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Revealing patterns and connections in the historic landscape of the northern Apennines (Vetto, Italy)

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ABSTRACT
In the Northern Apennines, significant modifications to the characteristic historical features of landscapes have occurred since the 1950s as agriculture declined in importance and villages were progressively depopulated. Today, European policies are promoting the repopulation of these regions to help preserve the cultural identity of territories and reduce demographic pressure inurban areas. Such initiatives increase the need for cultural and natural landscape management to be better integrated using interdisciplinary approaches. Sustainable landscape management is a dynamic process involving the formulation of strategies to underpin the preservation of landscape heritage and foster local development based on the values and opportunities provided by landscapes themselves. This study uses landscape archaeology and spatial statistics to provide insights into which parts of the historic landscape retain the greatest time-depth and which parts reflect the more recent radical change, enabling an understanding which goes beyond the basic spatial relationships between landscape components.

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Landscape archaeology; historic landscape characterisation; spatial statistics; local indicators for categorical data; point pattern analysis; landscape management

1. Introduction

Recent decades have seen a considerable increase in global awareness about the importance of landscape heritage (Fàbregas & Ramos, 2017). Deciphering the processes that created today's landscapes is fundamental to understanding how human economic development, land-use change and population growth have altered natural resources in the past (Stephens et al., 2019). The importance of socio-economic values attached to 'natural' and 'cultural' landscape heritage has received much attention even beyond the heritage sector (Kalman & Létourneau, 2020), justifying the definition of strategies necessary to ensure the management of landscapes (Harvey, 2015). Furthermore, international treaties and policies (Fredholm et al., 2018; Mitchell et al., 2009) indicate that it is fundamental to develop sustainable plans to guide and harmonise changes in response to social needs, economic activities and environmental processes.

Landscape change has occurred with unprecedented intensity over the last 70 years (Baessler & Klotz, 2006; Di Fazio & Modica, 2018; Malandra et al., 2018). In mountainous areas of the Mediterranean, the decline in the importance of agriculture has led to a significant reduction of activities in rural zones, with progressive depopulation of villages and significant modifications to the characteristic historical features of landscapes (Arnaez et al., 2011; Modica et al., 2017). Over the last decade the European Union has promoted the repopulation of these regions through economic incentives for newcomers who decide to move from highly urbanised to rural areas (EU Commission, 2020). The aim of this kind of policy has been to mitigate the depopulation process, avoiding the loss of cultural identity in rural regions and lowering population pressure in the cities (Karcagi Kováts & Katona Kovács, 2012). In response to such policies, the creation of sustainable landscape management plans is a dynamic process. It embraces the formulation of a set of strategies to underpin the preservation of landscape heritage and foster local development based on the values and opportunities provided by landscapes themselves.

Humanities researchers can actively contribute to this process by exploring the interactions of social and environmental systems over long periods (Fisher, 2020). In particular, landscape archaeology can make distinctive contributions to the development of sustainable management plans by deciphering the cultural and natural dynamics, which have shaped the evolution of a territory (Turner et al., 2020). Historic Landscape Characterisation (HLC) is a specific landscape archaeological tool for understanding and representing landscapes with particular reference to their historical development (Turner, 2006) through a systematic recording of landscape components (e.g.

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field patterns, boundaries, etc.) (Herring, 2009). As indicated by the guidelines for implementation of the Council of Europe's Landscape Convention (Fàbregas & Ramos, 2017), the first phase in any landscape management project must be the preliminary analysis of the territory. Implementation of HLC provides an effective way to address this requirement since it results in a detailed multi-temporal map of the region considered.

This paper explores patterns and connections in the landscape of the Northern Apennines using HLC (Vetto d'Enza, Emilia Romagna Region – Italy). Its aim is to provide information of value to stakeholders who can underpin the development of sustainable strategies for managing this historical landscape and its heritage. The research objectives have been addressed in two steps. Firstly, HLC mapping was created to present an interpretation of the evolution of the landscape's components. Secondly, spatial statistical analysis was performed to assess the existence of connections between different elements of the landscape quantitatively.

2. Study area

This research focuses on the landscape heritage of a portion of the Northern Apennines (Reggio Emilia province, Italy) (Figure 1). The vast majority of the area has a warm temperate climate without a dry season but with warm summers (Köppen-Geiger Climate Classification: Cf, sub-continental/continental temperate) (Fratianni & Acquaotta, 2017; Kottek et al., 2006). The lithological composition is mainly sedimentary rocks with high clay components (i.e. sandstone and marl) (Haller & Bender, 2018), and geomorphological slope processes are particularly prevalent (Mariani et al., 2019; Montrasio et al., 2012). Soils in the area are scarce to moderately developed, moderately alkaline, deep and fertile; they are nevertheless prone to erosion, particularly those developed from silty-clayey flysch formations (Bini, 2013).

Human occupation has been well-documented since the mid-Holocene (Cremaschi et al., 2018; Tirabassi, 1979), but a profound reorganisation of the rural environment appears to have taken place in the Early Middle Ages (seventh–twelth centuries CE) (Rombai & Bomcompagni, 2010; Sereni, 1961). The area was affected by social changes resulting from the establishment of one of the most important pilgrimage routes in medieval Europe (the *Via Francigena*) (Scurani, 1895) and the foundation of fortresses in strategic positions (Mariani et al., 2019). These processes influenced the development of settlements and land management systems that continued into the mid-twentieth century CE. Since the 1950s, the decline of agrarian activities in the area has resulted in land-use change, which was often related to the abandonment of farmland and a progressive depopulation of the mountains (Haller & Bender, 2018). In 2020, regional policies were implemented to provide economic incentives for repopulation in the region (Emilia Romagna, 2020).

Vetto d'Enza (commonly referred as *Vetto*) is a small town located on the right bank of the Enza River in the Man and the Biosphere (MAB) Unesco reserve of the Tuscan – Emilian Apennines. The Region of Interest (ROI) coincides with the Vetto municipality (53.37 km^2), including several hamlets dispersed across the territory. Among the most distinctive characteristics of the cultural landscape are well-preserved systems of agricultural terraces, usually built on the south- and west-facing slopes and faced with large blocks of local sandstone (Main Map, Figures 1 and 2). Their date of origin is uncertain. According to historical documents, the establishment of agricultural terrace systems in the northern Apennines started during the Renaissance (fourteenth – fifteenth century CE) (Sereni, 1961). Nevertheless, recent analogous case studies have pushed the construction of large-scale terrace systems back to the tenth–twelth centuries CE (Turner et al., 2021). In the study area, stone walls which are very similar to the terrace walls, have also been used widely between steeply-sloping fields, presumably to control soil erosion and delimit tenurial boundaries. Indeed, the historic rural landscape of the area is still characterised mainly by a mosaic of irregular fields often delimited by hedgerows with trees and shrubs. The genesis of this historic landscape is likely to date back to the thirteenth-century CE, when the sharecropping system was largely adopted in the region (Piccinni, 2010; Rombaldi, 1965) along with agroforestry practices (known as 'alberata emiliana') (Montanari, 2010; Sereni, 1961) (Figure 2). The area's land management system appears to have remained largely unaltered until the end of the nineteenth-century CE (Cafasi, 1980; Cazzola, 2010; Rombai & Bomcompagni, 2010).

3. Material and methods

Geographic Information Systems (GIS) and remote sensing technologies are increasingly recognised as effective tools in landscape studies across different disciplines (Otto et al., 2018; Popescu & Gibbs, 2010; Wheatley & Gillings, 2013). The development of FOSS (Free and Open Source Software) geospatial tools has further broadened the community of users (Brandolini et al., 2021; Steiniger & Hay, 2009).

Each HLC study uses GIS (Dabaut & Carrer, 2020) to map 'historic landscape character types' (HLC types) based on distinctive characteristics, which result from known historical processes. HLC uses a qualitative but formalised method to map the chronological

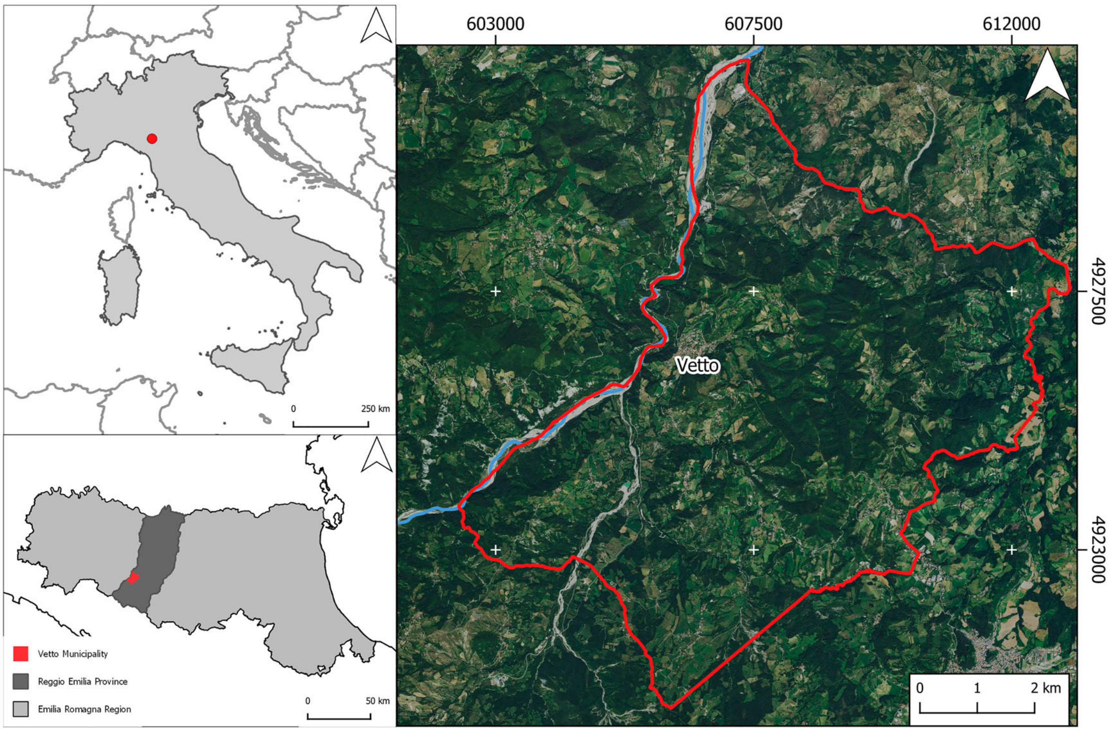

Figure 1. Location of Vetto on the Northern Apennines (Reggio Emilia province, Italy).

and spatial complexity of historic landscapes (Turner, 2018; Turner & Crow, 2010).

The HLC mapping of an area consists in the identification of the smallest 'Uniform Diachronic Unit' (UDU) with distinct landscape character through time. In this project, the specific threshold chosen corresponds to an area of 0.5 ha (=5000 m^2). Each UDU consists of a polygon, whose size and shape depend on the variability of the HLC type throughout time. Initially, the spatial data sources were organised in Time Layers (TLs) according to their chronological phase. By comparing data from the oldest through to the most recent TLs, the smallest UDUs above the threshold of 0.5 ha were defined (Dabaut & Carrer, 2020) (Figure 3).

In this research, the various sources employed include historical maps, nineteenth-century cadastral records, aerial photography and satellite images (for details, see Table 1).

Two sets of historic orthoimages (i.e. the *Volo GAI* and *Volo CGRA*, Table 1) were provided in photogrammetric TIFF format (2500 dpi), while the sheets of the nineteenth-century cadastral map (i.e. *Nuovo Catasto Terreni*, Table 1) were digitised using a photogrammetric approach (Brandolini & Patrucco, 2019) with the software Agisoft Metashape (Agisoft, 2020). All the sources not available in Web Map Service (WMS) format were georectified in QGIS 3.16.5-Hannover (QGIS Development Team, 2021) with Thin Plate Spline (TPS) and cubic resampling methods (Baiocchi et al., 2013; Brandolini et al., 2020), using Ground Control Points (GCPs) identified in WMS cartographic sources (e.g. the topographic map called 'Carta Tecnica Regionale', Table 1). Moreover, to minimise the spatial inaccuracy, the 'backdating approach' was employed (Bednarczyk et al., 2016), which consists of verifying and correcting the positions of the points in older maps according to recent and more accurate maps (Brandolini et al., 2020; Lieskovský et al., 2018). The resulting HLC Spatio-temporal database consists of a GeoPackage (.gpkg) vectorial layer, in which all the information regarding the UDUs identified in the study area is stored and sorted in an attribute table. These values concern not only the physical characteristics of the UDUs (e.g. Land Use, Number of Fields, Pattern Morphology) but also a qualitative assessment of the accuracy of the data recorded (i.e. Confidence: Certain, Possible, Probable) and its legibility (i.e. Complete, Significant, Partial, Fragmentary, Invisible).

In the second stage of the project, this dataset was explored with two spatial statistical tools using the programming language R (R Core Team, 2021): *Local Indicators for Categorical Data* (LICD) (Bivand et al., 2017; Boots, 2006) and *Point Pattern analysis* (PPA) (Baddeley et al., 2015). The LICD method is based on join-count statistics (JCS), measuring the correlation between binomial variables and the distance between observations (Cliff & Ord, 1973). LICD has been recently used in landscape archaeological studies for verifying visible patterns and disclosing hidden spatial relationships. It uses JCS to verify the occurrence of events (categories) in each spatial unit within the study area classifying the cells in the

Figure 2. Remnants of historical agroforestry systems that are still recognisable in the Vetto area. Regular rows of service trees were used to be cultivated with vineyards and crops (Photo: © Brandolini F. 2021).

event (B) and non-event (W) regions. The resulting regional combinations are clumps (groups of B cells sharing an edge); cluster (significant number of *B*s and significant BB); outlier (significant number of non-B); dispersed (significant BW); outlier in the heterogeneous area (significant outlier with significant BW) (Carrer et al., 2021). In this research, LICD was used to address the local spatial associations between the UDUs.

PPA is the statistical study of point patterns to identify spatial trends in their density (Baddeley et al., 2015). The application of PPA in landscape studies has been widely applied in Ecology (Ben-Said, 2021), and it is growing popular also in Archaeology (Brandolini & Carrer, 2020; Costanzo et al., 2021; Knitter & Nakoinz, 2018). In this study, PPA was used to provide a quantitative assessment of the correlations between different components of the Vetto landscape. Three spatial variables were defined: the euclidean distances from irregular fields and combined fields, respectively and *geomorphon* (Jasiewicz & Stepinski, 2013). The latter was selected as a 'control-covariate' to check whether the topography of the area conditioned the position of historic settlements and abandoned rural buildings. Schwarz's Bayesian Information Criterion (BIC) was employed to compare the competing models (Model 0 and Model 1) and assess the performance of each covariate (Zimmerman, 2010). Following the principle of parsimony, stepwise selection of covariates enables the identification of the combination of variables that minimises BIC values, and the covariates that show no significant correlation with the points are excluded during the process. BIC and stepwise model selection can be performed with the R package `MASS` function `stepAIC` (Akaike Information Criterion) (Venables & Ripley, 2002). The significance of BIC-selected covariates was validated against the stationary model (Model 0), using BIC weights.

4. Results

The first stage consisted of the definition of HLC Types based on the information retrieved in the sources listed in Table 1 at a grade that permits the definition of a sufficiently large range of types to avoid losing useful distinctions. In this study, the UDUs were classified into 7 classes and 16 types (Table 2).

According to the sources available, four main TLs were defined for the HLC mapping: 2010s, 2000s, 1970s and 1950s. The nineteenth-century regional cadastral map (Table 1) matches largely with the 1950s fields, whose pattern might be dated back to the Late Medieval period (thirteenth–fifteenth century CE). Nevertheless, in the absence of certain

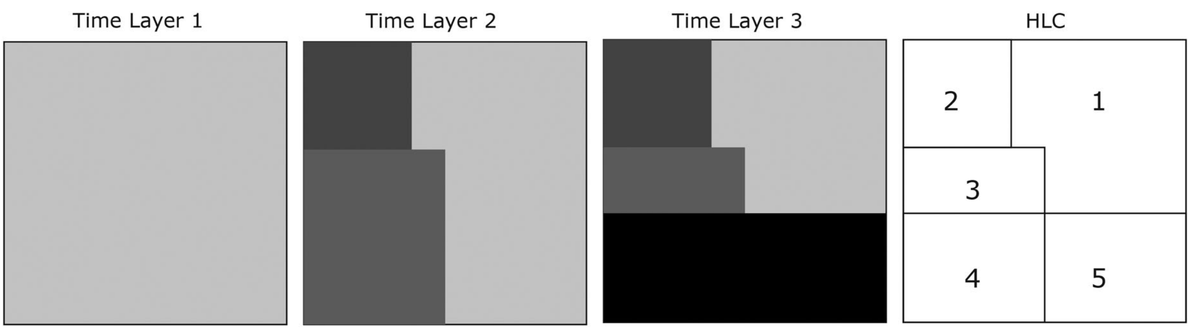

Figure 3. Schematic representation of the 'uniform diachronic unit' principle used for Historic Landscape Characterisation (modified from Dabaut & Carrer, 2020).

Table 1. Details of the sources employed for the HLC mapping in the study area.

Name	Publication	Type	Scale	Source	HLC Period
Google© Satellite	2020	Satellite Images	–	QuickMapServices plugin (NextGis, 2019) in QGIS 3.16-Hannover (QGIS Development Team 2021)	2010s
Bing© Satellite	2020	Satellite Images	–	QuickMapServices plugin (NextGis, 2019) in QGIS 3.16-Hannover (QGIS Development Team 2021)	
Carta Tecnica Regionale (CTR)	2018	Cadastral Map	1:5.000	WMS service ('CTR' 2018)	
Compagnia Generale Riprese (CGR) Aeree	2018	Aerial Photos	–	WMS service (CGR' 2018)	
AGEA (Agenzia per le Erogazioni in Agricoltura) 11	2011	Aerial Photos	–	WMS service ('AGEA' 2011)	
AGEA (Agenzia per le Erogazioni in Agricoltura) 08	2008	Aerial Photos	–	WMS service ('AGEA' 2008)	2000s
Volo Compagnia Generale Riprese Aeree (CGRA)	1976–1978	Aerial Photos	1:13.500	Photos retrieved at the Ufficio cartografico della Provincia di Reggio Emilia ('CGRA' 1976)	1970s
KH-9 (Hexagon)	1974	Satellite Images	–	Declassified image retrieved at the U.S. Geological Survey website ('USGS EROS Archive – Declassified Data – Declassified Satellite Imagery – 3' n.d.)	
Volo GAI (Gruppo Aereo Italiano)	1954–1955	Aerial Photos	1:33.000	Photos retrieved at the Istituto Geografico Militare (IGM) website ('IGM' 1954)	1950s
Nuovo Catasto Terreni	1886–1900	Cadastral Map	1:2.000	Map retrieved at the Ufficio cartografico della Provincia di Reggio Emilia ('Nuovo Catasto Terreni' 1900)	<1950s
Carta Storica Regionale Emilia Romagna	1853	Historical Map	1:50.000	WMS service ('Carta Storica Regionale' 1853)	
Second military survey of the Habsburg Empire	1818–1829	Historical Map	1:28800	Map retrieved at the Mapire website (Ostafin et al., 2021; Timár et al., 2006)	

Table 2. HLC Types defined in the research area.

Class	Type	Shape description
Field	*Strip Field*	Narrow and long fields, which are adjacent.
	Irregular Field	Small fields with irregular and irregular/sinuous boundaries.
	Sub-Rectangular Field	Sub-rectangular and long fields with irregular and sinuous boundaries.
	Combined Field	Fields have been created by the amalgamation of earlier patterns of fields whose boundaries are still recognisable partially.
	Regular Field	Rectangular fields characterised by a regular pattern of boundaries and created by modern agricultural methods.
Terrace	*Step Terrace*	Parallel lines made of stone-built walls.
	Contour Terrace	Terraces that follow topographic contour lines on the slopes.
Settlement	*Nucleated Settlement*	Areas of residential housing, including shops and public houses, built together around a core.
	Public Building	Large, often insulated public building (e.g. cemetery, sport centre, etc.).
Industry	*Power Plant*	Electric power plant.
	Quarry	Area of lithological materials extraction.
	Organised Industrial Zone	Industrial production centres, often related to agriculture.
Rough Ground	*Rough Ground*	Uncultivated lands without maquis vegetation often reflect areas cleared from woodland or forest.
	Cliff/Outcrop	Steep, rocky ground on remote hillsides and badlands on clay materials.
Woodland	*Plantation*	Zones with deliberately planted conifers, nursery or memorial forests.
	Woodland	Deciduous and coniferous woodlands, encompassing natural and semi-natural forest.
Water Source	*River*	Rivers that flow through the study areas.

chronology, this periodisation has been omitted in the pie charts (Figure 4) but has been recorded in the map in a generic *ante-quem* category (i.e.'<1950s' in the Main Map).

By comparing the occurrence of HLC types diachronically over the last 70 years (Figure 4), it is immediately apparent that there has been a significant change, which includes the loss of many of the traditional *irregular fields* (i.e. small rural parcels with irregular boundaries). The disappearance of *irregular fields* largely coincides with the progressive increase of *combined fields* (i.e. open areas which have been created by the amalgamation of earlier patterns of fields whose boundaries are still recognisable partially) or abandoned areas (e.g. *woodland*) (Figure 4). This significant landscape change is probably linked to the economic transformations and depopulation processes that have affected these mountainous areas since the 1950s (Haller & Bender, 2018).

The occurrence of subtler patterns of landscape transformation was addressed by examining the distributions of UDUs according to their chronology (Main Map – LICD/HLC Periods) and according to the HLC types (Main Map – LICD/HLC Types) that occur most frequently in the ROI: *irregular fields*, *combined fields* and *nucleated settlements* (Figure 5).

In detail, the LICD analysis applied to the HLC chronology shows no significant spatial association in landscape components related to the 2010s. In the 2000s, landscape patterns might be due to the urban

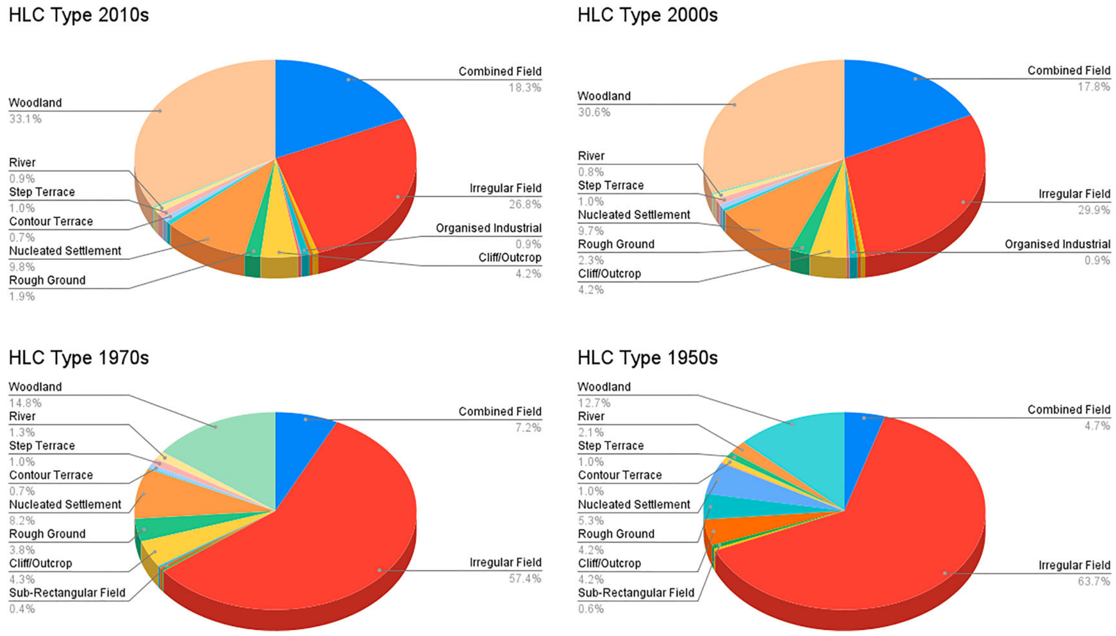

Figure 4. Pie charts representing the occurrence of HLC Types in the four different periods: 1950s, 1970s, 2000s, 2010s.

development of Vetto (Main Map, Figure 4) and the establishment of dispersed *combined fields* in the southern portion of the ROI. In the 1950s, a clumped area was detected in the northwest part of the ROI. Finally, the historic landscape mostly belongs to the pre-contemporary period (<1950s), and the LICD analysis shows two large clumped zones in the north and south. These two areas seem to be the best-preserved parts of the historic landscape, which is probably attributable to post-medieval land management strategies (Figure 6).

Considering the most common HLC types (Main Map – LICD/HLC Types), *irregular fields* show a clear spatial association, especially in the northern area of the ROI, while the *combined fields* are mildly correlated to the south of Vetto. These LICD results could mean that the *irregular fields*, historically related to post-medieval sharecropping, are better preserved in the northeast sector of the ROI. On the contrary, *irregular fields* tend to have been replaced by *combined fields* moving to the south of Vetto and this might correspond to a general abandonment of small agricultural properties, especially in remote areas at higher altitudes. *Nucleated settlements* show clustering only in correspondence to Vetto due to the progressive urbanisation that has occurred here since the 1950s (Figure 7).

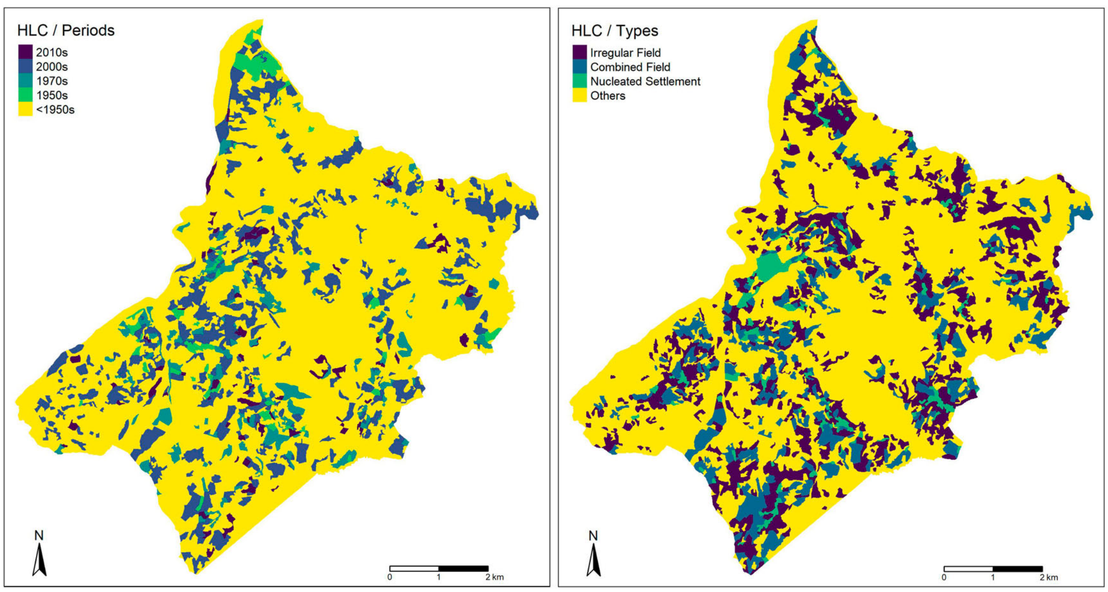

Figure 5. HLC maps representing the UDUs according to their chronology (on the left) and the most common HLC type in the current landscape (on the right).

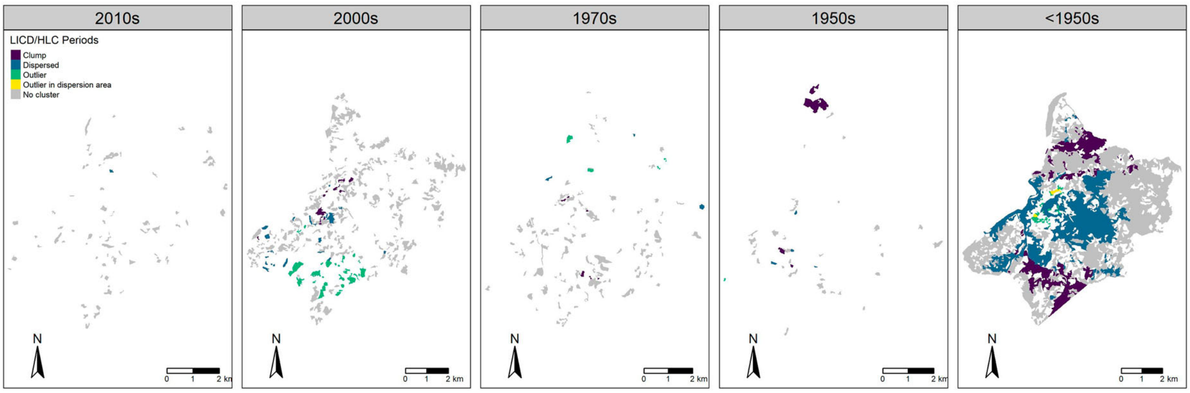

Figure 6. Results of the LICD analysis applied to the HLC chronology.

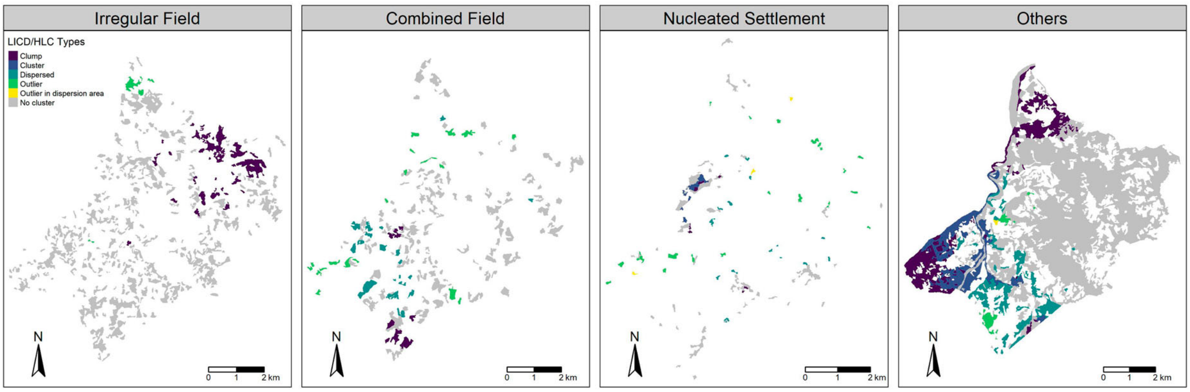

Figure 7. Results of the LICD analysis applied to the HLC types.

Table 3. Results of PPA with the historic settlement point pattern.

Model	Covariates Considered	AIC Values	Covariates Discarded	BIC Values	Weights Model 0–1
0	–	–	–	1041.503	0
1	*Euclidean distances from IF*	1004.9	*Euclidean distances from CF*	1003.898	1
	Geomorphon	1037.3			

Note: IF: Irregular Fields; CF: Combined Fields.

Table 4. Results of PPA with the abandoned rural buildings point pattern.

Model	Covariates Considered	AIC Values	Covariates Discarded	BIC Values	Weights Model 0–1
0	–	–	–	634.795	0.109
1	*Euclidean distances from CF*	1 634.80	*Geomorphon,Euclidean distances from IF*	630.613	0.890

Note: IF: Irregular Fields; CF: Combined Fields.

There appear to be spatial relationships between some HLC types and different components of the settlement pattern, for example, between *irregular fields* and historical settlements (first recorded on maps from the nineteenth-century CE), and between *combined fields* and abandoned rural buildings (i.e. structures identified from cartography and satellite imagery but now abandoned) (see Main Map). PPA was employed to assess spatial dependencies, and Model 1 scored the best performance against the stationary model (Model 0) in both cases. In other words, PPA shows a clear spatial correlation between historic settlements and *irregular fields* (Table 3) and abandoned rural buildings and *combined fields* (Table 4), respectively.

5. Discussion and conclusions

In the resulting Main Map, pre-twentieth-century (<1950s) landscape components can be easily distinguished from those which show substantial later change after the 1950s. Farmland and residential zones, in particular, reflect a mixture of types and historical processes relating to the last ≈ 70 years of landscape change. This should be especially relevant for development planning since it may help identify areas likely to be particularly sensitive to future change.

The application of LICD highlights localised processes of landscape development, revealing interesting and previously unrecognised spatial patterns. In detail, modern and contemporary HLC types are largely isolated among character types of older chronology and present no particular spatial association (Figure 6). On the contrary, pre-1950s types (i.e. *irregular fields*) are more spatially interwoven than expected, and the local landscape character is not strongly affected by the change occurring in neighbouring regions (Figure 7). In detail, pre-twentieth-century *irregular fields* are predominant around historic settlements (Table 3), while the advent of *combined fields* seems correlated to the presence of abandoned rural buildings (Table 4). PPA confirmed this spatial association between different landscape components. Even if correlation does not necessarily mean causation (Baddeley et al., 2015), such unpredicted spatial relations between landscape change and historical character can have important implications for future landscape management and development. In this case, for example, historic settlements and their surrounding *irregular fields* need to be considered in future landscape management plans.

Software

The historical cadastral maps were digitised using the software Agisoft Metashape 1.7.5. Data processing and map design were performed with open-source GIS software QGIS 3.16.5 Hannover (2021 QGIS Development Team). The LICD and PPA analysis were conducted with the programming language R (R Core Team, 2021) in Rstudio (RStudio Team, 2021). Spatial covariates have been developed in GRASS GIS (GRASS Dev. Team, 2020).

Open Scholarship

This article has earned the Center for Open Science badge for Open Data. The data are openly accessible at https://doi.org/10.5281/zenodo.5907229.

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Disclosure statement

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Data availability statement

The R script Code, HLC dataset and PPA spatial covariates are available on Zenodo: https://doi.org/10.5281/zenodo.5907229. For a detailed description of LICD, please refer to Carrer et al. (2021) while for an exhaustive explanation of the use of PPA in landscape archaeology, consider the paper of Knitter and Nakoinz (2018).

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