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The Evolution of Historic Agroforestry Landscape in the Northern Apennines (Italy) and Its Consequences for Slope Geomorphic Processes

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Abstract: Historic agricultural practices have played a dominant role in shaping landscapes, creating a heritage which must be understood and conserved from the perspective of sustainable development. Agroforestry (i.e., the practice of combining trees with agriculture or livestock) has existed since ancient times in European countries, and it has been recognised as one of the most resilient and multi-functional cultural landscapes, providing a wide range of economic, sociocultural, and environmental benefits. This research explores aspects of the history, physical characteristics, decline, and current state of conservation of historic agroforestry systems on the Northern Apennines in Italy, using an interdisciplinary approach combining archival sources, landscape archaeology, dendrochronology, and GIS analysis. Furthermore, through computer-based modelling, this research aims to evaluate how the abandonment of this historic rural land-use strategy impacted slope geomorphic processes over the long term. The importance of environmental values attached to traditional rural landscapes has received much attention even beyond the heritage sector, justifying the definition of transdisciplinary approaches necessary to ensure the holistic management of landscapes. Through the integration of the Unit Stream Power-Based Erosion Deposition (USPED) equation with landscape archaeological data, the paper shows how restoring the historic agroforestry landscape could significantly mitigate soil mass movements in the area. Thus, the interdisciplinary workflow proposed in this study enables a deep understanding of both the historical evolution of agroforestry systems and its resulting effects for cumulative soil erosion and deposition in the face of climate change.

Keywords: remote sensing and GIS; historic landscape characterisation; slope processes; landscape archaeology; landscape modelling; transdisciplinary landscape studies; geomorphometry; alberata emiliana

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1. Introduction

Agriculture represents the largest land-use type worldwide, and deciphering the processes that created today's rural landscapes is fundamental to understanding how human activities have altered natural resources and geomorphic processes in the past [1–5]. Recent environmental studies and policies have recommended maintaining traditional rural landscape features such as intercropping, agroforestry, and cross-slope barriers (e.g., hedgerows, stone walls, earth banks, ridges, and furrows) for their potential benefits to ecosystems [6,7]. Over the long term, agroforestry systems (i.e., the practice of combining trees with agriculture or livestock) are among the most resilient types of rural land use [8].

Agroforestry has existed since ancient times in European countries, and it has given rise to a wide variety of multifunctional historic landscapes [9], such as *dehesa* in Spain [10], *montado* in Portugal [11], *plužiny* in the Czech Republic [12], and *streuobst* in Germany [13]. Agroforestry systems are still widely implemented [14] in tropical areas where geoarchaeological studies have also demonstrated their central economic, cultural, and ecological role even in past societies [15–17]. During the 20th century, as climate change emerged as a pressing global issue, agroforestry as a polyculture strategy garnered significant attention as a promising way to manage land, providing a wide range of economic, sociocultural, and environmental benefits [18,19]. Some of those include sustaining biodiversity [14], promoting carbon sequestration [20], improving the water balance, lowering risk of wildfire, and preserving traditional agricultural landscapes and rural knowledge [21]. Moreover, numerous studies [21–24] have demonstrated the significant impact of agroforestry systems on slope stability. Furthermore, the practice of integrating trees, shrubs, and other perennial plants with crops plays a crucial role in holding soil together and resisting mass movement in landslides, making them an effective measure to prevent slope instability and promote soil conservation.

Soil erosion caused by water is a complex process that occurs in three stages. Firstly, the soil particles become detached from the soil mass due to the force of rainfall or runoff. Secondly, the detached particles are transported by the moving water, as either dissolved or suspended solids. Finally, the transported soil is deposited somewhere away from its original location [25]. The extent and severity of soil erosion can vary widely depending on a range of site-specific and regional factors. These include the slope gradient, soil type, vegetation cover, and rainfall intensity and frequency [26,27]. Intensive storm events can trigger rainfall-induced landslides [28] with severe consequences on the environment (e.g., loss of topsoil and destruction of vegetation and habitat for wildlife) [29], human settlements (e.g., damage to infrastructure), economy (e.g., increased costs for disaster response and recovery efforts) [30], and cultural heritage [31,32]. Since land-use and land-cover dynamics are the major anthropogenic drivers of soil erosion and degradation [33], the development of sustainable rural strategies is fundamental to cope with this environmental hazard.

Italy is among the European countries most affected by the natural hazard of slope instability, which leads to an increased risk of landslides [34]. In Northern and Central Italy, agroforestry was widespread in the past [35] but survives only in a few areas in the form of relics. The Italian term *coltura promiscua* indicates the typical association of trees, vines and arable crops. It was practised widely in the Po-Venetian Plain and on the Tuscan–Emilian Apennines under different names corresponding to regional agroforestry subtypes with their own technical characteristics (*alteno* in Piedmont, *piantata* in Lombardy, Emilia Romagna, and Veneto, and *alberata* on the Apennines) [36–38].

Through an interdisciplinary archaeo-historical approach, this research aims to reconstruct the origin and physical characteristics of the typical *coltura promiscua* of the Northern Apennines (aka “*alberata emiliana*”) and to evaluate its current state of conservation. Furthermore, in the last two decades, intensive rainfall events have triggered dozens of soil slips in the Northern Apennines [39], and recent climate change projections indicate that increasingly severe storm intensity will induce greater soil mass movements via water erosion in the future than in the past [40,41].

To address these challenges, GIS (Geographic Information Systems) modelling has been employed to simulate the effect of historic rural landscape change for slope geomorphic processes. Computer-based modelling can provide a quantitative and consistent approach to estimate soil erosion under a wide range of conditions, representing one of the most versatile tools for planning suitable landscape protection measures. In the Central and Northern Apennines, researchers have employed several computational methods to measure, estimate, and monitor soil erosion rates [42,43]. Of these methods, the Revisited Universal Soil Loss Equation (RUSLE) is the most widely applied model for identifying areas susceptible to soil erosion in a region of interest. This empirical model predicts annual soil loss due to sheet and rill water erosion [44]. The results of RUSLE modelling often identify human activities such as grazing, forestry, and agriculture as the most responsible factors for land degradation [45].

However, one limitation of the RUSLE equation is its inability to simulate deposition processes. Conversely, the GIS modelling approach adopted in this study provides a comprehensive understanding of soil mass movements, highlighting areas where soil is removed and deposited using the Unit Stream Power-Based Erosion Deposition (USPED) equation. A similar approach was successfully employed in the Central Apennines to assess human-induced soil erosion processes resulting from forest harvesting [46]. This previous study revealed that forestry activities led to a noticeable increase in soil mass movements, although it did not account for the effects of historic landscape transformation in the model. On the other hand, a recent paper used a GIS modelling approach to estimate soil loss variation in the Northern Apennines in accordance with the level of conservation of historic landscape features (e.g., terrace farming and field boundaries) [47], but it did not explore the effect of historic land-use change on soil deposition processes.

The main innovation of this study is the integration of the USPED equation with information regarding changes in the historic rural landscape. This could be used to develop more effective landscape conservation strategies in the region. Therefore, this research not only aims (1) to understand the historic background of polyculture strategies in the study area (see Section 4.1), but also seeks (2) to explore its potential for mitigating downslope soil erosion and deposition in the face of climate change (see Section 4.2).

2. Study Area

This research focused on a portion of the Tuscan–Emilian Apennines coinciding with the municipality of Vetto d'Enza (Emilia Romagna Region, northern Italy). The main characteristics of this historic rural landscape trace their origin back to the Middle Ages in the period of the Great Countess Matilda of Canossa (10th–11th century CE) and the area's land management system appears to have remained largely unaltered until the end of the 19th century CE [47] (Figure 1).

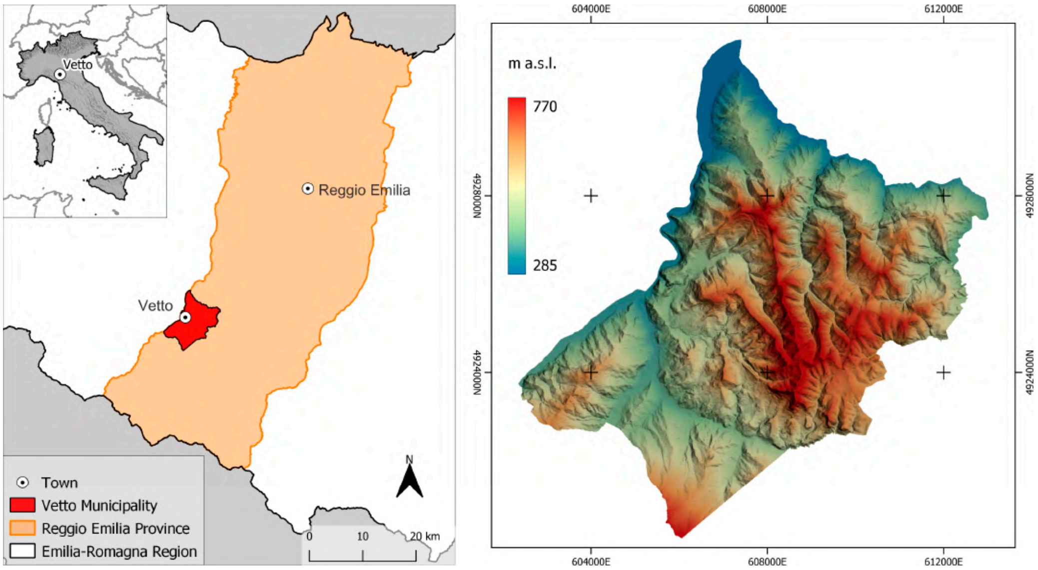

Figure 1. Location of the study area and its topographical setting.

Among the most distinctive characteristics of this historic landscape are relics of traditional *alberata emiliana* and well-preserved stone walls and earth banks that have been used extensively between steeply sloping fields to delimit tenurial boundaries and to face agricultural terraces [48].

The environmental setting of the study area, including the lithological composition, fault systems, soil properties, and climatic factors, contribute to the prevalence of geomorphological slope processes [49]. According to the Köppen–Geiger Climate Classification, the prevailing climate in the study area is warm-temperate, with warm summers and no distinct dry season (Cf—subcontinental/continental temperate) [50]. The faults are mainly located close to the surface, and, when combined with the active uplift of the external rim of the outer chain, they significantly amplify the surface effects of seismic events [49]. The predominant rock type in the study area consists of sedimentary rocks that exhibit a high proportion of clay, such as sandstone and marl [51]. Soils in the area exhibit varying levels of development, ranging from scarce to moderately developed, and are characterised by moderate alkalinity, considerable depth (ranging from 3 to 4 m), and high fertility. Slope geomorphic processes are particularly evident in soils that originate from silty–clayey flysch formations which are particularly vulnerable to erosion and degradation [52,53] (Figure 2).

Figure 2. Geolithological setting of the study area [54].

3. Materials and Methods

The interdisciplinary approach proposed combines different disciplines and tools to study the transformation of the historic landscape in the area and the resulting implications for slope geomorphic processes. The first part focuses on the development of the historic AFS landscape. Historical sources (see Section 3.1) were employed to reconstruct the genesis and development of the historic AFS. Using historic cartography, as well as aerial and satellite images, Historic Landscape Characterisation (HLC, see Section 3.2) was used to analyse the landscape transformation of the area from the late 19th century CE to the present day. Dendrochronological analysis (see Section 3.3) on relics of AFS completed the HLC retrogressive analysis, marking the last possible phase of use of AFS in the region. Secondly, the GIS HLC data were employed to model the effect of historic landscape transformation for slope geomorphic processes (see Section 3.4) in order to provide insights for potential future holistic landscape management strategies.

3.1. Historical Sources

For a general overview of the origin of the *alberata emiliana*, the book published by Emilio Sereni in the mid-20th century CE [55] provides a helpful starting point. The oldest agronomical documentation available about *coltura promiscua* dates back to 1674 [56], while the most exhaustive historical report about the rural landscape of the study area was carried out in the 19th century CE [57].

3.2. GIS—Historic Landscape Characterisation

The application of GIS and remote sensing technologies is becoming increasingly acknowledged as a potent tool in landscape archaeology [58,59], as well as in geomorphological studies [60]. Furthermore, the advent of free and open-source software (FOSS) geospatial tools has further widened the user base and improved accessibility to these powerful technologies [61].

HLC is a specific landscape archaeological GIS tool to map the chronological and spatial complexity of historic landscapes with particular reference to their historical development through a systematic interpretation of rural landscape components [62,63]. In each

HLC study, GIS is used to map the "Historic Landscape Character types" (HLC types) on the basis of unique features resulting from known historical processes. The HLC method employs a qualitative but formalised technique to map the chronological and spatial intricacies of historical landscapes [64]. The mapping procedure involves identifying the smallest "uniform diachronic unit" (UDU), represented by a polygon whose size and shape depend on the variability of the HLC type over time [63]. In the study area, the GIS HLC dataset was developed using various sources including historical maps, 19th century cadastral records, declassified satellite images, and aerial photography (Table 1). Further data about historic land use were recovered in the regional geodatabase [65]. The resulting geodataset consisted of a GeoPackage (.gpkg) [66] vectorial layer of the historic landscape changes that occurred since the 19th century CE [48].

Table 1. List of the historic sources employed in this study.

Name	Publication	Type	Scale	Source
Google© Satellite	2022	Satellite images	-	QuickMapServices plugin [67] in QGIS 3.22 [68]
Bing© Satellite	2022	Satellite images	-	QuickMapServices plugin [67] in QGIS 3.22 [68]
Carta Tecnica Regionale (CTR)	2018	Cadastral map	1:5000	WMS service [69]
Compagnia Generale Riprese (CGR) Aeree	2018	Aerial photos	-	WMS service [70]
AGEA (Agenzia per le Erogazioni in Agricoltura) 11	2011	Aerial photos	-	WMS service [71]
AGEA (Agenzia per le Erogazioni in Agricoltura) 08	2008	Aerial photos	-	WMS service [72]
Volo Compagnia Generale Riprese Aeree (CGRA)	1976–1978	Aerial photos	1:13,500	Photos retrieved at the Ufficio cartografico della Provincia di Reggio Emilia [73]
KH-9 (Hexagon)	1974	Satellite images	-	Declassified image retrieved at the US Geological Survey website [74]
Volo GAI (Gruppo Aereo Italiano)	1954–1955	Aerial photos	1:33,000	Photos retrieved at the Istituto Geografico Militare (IGM) website [75]
Nuovo Catasto Terreni	1886–1900	Cadastral map	1:2000	Map retrieved at the Ufficio cartografico della Provincia di Reggio Emilia [76]
Carta Storica Regionale Emilia Romagna	1853	Historical map	1:50,000	WMS service [77]
Second military survey of the Habsburg Empire	1818–1829	Historical map	1:28,800	Map retrieved at the Mapire website [78,79]
Viaggio Agronomico per La Montagna Reggiana E Dei Mezzi Di Migliorare L'agricoltura Delle Montagne Reggiane	1800	Historic document	-	[57]
L'economia del cittadino in villa, del signor Vincenzo Tanara libri 7. Riueduta, ed accresciuta in molto luoghi dal medesimo auttore, con l'aggiunta delle qualita del cacciatore	1713	Historic document	-	[56]

3.3. *Dendrochronology*

Dendrochronology as a method for scientific dating provides accurate chronologies because, in principle, each ring represents a year in a tree's life. In geomorphological studies this technique has been employed in exploring the temporal variation of slope geomorphic processes and the resulting impact on slope instability in recent decades [80,81]. Furthermore, tree-ring analyses have been applied to the study of agroforestry, especially to assess which species return the best benefit in terms of climate change mitigation (e.g., carbon storage) [82,83].

In this study, dendrochronological analysis was employed to assess the last phase of *alberata emiliana* in relics of agroforestry systems detected during the GIS HLC mapping process. An increment borer (Pressler; inner diameter: 5 mm) was used to extract core samples from the trunks at "breast height" (about 1.30 m above the ground) [84]. All extracted samples were dried at room temperature, glued on wood profiles, and sanded, to clearly expose all tree rings. The number of annual rings was used to estimate the *terminus post quem* since each tree was established.

3.4. GIS Geomorphic Modelling

The Geographic Resources Analysis Support System (GRASS) GIS software [85] was employed to simulate how historic land-use changes affected downslope soil erosion and deposition. The module `r.landscape.evol` was specifically designed to simulate the cumulative effect of erosion and deposition on a landscape over time [86]. It takes as input a raster digital elevation model (DEM) of surface topography and an input raster DEM of bedrock elevations, as well as several environmental variables, such as the rainfall erosivity factor (R factor, measured in $\text{MJ}\cdot\text{mm}\cdot\text{ha}^{-1}\cdot\text{h}^{-1}\cdot\text{year}^{-1}$), the soil erodibility factor (K factor, $\text{Mg}\cdot\text{h}\cdot\text{MJ}^{-1}\cdot\text{mm}^{-1}$), the land-cover management factor (C factor, dimensionless value ranging between 0 and 1), and the support practices factor (P factor, dimensionless value ranging between 0 and 1). The R factor represents the erosive power of raindrops on the soil surface, while the K factor represents the susceptibility of the soil to erosion. The C factor represents the effect of vegetation and land management practices on erosion. Vegetation cover can protect the soil from erosion by intercepting raindrops and reducing runoff [87]. Lastly, the P factor represents the effect of erosion control practices to reduce erosion by slowing down water flow and reducing the length of slope (e.g., contour farming, terracing, and hedgerows) [44].

In the module `r.landscape.evol`, three different equations can be used to compute the net change in elevation due to erosion and deposition: the stream power equation, the shear stress equation, and the USPED equation [88]. All three equations estimate transport capacity as the force required to move a unit area of fluid at a unit velocity ($\text{kg/m}\cdot\text{s}$), thus eventually yielding the erosion/deposition (ED) rate as mass flux per unit area per unit time ($\text{kg/m}^2\cdot\text{s}$). The unit $\text{kg/m}^2\cdot\text{s}$ represents a measure of mass flux density or mass transfer rate per unit area per unit time. It is commonly used in chemical engineering and related fields to express the rate of mass transfer between two phases or the rate of mass flow through a surface. It is also the standard unit of *momentum* (i.e., mass in motion) [89].

The USPED equation was employed in this study because it is best suited for modelling erosion and deposition on hillslopes and relies on the rainfall intensity factor during the simulation process.

The DEM (5 m resolution), R, and K environmental parameters employed in this study were supplied by the Emilia–Romagna region geological service [90], as well as the regional soil maps used to generate the bedrock elevation raster map. The first modelling step focused on estimating the soil depth. This parameter is crucial as it provides a depth-based limitation on the amount of erosion that can occur at any particular cell. In this research, these data were retrieved from the regional soil map vector file [65] and transformed into a raster file using the GRASS module `v.to.rast`. Then, a bedrock elevation map was estimated subtracting the soil depth raster from the DEM using the GRASS module `r.mapcalc`. To simulate the potential of historic agroforestry landscapes in mitigating downslope soil erosion and deposition in the face of climate change, the global rainfall erosivity projections for the year 2050 [91] were employed in the modelling process. Moreover, the C and the P factors were developed using the HLC data about historic land-use changes that occurred during the 20th century CE. The cover management factor was obtained by associating the European Soil Data Centre (ESDAC) C Factor numerical values [87] to the corresponding Regional LULC categorical data [65] for each HLC chronological period. The ESDAC C factor values were chosen to potentially extend the reproducibility of this protocol in other European regions. Lastly, the support practices factors (i.e., P factors) were developed using the equation proposed in Brandolini et al., 2023 [47], which calculates the effectiveness of historic landscape features (i.e., terraces and field boundaries) in reducing soil erosion hazards according to their state of conservation and regional topography (Figure 3).

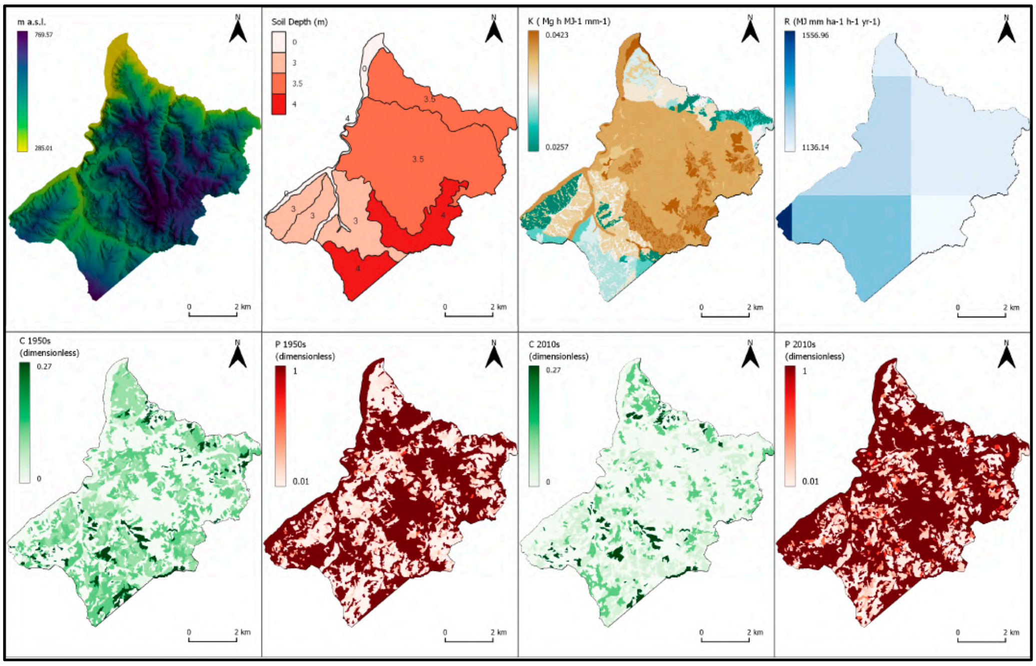

Figure 3. Parameters employed in the GIS geomorphic modelling. From top left to bottom right: DEM, soil depth, K factor, R factor, C factor 1950s, P Factor 1950s, C Factor 1950s, and C Factor 2010s.

4. Results

4.1. Historic Agroforestry Landscape: Genesis, Characteristics, and Decline

In Northern Italy, agroforestry systems have been documented in written sources since Roman times [92]. In his "*Naturalis Historia*", Pliny the Elder mentioned the use of agroforestry to grow grapes and fruit trees together. The same technique was reported by Varro ("*De re rustica*", first century BCE), Columella ("*De re rustica*", first century CE), and finally by Palladius in his "*Opus agriculturae*" (fourth century CE). These authors provide evidence that agroforestry was a common practice in Northern Italy during the Roman Empire [55,92]. The 14th century the Italian agronomist Pietro de' Crescenzi wrote about the practice of planting trees among crops to provide shade and shelter for animals in his book "*Ruralia commoda*" [55]. In 1674, the agronomist Vincenzo Tanara still described this polyculture strategy with the Latin terms *arbustum gallicum* and *arbustum italicum* [56]. In these agroforestry systems, fields were divided into long arable strips separated by rows of vines trained on the trees with intercrops of cereals, vegetables, or forage [37]. The *alberata* (*arbustum italicum*) differs from the *piantata* (*arbustum gallicum*) in terms of the field's extension (15–30 m), the width of the arable strips (4–6 m), and the species (elm—*Ulmus minor*; mulberry—*Morus nigra*; maple—*Acer campestre*) used to sustain the branches of the vines woven from one tree to another along the same row. The *Piantata* was typically adopted in the Po-Venetian Plain, while the *alberata* (aka, *alberata emiliana* and *alberata tosco-umbro-marchigiana*) was largely employed in the Northern Apennines [55,93,94].

The integration of different plants in the same field provides multiple benefits, in addition to food production such as hay and tree fodder to feed animals, domestic fuel (logs), and construction materials (timber) [55]. In the study area, the *alberata* was largely adopted since the 13th century CE, along with a sharecropping system [93,95,96]. In 1800, the agronomist Filippo Re described [57] this rural land management system which appeared to have persisted largely unaltered until the end of the 19th century CE [97–99]. However, in the early 20th century CE, this traditional agroforestry system experienced a substantial decline of around 20% between 1913 and 1957 [55].

The GIS HLC mapping process enables the identification of the relics of *alberata* and quantification of its progressive reduction over the last 70 years (1950s, 1970s, 2000s, and 2010s). Indeed, in the absence of reliable land-use data for the 19th century chronological phase, this period is not considered in this research. Information retrieved in the sources available (Table 1) enabled the compilation of detailed information about the land-use changes that occurred since 1954.

In the mid-20th century, the extent of agroforestry in the study area began to decline. Between the 1950s and the 1970s, the area covered by polyculture fields decreased from 10.2% to 3.7%. This decline continued over the years; today, the historic agroforestry landscape has almost completely disappeared, representing only 0.1% of the study area (Figure 4).

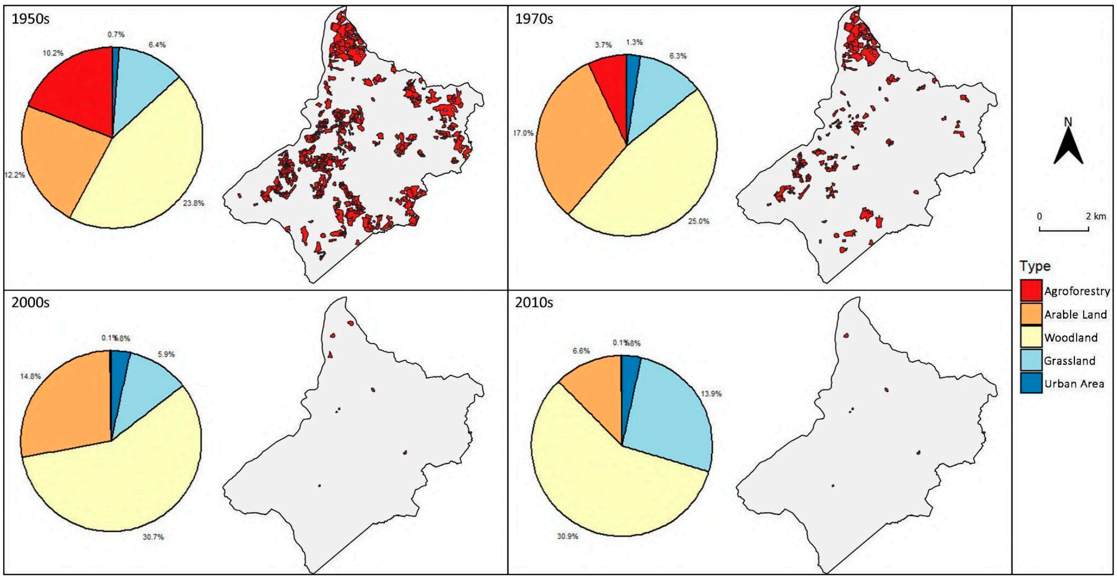

Figure 4. Pie charts summarising the land-use changes in the study area since the 1950s showing the gradual disappearance of *alberata emiliana* (i.e., agroforestry). To highlight the progressive decline in agroforestry, key ESDAC land-use types were merged in the pie charts as follows: woodland ("*mixed forest*" and "*transitional woodland/shrub*"); grassland ("*natural grassland*" and "*pastures*"), and arable land ("*complex cultivation patterns*" and "*non-irrigated arable land*"). The maps show schematically where agroforestry was located in the study area for each time period.

Relics of *alberata* near Vetto d'Enza conserve some of the main characteristics of this historic agroforestry landscape as they were described in historical sources: small fields (max 15–20 m side) divided into strips by regular rows (ca. 5 m distance) of vines trained on maple trees (*Acer campestre*). The tree management and shade-regulation operation employed is pollarding, and all branches are cut at a height of ca. 2 m above ground (Figure 5). Dendrochronological analysis was performed on these remnants of historic agroforestry systems detected remotely through the GIS HLC mapping process. The maples (*Acer campestre*) sampled on the historical agricultural terraces of Vetto d'Enza were likely planted between 1949 and 1980, marking the last phase of the historic agroforestry landscape in the area.

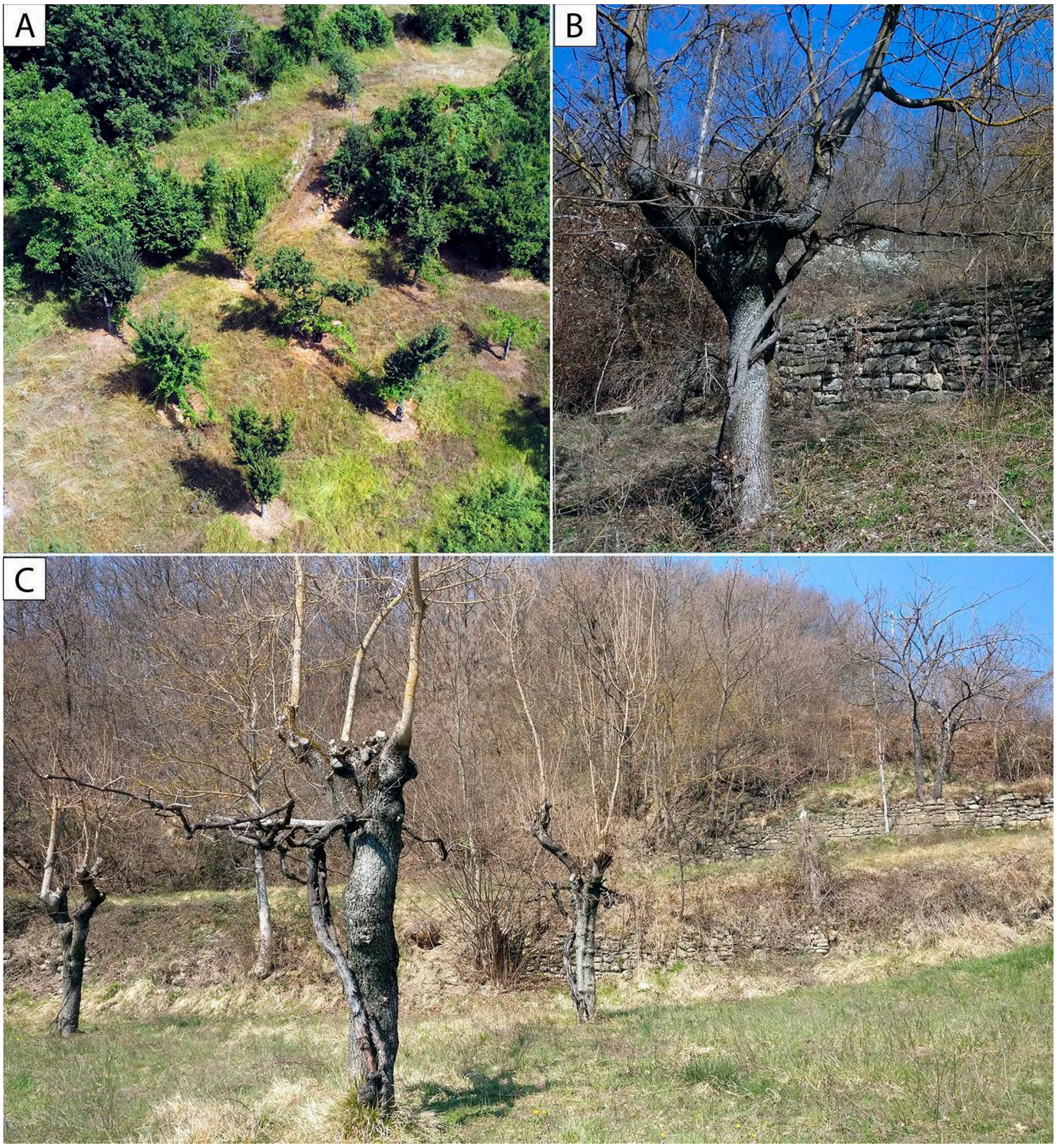

Figure 5. Relics of agroforestry on the historic agricultural terraces of Vetto d'Enza (RE, Italy): (**A**) aerial view of a traditional *alberata emiliana* field; (**B**) detail of a pollarded maple tree; (**C**) ground view of vines trained on pollarded maple trees (© F.B.).

4.2. GIS Modelling of Slope Geomorphic Processes

Three models were developed to simulate changing slope geomorphic processes across the landscape in three different scenarios. Four environmental parameters were constant (DEM, bedrock elevation map, K factor, and R factor) in all the three models, while the P and C factors were changed to reproduce three different scenarios. The first model (model "1950") considers the historic rural landscape as it was in the 1950s before changes due to 20th century socioeconomic dynamics. In this model, agroforestry is still the dominant component of the rural landscape (Figure 4). The second model (model "2020") reflects present-day land management practices in the area, with the C and P factors adjusted accordingly. In this model, the historic agroforestry landscape has almost completely disappeared, and the rural activities are now primarily devoted to forage production for the local dairy industry (Figure 4). The third model (model "AFS") represents a scenario in which the present-day rural landscape is occupied only by historic polyculture activities (i.e., "*agroforestry*"). In this model, the historic agroforestry landscape replaces all other agro-pastoral land-use types (i.e., "*complex cultivation patterns*", "*non-irrigated arable land*", "*natural grassland*", and "*pastures*") (Figure 6).

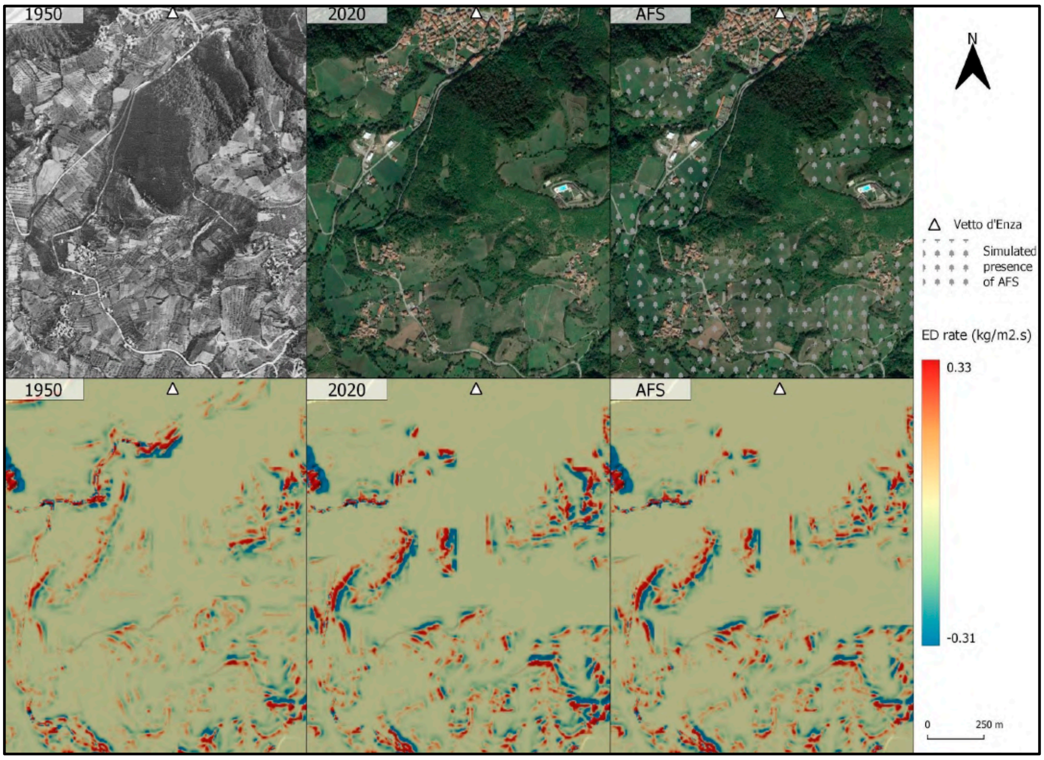

Figure 6. Details of the three GRASS models (1950, 2020, AFS) are shown in correspondence with the area south of Vetto d'Enza (RE, Italy). The estimates of erosion/colluvial deposition rates vary significantly across the three models due to differences in the distribution of agroforestry systems in the study area. Shades of red indicate areas of soil colluvial deposition, while shades of blue represent zones prone to erosion. The full rasters covering the entire study area are provided in the Supplementary Materials.

As displayed in Figure 6, the estimates of erosion/deposition rates varied significantly across the three models due to differences in the distribution of agroforestry systems in the study area. In particular, shades of red indicate areas of soil colluvial deposition, while shades of blue represent zones prone to erosion. The results of the GIS geomorphic modelling conducted in the study area revealed that Model "1950" exhibited the highest soil loss score (Table 2). Although the total soil loss in Model "2020" was 8% lower than in Model "1950", it remained slightly higher than that in Model "AFS" (+1.5%) (Figure 7).

Table 2. Simulated soil loss (i.e., the result of erosion and deposition processes) (t·ha^{-1}·year^{-1}) in the three models ("1950", "2020", and "AFS") for each land-use type and totals. Positive numbers indicate depositions, while negative numbers indicate erosion.

Land Use Type	Model "1950"		Model "2020"		Model "AFS"	
	Area (ha)	Soil Loss (t·ha^{-1}·year^{-1})	Area (ha)	Soil Loss (t·ha^{-1}·year^{-1})	Area (ha)	Soil Loss (t·ha^{-1}·year^{-1})
Agroforestry	1024.83	0.93	5.66	0.02	1730.15	−1.54
Arable land	1220.20	−4.65	657.00	−1.55	nd	nd
Grassland	253.66	0.63	1067.49	−0.89	nd	nd
Rough ground	190.02	−3.29	190.74	−6.50	190.74	−6.55

Table 2. *Cont.*

Land Use Type	Model "1950"		Model "2020"		Model "AFS"	
	Area (ha)	Soil Loss ($t \cdot ha^{-1} \cdot year^{-1}$)	Area (ha)	Soil Loss ($t \cdot ha^{-1} \cdot year^{-1}$)	Area (ha)	Soil Loss ($t \cdot ha^{-1} \cdot year^{-1}$)
Urban area	65.24	−0.28	184.26	−0.45	184.26	−0.30
Woodland	2577.43	2.86	3226.22	5.90	3226.22	4.98
Total	5331.37	−3.80	5331.37	−3.47	5331.37	−3.41

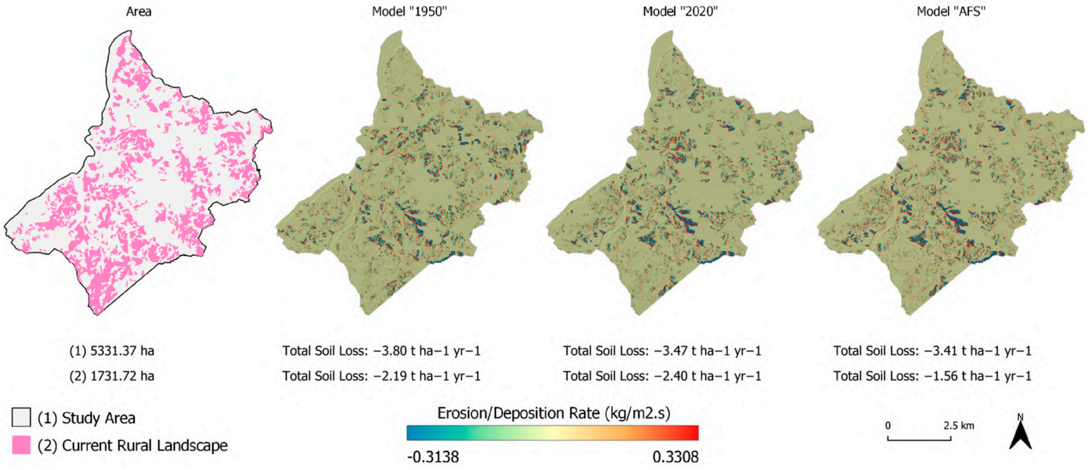

Figure 7. Estimation of the total soil loss ($t \cdot ha^{-1} \cdot year^{-1}$) in the three models (1950, 2020, and AFS). The simulation indicates that replacing current agro-pastoral land management with agroforestry systems would reduce the soil loss by 40%. Images in .tiff format covering the entire study area are provided in the Supplementary Materials.

In Model "1950" and Model "2020", soil loss generated by rural activities accounted for 57% and 69% of the total, respectively. Thus, focusing only on rural areas can help in highlighting the effects of historic landscape changes for slope geomorphic processes. To ensure consistency in the comparisons among the three models, we only considered the present rural area. Indeed, farmland extension has experienced a decline since the 1950s, primarily replaced by urban areas and woodlands (Figure 4). The present-day agro-pastoral activities represent 32.4% of the study area with an extension of 1731.72 ha (Figure 7). Interestingly, in this context, Model "2020" presented the highest soil loss with a percentage increase of 9.7% compared to Model "1950". Conversely, as displayed in Model "AFS", the simulated restoration of historic agroforestry systems generated a reduction in the total amount of soil loss in rural areas by 40% (Figure 7).

To evaluate the efficacy of restoring historic agroforestry land use in mitigating downslope soil erosion and deposition in the face of climate change, two additional models were developed. Climate change projections indicate that the increasing severity of storms will result in greater water erosion and soil loss in the future compared to the past [40,41]. In light of this, we updated Model "2050" and Model "AFS" with global rainfall erosivity projections for 2050 [91]. Model "2050LU20" estimated erosion and deposition rates in the study area by simulating the interaction between existing environmental factors and land management practices with rainfall erosivity projections for 2050. Similarly, Model "2050AFS" evaluated the response of agroforestry systems in mitigating soil loss with the same forecasts of rainfall-induced erosion.

The results of these two models showed the same trends as observed in Models "2050" and "AFS". When considering the entire region, the benefits of replacing current agro-pastoral systems with agroforestry strategies to reduce erosion and deposition rates appear to be limited. However, when looking only at the current rural area, the total soil loss due to future rainfall-induced erosion was projected to be 36% lower in “Model 2050AFS” than in Model “2050LU20” (Figure 8).

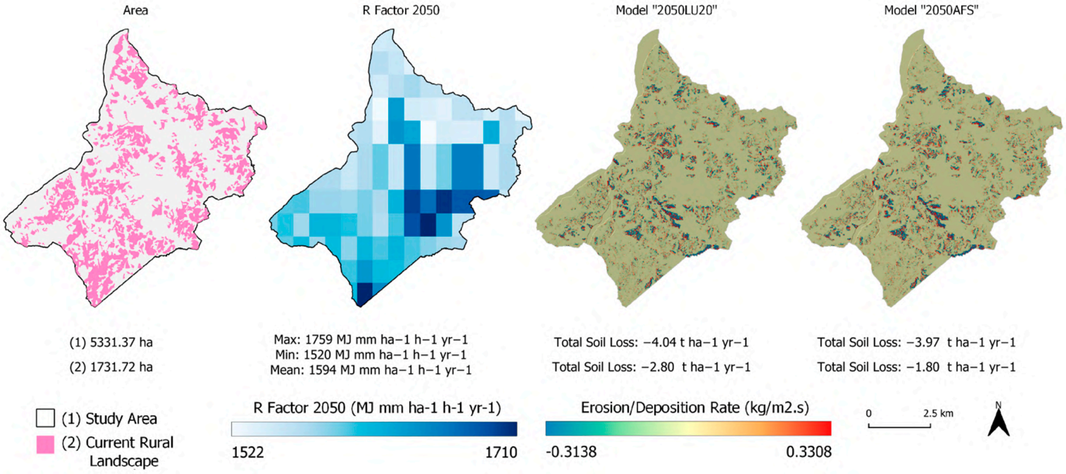

Figure 8. Estimation of the total soil loss (t·ha^{-1}·year^{-1}) in Model “2050LU20” and in Model “2050AFS” considering the rainfall erosivity projections for the year 2050. The simulation indicates that restoring agroforestry systems would reduce the soil loss of rural area by 36%. Images in .tiff format covering the entire study area are provided in the Supplementary Materials.

5. Discussion

The combination of historical sources and landscape archaeological mapping enabled the analysis of agroforestry systems in the Northern Apennines. This ancient historic rural strategy is mentioned in Roman and Mediaeval documents, and it was still widely employed in the 19th century as reported by the agronomist Filippo Re in 1800. The GIS HLC retrogressive analysis enabled a quantitative assessment of the progressive abandonment of agroforestry and the resulting historic landscape changes which occurred during the 20th century CE. The last phase of use of *alberata emiliana* occurred in the 1980s as suggested by preliminary dendrochronological analysis. As registered in other European regions [100], the decline in polyculture strategies such as the *alberata* in the study area appears to be a consequence of post-World War II socioeconomic dynamics such as the rapid modernisation and mechanisation of agriculture and the expansion of urban areas (Figures 3 and 9). Furthermore, in the study area, the progressive decline of agroforestry systems since the mid-20th century CE reflects further local socioeconomic trends: the progressive reduction in rural activities in mountainous regions, the consequent process of rewilding abandoned agricultural areas [101], and the need for forage for the regional dairy industry [102]. These dynamics led the agroforestry fields to be replaced mainly by woodland, pastures, and grassland (Figures 3 and 9).

The disappearance of historic agricultural practices had relevant consequences on land vulnerability. The results of the GIS geomorphic modelling showed how the current overall erosion/deposition rate in the study area (Model “2020”) was lower than in the past (Model “1950”) (Figure 7), a situation likely due to the afforestation process that occurred in the last 70 years. Indeed, the extension of woodland in the area, higher than in the mid-20th century, has positive benefits in mitigating land degradation (Table 2). Furthermore, the overall soil loss scores of the three models seem to suggest that the reconversion of the present-day agro-pastoral activities to agroforestry appear to be limited when considering the entire region (Figure 7). Nevertheless, the interpretation of the geomorphic simulations cannot ignore the fact that the current rural area accounts for more than 60% of the total soil loss registered, despite being only one-third of the entire region (Table 2). In addition, the current extent of the agricultural area is lower than in the 1950s, but the simulation returned a higher soil loss score than in the past (Table 2). The potential benefits of restoring the historic agroforestry systems (still widely employed in the mid-20th century) in place of the current agro-pastoral strategies were highlighted by Model "AFS". The third simulation returned a significant reduction of potential soil loss in the area, giving valuable indications for future landscape management strategies. Even in the future scenario of increasingly severe storm intensity (Model "2050LU20" and Model "2050AFS"), the replacement of current agro-pastoral strategies with agroforestry seems to be particularly effective in mitigating downslope soil erosion and deposition (Figure 8).

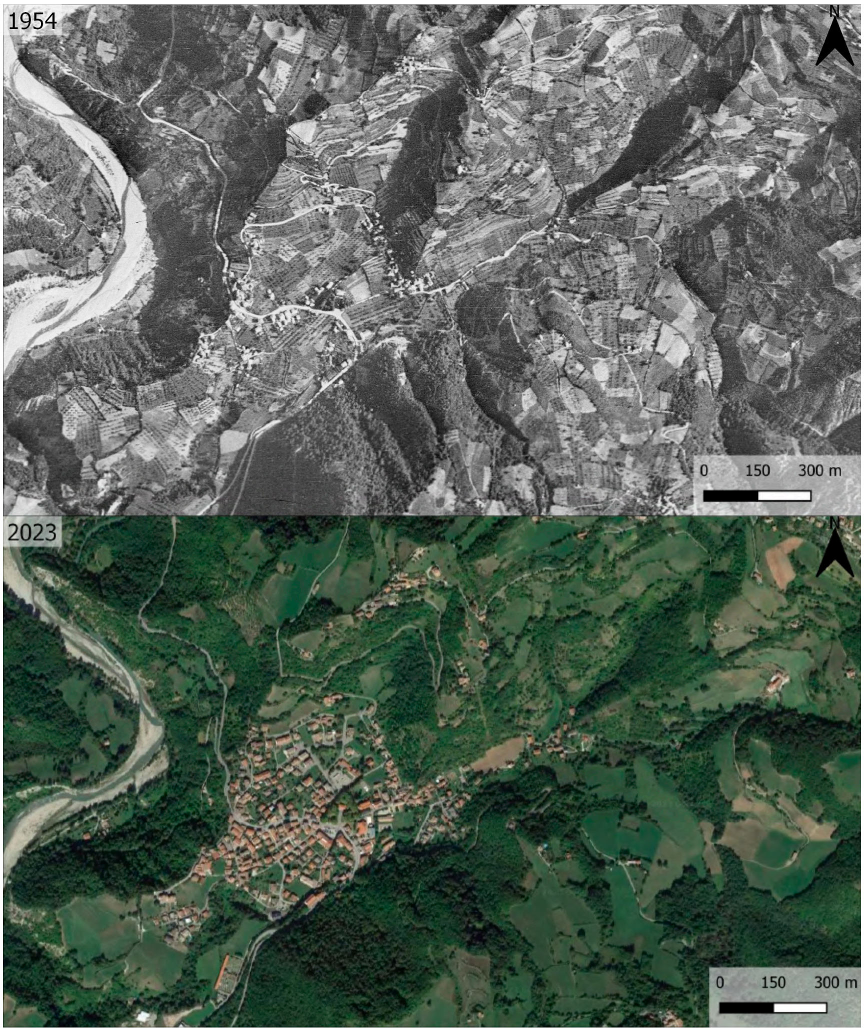

Figure 9. The area of the town of Vetto d'Enza (RE, Italy) as it appeared in 1954 [70] (**top**), compared to the current situation (**bottom**) [64].

The abandonment of agroforestry in the area also had negative consequences for the cultural values of landscape. Indeed, in addition to an environmental deterioration, the progressive loss of farmers' know-how of such rural practices correspond to deep physical modifications of the regional landscape heritage [21]. In the last 10 years, both EU and regional policies have encouraged repopulation in rural mountain areas by providing economic incentives to newcomers who choose to relocate from cities [103,104]. The aim of such a policy is to limit the process of depopulation, thereby avoiding the loss of cultural identity in rural regions while lowering population pressure in urban areas [105]. Furthermore, according to the latest Horizon Europe Strategic Plan [106] and the Agricultural European Innovation Partnership workshop, the major challenge facing current and future agricultural systems is reconciling production with sustainable land management [107]. To address this challenge, EU agencies encourage the development of innovative landscape management approaches that utilise nature-based solutions. Additionally, cultural heritage is identified as a potential driver for improving rural wellbeing and long-term socioeconomic prospects [106].

Furthermore, the restoration of historic AFS has the potential to mitigate the negative impacts of anthropogenic landscape fragmentation and support the conservation of biodiversity in mountain ecosystems. Anthropogenically induced landscape fragmentation, which results from direct physical transformations such as deforestation, agriculture, urbanisation, and road building, is widely acknowledged as a significant threat to biodiversity [108,109]. However, the depopulation of rural mountain areas and the consequent abandonment of traditional land management practices have emerged as major driving forces behind changes in mountain ecosystems in Europe. This has led to decreased landscape connectivity, negatively impacting fauna associated with abandoned traditional agro-pastoral habitats [110]. Several studies have shown that AFS can play a crucial role in improving landscape connectivity. By creating corridors and connecting fragmented habitats, AFS can enhance biodiversity, improve ecosystem services, and promote ecological resilience [111,112].

On the other hand, environmentally sustainable rural LU types very often do not provide an immediate and desirable economic return to farmers and these solutions need to be implemented and adapted to meet site-specific needs at the local scale by inviting stakeholders to contribute to policy development [113]. Nevertheless, EU-funded research focused on AFS strategies have shown a return-on-investment time of about 5 years to recover from workforce training and machinery costs [114], and it has been demonstrated that even the partial integration of historical AFS within arable lands and pastures can contribute strongly to lowering environmental pressures on landscape [20].

Thus, the development of transdisciplinary strategies is crucial to inform an environmentally sustainable conservation of landscape heritage [115–118]. Synergies between disciplines can actively contribute to achieving this goal, deciphering the ecological and historical background of traditional and multifunctional cultural landscapes [119] such as the *alberata emiliana*.

The workflow adopted in this research represents an effective interdisciplinary approach to inform potential holistic landscape strategies. By combining historical sources, dendrochronology, and GIS retrogressive analysis, we were able to reconstruct the long-term sociocultural values of AFS in the area. Furthermore, GIS modelling permitted us to simulate the effects of the abandonment of traditional LU systems on slope instability. However, assessing the accuracy of model predictions is still challenging. Direct measurements on the fields are the most effective way to validate this type of model [46,120]. Even when validation data can be collected, it is usually limited to a small number of sites and a short period, which may not be representative of the entire region or different climatic conditions. As a result, the validation process may not capture the full range of spatial and temporal variability [121]. Nevertheless, GIS modelling tools such as `r.landscape.evol` represent invaluable multiscale sources to simulate long-term annual land degradation across different land management activities and environmental conditions. The scenarios proposed in this study can simulate the effects of historic landscape transformation for the cumulative soil erosion and deposition rates in the area to highlight the potential environmental benefits of restoring historic AFS. Therefore, the development of landscape modelling approaches such as that adopted in this research responds to the need of transdisciplinary tools for landscape management. Indeed, the integration of retrogressive analysis within GIS modelling tools has the potential to yield invaluable insights for embracing natural and cultural values of landscapes as components of the same holistic landscape plans.

6. Conclusions

This study integrated historical documents, landscape archaeology, and GIS tools to trace the evolution of the historic agroforestry (*alberata emiliana*) in the Northern Apennines. It also quantified the decline in *alberata emiliana* during the 20th century CE and assessed its impact on cumulative soil erosion and deposition. Moreover, the GIS HLC mapping process was utilised to create a comprehensive geospatial dataset to monitor the current state of traditional AFS and provide recommendations for their future maintenance and revitalisation while preserving the region's historical landscape characteristics. Considering the potential benefits of agroforestry systems in mitigating downslope soil erosion and deposition, the GIS modelling showed that restoring the historic agroforestry landscape could significantly reduce the land degradation rate in the area. This interdisciplinary approach could inform the development of transdisciplinary management plans that balance mitigating land degradation with preserving the landscape character and cultural identity of a region. The workflow adopted in this research is potentially reproducible in other areas with similar sociocultural and environmental characteristics, and it helps in making historical knowledge useful for future landscape management.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/land12051054/s1: the GIS modelling rasters are provided in a .zip folder.

Author Contributions: Conceptualisation, F.B.; methodology, F.B.; software, F.B.; validation, F.B.; formal analysis, F.B.; investigation, F.B.; resources, F.B. and S.T.; dendrochronological analysis, C.C.; geomorphological review and supervision, M.P.; data curation, F.B. and C.C.; writing—original draft preparation, F.B.; writing—review and editing, M.P. and S.T.; visualisation, F.B.; supervision, F.B.; project administration, F.B. and S.T.; funding acquisition, F.B. and S.T. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The HLC dataset used to develop the C and P factors is available on Zenodo: doi: 10.5281/zenodo.6622607 (accessed on: 1 May 2023). The raw raster products derived from the GRASS GIS simulation are available upon request from the corresponding author.

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