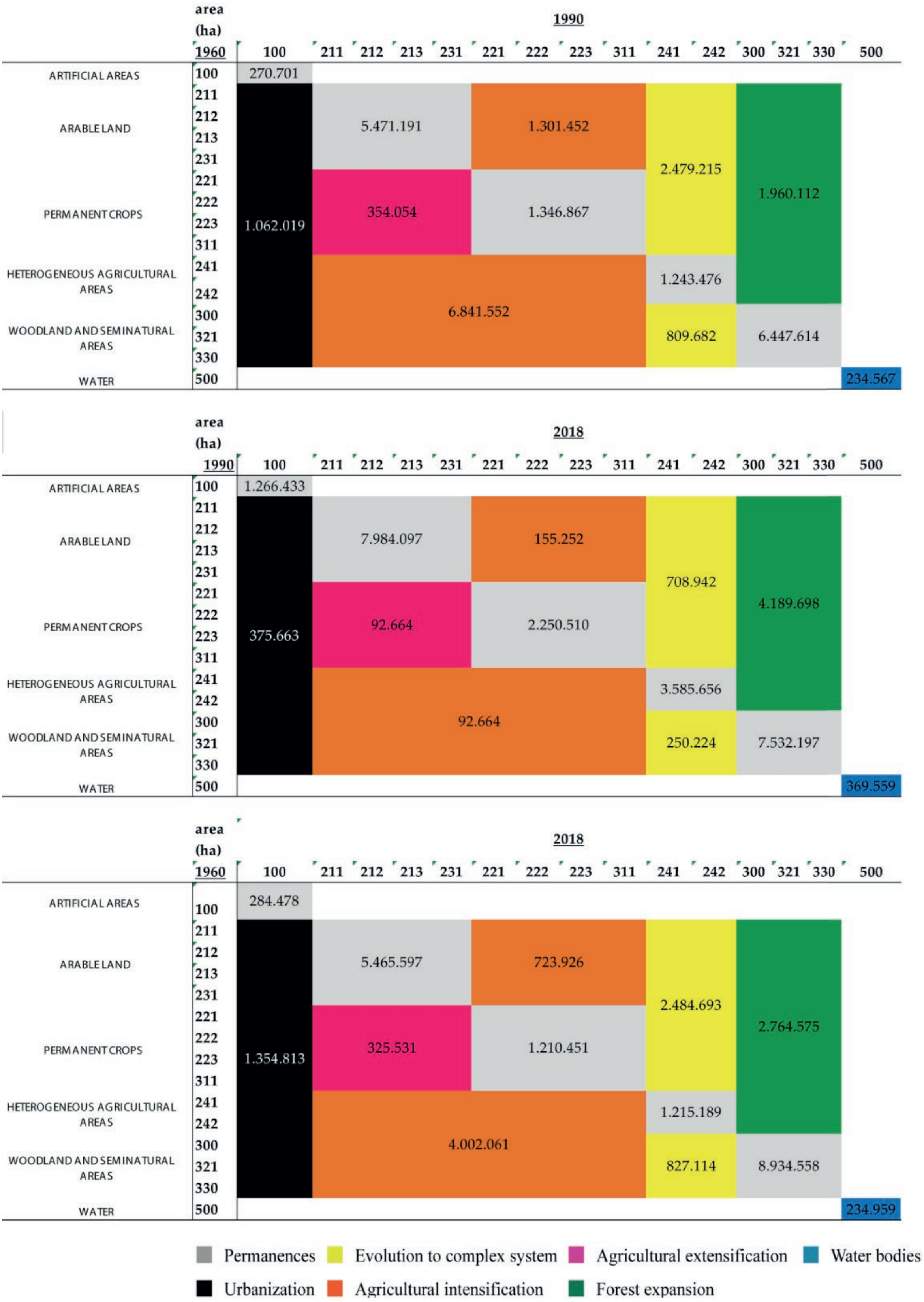


Fig. 3. Transition categories matrix between 1960-1990, 1990-2018, 1960-2018.



ous agricultural areas to arable land and grassland. An area of 27,645 km^2 underwent natural forest expansion, while 33,118 km^2 were converted into complex systems and just 3,255 km^2 agricultural areas were subjected to extensification. Lastly, 13,548 km^2 were converted from agricultural and woodland to urban areas.

Some differences can be observed between the two time periods we studied: forestation was more intense during the second period (1990-2018) while agricultural intensification characterizes a large part of the changes that occurred in the first period (1960-1990). Those processes are reflected in the maps below. Between 1960-1990, furthermore, urbanization was higher than in the second period. Evolution to complex systems and agricultural extensification are other categories that are more represented in the first than in the second period.

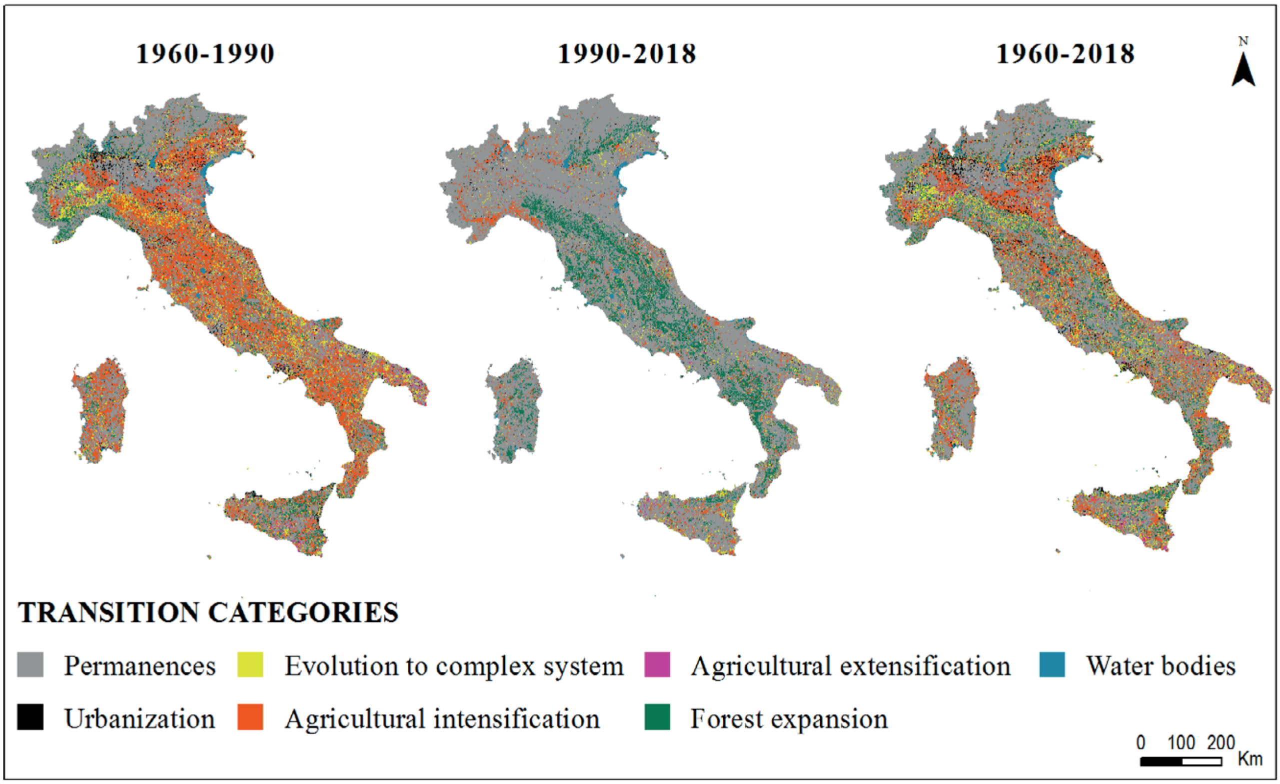
With regard to the transition categories spatial distribution, agricultural intensification is highly representative of the changes that occurred in the NE, especially in the Po Valley area, and in the E-NE, along the Adriatic coasts (Fig. 4). Evolution to heterogeneous agricultural areas invloved large parts of the NW, as in Piedmont region, also on Sicily in the S. Forest expansion is particularly extended and concentrated in the NE area in Liguria and Tuscany. Concerning the urbanization category, this is significant above all in the Milan and Rome areas but, as the other categories, can be found in lesser or greater concentration all over Italy.

3.2. Transition Categories-ES variation analysis

LULC produced different variations in ES supply over the periods studied. These values are distributed differently among Italian regions (Fig. 4). In the periods investigated there was a generalized loss of ES caused by agricultural intensification, urbanization, and, to a lesser extent, the permanence of arable land.

In the 1960-1990 period there was a greater variation in ES supply than in 1990-2018. The processes of agricultural intensification and urbanization caused a decrease in all regulation and cultural ES and some of the ES provision. This decrease has been balanced, with varying intensity, by the permanence and forest expansion. In 1960-1990, the increase in anthropogenic pressure on agriculture triggered the intensification process caused mainly by the transition from extensive to intensive farming and agricultural mechanization, which also affected hilly areas (Tab.3 and Fig. 5).

Fig. 4. Transition categories map of the LCC occurring between 1960-2018.



Tab. 2. ES variation qualitative and transition categories of LCC.

Transition categories and SE variation	1960-1990				1990-2018				1960-2018			
	P	R	C	TOT	P	R	C	TOT	P	R	C	TOT
Agricultural intensification	-18,1	-68,4	-13,8	-100,4	-11,6	-36,0	-6,9	-54,5	-38,9	-130,0	-36,1	-205,0
Urbanization	-19,5	-27,2	-8,0	-54,6	-5,3	-8,5	-2,3	-16,1	-24,5	-34,1	-9,9	-68,5
Arable land permanence	-1,3	-8,6	-1,1	-11,0	-4,6	-2,9	-0,1	-7,6	-3,7	-9,6	-1,1	-14,3
Agricultural extensification	3,6	-2,7	-4,4	-3,5	0,4	-1,9	-1,5	-3,0	3,3	-2,5	-4,0	-3,2
Crop permanence	3,9	7,1	2,6	13,6	0,0	0,2	-0,1	0,2	1,3	1,4	1,4	4,2
Heterogeneous agricultural area permanence	3,6	14,3	0,0	17,9	0,4	1,7	0,0	2,1	3,6	14,3	0,0	17,9
Evolution to complex systems	-2,3	34,2	-4,1	27,7	-1,4	5,6	-4,0	0,3	-1,5	34,9	-4,7	28,8
Forest permanence	2,2	56,9	3,7	62,8	3,1	4,5	2,1	9,7	5,3	80,7	4,8	90,9
Forest expansion	38,1	107,1	38,3	183,5	7,7	17,3	7,3	32,3	56,0	164,1	57,1	277,1
Water bodies	-2,7	-2,1	1,2	-3,7	-0,4	-0,3	0,3	-0,4	-2,9	-2,1	1,4	-3,6
Water body variation	1,0	1,0	-0,5	1,5	0,1	0,1	-0,2	0,1	1,0	1,1	-0,5	1,6
Total	8,5	111,7	13,7	133,9	-11,5	-20,2	-5,3	-37,0	-1,0	118,3	8,4	125,7

Legend: P= Provisioning ES; R = Regulation ES; C= Cultural ES.

Regions with high coverage of intensive agricultural areas (i.e., permanent crops, arable land and fertilized grasslands) have lower ES values than regions with higher forest area. The process of forest expansion is critical to the provision of regulating ES such as carbon sequestration (R1), local climate regulation (R2), biological control (R8), and protection from hydrological disaster (R6) in addition to the provision of wood and fFibre (F4) and the values of recreation (C2) and inspiration for art and culture (C3). Increased forest expansion has only partially offset the loss of ES due to agricultural intensification (Tab. 2 and Fig. 5).

Each transition category influences with a different weight the supply of individual ES compared also to the investigated periods (Fig. 4 and Fig. 5). As the results show, the conversion from forests and pastures to agricultural land (agricultural intensification) has led, on the one hand, to an increase in the ES of food production and, on the other, to a reduction in the capacity of soils to provide mainly regulatory ES. In fact, intensive agricultural practices, especially in lowland and hilly areas, reduce the capacity to absorb carbon, increase vulnerability to surface erosion and cause the loss of natural habitats.

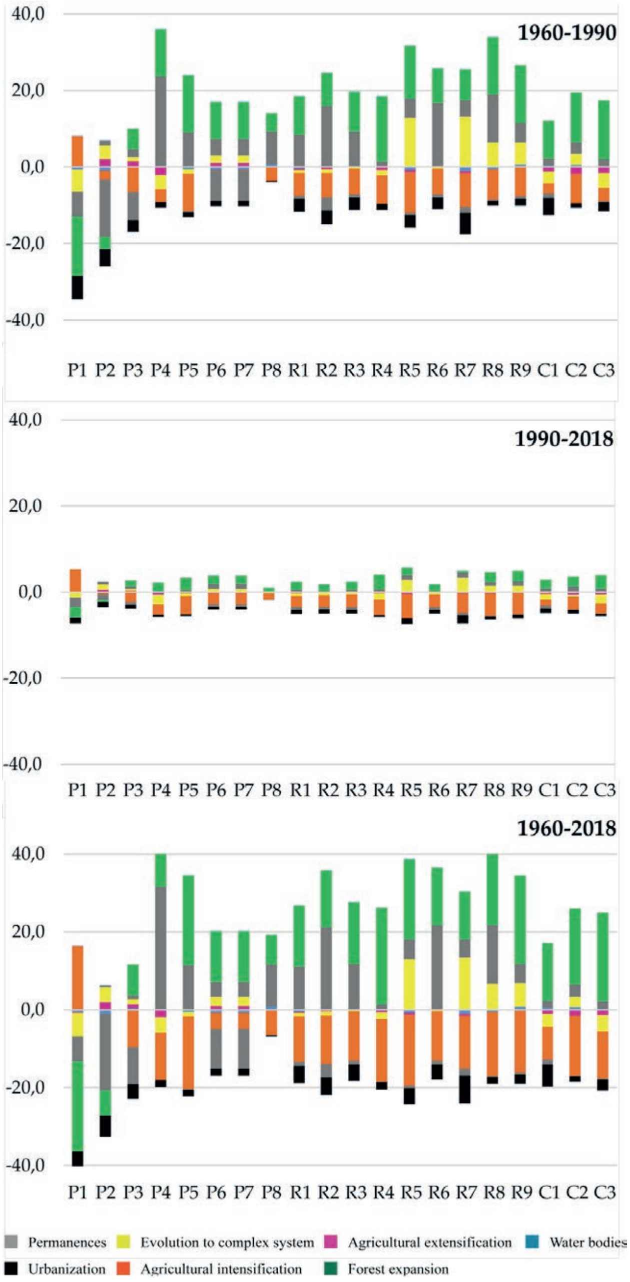
Agricultural intensification is more concentrated in the Po Valley, NE, and the mid-Adriatic coast than in the rest of Italy (Fig. 4). Areas where there was no transition between different land use and cover categories (Fig. 4) maintained medium-high values in ES supply (Fig. 6). Medium-high values were also recorded along the Alps and Apennines where forest expansion occurred. In these areas, forest expansion resulted in an increase in the supply of all ES with the exception of ES P1 (crops) and P2 (forage production). The transition towards the evolution into complex systems has affected in a widespread way the internal areas from north to south, contributing to the protection of biodiversity. In fact, this transformation, between 1960-2018, led to an increase in the ES supply linked to biodiversity such as R5 (protection from erosion and geological instability), R7 (pollination), R8 (biological control), R9 (habitats for biodiversity).

4. DISCUSSION

The results of the paper showed how changes in LULC affect ES supply and this is consistent with studies conducted in other areas in Europe (García-Llamas *et al.*, 2019; Schirpke *et al.*, 2021). Most of the LULC changes that have occurred in the Mediterranean are due to human activities and mainly involve agriculture and urban expansion (Vogiatzakis *et al.*, 2020; Parcerisas *et al.*, 2012). These changes can negatively affect natural capital and lead to a decline in biodiversity and ecosystem services (Ioannidou *et al.*, 2021). This has led to the need to monitor such changes at spatial and temporal scales and link them to the provision of ES. In Europe these changes differently affect the provision of different ES because they depend on some factors such as latitude, altitude zone and specific spatial characteristics of the investigated areas (Ioannidou *et al.*, 2021; Sil *et al.*, 2016).

The results of the study highlight the trade-offs between different land uses. In fact, the intensification of agricultural activity has led to a contraction in the sup-

Fig. 5. ES Variation at national level between 1960 and 2018.



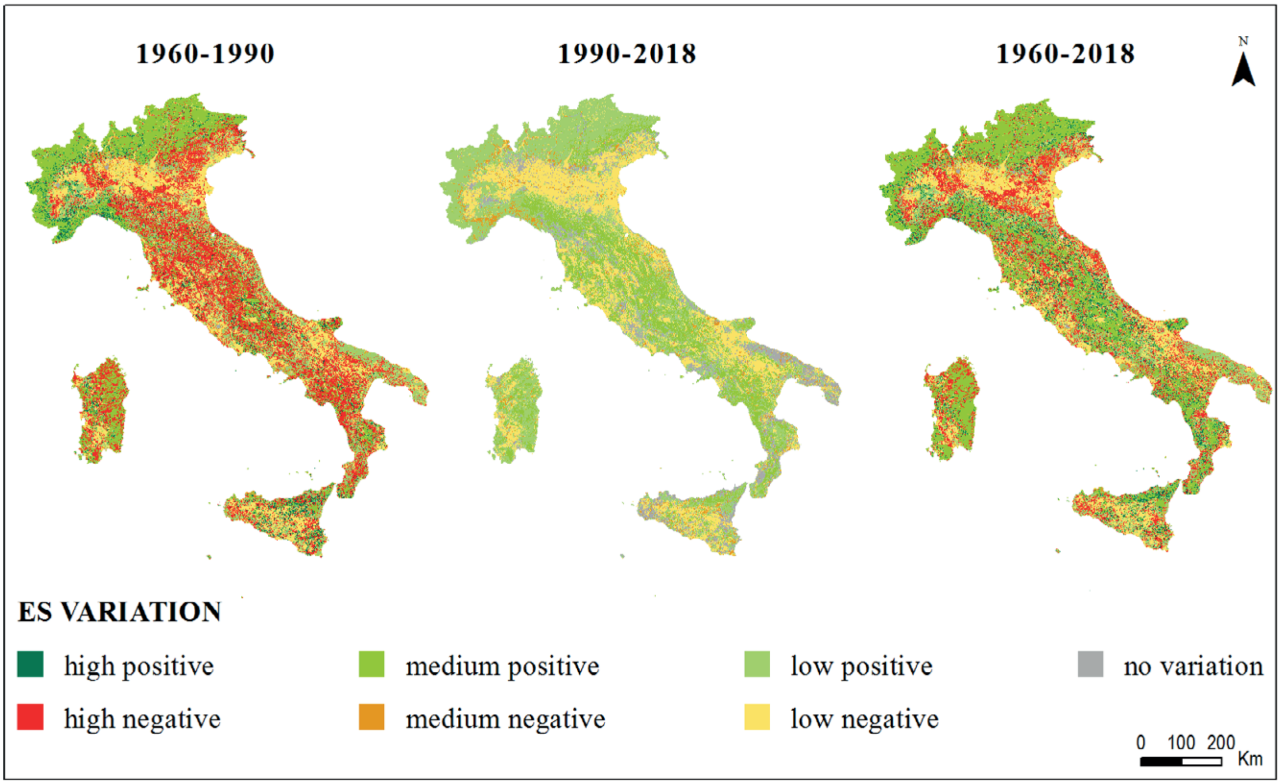
ply of ES, especially ES regulation. Urbanization has also caused a decrease in ES supply. This has led to the expansion of urban areas and the building over of soil previously occupied by agricultural land, natural and semi-natural areas. In these areas land consumption has permanently changed the ecosystem function of protecting the territory from hydrogeological instability, of mitigating climate change (absorption of carbon dioxide, removal of pollutants) and habitats for biodiversity. Over the period analyzed, the difference between gain and loss of ES was 125.7 points. The loss in ES provision associated with agricultural intensification (-205 points) and urbanization (-68.5 points) was offset by an increase in ES provision due to forest expansion, (+277.1 points), and forest permanence (+90.9 points). Agricultural intensification in Italy is in line with what is happening in Europe. In particular, the use of new technologies foreseen by the Green Revolution, and the Common Agricultural Policy (CAP) in the last 50 years have driven the intensification of agriculture, promoting the simplification and specialization of agroecosystems through the decline of landscape heterogeneity, the increase in the use of chemicals per unit area and the abandonment of less fertile areas (Emmerson *et al.*, 2016). These processes have eroded the quantity and quality of habitat for many plants and animals, and thus reduced natural capital and biodiversity across Europe (Rolando *et al.*, 2017). The increased forest expansion occurred mainly as a result of abandonment in rural hill and mountain areas. These processes took place mainly in the post 1990 period with the establishment of several protected natural areas and N2000 sites along the Apennines. The Management Plans of the Parks and N2000 sites have regulated human activities in these territories and contributed, through interventions, to ensure the ecological integrity of ecosystems. Agricultural land over the years has been transformed as a result of the evolution of ecological conditions and social and economic dynamics of rural areas into natural and semi-natural environments. In the 2014-2020 period, the mountain territories of the Alps and Apennines have benefited from funding from the National Strategy for Internal Areas under the EU's Cohesion Policy (CP). The objective of this strategy was to counteract the abandonment of internal areas, promote economic development and improve the maintenance of the territory.

These processes often lead to a trade-off between ES supply. The loss of some ES can adversely affect the provision of others. For example, soil sealing can compromise natural groundwater recharge function, hydrogeological protection function, water cycle regulation, etc. The ES regulation is the category that has registered a substantial increase followed by cultural SE. The supply ES, instead, is the category in which this increase is lowest. In fact, forest expansion has counteracted the loss of ES due to the intensification of agricultural areas and urbanization.

5. CONCLUSIONS

The matrix method simplifies landscape functionality by producing uncertainties about the quantification

Fig. 6. ES variation between 1960-2018.



of ES. For example, the delivery of many ES depends not only on the presence of certain land use and land cover types but also on the spatial configuration and management of each land use (Santana-Cordero *et al.*, 2016; Schirpke *et al.*, 2017). The approximate spatial resolution and thematic generalizations of CORINE data may limit the results presented here. With local or regional scale levels of analysis, additional data must be integrated in order to obtain a better representation of landscape and LULC characteristics (Madrigal-Martínez *et al.*, 2019). Involving the expert panel in the development of the matrix can improve many aspects, such as the determination of LULC classes and relevant ES types.

The results of this paper can provide important knowledge to support land use planning (Kandziora *et al.*, 2013). In fact, through historical analysis it is possible to understand how the impacts of human activities affect changes in LULC and the causes that determine the variation in ES supply (Bürgi *et al.*, 2015). In this context, GIS analysis has allowed us to map ES at different spatial and temporal scales and to analyze trade-offs between different ES in relation to LULC changes. The analysis GIS coupled with qualitative ES provision matrices assumes high potential for land management analysis. Maps of landscape capacity to deliver ES provide information on the potential to deliver goods and services, socioeconomic conflicts, and in environmental management. Supplementing the analysis with additional data such as biotic and abiotic information could improve the data analysis (Burkhard *et al.*, 2009). Finally, ES variation maps (Fig. 5) if analysed in synergy with maps representing the territory (e.g. geological maps, hydrogeological risk maps, urban maps, ecoregions, etc.) could provide useful information to evaluate trade-offs between ES supply and improve land management. These further investigations could be the basis for future research developments.

Furthermore this study could be deepened by analyzing the ES variation also in function of the ES demand. In fact, the relationship between ES supply and demand can contribute to improving ES governance (Marino *et al.*, 2021). In our study we highlighted that LULC changes happen at a different speed depending on the period analyzed. The influencing factors of LULC change are anthropogenic activities such as urbanization, the intensification of agriculture and the socio-economic processes that determine a migration of the population from rural areas to urban and peri-urban areas. To these factors are added the climatic changes that affect the choices of economic and social investment in the territory. Predicting trends in ES supply is complex and depends on how quickly the LULC changes in relation to ES demand. In addition, to respond to environmental policy recommendations, research could be improved by also considering the change in economic value of ES in relation to LULC changes. Economic valuations are an essential part of human-environment systems research. They support awareness of the dependence of human societies on nature and help design instruments for the conservation of important natural systems (Schirpke *et al.*, 2108; Heal *et al.*, 2000; Marino *et al.*, 2016).

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APPENDIX

Tab. A.1. Legend conversion from TCI and CLC to the classes used for transition categories analysis.

TCI classes	CLC Classes	Classes (for transition categories analysis)	New code
01 Arable land (dry)	2.1.1 Non-irrigated arable land (2.1.1.1. Intensive crops; 2.1.1.2. Extensive crops)	Non-watering plants	211
02 Arable land (dry); 04 Arborated irrigated arable land	2.4.1. Annual crops associated with permanent crops	Tree crops in association	241
03 Irrigated arable land	2.1.2. Arable land in irrigated areas	Irrigated arable land	212
05 Paddy field	2.1.3. Paddies	Paddy field	213
06 Vegetable garden; 09 Vineyard - Olive grove	2.4.2. Complex crop and particle systems; 2.4.3. Areas mainly occupied by agricultural crops with the presence of natural spaces	horticultural crops and complex systems	242
07 Vineyard	2.2.1. Vineyards	Vineyard	221
08 Olive grove	2.2.3. Olive groves	Olive grove	223
10 Citrus grove 11 Fruit trees (pulpy fruit) 12 Fruit trees (hard nuts or pods)	2.2.2. Fruit trees and minor fruits	Fruit trees	222
13 Coppice; 14 Tall forest; 15 Promiscuous forest	3.1.1. Broad-leaved woods; 3.1.2. Coniferous forests; 3.1.3. Mixed woods; 2.4.4 Agroforestry areas; 3.3.3. Areas with sparse vegetation; 3.3.4. Areas affected by fires 3.2.2. Moors and bushes; 3.2.3. Areas with sclerophyllous vegetation; 3.2.4. Areas with evolving woodland and shrub vegetation)	Forest	300
16 Chestnut grove (for fruit)	3.1.1.4; Woods with a prevalence of chestnut	Chestnut	311
17 Lawn and wooded meadow (dry) 18 Lawn and wooded lawn (irrigated)	2.3.1. Stable lawns	Lawn and wooded	231
19 Pasture and uncultivated production even if partially or temporarily used for arable land	3.2.1. Natural pasture areas and high altitude grasslands	Pasture	321
20 Open spaces with little or no vegetation	3.3.1. Beaches, dunes, sands; 3.3.2 Bare rocks, cliffs, outcrops; 3.3.5. Glaciers and perennial snows	Open spaces with little or no vegetation	330
21 Settlements and other forms of use; 22 Other uses	1.1.1. Continuous urban fabric; 1.1.2. Discontinuous urban fabric; 1.2.1. Industrial or commercial areas; 1.2.2. Road and railway networks and ancillary spaces; 1.2.3. Port areas; 1.2.4. Airports; 1.3.2. Landfills; 1.3.3. Construction sites; 1.4.1. Urban green areas; 1.4.2. Sports and recreational areas; 1.3.1. Mining areas	Settlements	100
23 Water bodies	5.1.1. Waterways, canals and waterways; 5.1.2. Water basins; 5.2.1. Lagoons; 5.2.2. Estuaries; 4.1.1. Inner marshes; 4.1.2. Peat bogs; 4.2.1. Brackish marshes; 4.2.3. Intertidal zones; 4.2.2. Saline	Water bodies	500

Tab. A.2. Pivot table represents changes from one to another LULC between 1960-1990, 1990-2018, 1960-2018. Percentage permanences can be read along the diagonal.

Area%	1990															
1960	**100**	**211**	**212**	**213**	**221**	**222**	**223**	**231**	**241**	**242**	**300**	**311**	**321**	**330**	**500**	**Tot**
100	*0.9*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.4*
211	*0.8*	*13.0*	*0.1*	*0.0*	*0.6*	*0.4*	*0.7*	*0.5*	*0.5*	*4.5*	*2.1*	*2.1*	*0.9*	*0.1*	*0.1*	*26.3*
212	*0.3*	*2.6*	*0.0*	*0.5*	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.3*	*0.1*	*0.1*	*0.0*	*0.0*	*0.0*	*4.0*
213	*0.0*	*0.0*		*0.3*		*0.0*	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.4*
221	*0.2*	*0.5*	*0.0*	*0.0*	*0.5*	*0.1*	*0.3*	*0.0*	*0.1*	*1.0*	*0.3*	*0.1*	*0.0*	*0.0*	*0.0*	*3.3*
222	*0.2*	*0.3*	*0.0*	*0.0*	*0.1*	*0.4*	*0.3*	*0.0*	*0.0*	*0.4*	*0.1*	*0.1*	*0.0*	*0.0*	*0.0*	*1.8*
223	*0.1*	*0.3*	*0.0*	*0.0*	*0.1*	*0.1*	*1.4*	*0.0*	*0.1*	*0.6*	*0.3*	*0.2*	*0.0*	*0.0*	*0.0*	*3.3*
231	*0.2*	*0.8*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.3*	*0.0*	*0.6*	*1.0*	*0.3*	*0.2*	*0.0*	*0.0*	*3.5*
241	*1.0*	*5.9*	*0.0*	*0.0*	*0.2*	*0.2*	*0.7*	*0.1*	*0.3*	*3.6*	*0.6*	*0.9*	*0.1*	*0.0*	*0.0*	*13.8*
242	*0.1*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.2*	*0.0*	*0.0*	*0.2*	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.8*
300	*0.2*	*0.8*	*0.0*	*0.0*	*0.1*	*0.0*	*0.2*	*0.2*	*0.1*	*1.1*	*7.8*	*6.9*	*0.5*	*0.1*	*0.1*	*17.9*
311	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.5*	*0.8*	*0.0*	*0.0*	*0.0*	*1.5*
321	*0.2*	*2.2*	*0.0*	*0.0*	*0.1*	*0.1*	*0.2*	*0.3*	*0.1*	*1.3*	*7.6*	*3.0*	*2.9*	*0.6*	*0.2*	*18.8*
330	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.6*	*0.0*	*0.2*	*1.2*	*0.0*	*2.2*
500	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.8*	*1.0*
Tot	*4.4*	*26.8*	*0.1*	*0.9*	*1.8*	*1.3*	*4.2*	*1.5*	*1.3*	*13.9*	*21.2*	*14.5*	*4.8*	*2.0*	*1.3*	*100.0*

Area%	2018															
1990	**100**	**211**	**212**	**213**	**221**	**222**	**223**	**231**	**241**	**242**	**300**	**311**	**321**	**330**	**500**	**tot**
100	*4.2*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*4.4*
211	*0.6*	*24.1*	*0.1*	*0.1*	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*1.0*	*0.1*	*0.0*	*0.1*	*0.0*	*0.0*	*26.8*
212	*0.0*	*0.0*	*0.1*			*0.0*	*0.0*	*0.0*		*0.0*	*0.0*				*0.0*	*0.1*
213	*0.0*	*0.0*	*0.0*	*0.9*		*0.0*		*0.0*		*0.0*	*0.0*	*0.0*		*0.0*	*0.0*	*0.9*
221	*0.0*	*0.1*	*0.0*		*1.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.8*
222	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.9*	*0.0*	*0.0*	*0.0*	*0.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.3*
223	*0.1*	*0.1*	*0.0*	*0.0*	*0.0*	*0.1*	*3.3*	*0.0*	*0.1*	*0.4*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*4.2*
231	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.0*	*0.0*	*0.1*	*0.1*	*0.0*	*0.1*	*0.0*	*0.0*	*1.5*
241	*0.0*	*0.2*	*0.0*		*0.0*	*0.0*	*0.1*	*0.0*	*0.4*	*0.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.3*
242	*0.4*	*1.2*	*0.0*	*0.0*	*0.3*	*0.1*	*0.2*	*0.1*	*0.1*	*10.9*	*0.5*	*0.0*	*0.1*	*0.0*	*0.0*	*13.9*
300	*0.1*	*0.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.0*	*0.0*	*0.5*	*18.1*	*1.3*	*0.8*	*0.1*	*0.0*	*21.2*
311	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.2*	*12.6*	*1.5*	*0.0*	*0.0*	*0.0*	*14.5*
321	*0.0*	*0.3*	*0.0*		*0.0*	*0.0*	*0.0*	*0.2*	*0.0*	*0.2*	*0.6*	*0.0*	*3.4*	*0.0*	*0.0*	*4.8*
330	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.2*	*0.0*	*0.1*	*1.7*	*0.0*	*2.0*
500	*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*	*1.2*	*1.3*
tot	*5.5*	*26.4*	*0.2*	*1.0*	*2.1*	*1.3*	*3.9*	*1.4*	*0.8*	*14.4*	*32.5*	*2.9*	*4.6*	*1.8*	*1.3*	*100.0*

Area%	2018															
1960	**100**	**211**	**212**	**213**	**221**	**222**	**223**	**231**	**241**	**242**	**300**	**311**	**321**	**330**	**500**	**tot**
100	*0.9*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*1.4*
211	*1.1*	*13.1*	*0.1*	*0.0*	*0.7*	*0.4*	*0.7*	*0.4*	*0.3*	*4.5*	*3.9*	*0.2*	*0.7*	*0.1*	*0.1*	*26.3*
212	*0.4*	*2.5*	*0.0*	*0.5*	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.3*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*4.0*
213	*0.0*	*0.0*		*0.3*		*0.0*	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*		*0.0*	*0.0*	*0.4*
221	*0.3*	*0.5*	*0.0*	*0.0*	*0.6*	*0.1*	*0.3*	*0.0*	*0.0*	*1.1*	*0.4*	*0.0*	*0.0*	*0.0*	*0.0*	*3.3*
222	*0.2*	*0.3*	*0.0*	*0.0*	*0.1*	*0.3*	*0.3*	*0.0*	*0.1*	*0.5*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*1.8*
223	*0.2*	*0.2*	*0.0*	*0.0*	*0.1*	*0.1*	*1.4*	*0.0*	*0.1*	*0.6*	*0.4*	*0.0*	*0.0*	*0.0*	*0.0*	*3.3*
231	*0.3*	*0.7*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.3*	*0.0*	*0.6*	*1.1*	*0.2*	*0.1*	*0.0*	*0.0*	*3.5*
241	*1.3*	*5.8*	*0.0*	*0.0*	*0.3*	*0.2*	*0.6*	*0.1*	*0.2*	*3.6*	*1.4*	*0.1*	*0.1*	*0.0*	*0.0*	*13.8*
242	*0.1*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.2*	*0.0*	*0.0*	*0.2*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.8*
300	*0.2*	*0.8*	*0.0*	*0.0*	*0.1*	*0.0*	*0.1*	*0.2*	*0.0*	*1.2*	*13.4*	*1.3*	*0.5*	*0.1*	*0.1*	*17.9*

311	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.6*	*0.7*	*0.0*	*0.0*	*0.0*	*1.5*
321	*0.3*	*2.2*	*0.0*	*0.0*	*0.1*	*0.1*	*0.2*	*0.3*	*0.1*	*1.4*	*10.3*	*0.2*	*3.0*	*0.5*	*0.2*	*18.8*
330	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.7*	*0.0*	*0.2*	*1.1*	*0.0*	*2.2*
500	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.8*	*1.0*
tot	*5.5*	*26.4*	*0.2*	*1.0*	*2.1*	*1.3*	*3.9*	*1.4*	*0.8*	*14.4*	*32.5*	*2.9*	*4.6*	*1.8*	*1.3*	*100.0*

Tab. A.3. LULC and qualitative potencial ES values matrix.

Cod	F1	F2	F3	F4	F5	F6	F7	F8	R1	R2	R3	R4	R5	R6	R7	R8	R9	C1	C2	C3
111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
123	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
124	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
132	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
141	0	0	0	0	0	0	0	0	1	2	2	1	1	0	1	1	1	1	2	0
142	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
211	3	2	1	0	0	1	1	0	1	1	1	0	0	1	1	0	0	1	0	0
212	3	1	0	0	0	1	1	0	1	2	1	0	0	1	1	0	0	1	0	0
213	3	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	1	0	1
221	3	0	0	1	0	0	0	0	1	1	1	0	0	1	1	0	0	2	1	1
222	3	0	0	2	0	0	0	0	2	2	1	1	1	1	3	0	0	2	1	1
223	3	1	0	2	0	0	0	0	1	1	1	1	1	1	1	0	0	2	3	2
231	1	3	3	0	1	0	0	0	1	1	1	0	2	1	3	1	2	2	2	1
241	3	2	1	0	0	0	0	0	1	1	1	0	1	1	2	0	0	1	1	0
242	2	2	1	0	0	1	1	0	1	1	1	0	2	1	3	1	1	1	1	0
243	2	2	2	2	2	1	1	0	2	2	1	1	2	1	2	2	2	2	1	1
244	2	2	1	2	1	0	0	0	1	2	1	1	2	1	2	1	1	1	1	0
311	0	1	2	3	3	2	2	1	3	3	3	3	3	3	3	3	3	3	3	3
312	0	1	2	3	3	2	2	1	3	3	3	3	3	2	3	3	3	3	3	3
313	0	1	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3
321	0	3	3	0	2	3	3	0	2	1	2	3	3	1	3	2	3	3	3	3
322	0	1	3	1	1	1	1	0	2	2	2	3	2	2	2	1	3	2	3	1
323	0	1	1	1	1	2	2	0	1	1	1	1	2	1	2	2	3	2	1	1
324	0	1	2	1	1	2	2	0	1	1	1	1	2	2	2	2	3	2	1	2
331	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	0	1	3	3	2
332	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
333	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1	1	0
334	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
335	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	3	3	2
411	0	1	1	1	0	0	0	0	1	1	3	3	0	1	1	1	2	2	1	1
412	0	0	0	0	0	1	1	0	3	3	3	3	0	2	1	1	2	1	1	1
421	0	0	1	0	0	0	0	0	1	2	0	1	0	1	0	0	2	1	1	1
422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
423	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	2	2	1
511	0	0	2	0	0	0	0	3	0	1	3	2	0	1	0	0	3	3	3	2
512	0	0	2	0	0	0	0	3	1	1	3	1	0	2	0	0	3	3	3	3
521	0	0	3	0	0	0	0	0	1	1	0	0	0	1	0	0	3	3	3	3
522	0	0	3	0	0	0	0	0	1	0	0	1	0	2	0	0	2	3	2	2
523	0	0	3	0	0	0	0	0	2	2	0	0	0	0	0	0	2	3	3	2