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How Land-Take Impacts the Provision of Ecosystem Services—The Case of the Province of Monza and Brianza (Italy)

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Abstract

Non-urbanized areas (NUAs), including residual urban green areas, urban parks, agricultural, natural and semi-natural areas, are a fundamental part of the green infrastructure. They are essential in sustaining life and future development, providing a series of ecosystem services (ESs) vital to human society. However, the rapid expansion of urban areas has led to a significant reduction in green spaces. Land-take, reducing available land resources, impacts ecosystem functionality, making it crucial to preserve high-quality territories and the relative ESs provided. In this context, the aim of this study was to evaluate the reduction in ESs due to the land-take having occurred in the last 20 years in the Province of Monza–Brianza, the Italian province with the highest land-take. To achieve this goal, authors used the official data of land use/cover of the Lombardy Region, with three time thresholds (T0: 1999–2003, T1: 2012–2013, T2: 2021) and applied a methodology for ESs assessment originally developed for the municipal level, adapting it to the provincial scale. The study analyzes trends in land-take and land-use changes and assesses how these changes have led to variations in ES provision. The approach involves calculating multiple indices reflecting different ESs provided by NUAs: provisioning ESs coming from agriculture, regulating ESs provided by natural resources, cultural ESs provided by landscape. Findings reveal that urban expansion has decreased provisioning ESs coming from agriculture, while ESs provided by landscape and natural resources have remained stable or improved, respectively. The natural quality index has improved due to conservation policies, despite the high land-take recorded. Anyway, although regional policies have mitigated some negative effects, the overall reduction in green spaces remains a critical issue.

Keywords: land-take; green infrastructure; ecosystem services

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1. Introduction

Green infrastructure, which includes urban green spaces, agricultural areas, natural and semi-natural areas, can largely be traced back to all non-urbanized areas (NUAs). It represents a fundamental element for supporting present and future society [1–5]. Natural ecosystems are fundamental to human life as they provide a series of ecosystem services (ESs) from which humans benefit [6], essential for human survival and well-being.

Despite its fundamental role, green infrastructure is constantly being eroded by land-take, the irreversible transformation of natural or agricultural land into urbanized areas [7,8], which consequently leads to a reduction in the ecosystem services provided by the land taken. Land-take is a process, often driven by economic development needs, that transforms natural and semi-natural areas (including agricultural and forestry land, gardens, and parks) into artificial land development. It is a land-use change in favor of artificial areas and at the expense of natural and agricultural land. For this reason, the European Union, with Decision No. 1386/2013/EU of the European Parliament and of the Council, has set the ambitious goal of achieving "zero net land-take by 2050".

The Lombardy Region, the leading Italian region in terms of land-take [9], has adopted this objective with the Regional Law 31/2014. With this law, provinces and municipalities are obliged to reduce, on one hand, the land-take and, on the other, to assess the quality, in terms of agricultural, pedological, naturalistic, and landscape values, of non-urbanized areas in their land use plan [10,11].

In this framework, assessing the ESs provided by urban and rural green areas can be a valuable approach to evaluating the overall quality of the territory [12–15]. In fact, the types and amounts of ESs lost due to land-take depend on the territorial quality [16]. The analysis of the temporal variation in ecosystem services provided by a specific portion of territory allows us to evaluate the effects of land-take on the overall territorial quality.

The heterogeneity of ecosystem services and the contexts in which they occur has led to the development of a variety of methodological approaches for their assessment, with a tendency to focus on a limited number of services, often using highly diverse techniques, making it difficult to compare and integrate different studies.

Some studies evaluate ESs by assigning an economic value to the benefits produced. Costanza et al. [17] were the first to lay the foundations for determining Ecosystem Service Value (ESV), and since then, ESV research has been further developed and applied in various parts of the world [18–21], especially in China, where a Chinese-specific ESV calculation method has been developed [22]. ESV has often been used as the average value at a regional or national scale, without being able to take into account the spatial variability of the phenomena analyzed [23–25]. Some studies on ESV use the economic value of food produced to adapt the global approach to the local scale [18,20,26]; others use net primary productivity (NPP) [25,27–29]; others use the changes in agricultural carbon emission and carbon fixation related to agricultural production [30]. Finally, several authors have used ESV to calculate the effect of changes in Land Use/Land Cover (LULC) on ESs provided. In these cases, each land use is given a score that quantifies the economic value of the specific LULC class, which is then multiplied by the area of each LULC class [31–34]. Sometimes, a weighting value for each ES is defined to account for the relative importance of different ESs in relation to food production from cultivated land [35–38].

Other studies investigate the topic by involving experts, stakeholders, and citizens, seeking, in particular, to highlight the social and cultural values attributed to ecosystem services. Erős et al. [39] used a stakeholder-based participatory approach to assign the value of three categories of ESs (biodiversity conservation, human utilization, recreational use) for several water bodies in Hungary. Montoya-Tangarife et al. [40] used an expert consultation to assess the potential of each LULC class to provide specific ESs in the Santiago-Valparaíso region in Chile, using a qualitative 0 to 5 scale. Ramirez-Gomez et al. [41] assessed through focus group discussions the impact of changes in the provision of important ESs that indigenous peoples in the lower Caquetá River basin in Colombia have experienced after conducting participatory mapping activities. Kopperoinen et al. [42] involved both experts as well as local and regional stakeholders in assessing ES provision in southern Finland, while Frank et al. [43] formulated six possible scenarios together with experts from the regional planning authority and used Multi-Criteria Evaluation to calculate the contribution of all land-use classes to the provision of ESs on a 0 to 100 scale.

Finally, several studies use LULC data within spatially localized models, the most widely used of which is InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), consisting of a set of modeling 3.16.2. software used to map and evaluate ecosystem services. Different InVEST models have been used: the Habitat Quality model, to assess habitat quality and the impact of anthropogenic pressures on biodiversity [44–46]; the Sediment Delivery Ratio model, which estimates the amount of sediment transported and retained, is useful for soil management and assess water quality [44,47–49]; the Carbon Storage model, which aims to quantify the carbon stored in the various components of the environmental system (vegetation, soil, etc.) [44,50]; the Water Yield model, which estimates potential water availability as a function of land use as well as climatic and topographical characteristics [44,47,48,50,51]; and the Nutrient Delivery Ratio model, which evaluates the transport of nutrients (such as nitrogen and phosphorus) across the land, contributing to the analysis of eutrophication and diffuse pollution [47,52].

Several studies combine, in different ways, one or more of the approaches/methodologies outlined above [53]. Among the methodologies that use spatially localized LULC data to assess ESs, simultaneously applying Multi-Criteria Analysis to determine the relative importance of the different ESs and developing hypothetical scenarios involving interested stakeholders, the one developed by Senes et al. [54] seems to be extremely valid, even if it has been applied at the municipal level and only to quantify the actual situation. This methodology, providing relative indicators on a 0 to 1 scale, does not produce an economic estimate of ESs, which is often very difficult (or arbitrary), especially for those services that are difficult to monetize.

Furthermore, it is able to incorporate stakeholder engagement without losing the spatialization of the information. Moreover, compared to other spatially based methodologies such as InVEST models, it is able to more easily integrate the different types of ESs (particularly cultural ones) in order to calculate a composite index. Finally, it is particularly suited to the Italian context, with its typical socio-territorial variability and limited data availability.

This methodology constructs a composite quality index (CQI) that synthesizes various indicators derived from spatial and environmental data, each associated with specific ecosystem services, identified using the CICES V.5.1 classification [55]. It also involves the use of the Analytic Hierarchy Process (AHP) to assign weights to the indicators, thus allowing for the production of flexible and territorially contextualized assessment scenarios. A further strength of the methodology is the exclusive use of official, accessible, and easily available data from institutional sources (such as regional, provincial, and municipal databases), which ensures the reproducibility of the analysis and the possibility of extending it to other territorial contexts.

In this context, the aim of the study was to assess the impact of land-take over time, one of the main threats to environmental quality and territorial sustainability, on the provision of ecosystem services. The analysis focuses on the Province of Monza–Brianza, the Italian province with the highest land-take, examining the evolution of ecosystem services provided by NUAs between 1999 and 2021. Given the successful application of the methodology developed by Senes et al. [54], this was utilized as a basis for the present study adapting it to the provincial scale.

2. Materials and Methods

The study area (Figure 1) is the Province of Monza–Brianza (Lombardy Region, Northern Italy), consisting of 55 municipalities with a total area of 405.1 sq.km. It is a very densely populated area, with about 880,000 inhabitants and a population density of approximately 2170 inhabitants per sq.km, according to 2024 data from the Italian National Institute of Statistics [56]. Approximately 56% of the territory is urbanized, 33% is agricultural, and the remaining 11% consists of wooded areas and natural/semi-natural environments, according to the most recent LULC data available at the regional level, coming from the DUSAF (Agricultural and Forestry Land Use) database, version 7.0 (dated 2021), a geographic database (with a resolution of 1:10,000) based on the photointerpretation of digital orthophotos.

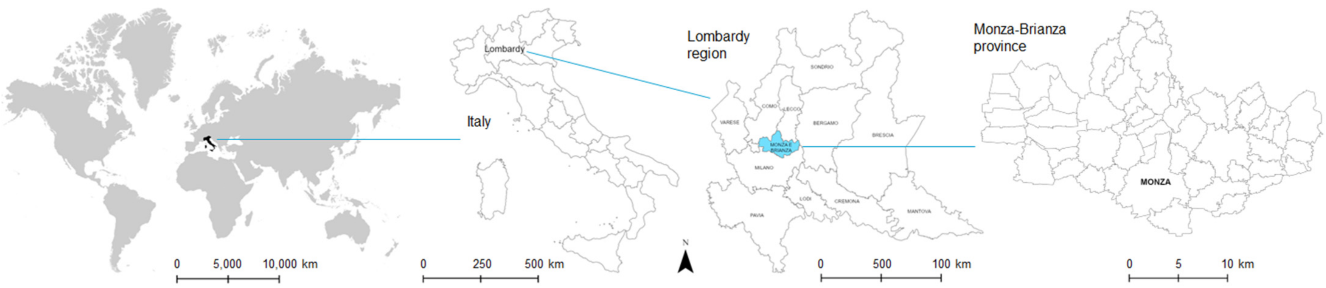


Figure 1. The study area.

The methodology, based on the study of Senes et al. [54], consists of 3 main steps, each of which is divided into one or more phases (Figure 2).

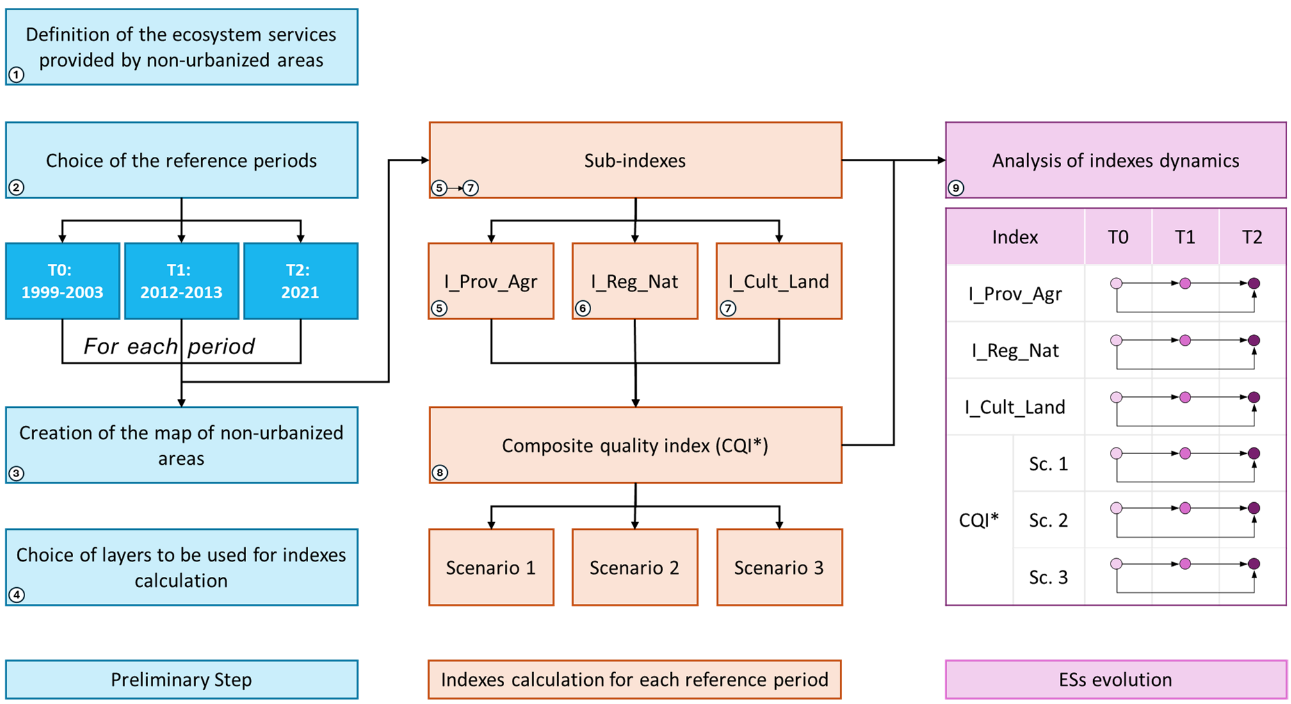


Figure 2. Methodological scheme.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

2.1. Preliminary Step

This is the first step, which includes the preliminary phases in which the initial choices regarding the ES and the periods to be considered are made, as well as the basic information to be used for calculating the indices and defining the NUAs is decided.

2.2. Phase 1: Definition of the ESs Provided by NUAs

The ecosystem services (ESs) provided by NUAs considered in this study are based on the CICES V.5.1 classification and the methodology of Senes et al. [54] (Figure 3). The ESs are assessed through a series of indices, related to agricultural production, natural resources, and landscape, and then summarized through a composite index.

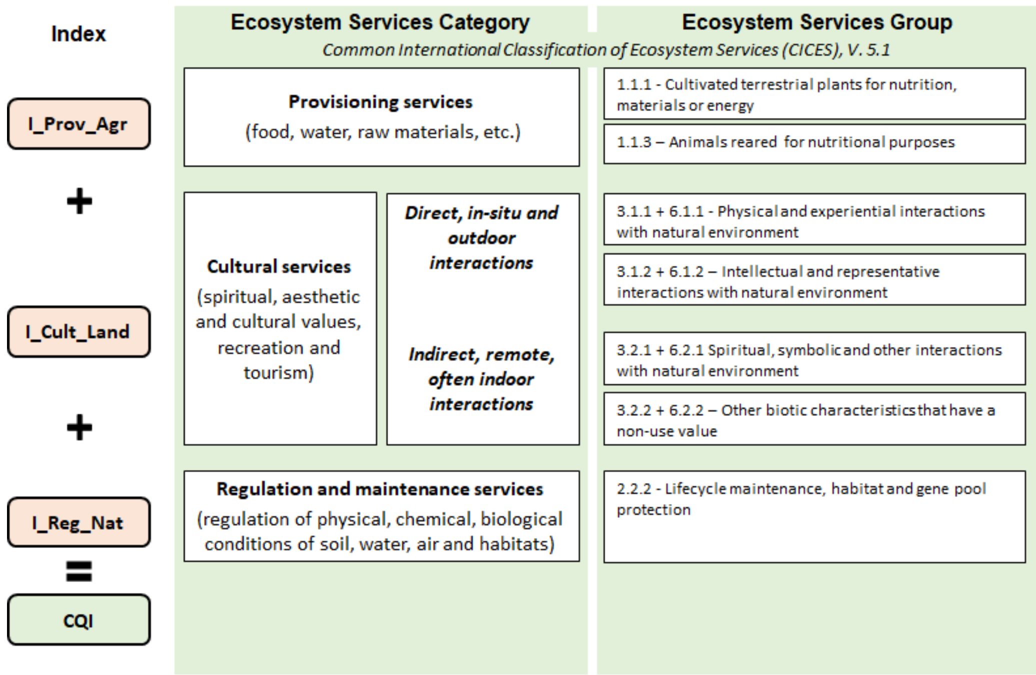


Figure 3. Ecosystem services considered for the index calculation. CQI, composite quality index. Modified from Senes et al. [54].

2.3. Phase 2: Choice of the Reference Periods

Given the aim of the study was to analyze the temporal evolution of ESs, it was necessary to define time thresholds for assessing the capacity of NUAs provided to them. The choice of these thresholds was primarily driven by the availability of data, which had to be official, accessible, available at the appropriate scale, and with a defined update or creation date. At the end of the evaluation phase, three time periods, not perfectly coeval, were identified: (i) the first between 1999 and 2003 (T0); (ii) the second between 2012 and 2013 (T1); (iii) the third referring to 2021 (T2). In T0 and T1, time intervals have been used because data with the same reference date were not always available. The data used are derived from regional or provincial databases (updated to 2003, 2013, and 2021). For LULC data (coming from the DUSAF database, Lombardy Region, scale 1:10,000) the dates closest to these time periods were chosen, i.e., 1999 (DUSAF 1.1), 2012 (DUSAF 4.0), and 2021 (DUSAF 7.0).

Using periods rather than specific dates can certainly lead to potential bias in trend attribution, even though the temporal variations in ESs provided by NUAs due to land-take are appreciable in the long term, while they are negligible from one year to the next, especially at the provincial scale. The impact of small time variations within the same period (at most 4 years, in T0) has very little impact on the index value and its trend, while the advantage of using official data produced by the region is enormous, as the databases used to calculate the indices are the same ones used by municipalities, provinces, and the region for urban and territorial planning.

2.4. Phase 3: Creation of the NUAs Map

The identification of NUAs was based on the LULC classes derived from the Lombardy Region's DUSAF databases for 1999 (DUSAF 1.1), 2012 (DUSAF 4.0), and 2021 (DUSAF 7.0). The following steps were undertaken: (i) selection of non-urbanized areas; (ii) verification of dubious land use classes using satellite images; (iii) creation of NUA maps for each period (Figure 4). The image verification were performed using digital orthophotos available through the Lombardy Region geo-portal.

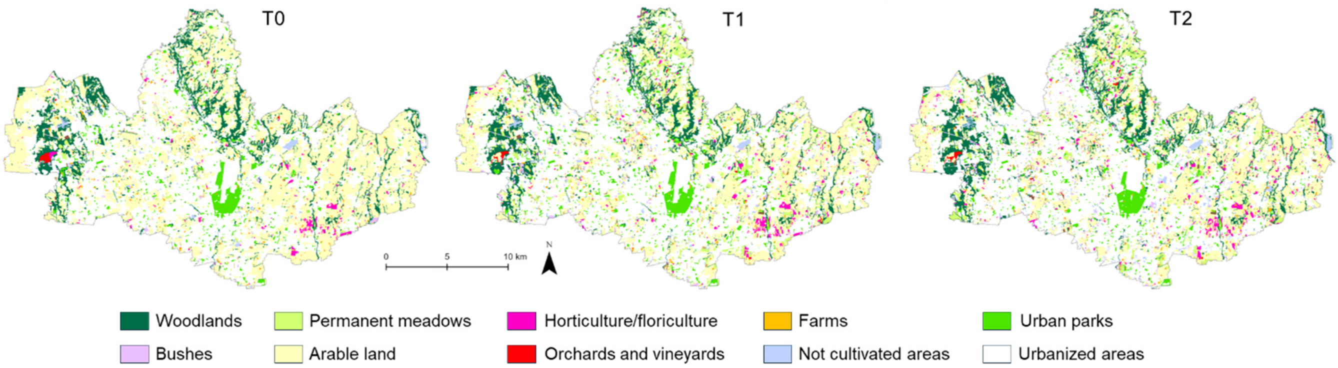


Figure 4. Land-use maps of the study area in the three reference periods (colored areas represent NUAs).

2.5. Phase 4: Choice of the Layers to Be Used for Indexes Calculation

For each ecosystem service, the most suitable databases for calculating the relative index were identified. The data had to be official, accessible, available at the appropriate scale, and updated to one of the dates considered (Table 1).

Table 1. Databases utilized in the study.

Index	Databases
I_Prov_Agr	Agricultural land uses coming from DUSAF
I_Reg_Nat	Naturalistic value of soils, Parks and protected areas, Priority areas for biodiversity, Provincial ecological network, Regional ecological network, DUSAF
I_Cult_Land	Landscape restrictions, Historical and Scenic trails, Landscape Elements from Provincial Plans, DUSAF

In this study, the I_Reg_Soil index defined by Senes et al. [54] to evaluate the regulating ESs related to the soil characteristics was not calculated. There are no data available for the different periods considered since the soil characteristics did not change in the last 25 years.

2.6. Step 2: Indexes Calculation for Each Reference Period

This is the second step, in which, for each reference period, the indices were calculated for each of the three scenarios considered.

2.7. Phase 5: Assessment of Provisioning ESs and Calculation of the I_Prov_Agr Index

To calculate the index related to provisioning ESs coming from agriculture, the methodology of [54] was adapted to the current study. The calculation of the *I_Prov_Agr* index involves the assignment of a score (*SAgr*) that expresses the intensity and the economic value of the agricultural activity (Table 2). The calculation was performed for each time threshold, applying the following formula:

$$I\_Prov\_Agr_{[0-1]} = \frac{SAgr}{125}$$

where

I_Prov_Agr is the index that expresses provisioning Ess related to agricultural activity;

SAgr is the score related to the intensity and the economic value of the agricultural land-use class.

Table 2. Scores (*SAgr*) assigned to land-use classes and calculation of the *I_Prov_Agr* Index.

Land Use Class	*SAgr*	*I_Prov_Agr*
Vineyards and orchards	125	1.00
Horticulture, floriculture, and plant nurseries in greenhouses	110	0.88
Crops, vegetable gardens, meadows, horticulture, floriculture, and plant nurseries (not in greenhouses).	100	0.80
Farms and agricultural production settlements	90	0.72
Poplars	25	0.20

2.8. Phase 6: Assessment of Regulating ESs and Calculation of the I_Reg_Nat Index

The index related to regulating ESs provided by natural resources was calculated by assigning differentiated scores based on the naturalistic value of the land, its capacity to protect biodiversity, and the land use/cover (natural or agricultural). The assigned scores have been partially modified from Senes et al. [54] (Tables 3 and 4). The index was calculated, for each period, by applying the following formula:

$$I\_Reg\_Nat_{[0-1]} = \begin{cases} BioProt \cdot NVS \cdot L\_Use & , \; BioProt > 0 \\ 0,1 & , \; BioProt = 0 \wedge L\_Use = 1 \\ 0 & , \; BioProt = 0 \wedge L\_Use \neq 1 \end{cases}$$

where

BioProt represents the score based on the level of Biodiversity Protection;

NVS indicates the score based on the Naturalistic Value of Soils;

and *L_Use* corresponds to the score based on the type of land use.

Table 3. Scores assigned to the different typologies of biodiversity protection.

Layer	Typology	Score
Protected area and local park	Natura 2000 sites	1.00
	Priority areas of intervention	1.00
	Natural parks	0.75
	Regional parks	0.50
	Local parks	0.25
Regional ecological network	Primary elements	0.50
	Secondary elements	0.25
Priority areas for biodiversity	Priority areas for biodiversity	0.50
Provincial ecological network	Primary corridors	0.25
	Secondary corridors	0.15

Table 4. Scores assigned to the naturalistic value of soils and to LULC classes.

Naturalistic Value of Soils		Land Use/Land Cover	
Class	**Score**	**Class**	**Score**
High *	1.1	Natural	1.0
Medium	1.0	Agricultural	0.9
Low	1.0	Urban	0.0

* According to ref. [54], only an high naturalistic value of soils can slightly increase the naturalistic quality of a territory.

2.9. Phase 7: Assessment of Cultural ESs and Calculation of the I_Cult_Land Index

The *I_Cult_Land* index was calculated by assigning scores related to the ESs provided by landscape, using those of Senes et al. [54], if possible, and assigning new ones when different databases were used. Table 5 shows all the scores used. The index was calculated, for each period, by applying the following formula:

$$I\_Cult\_Land_{[0-1]} = Max\ (Land\_Res; Sc\_Trails; LEPP; LULC)$$

where

$Land\_Res$ represents the score based on the Landscape Restrictions;

Sc_Trails indicates the score based on the presence of Historical and Scenic trails;

$LEPP$ corresponds to the score based on the presence of Landscape Elements coming from Provincial Plans;

and $LULC$ corresponds to the score based on the LULC class.

Table 5. Scores assigned to calculate the *I_Cult_Land* Index.

Landscape Restrictions (*Land_Res*) *		Historical and Scenic Trails (*Sc_Trails*)		Landscape Elements from Provincial Plans (*LEPP*)		Land Use/Land Cover (*LULC*)	
Class	**Score**	**Class**	**Score**	**Class**	**Score**	**Class**	**Score**
yes	1.0	yes	1.0	Historical gardens	1.0	Woods	0.8
no	0.0	no	0.0	Monumental trees	1.0	Vineyards	0.6
				Geosites	1.0	Riparian woods	0.4
				Areas of landscape significance	0.8	Wetland vegetation	0.4
				Rural settlements of landscape significance (50 m buffer)	0.6	Bush with trees	0.4

* According to ref. [54], landscape restrictions are areas, identified by the regional landscape plan, to be protected from transformation for their high landscape value. For this reason, they have been assigned a maximum score of 1.

2.10. Phase 8: Calculation of Composite Index

For each of the three periods considered, the previously calculated indices were aggregated to calculate an overall quality index (*CQI**), which represents the total ESs provided by the NUAs and differs from the CQI of [54] in that it does not include I_Reg_Soil. However, as previously highlighted, since its value has not changed over the last 20 years, the trend evaluation of the other three calculated indicators and of *CQI** are not influenced by this exclusion.

The composite quality index is calculated using a weighted sum:

$$CQI_i^* = I_{Prov_{Agr}} \cdot W_{Agr} + I_{Reg_{Nat}} \cdot W_{Nat} + I_{Cult_{Land}} \cdot W_{Land}$$

where
W_{Agr} is the weight of provisioning ESs coming from agriculture;
W_{Nat} is the weight of regulating ESs related to natural resources,
W_{Land} is the weight of cultural ESs related to landscape;
and

$$W_{Agr} + W_{Nat} + W_{Land} = 1$$

The weight of each indicator expresses the relative importance that the related indicator assumes in the calculation of the composite index. To evaluate how the attribution of a different importance to each index by planners and the communities involved can influence the final value of the composite index, three alternative hypothetical scenarios were defined using the Analytic Hierarchy Process [57].

Three categories of stakeholders were involved (local planners, environmental associations, university researchers) for a total of 15 people. The weights for each scenario have been calculated as the average of the scores each stakeholder entered in the corresponding Saaty matrix.

The three scenarios are as follows (Table 6): (i) the three indices have the same importance; (ii) ESs related to natural resources have greater importance than the others; (iii) ESs provided related to landscape have greater importance than the others.

Table 6. Weights assigned to the indices in the different scenarios.

Index	Scenario 1	Scenario 2	Scenario 3
I_Prov_Agr	0.33…	0.25	0.25
I_Reg_Nat	0.33…	0.50	0.25
I_Cult_Land	0.33…	0.25	0.50
Sum of the wights	**1.00**	**1.00**	**1.00**

2.11. Step 3: ESs Evolution

It is the final step, in which the evolution of the ESs provided by NUAs in the study area was evaluated, through the analysis of the variation over time of the individual indices and of the composite one in the different hypothesized scenarios.

2.12. Phase 9: Analysis of Indexes Dynamics

In order to assess the variations over time of the various calculated indices, the value of each index was calculated for each municipality (IMUN) and for the entire study area (IPROV), considering both the entire municipal (MUN) or provincial (PROV) area and only the portion of non-urbanized areas (NUAs). Specifically, the following formulas were applied:

$$I_{MUN_x} = \frac{\sum_{i=1}^{n}(I_i \cdot A_i)}{MUN_x}$$

$$I_{NUAs_x} = \frac{\sum_{i=1}^{n}(I_i \cdot A_i)}{NUAS_x}$$

where

I_{MUN_x} represents the global value of the index (I_Reg_Nat, I_Cult_Land, I_Prov_Agr, CQI_i^*) referred to the surface area of the x-th municipality (MUN_x);

I_i represents the value of the index (I_Reg_Nat, I_Cult_Land, I_Prov_Agr, CQI_i^*) of the i-th area of the x-th municipality;

A_i represents the extension in sq.km of the i-th area of the x-th municipality;

I_{NUAs_x} represents the global value of the index referred only to the non-urbanized areas of the x-th municipality ($NUAS_x$);

$$I_{PROV} = \frac{\sum_{i=1}^{n}(I_i \cdot A_i)}{PROV}$$

$$I_{NUAs_{PROV}} = \frac{\sum_{i=1}^{n}(I_i \cdot A_i)}{NUAS_{PROV}}$$

where

I_{PROV} represents the global value of the index (I_Reg_Nat, I_Cult_Land, I_Prov_Agr, CQI_i^*) referred to the surface area of province (PROV);

I_i represents the value of the index (I_Reg_Nat, I_Cult_Land, I_Prov_Agr, CQI_i^*) of the i-th area of the province;

A_i represents the extension in sq.km of the i-th area of the province;

$I_{NUAs_{PROV}}$ represents the global value of the index referred only to the non-urbanized areas of the province ($NUAS_{PROV}$).

Once the values of each index (I_Reg_Nat, I_Cult_Land, I_Prov_Agr, CQI_i^*) has been calculated for each municipality and for the province, the absolute and percentage variation that occurred over time was calculated. For the municipal indices, the results were divided into classes to facilitate their analysis and highlight which municipalities had experienced (i) a decrease in the value of the municipal index greater than 20%, (ii) a decrease between 5% and 20%, (iii) a variation within ±5% (stable value), and (iv) an increase between 5% and 20%, (v) or greater than 20%.

3. Results and Discussion

3.1. Land-Take and NUAs Evolution

Between T0 and T2, a loss of 18.4 sq.km of NUAs (−8.3%) was recorded in the Province of Monza–Brianza (Table 7). The reduction was more pronounced in the first period (T0-T1), when 7.7% of NUAs were lost; in the second period (T1-T2), the reduction was smaller, being equal to 0.7%.

Table 7. Trend of NUAs over time.

NUAs	T0		T1		Δ_{T1-T0}		T2		Δ_{T2-T1}		Δ_{T2-T0}	
	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%
Arable land	157.0	38.8%	119.1	29.4%	−37.9	−24.1%	120.9	29.8%	+1.8	+1.5%	−36.1	−23.0%
FNSNAs *	47.1	11.6%	64.7	16.0%	+17.6	37.4%	59.4	14.7%	−5.3	−8.2%	+12.3	+26.1%
Other NUAs **	17.5	4.3%	20.8	5.1%	+3.3	18.9%	23.0	5.7%	+2.2	+10.6%	+5.5	+31.4%
Total NUAs	221.6	54.7%	204.6	50.5%	−17.0	−7.7%	203.3	50.2%	−1.3	−0.6%	−18.3	−8.3%
UAs ***	183.5	45.3%	200.5	49.5%	+17.0	+9.3%	201.8	49.8%	+1.3	+0.6%	+18.3	+10.0%
Study area	405.1	100%	405.1	100%			405.1	100%				

* Forests and natural and semi-natural areas. ** Other NUAs: parks, degraded, unused, and unvegetated areas, uncultivated green areas, riverbeds, and water basins. *** UAs: urbanized areas.

Overall (T0–T2), despite a significant decrease in arable land (−36.1 sq.km), there was an increase in forests and natural and semi-natural areas (+12.3 sq.km) and other NUAs (+5.4 sq.km) (Table 7 and Figure 5). The slight increase in arable land recorded between T1 and T2 is due to the change in the interpretation of some LULC classes, such as the green areas of motorway junctions, which were included in the "Infrastructure" class in T0, while they were included in the "green areas attached to road infrastructures" class in T1. This is, of course, a limitation that generates some uncertainty in the interpretation of the results, even if at the provincial scale the impact is truly limited.

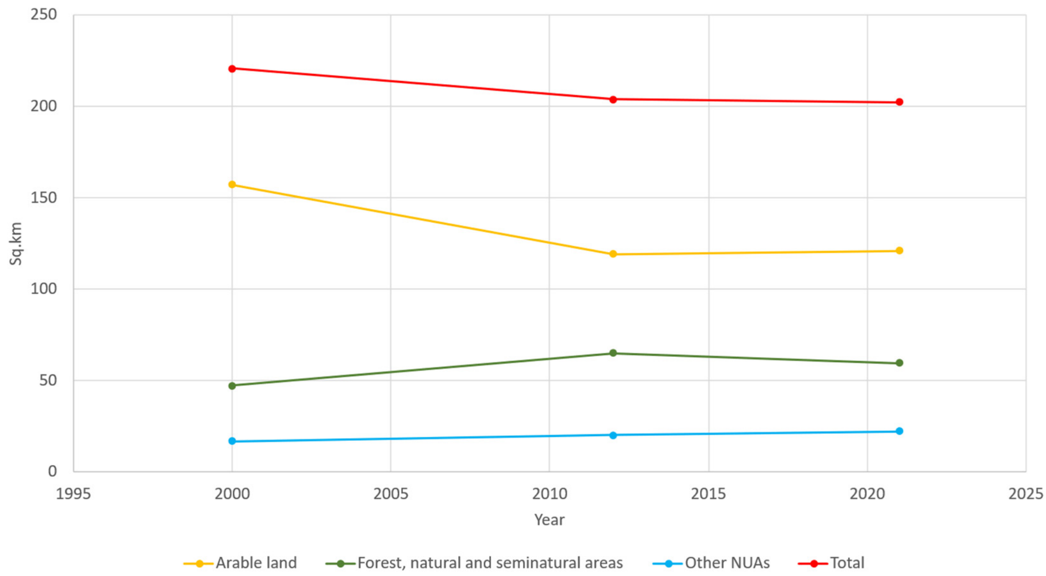


Figure 5. Trend of NUAs and their components over time.

Analyzing the changes between each LULC class (Table 8, Figure 6), it can be seen that more than 70% of the arable land has remained unchanged, more than 10% has been transformed into the forest and natural and semi-natural class, and the same amount transformed into urbanized areas (UAs), mainly industrial, commercial, and sport areas (the main driver of land-take). The forest and natural and semi-natural class, on the one hand, showed an increase (+12.2 sq.km), essentially due to the abandonment of agricultural land (20.4 sq.km of arable land has transformed into forest and natural and semi-natural areas). On the other hand, we recorded a worrying phenomenon of land-take in favor of residential areas (1.7 sq.km) and industrial, commercial, and sport areas (1.7 sq.km).

Table 8. LULC changes from T0 to T2.

T0		**T2**						
		Arable Land	**FNSNAs ***	**Other NUAs ****	**Residential Areas**	**Industrial, Commercial and Sport Areas**	**Other UAs *****	**Infrastructures**
Arable land	157.0	112.4	20.4	4.0	7.5	8.8	1.4	2.5
FNSNAs *	47.1	4.1	36.2	2.2	1.7	1.7	0.6	0.6
Other NUAs **	17.5	0.8	1.0	12.2	1.1	1.8	0.3	0.3
Residential areas	113.8	2.1	0.6	1.8	102.9	3.8	0.4	2.2
Industrial, commercial, and sport areas	56.9	0.9	0.7	1.7	2.4	49.2	0.5	1.5
Other UAs ***	6.8	0.5	0.4	0.7	1.1	0.9	3.0	0.2
Infrastructures	6.0	0.0	0.0	0.3	0.0	0.0	0.0	5.7
Total	**405.1**	**120.8**	**59.3**	**22.9**	**116.7**	**66.2**	**6.2**	**13.0**

* Forests and natural and semi-natural areas. ** Other NUAs: parks, degraded, unused and unvegetated areas, uncultivated green areas, riverbeds, and water basins. *** UAs: urbanized areas.

The analysis at the municipal level across the 55 municipalities confirms a generalized reduction in NUAs across all the municipalities examined. Specifically, one municipality (Varedo) experienced a decline of more than 20%, 44 municipalities experienced a reduction between 5 and 20%, and 10 municipalities experienced general stability (variation within ±5%) (Figure 7).

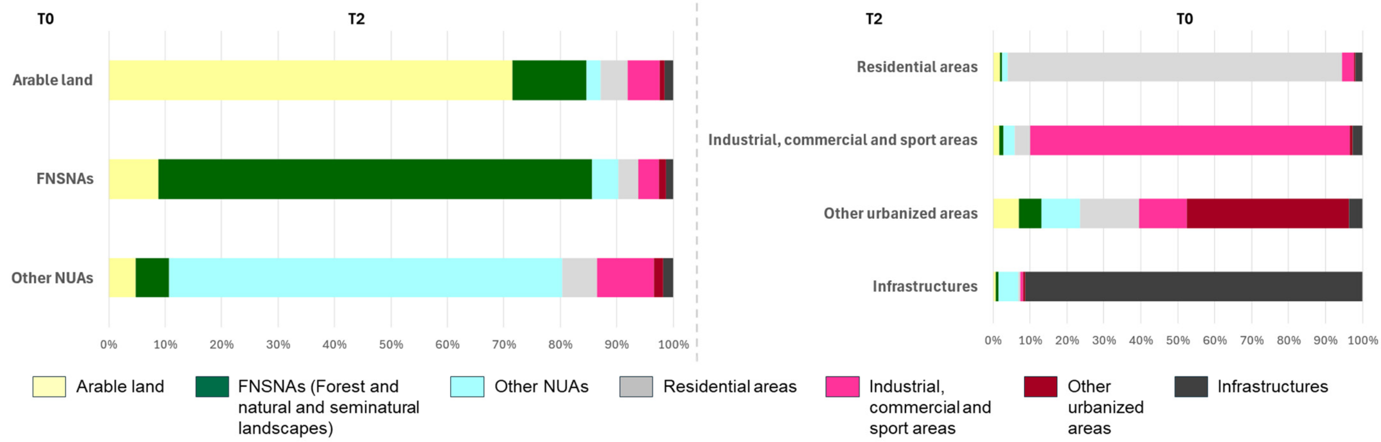


Figure 6. How NUAs changed from T0 to T2 (on the left) and what actual UAs were at T0 (on the right).

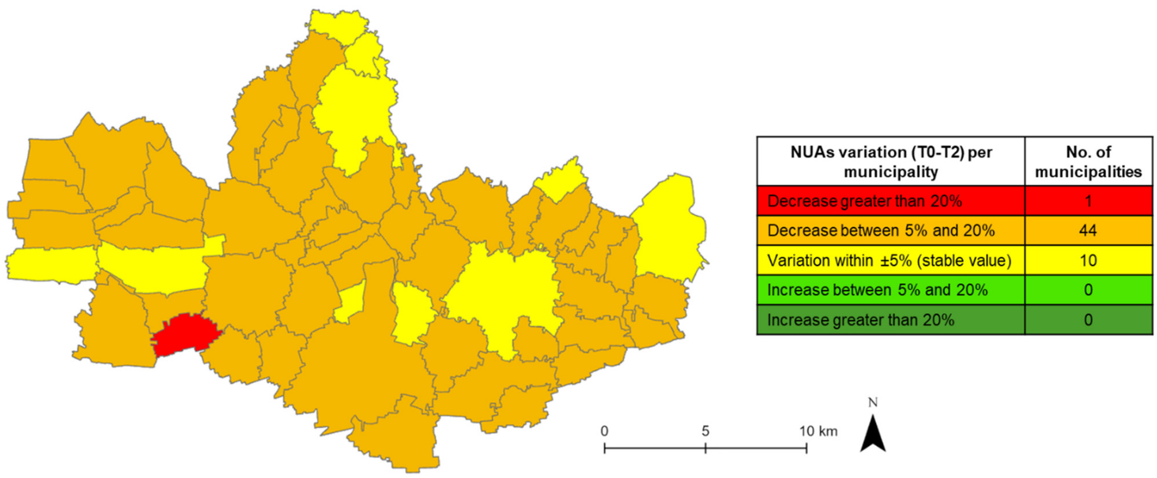


Figure 7. NUAs variation (T0–T2) per municipality.

3.2. Evolution of the Provisioning ESs Coming from Agriculture (I_Prov_Agr Index)

The $I\_Prov\_Agr_{PROV}$ of the study area from T0 to T2 decreased from a value of 0.340 (T0) to 0.284 (T2). This trend reflects the progressive land-take within the province. When referring only to NUAs, $I\_Prov\_Agr_{NUAs}$ records a less marked decrease, from 0.624 (T0) to 0.569 (T2) (Table 9).

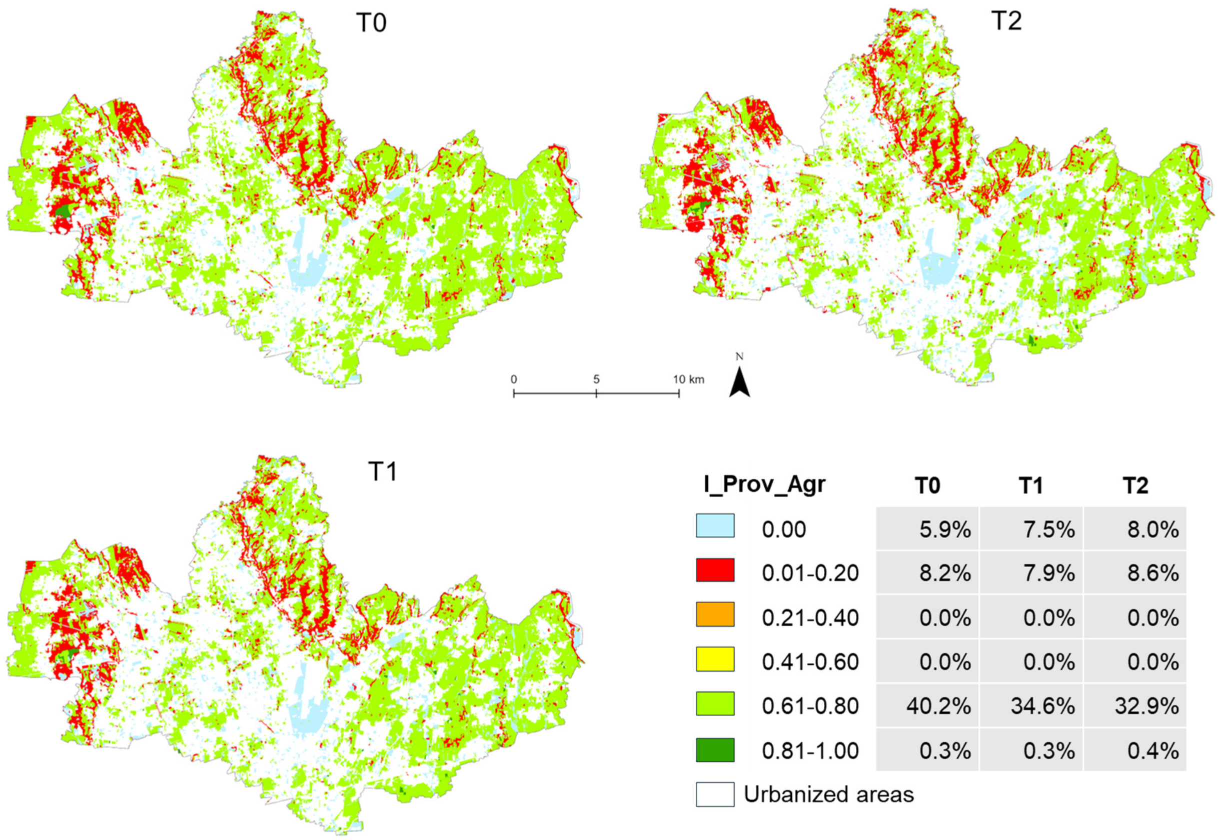
Table 9. Trend of the calculated indexes over time.

Index		T0	T1	Δ_{T1-T0}		T2	Δ_{T2-T1}		Δ_{T2-T0}	
I_Prov_Agr	$I\_Prov\_Agr_{PROV}$	0.340	0.295	−0.045	−13.2%	0.284	−0.011	−3.7%	−0.056	−16.5%
	$I\_Prov\_Agr_{NUAs}$	0.624	0.588	−0.036	−5.8%	0.569	−0.019	−3.2%	−0.055	−8.8%
I_Reg_Nat	$I\_Reg\_Nat_{PROV}$	0.091	0.143	+0.052	+57.1%	0.157	0.014	+9.8%	0.066	+72.5%
	$I\_Reg\_Nat_{NUAs}$	0.167	0.284	+0.117	+70.1%	0.315	0.031	+10.9%	0.148	+88.6%
I_Cult_Land	$I\_Cult\_Land_{PROV}$	0.274	0.267	−0.007	−2.6%	0.272	0.005	+1.9%	−0.002	−0.7%
	$I\_Cult\_Land_{NUAs}$	0.503	0.531	+0.028	+5.6%	0.545	0.014	+2.6%	0.042	+8.3%

Although indices calculated only on NUAs may lead to an overestimation of the ESs provided, data suggest that the reduction in ESs provided by agricultural areas is mainly due to their reduction over time and that the remaining agricultural areas maintain a reasonable capacity to provide ESs. This is the first negative consequence of land-take: the erosion of the green infrastructure leads to an inevitable reduction in ESs provided, with a detriment to human society. The overall decrease of −0.056 (−16.5%) reflects the significant decline in agricultural areas (−23.0% of arable land between T0 and T2) (Table 7). Furthermore, the reduction of $I\_Prov\_Agr_{NUAs}$, although significantly smaller, highlights that the amount of ESs provided per unit of non-urbanized area has also decreased, demonstrating that land-use planning policies have failed to safeguard and enhance the most valuable agricultural areas, thus counteracting the reduction in agricultural area.

Finally, it is clear that the increase in forests and natural and semi-natural areas has failed to provide the ESs typical of agricultural areas.

The distribution within the study area of the provisioning ESs coming from agriculture is not homogeneous (the areas with the lowest levels of ESs provision are located in the west and east of the province), and the greatest decrease was recorded in areas with high *I_Prov_Agr* values (class 0.61–0.80), which decreased from 40.2% of the provincial territory to only 32.9% (Figure 8).



I_Prov_Agr	T0	T1	T2
0.00	5.9%	7.5%	8.0%
0.01-0.20	8.2%	7.9%	8.6%
0.21-0.40	0.0%	0.0%	0.0%
0.41-0.60	0.0%	0.0%	0.0%
0.61-0.80	40.2%	34.6%	32.9%
0.81-1.00	0.3%	0.3%	0.4%
Urbanized areas			

Figure 8. Provisioning ESs coming from agriculture in T0, T1, and T2.

Approximately 42.1% of the study area (170.7 sq.km) did not record a change in *I_Prov_Agr* from T0 to T2. Only a small portion of the territory showed changes: 3.9% (15.9 sq.km) recorded a worsening of the index, and just 1.4% (5.7 sq.km) an improvement (Figure 9).

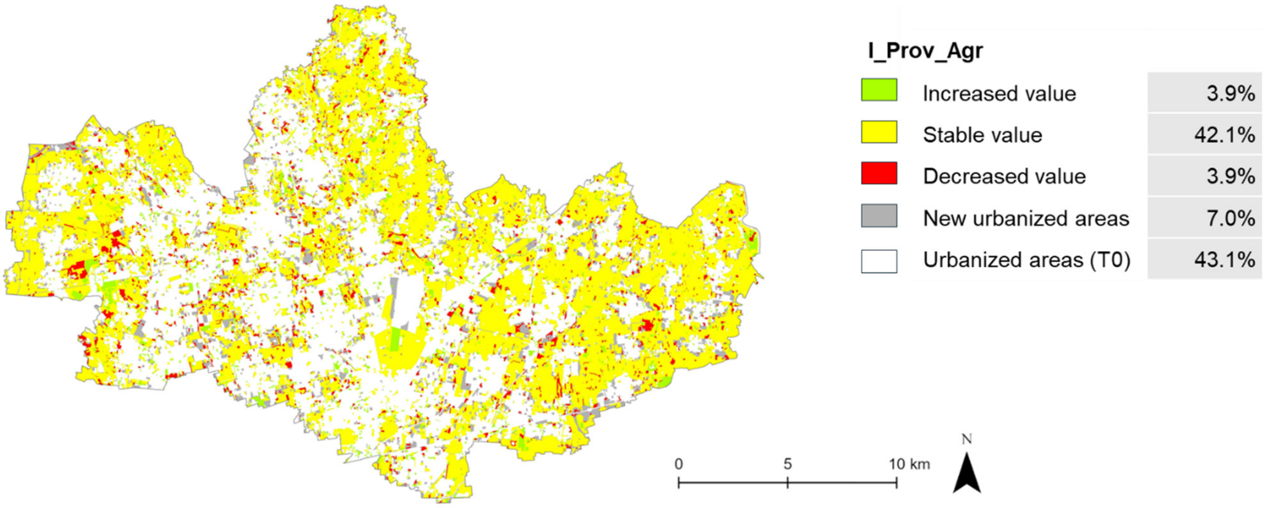
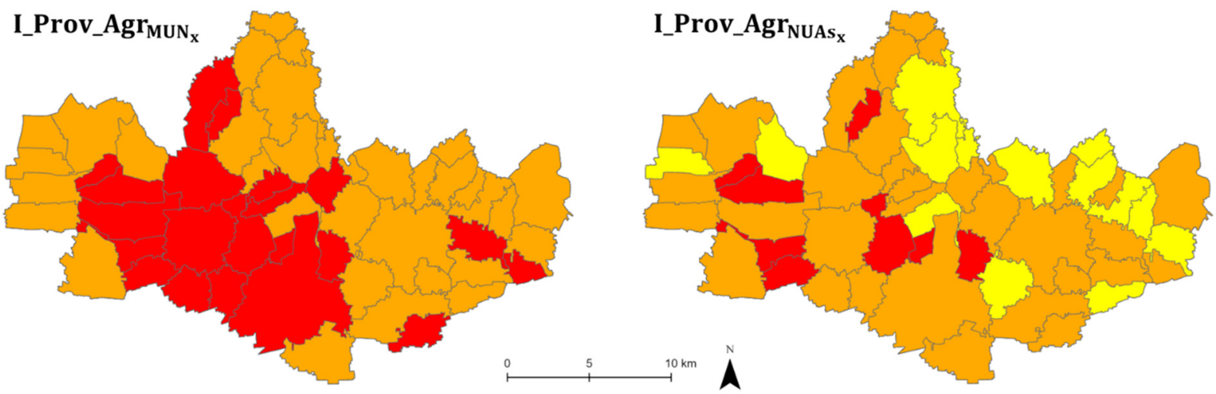


Figure 9. Variation (T0–T2) of the provisioning ESs coming from agriculture.

Analyzing the trend of the index at the municipal level, both for the entire municipal area ($I\_Prov\_Agr_{PROV}$) and for the NUAs alone ($I\_Prov\_Agr_{NUAs}$), it is noted that no municipality recorded an improvement, a clear sign that municipal planning has failed to safeguard the ESs provided by agriculture. $I\_Prov\_Agr_{PROV}$ recorded a decrease in all municipalities (significant in 21, more moderate in the other 34), while $I\_Prov\_Agr_{NUAs}$ remained fairly constant in 14 municipalities (Figure 10).



I_Prov_Agr variation (T0-T2) per municipality	No. of municipalities	
	$I\_Prov\_Agr_{MUN_x}$	$I\_Prov\_Agr_{NUAs_x}$
Decrease greater than 20%	21	8
Decrease between 5% and 20%	34	33
Variation within ±5% (stable value)	0	14
Increase between 5% and 20%	0	0
Increase greater than 20%	0	0

Figure 10. Variation (T0–T2) of the provisioning ESs coming from agriculture at the municipal level.

3.3. Evolution of the Regulating ESs Provided by Natural Resources (I_Reg_Nat Index)

The $I\_Reg\_Nat_{PROV}$ of the study area from T0 to T2 increased (+72.5%) from a very low value of 0.091 (T0) to 0.157 (T2).

This trend may be due to several factors. First is the growing attention that the institutions (Region, Provinces and municipalities) placed on nature conservation over the last two decades: they established new parks and protected areas of different type and size (in the province of Monza–Brianza for approximately 95 sq.km) and planned and implemented the ecological network, with both at the regional, provincial, and municipal level. Secondly, there has been an increase in forests and natural and semi-natural areas (+26%, +12.2 sq.km) (Table 8), due to both re-naturalization, both spontaneous and planned, of agricultural or anthropized areas

When referring to NUAs, $I\_Reg\_Nat_{NUAs}$ records an even more pronounced increase (+88.6%), from 0.167 (T0) to 0.315 (T2) (Table 9), suggesting an important increase in the regulating ESs provided by green infrastructure, although it can be noted that indices calculated only on NUAs may lead to an overestimation of the ESs provided. The distribution of these ESs within the study area is not homogeneous, although a general decrease in the two lowest classes (≤0.20) is observed, which went from 38.1% in T0 to 16.3% in T2. Conversely, the two highest classes (>0.60) went from 2.0% in T0 to 19.5% in T2 (Figure 11). It is also noticeable how the change was gradual, especially observing the areas of the intermediate class (0.41–0.6), especially in the central part in the north of the province (yellow classes in Figure 11): from T0 to T1 the yellow strip increases (in total, it increases from 9.6% to 12.8%), but some of the yellow areas turn light green (class 0.61–0.80); from T1 to T2, the yellow areas disappear to make room for green areas (of both highest classes).

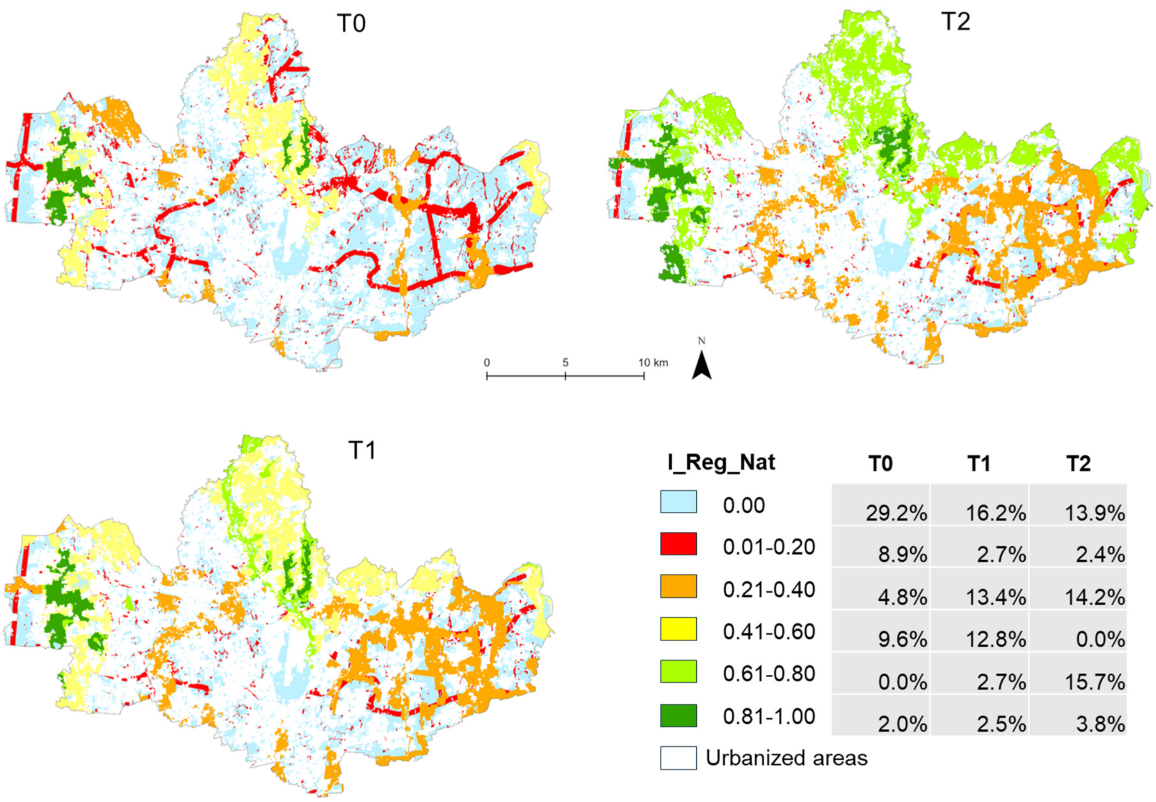


Figure 11. Regulating ESs provided by natural resources in T0, T1, and T2.

Another interesting aspect is linked to the "red corridors" in Figure 11. In T0, they are very evident and represent the initial structure of the ecological network. Over the years, the implementation and strengthening of this ecological network has led to a gradual increase in ESs provided, with more and more areas moving up a class (orange and yellow).

Only 23.1% of the study area (93.8 sq.km) did not record a change in *I_Reg_Nat* from T0 to T2, while 26.0% (105.2 sq.km) recorded an improvement and only 0.8% recorded a decrease (Figure 12).

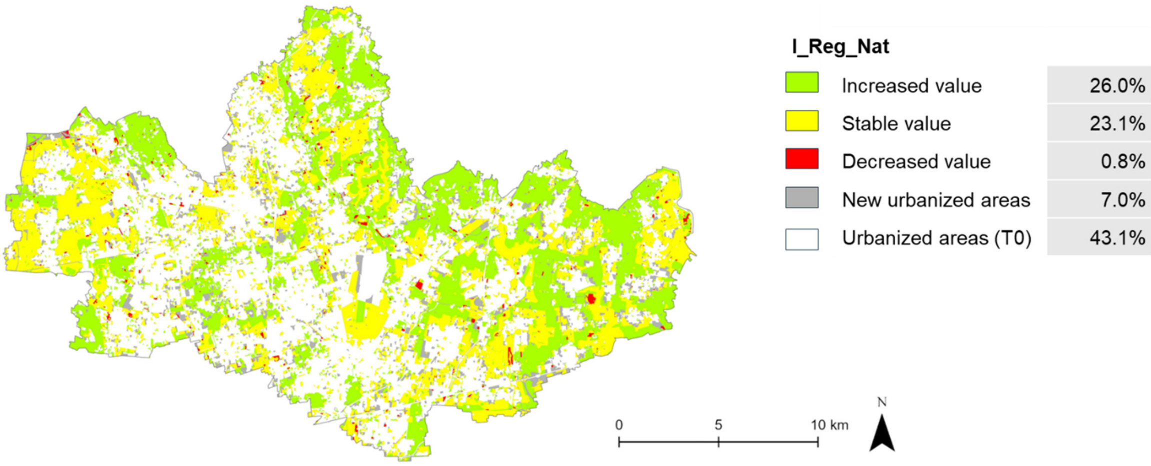
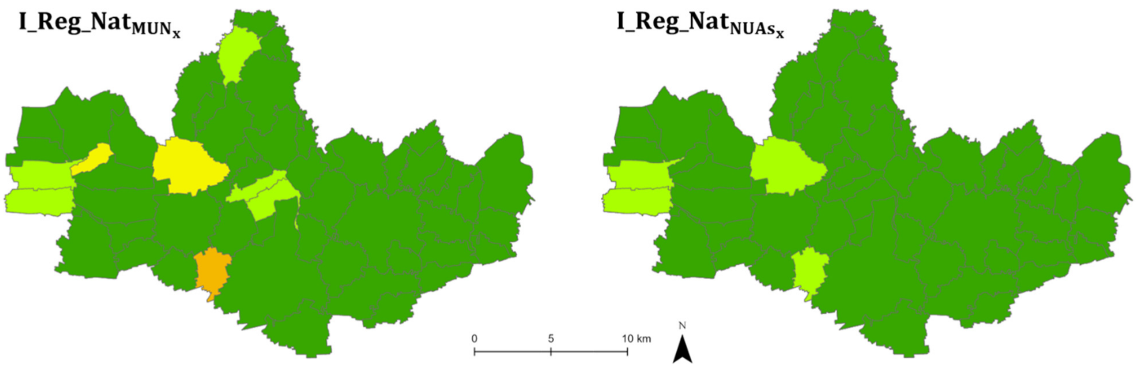


Figure 12. Variation (T0–T2) of the regulating ESs provided by natural resources.

Analyzing the trend of the index at municipal level, both on the entire municipal area (*I_Reg_Nat*$_{PROV}$) and on only the NUAs (*I_Reg*$_{\_NatNUAs}$), it can be noted that in all municipalities (for *I_Reg_Nat*$_{NUAs}$) or almost all (for *I_Reg_Nat*$_{PROV}$), there has been an improvement, a clear sign that municipal planning has succeeded in safeguarding and improving the ESs provided by natural resources (Figure 13).



I_Reg_Nat variation (T0-T2) per municipality	No. of municipalities	
	$I\_Reg\_Nat_{MUN_x}$	$I\_Reg\_Nat_{NUAs_x}$
Decrease greater than 20%	0	0
Decrease between 5% and 20%	1	0
Variation within ±5% (stable value)	2	0
Increase between 5% and 20%	5	4
Increase greater than 20%	47	51

Figure 13. Variation (T0–T2) of regulating ESs provided by natural resources at municipal level.

3.4. Evolution of the Cultural ESs Provided by Landscape (I_Cult_Land Index)

The *I_Cult_Land*$_{PROV}$ of the study area from T0 to T2 remained almost constant (−0.7%), going from 0.274 (T0) to 0.272 (T2) (Table 9). This trend depends, on the one hand, on the land-take of the last 20 years, which has reduced the green areas capable of providing cultural ESs and, on the other, on the increase in the quality of the remaining part of the green infrastructure, which has allowed the level of ESs provided to be kept almost constant. In fact, although urbanization has caused the loss of 18.3 sq.km of NUAs (−8.3%) (Table 7), the level of cultural ESs provided by the provincial territory has dropped by only 0.7%. Looking at the temporal trend, it can be noted there is a greater decline (−2.6%) from T0 to T1 and a recovery (+1.9%) from T1 to T2, demonstrating a growing awareness of the issue in recent years. The trend of the index referring only to NUAs (*I_Cult_Land*$_{NUAs}$)

confirms this interpretation, recording an even more pronounced increase (+8.3%), from 0.503 (T0) to 0.545 (T2) (Table 9), although it can be noted that indices calculated only on NUAs may lead to an overestimation of the ESs provided.

The distribution of the cultural ESs provided by landscape within the study area is not homogeneous, with the areas with the highest index values concentrated in the more peripheral parts of the study area. Between T0 and T2, a decrease in the areas in the lowest class was observed (from 21.1% in T0 to 16.3% in T2) and a slight increase in the areas in the higher classes (Figure 14). In fact, only 6.3% of the study area (25.5 sq.km) recorded an increase in the *I_Cult_Land* value from T0 to T2, while 42.2% remained essentially stable and only 1.4% showed a decrease (Figure 15).

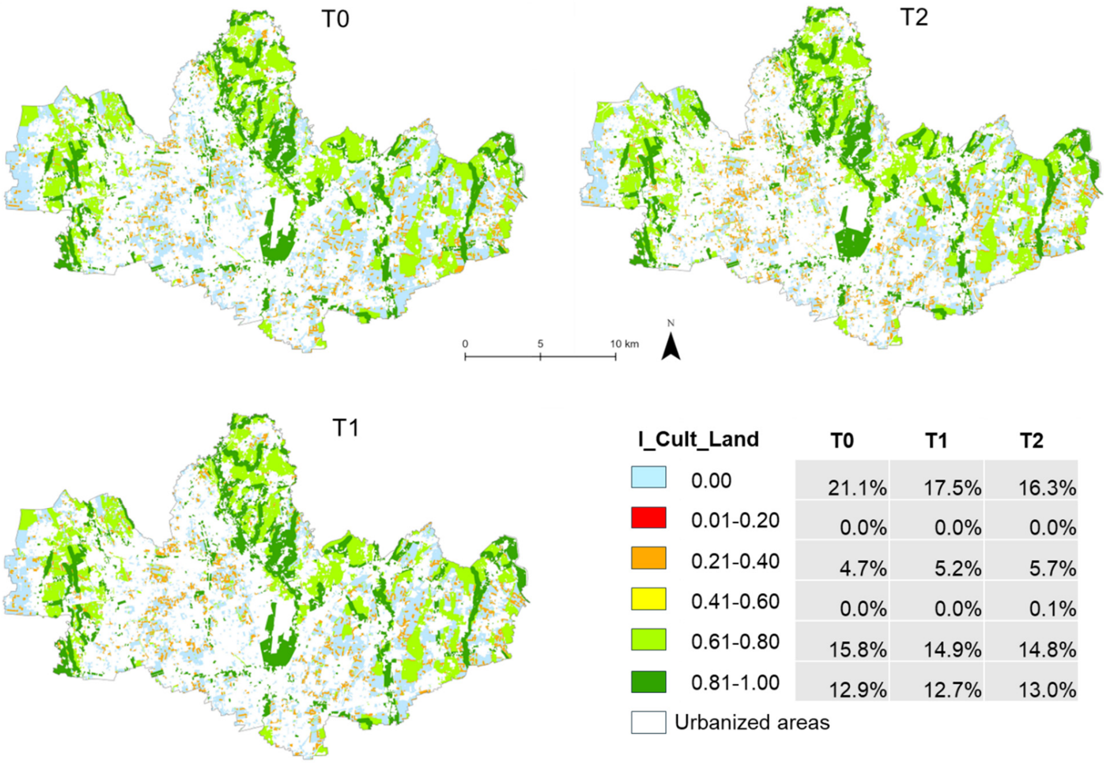


Figure 14. Cultural ESs provided by landscape in T0, T1, and T2.

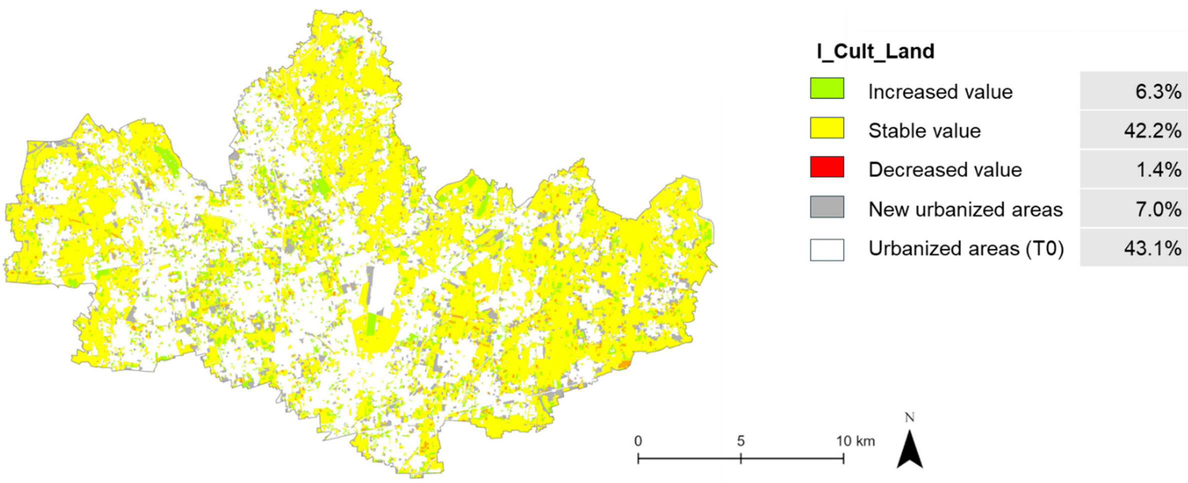
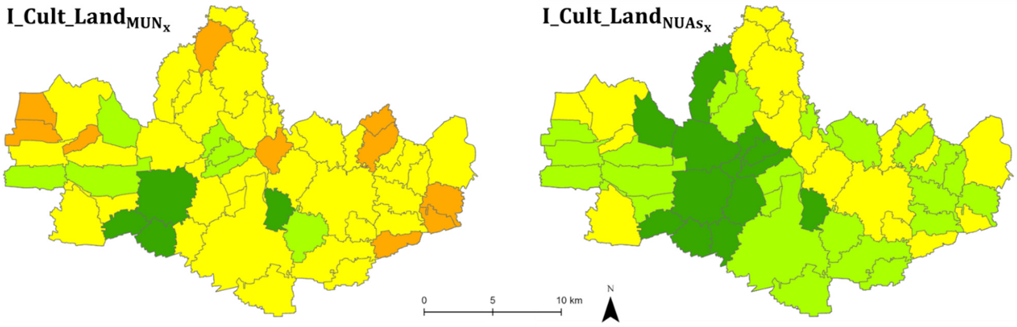


Figure 15. Variation (T0–T2) of the cultural ESs provided by landscape.

Analyzing the trend of the index at the municipal level, it can be noted that the index calculated for the entire municipal area ($I\_Cult\_Land_{PROV}$) shows an improvement in 11 municipalities but also a deterioration in other 10 municipalities, all located on the periphery of the province. These are municipalities with high values of the index and therefore have suffered the most the decrease in NUAs. However, considering the index calculated only for NUAs ($I\_Cult\_Land_{NUAs}$), it can be noted that an improvement was recorded in 36 municipalities, a clear sign that municipal planning has succeeded in safeguarding and enhancing the cultural ESs provided by the landscape (Figure 16).



I_Cult_Land variation (T0-T2) per municipality	No. of municipalities	
	I_Cult_Land$_{MUN_x}$	I_Cult_Land$_{NUAs_x}$
Decrease greater than 20%	0	0
Decrease between 5% and 20%	10	0
Variation within ±5% (stable value)	34	19
Increase between 5% and 20%	7	24
Increase greater than 20%	4	12

Figure 16. Variation (T0–T2) of cultural ESs provided by landscape at municipal level.

3.5. Evolution of the Overall ESs Provided by Non-Urbanized Areas (CQI Index)*

For each of the considered periods, the three indices were aggregated to calculate the composite quality index (CQI^*), which represents the overall ESs provided by the NUAs, according to the following formula:

$$CQI_i^* = I_{Prov_{Agr}} \cdot W_{Agr} + I_{Reg_{Nat}} \cdot W_{Nat} + I_{Cult_{Land}} \cdot W_{Land}$$

where W_{Agr}, W_{Nat}, and W_{Land} (whose sum equals 1) are the weights representing the relative importance given to the three types of ESs (provisioning, regulating, and cultural).

In this study, to assess how any differences in assigning weights between planners and the communities involved could affect the value of the overall index, three hypothetical alternative scenarios were defined using the Analytic Hierarchy Process: (i) scenario 1, in which the three indices have the same importance; (ii) scenario 2, in which the regulating ESs provided by natural resources have greater importance than the others; (iii) scenario 3, in which the cultural ESs provided by landscape have greater importance than the others. (Table 6).

The CQI^*_{PROV} of the study area from T0 to T2 remained virtually constant in scenarios 1 (+1.1%) and 3 (+0.1%), while it increased significantly (+25.9%) in scenario 2 (Table 10). This trend is due to the greater weight (0.50) assigned to the *I_Reg_Nat* index in scenario 2. Conversely, in scenario 3, the greater weight (0.50) assigned to the *I_Cult_Land* index is not sufficient to increase the CQI value. This situation can be explained by looking at the CQI^*_{PROV} values at T0. In scenarios 1 and 3, they are very similar to each other (0.233 in scenario 1 and 0.257 in scenario 3), while it is significantly lower (0.152) in scenario 2. The growing attention over the years for the role of natural resources and the low starting level generate, in scenario 2, a very important % increase.

Table 10. Trend of *CQI** over time and for different scenarios.

Scenario	Index	T0	T1	Δ_{T1-T0}		T2	Δ_{T2-T1}		Δ_{T2-T0}	
Scenario 1	CQI^*_{PROV}	0.233	0.233	0.000	0.0%	0.235	+0.003	+1.1%	+0.003	+1.1%
	CQI^*_{NUAs}	0.427	0.463	+0.036	+8.4%	0.471	+0.009	+1.8%	+0.044	+10.4%
Scenario 2	CQI^*_{PROV}	0.152	0.182	+0.030	+19.7%	0.191	+0.009	+5.1%	+0.039	+25.9%
	CQI^*_{NUAs}	0.278	0.361	+0.083	+29.7%	0.382	+0.021	+5.9%	+0.104	+37.4%
Scenario 3	CQI^*_{PROV}	0.257	0.254	−0.004	−1.4%	0.258	+0.004	+1.6%	+0.001	+0.1%
	CQI^*_{NUAs}	0.472	0.504	+0.032	+6.8%	0.516	+0.012	+2.3%	+0.044	+9.3%

The land-take of the last 20 years, which has reduced NUAs by 18.3 sq. km (−8.3%) (Table 7), appears to have been barely contained by land-use planning policies (scenarios 1 and 3), and only by emphasizing nature protection policies (scenario 2) can an improvement be observed.

Looking at the index referred only to NUAs (CQI^*_{NUAs}), an important increase is observed in all scenarios (Table 10). On the one hand, this demonstrates that, despite a significant loss of green infrastructure due to land-take (−18.3 sq.km of NUAs), it has been possible, so far, to stem the phenomenon thanks to an increasing capacity of the remaining green areas to provide ESs. On the other hand, it is clear that if the land-take policy continues at the current rate, without safeguarding the highest-quality land, the situation will deteriorate very quickly due to the fragmentation and reduced accessibility and connectivity of the ecosystems.

The distribution of the overall ESs provided by non-urbanized areas within the study area is also irregular, reflecting that of the individual indices. The areas with the highest values, regardless of the scenario, are concentrated in the most peripheral parts of the study area (Figure 17). Between T0 and T2, the class with an index value of 0.01–0.20 decreases significantly in scenarios 2 and 3, while remaining almost constant in scenario 1. The next class (0.21–0.40), however, decreases significantly in scenario 1 and much less in scenarios 2 and 3.

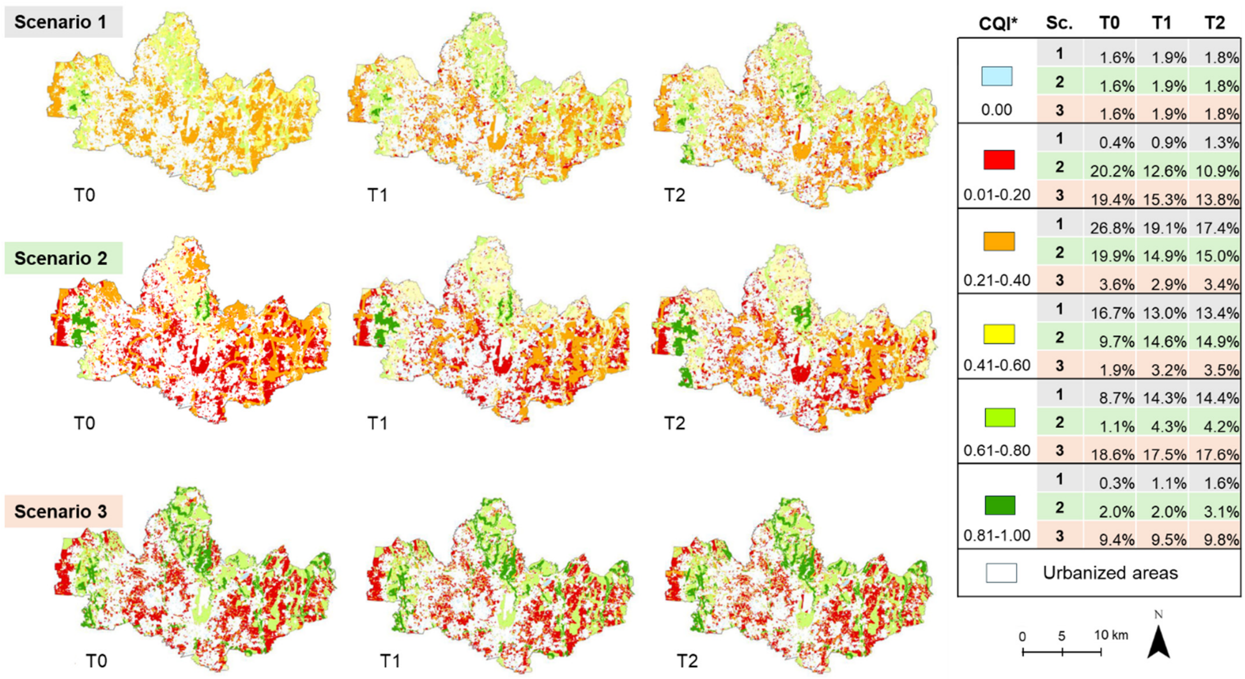
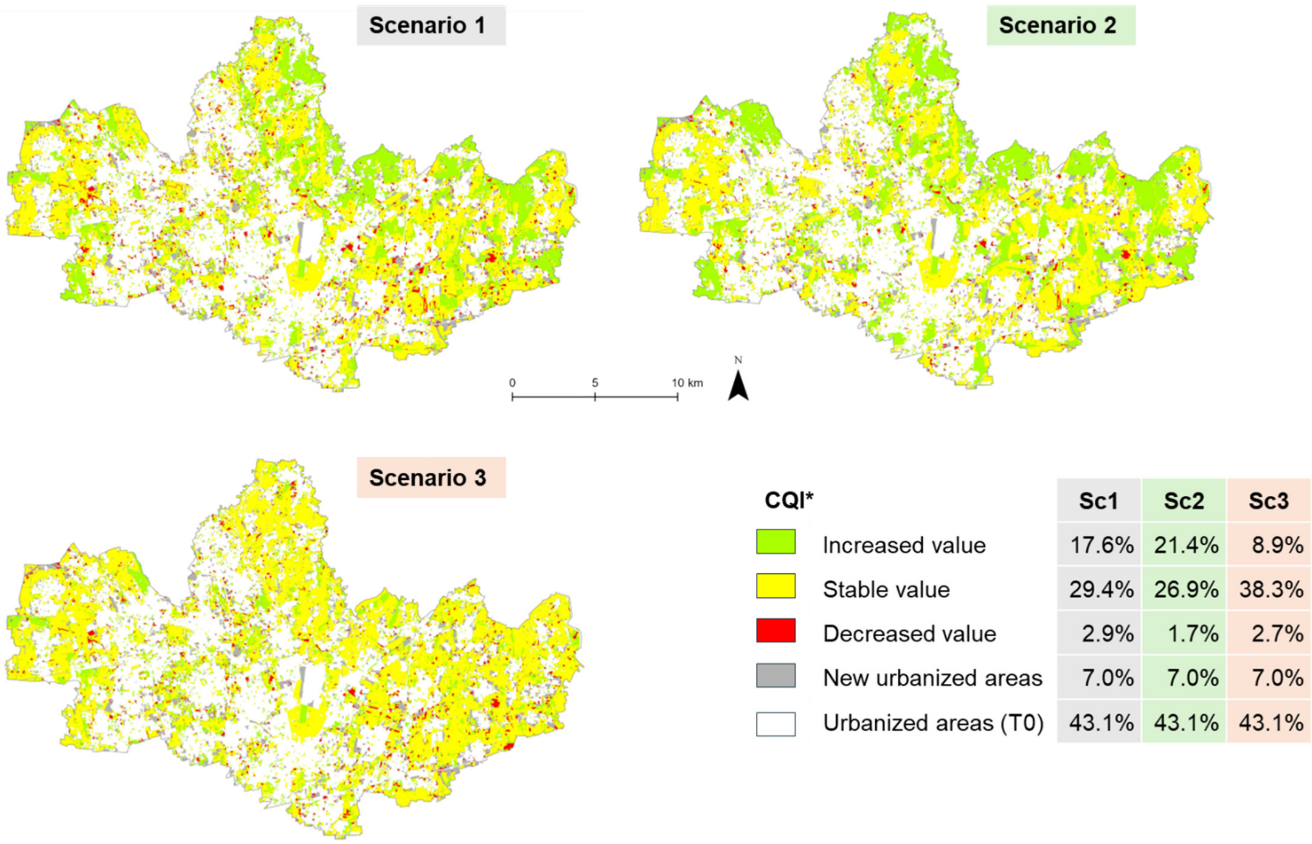


Figure 17. Overall ESs provided by non-urbanized areas (*CQI** index) in T0, T1, and T2, in different scenarios.

Regarding the higher classes (>0.40), a moderate increase is recorded in scenarios 1 and 2 (from 25.7% to 29.4% and from 12.8% to 22.2%, respectively), while they remain almost constant (from 29.9% to 30.9%) in scenario 3. This indicates a general increase over time in the ESs provided by green areas. This is confirmed by the fact that (Figure 18) 21.4% of NUAs increased their *CQI** value in scenario 2, compared to only 8.9% in scenario 3. Scenario 1, naturally more balanced (with equal weights for the three indices), is in the middle, with 17.6% of NUAs increasing their index value.

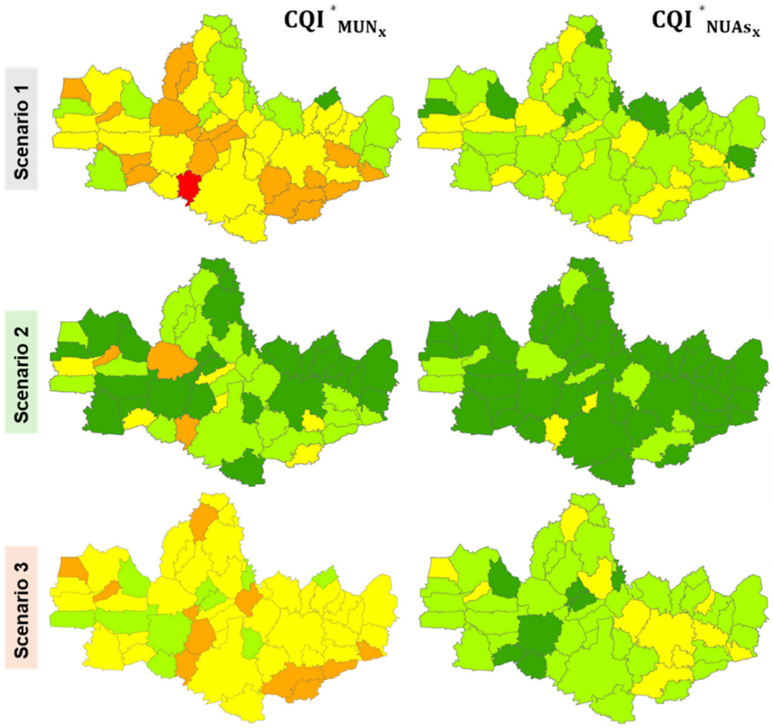


CQI*	Sc1	Sc2	Sc3
Increased value	17.6%	21.4%	8.9%
Stable value	29.4%	26.9%	38.3%
Decreased value	2.9%	1.7%	2.7%
New urbanized areas	7.0%	7.0%	7.0%
Urbanized areas (T0)	43.1%	43.1%	43.1%

Figure 18. Variation (T0–T2) of the overall ESs provided by non-urbanized areas (*CQI** index) in different scenarios.

Analyzing the trend of the index at the municipal level from T0 to T2 (Figure 19), it can be noted that the index calculated for the entire municipal area (CQI^*_{PROV}) shows a general stability in scenarios 1 (23 municipalities) and 3 (35 municipalities), with a similar number of municipalities recording a decrease (17 in scenario 1 and 10 in scenario 3) and an increase between 5 and 20% (13 in scenario 1 and 10 in scenario 3). Scenario 2, on the other hand, presents a complete different situation, with 46 municipalities showing an increase.

If we consider the index calculated only on NUAs (CQI^*_{NUAs}), it can be noted that an improvement was recorded in all scenarios (38 municipalities in scenario 1, 53 in 2, and 44 in 3), confirming what was previously stated regarding the ability to compensate for the loss of green infrastructure by increasing the capacity of the remaining green areas to provide ESs.



CQI* variation (T0-T2) per municipality	No. of municipalities					
	Scenario 1		Scenario 2		Scenario 3	
	$CQI^*_{MUN_x}$	$CQI^*_{NUAs_x}$	$CQI^*_{MUN_x}$	$CQI^*_{NUAs_x}$	$CQI^*_{MUN_x}$	$CQI^*_{NUAs_x}$
Decrease greater than 20%	1	0	0	0	0	0
Decrease between 5% and 20%	17	0	3	0	10	0
Variation within ±5% (stable value)	23	17	6	2	35	11
Increase between 5% and 20%	13	29	19	9	10	37
Increase greater than 20%	1	9	27	44	0	7

Figure 19. Variation (T0–T2) of the overall ESs provided by non-urbanized areas (*CQI** index) in different scenarios at municipal level.

It is important to note that calculating indices based only on NUAs may overestimate the contribution of green areas to the provision of ESs. This is because, by not taking into account the distribution and fragmentation of green areas within the urbanized fabric, it does not consider the relationship between ecosystem services and human pressure, a relevant factor for planning purposes.

Although scenario 1 appears to be the most balanced, authors believe that, in a highly urbanized context such as that of the study area, it is plausible that planners and local stakeholders may find it useful to give greater importance to ESs provided by nature and/or the landscape.

4. Conclusions

This study on the Province of Monza–Brianza provided an in-depth characterization of the transformation of the territory between 1999 and 2021. Specifically, an overall loss of green areas equal to 18.4 sq.km (−8.3%) was observed, with a more marked decline in the first period (T0–T1), when 7.7% of non-urbanized areas were lost, compared to the second period (T1–T2), which saw a more modest decline of 0.7%.

Agricultural areas were the most transformed (−36.1 sq.km), both through their conversion into forested, natural, or semi-natural areas (20.4 sq.km), and through their urbanization, especially into industrial, commercial, and sports areas (8.8 sq.km) as well as residential areas (7.5 sq.km). This confirms the severity of the land-take phenomenon in such a densely populated and highly urbanized province. In this context, it would be desirable to increase urban regeneration projects, implementing de-urbanization and de-sealing of urban areas to bring nature into the city, rather than reclaiming agricultural land for the creation of new forestry or natural areas.

The analysis of three specific indices (*I_Prov_Agr*, *I_Reg_Nat*, and *I_Cult_Land*) allowed to assess the evolution of ecosystem services in the province. The *I_Prov_Agr* index, designed to measure the provisioning ESs coming from agriculture, showed a downward trend, highlighting a progressive erosion of agricultural production capacity due to land-take and land-use planning policies that fail to safeguard and enhance the most valuable agricultural areas. Conversely, the *I_Reg_Nat* index, designed to measure the regulating ESs provided by natural resources, recorded a significant increase, demonstrating growing attention and effectiveness of natural resource conservation policies. Finally, the *I_Cult_Land* index, designed to measure cultural ESs provided by landscape, was found to be stable overall, with a trend toward improvement.

Based on these three indicators, the composite index *CQI** was calculated, which summarizes in a single value the quality of the territory, as a function of the quantity of ESs provided. The overall assessment of the *CQI** trend over time depends on the relative importance (weight) attributed to the different types of ESs (provisioning, regulating, and cultural). The scenario-based approach allowed us to explore different weighting configurations among the three components, which led to different results: overall, scenarios 1 and 3 showed a trend toward stability, while scenario 2 showed a marked improvement. Given the same land-take, the difference between scenario 1 (*CQI** + 1.1%), in which the three types of ESs have the same weight, and scenario 3 (*CQI** + 0.1%), in which cultural ESs provided by the landscape assume greater importance than the others, lies in the different positive balance of the areas that increased the index value: 14.7% (17.6% − 2.9%) in scenario 1 vs. 6.2% (8.9% − 2.7%) in scenario 3, which partially offset the land-take.

Scenario 2, in which regulating ESs provided by natural resources assume greater importance than the others, shows a decidedly positive overall trend in the index: an increase of almost 26% at the provincial level and a positive balance of almost 20% in the areas that increased the index value (21.4% − 1.7%). Undoubtedly, policies to protect natural areas have been effectively implemented over the past 20 years, but the picture portrayed by scenario 2 appears overly optimistic. The study area, already highly urbanized, has continued to erode green infrastructure, and natural resource protection policies alone cannot compensate for the loss of ecosystem services due to land-take over the past 20 years, which has reduced green areas by 18.3 sq.km (−8.3%). It is necessary to implement the green infrastructure development strategy through a diverse set of actions [4,58]: habitat restoration, increased connectivity, and reduced ecosystem fragmentation; land-take, urban sprawl, and soil sealing reduction; promotion of de-sealing and urban regeneration projects using nature-based solutions; implementation of multifunctional rural zones and agroecological farming. If land-take continues at its current rate, we will begin to measure its consequences in the near future.

The objective of the study, to assess the consequences on the provision of ecosystem services resulting from continued land-take in the study area, has been reached through the application, with the necessary adaptations, of the methodology proposed by Senes et al. [54]. Based on official and periodically updated data, the methodology allows for the creation of an ES assessment database capable of monitoring, also in the future, their trends over time and, consequently, guiding land-use policy decisions.

The use of AHP to construct alternative scenarios allows for the involvement of local planners and stakeholders in the assessment process.

The study, however, has some limitations. First, the availability of data in the past becomes increasingly limited the further back you go. Furthermore, the use of data from different periods limits the homogeneity of the information (in terms of resolution, detail, and significance). This aspect highlights the urgent need to improve the collection and preservation of spatial data over time in order to strengthen the monitoring of planning policies.

An additional limitation that emerged concerns the quality and reliability of the DUSAF database data, derived from photointerpretation. Although they represent an official and indispensable basis for reconstructing land uses, over the years they have shown interpretative and classification differences that can cause some uncertainty in temporal comparisons, especially at a local scale.

In the future, it may be useful to further validate the methodology conducting comparative studies on areas with different socioeconomic profiles, in order to verify the generalizability of the methodology, or use different data sources available to evaluate the potential bias of using periods of time rather than specific dates.

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