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# The role of historical cartography to evaluate the landscape evolution in the last two centuries: a case study in central Italy

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**ABSTRACT**

The study of landscape evolution in areas characterised by long-term anthropic presence needs a multidisciplinary approach, including the investigation of historical cartography. This work highlights the effectiveness of coupling the old cadastres and land registers within a GIS platform to reconstruct a digitised land use map to be compared with present-time data. The method proposed here can be applied wherever historical maps are available. The case study, I am going to discuss, is in Central Italy (Rieti) and the Gregorian Cadastre of the Papal State (1819) is chosen to be georeferenced and vectorised. The quality-quantitative results depict a rural world with few remnants from the past, with significant landscape changes compared to modern data. These findings provide relevant information for planning processes, nature conservation, and land management.

**KEYWORDS**

Gregorian Cadastre; landscape changes; land use comparison; past land use; Rieti

## Introduction

The Mediterranean region experienced cultural landscape change and development related to socio-economic variations through space and time. The complex mosaic of landscapes observed today is mainly the result of interactions between ecosystems and human practices that give rise to many cultural landscapes and contribute to making the Mediterranean a hotspot of biodiversity (Crutzen & Stoermer, 2021; Dupouey, Dambrine, Laffite, & Moares, 2002; Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000). Ecosystem management adopted by past societies still influences ecosystem services, thus the knowledge of historical land uses plays a key role in understanding the present features of landscapes (Mensing et al., 2013, 2018).

Information retrieved from historical cartography might help to depict the spatiotemporal continuity of ecosystems, identify patterns of biodiversity, and promote future management plans and conservation policies (Abadie et al., 2018; Ferrara et al., 2021; Magliocca et al., 2015; Sobala, 2024).

The research of past land uses relies on many documents and maps; most of them are available as digital images at high resolution, and the Geographic Information System technologies provide effective tools to treat and analyse geospatial data, serving different fields of application (e.g. archaeology, geography, geology and geomorphology, ecology, forestry) (Fuchs,

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Verburg, Clevers, & Herold, 2015 and references therein; Vassilopoulos, Evelpidou, Bender, & Krek, 2008). As a result, historical GIS has become a promising field of investigation within geographic science in the last decades (Gregory & Ell, 2007).

From the Roman Empire, cadastral inventories were introduced to ensure land census, valuation, and taxation, offering a description of properties but missing cartographic information (Bonnie, 2010; Kain & Baigent, 1992; Kaufmann, 2017). The Doomsday Book (1085) commissioned by William I the Conqueror was the first attempt to record land properties of the Kingdom of England (http://www.domesdaybook.co.uk/); given the effectiveness of that cadastre, it was successfully exported in Europe, especially Italy. During the Middle Ages, cadastres were compiled as descriptive; only in 1660-1661, the Alexandrine Cadastre promoted by Pope Alexander VII realised a partial mapping of the noble properties of the Roman countryside along the main consular roads.

A complete and rigorous method to record and map land properties was introduced with the geometric parcel-based cadastres at the end of the 18th century. The transition from a descriptive to a parcel-based system is the effect of the rational thinking dominating that period and can be interpreted as a social justice tool (Belli, Lucchesi, & Raggi, 2021). The cadastral unit is the parcel, defined as a continuous area identified by a unique set of homogeneous property rights (Dale & McLaughlin, 2000). Cadastral mapping required a significant managerial effort but led to a level of knowledge of the territory never reached before.

From a geographical perspective, ancient cadastres retraced the development of urban and rural territories, recording socio-economic and physical changes over time with punctual frameworks rich in details, thanks to the registers linked to the maps which evidenced land and owners' attributes of each parcel.

The comparison with the modern land cover and topographic cartography highlights the cultural and historical evolution of landscapes, the multiple relationships between past and present territorial uses, the transformation or the permanence of territorial elements (administrative boundaries, rural settlements, toponyms, hydrographic networks, viability, etc.) (Ferranti et al., 2001).

In pre-Unitarian Italy, many Cadastres were realised since the 18th century, coupling fine-scale maps and land registers. Charles VII of Augsburg and Vittorio Amedeo II of Savoy were the first to map their possessions in Italy (Duchy of Milan and Piedmont), followed by other ruling families (Malacarne & Di Fazio, 1989). When Napoleon conquered most of Northern Italy and the Papal State, he compiled a cadastre with precise parameters and information that served as a model for the following cadastres up to the end of the 19th century (Kain & Baigent, 1992). He also realised that modern geometric-parcel cadastres would be useful for military purposes because they recorded the exact position of strategic resources (wood, rivers, roads, mills, food supply, etc). Since that period, maps have been a central component of the modern European cadastres; their multi-purpose role has increased in the last decades, due to digitisation and the regular up-to-date processes (Williamson, 1985).

In Central Italy, after the restoration of the Papal State by the Congress of Vienna (1815), Pope Pius VII reformed the organisation of the public administration (6 July 1816). The result was the abandonment of the 12 existing provinces and the institution of 17 new Delegations in addition to the *Comarca* of Rome and its hinterland. In the same year, there was the institution of the Pontifical Cadastre based on the Napoleonic experience. The work lasted about 20 years, made of urban maps (at a scale of 1:2000), land maps (at a scale of 1:4000 or 1:8000), and their relative registers. In 1820, a new reform grouped the 17 delegations into 11 provinces. In 1835, Pope Gregory XVI activated the cadastre which took the name of 'Gregorian' (Magaudda & Vacca, 2019). The importance of this work is evidenced by the Italian post-Unitarian Cadastre (1874-1886) that referenced the Gregorian Cadastre and its geometric-parcel method.

Each original map of the Gregorian Cadastre shows numbered parcels of terrains or buildings, main and secondary roads, rivers, and lakes, while mountain reliefs are drawn in light and shade.

Where needed, the map includes detailed insights into small properties, isolated buildings, or rural villages scattered over the territory (Supplementary Material 1). Every map is accompanied by a land register (called *Brogliardo* or *Sommarione*) where information about soil use, owners, surface, and much more of each parcel are noted. The Gregorian Cadastre was released in two copies, the first was stored at the State Archive of Rome, and the second was split and sent to the local land registry offices according to their administrative pertinence area. The first update of the land registers was done in the middle of the 19$^{th}$ century, about 30 years after the cartographic compilation.

This work investigates the portion of the Gregorian Cadastre that covers the majority of the Rieti Plain and the Mounts Sabini (Latium, Central Italy) matching with the Municipality of Rieti. The area is characterised by a tectonic depression encompassed by mountains and occupied by the *Lacus Velinus* in ancient times (Madonna, Fenelli, Guaitoli, Vessella, & Ciccioli, 2021, Madonna, Murino, & Vessella, 2022). It represents a closed floodplain, within the Apennine Mountain complex, reclaimed since the Roman times with the opening of the Marmore Falls (Camerieri & Mattioli, 2014). Due to its geomorphologic features, the richness of water, and the human centuries-long presence, the Rieti Plain underwent several landscape transformations, thus it represents an interesting study case of the human-environment relationship towards the investigation of historical cartography. Because of this, the present study aims to: (i) reconstruct the land use of the early 19$^{th}$ century using the Gregorian Cadastre of the Municipality of Rieti and evaluate two centuries of agrarian and forest history throughout modern cartography, (ii) analyse the peculiarities of past landscapes currently disappeared, (iii) re-discover species cultivation and agrarian systems to be revived in the future.

## Materials and methods

After the administrative reform of 1820, the *Delegation of Rieti*, belonging to the Province of *Sabina*, covered a surface of 2516 km$^2$ northeast of Rome and bordered the Kingdom of the Two Sicilies (top-right box in Figure 1). The Gregorian Cadastre for that Delegation consists of 161 maps (Zannella, 2007), 19 of them falling within the actual municipal boundary of Rieti (Figure 1) with a surface of 166.78 km$^2$ (details of the maps in Supplementary Material 2). Maps 2 to 7 (centre-north area) cover the portion of the Rieti Valley belonging to the homonymous municipality (map 1 refers to the city itself); the remaining maps interest the mountainous area south of the Turano and Velino rivers (*Mounts Sabini*), map 10 excepted because includes a small section of *Mounts Reatini*. Map 11 (Moggio) is the north-western exclave of Rieti, neighbouring the Municipalities of Contigliano, Colli sul Velino, Greccio and the Province of Umbria. The easternmost part of the municipality is mainly excluded from the Papal State (dashed areas in Figure 1).

This study relied on the copy of the Gregorian Cadastre conserved at the State Archive of Rieti, which has the complete collection of maps and land registers for its Delegation. The cartographic section was acquired at high resolution with a professional scanner, and the maps of the study area were saved as tiff images (Sgambati et al., 2006). This material was first adjusted in contrast and brightness with an image editing software, then imported as a raster in QGis software to be rectified and geo-referenced. The land registers were digitised using the same method.

The effectiveness of georeferencing depends on the quality of the scan of the original paper and the resolution of the same. Some elements of inevitable difficulty for good georeferencing are paper injuries, folds, tears, optical deformation, etc (Bruno, Bianchi, Zerbi, & Roncella, 2015; Ravaschieri, 2011). Finally, there are maps that, for size, exceed those of the scanner surface and therefore require more scans, with an ease of error by the operator in positioning. Once errors in acquiring the map are minimised, the method of georeferencing relies on mathematical transformations that better match the coordinates of known points (Ground Control Points, or

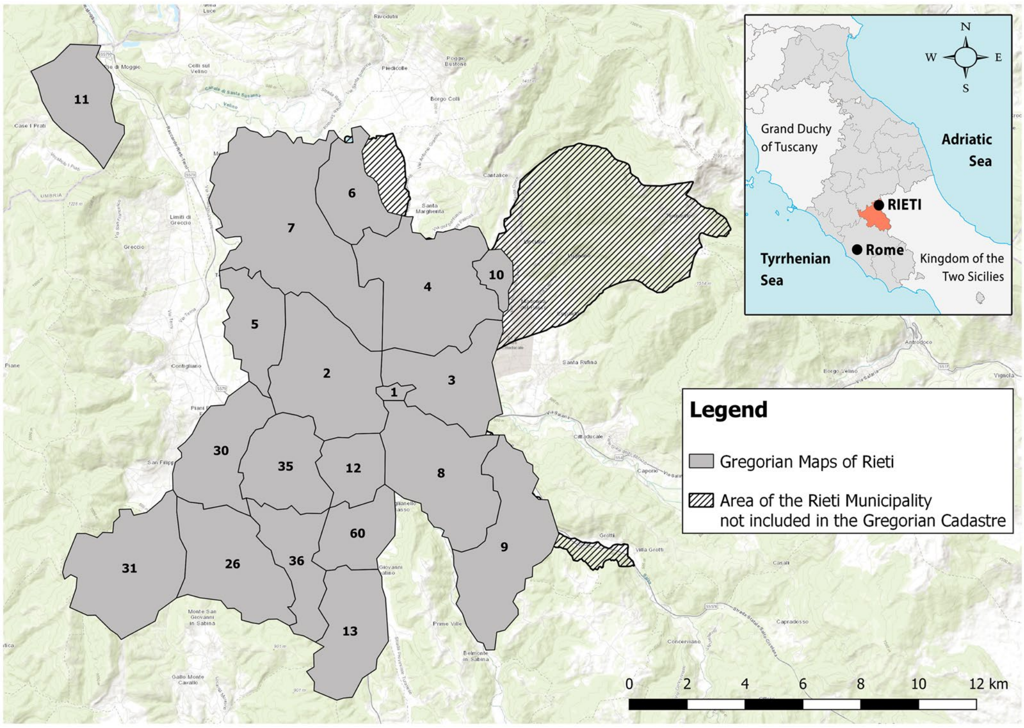


**Figure 1.** Case study location: The Municipality of Rieti with the 19 maps of the Gregoriano Cadastre composing most of its territory. Dashed areas belong to the Kingdom of the Two Sicilies, thus excluded from this work.

GCPs) on the map with the respective geographic coordinates of the reference system adopted in QGis (Baiocchi, Lelo, Milone, & Mormile, 2012; Boutoura & Livieratos, 2006; Vassilopoulos et al., 2008). A first-order transformation is limited to scaling, translating, rotating, and tilting the original image, so straight lines in the image before deformation will remain straight in the deformed image, while rectangles can become parallelograms. With higher-order transformations, straight lines will become curves, with one or more inflection points (Hackeloeer, Klasing, Krisp, & Meng, 2014).

In this study, the 19 maps of the Municipality of Rieti were geo-referenced with a thin-plate spline (TPS) transformation or a second-order polynomial transformation. The use of different transformation methods is related to the topographic features of the maps: open areas generally require less deformation than mountainous ones (Konias, 2000). The number of GCPs ranged between 25 and 70, and they are defined as elements of the Gregorian maps (historical buildings, churches, crossroads, etc.) found on the Numerical Regional Technical Map (CTRN) released in 2014 at a scale of 1:5000 by the Latium Region (Podobnikar, 2010). The need for a modern reference layer is fundamental for rectifying and georeferencing an old map not based on a geodetic network as the Gregorian Cadastre (Affek, 2013). The corrected raster images were adjusted to the local coordinate system of the CTRN (EPSG 32633 corresponding to 'ETRF2000 UTM33N'), then re-projected with the global reference system EPSG 102100, corresponding to 'WGS 1984 Web Mercator Auxiliary Sphere'. All the transformations produced a root mean square error (RMSE) of less than 3 metres, thus validating the geo-referencing methods (Podobnikar, 2010).

The geo-referenced raster maps were vectorised by hand. Despite the manual process taking much more time than an AI approach, it was preferred because of the major accuracy of human capacity in discriminating rivers, roads, buildings, and parcels' boundaries. The vectorised maps were saved as shapefiles of polygons and a field named 'Parcel number' was added to the attribute tables. The information retrieved from the land registers was transcribed into an Excel table, getting six fields: 'Parcel number', 'Subunit', 'Owner', 'Land use', 'District/City quarter', and 'Notes'. The two tables were joined into QGis using the field in common 'Parcel number' to get a digitised Gregorian Cadastre integrated with information from land registers (Ravaschieri, 2011). Those steps were repeated for the 19 maps of the Municipality of Rieti; finally, the function 'merge vectors' was used to get a single shapefile.

The vectorised version of the Gregorian Cadastre was compared to the 'Map of the natural and semi-natural formations' of the Latium Region made in 2010, intended as an improvement of the 4th and 5th Corine Land Cover classes at a scale of 1:10000 (https://dati.lazio.it/catalog/it/dataset/carta-forestale-su-base-tipologica-della-regione-lazio), and the geo-topographic database of Latium Region made in 2014 at a scale of 1:5000 (https://dati.lazio.it/catalog/it/dataset/2014-carta-tecnica-regionale-numerica-scala-1-5-000-provincia-di-rieti), as the last updated references of modern land uses.

The Gregorian Cadastre land registries show a heterogeneous description of the land use often more detailed than recommended by the official documents released from the Census Chancellery of the Papal State (Cancelleria del Censo, 1823). For example, 'house for rent at 1st/2nd/3rd floor', 'home ownership at 1st/2nd/3rd floor' and 'farmhouse with/without court' were clustered into a main category named 'houses', as well as 'coppiced oak forest', 'high oak forest', 'oak forest on stony ground' and 'fruit oaks' were joined into another main category called 'oak forests'. That is required given the hundreds of different nomenclatures adopted in the land registries, somehow related to the knowledge of the employer who described the parcels. An effective comparison with the modern land cover was possible through the restructuring processes of the ancient classes and the subsequent attempt to re-cluster them into more generalised groups to harmonise them into a description of land use categories minimising the loss of information (Gallinelli, 2020; Magaudda & Vacca, 2019; Marta, Morri, D'Agostino, & Maggioli, 2010) (Table 1). The harmonisation of different systems based on the land cover description is essential to cross-compare maps, especially with hundred years of difference and different original purposes (Yang, Li, Chen, Zhang, & Xu, 2017). An overview also interested the bodies of water and the road network. Given the target of the study, the large types of edifices identified in the Gregorian Cadastre were grouped into the generic class of 'Buildings and courtyards'.

## Results

The process of digitalisation of the Municipality of Rieti maps led to 16673 geometries (polygons) with 1250 different types of particle description; those were grouped into 70 categories, later into 28 converging classes considering the modern data, then into 10 macro-categories (see Table 1 for details). Figure 2 shows the summary of the landscapes in 1820. The study area can be divided according to the terrain morphology: the Rieti Valley, occupied by permanent crops and agroforestry systems, the latter extending in the southwest part, and the reliefs in the southern part (plus the exclave of Moggio) where forests and natural/seminatural open areas dominate. Wetlands in the northern part encompass the lakes, while plantations, productive and recreational green areas occur scattered in the southwest and northeast parts. Finally, anthropic infrastructures focus on the city of Rieti and in small districts along the main roads; only a few isolated buildings are in the countryside.

Two hundred years later, the territory has deeply changed, moving towards a simplification of the mosaic of the landscapes (Figure 3). From north to south, it is possible to assess those variations, which can be resumed as follows: wetlands mostly have disappeared around the lakes on the north side, as well as agroforestry systems in favour of simple permanent crops in the middle of the Rieti Valley; forests largely have extended their areas in the northeast and south, replacing ancient natural/seminatural open areas and many plantations, thus reducing fragmentation; urban development has spread from the historic city of Rieti to the Valley and eastward with many new districts and quarters at the expense of crops and agroforestry areas;

**Table 1.** List of the land use macro-categories in this study resulted from the convergence of the categories listed in the Gregorian Cadastre (1820) and in the modern map of natural and semi-natural formations (2009-2014).

| Macro-categories | Harmonized land use categories | N. of original Gregorian Cadastre categories | N. of parcels | Surface (ha) in 1820 | N. of original modern land use categories | N. of parcels | Surface (ha) in 2009-2014 |
|---|---|---|---|---|---|---|---|
| FORESTS | Deciduous forests | 6 | 1110 | 2093.5 | 7 | 40 | 3735.5 |
| | Coniferous forests | 1 | 0 | 0 | 3 | 96 | 185.9 |
| | Oak forests | 4 | 439 | 1176.5 | 6 | 156 | 2697.2 |
| | Chestnut forests | 2 | 165 | 115.4 | 1 | 12 | 63.5 |
| | Beech forests | 2 | 14 | 227.9 | 2 | 7 | 524.8 |
| | Willow forests | 2 | 3 | 12.8 | 1 | 16 | 92.1 |
| | Unspecified forests | 2 | 85 | 222.1 | 1 | 339 | 282.4 |
| | Neoformation forests | 3 | 170 | 194.6 | 1 | 34 | 78.2 |
| NATURAL/SEMI-NATURAL OPEN AREAS | Shrublands and Bushes | 4 | 248 | 245.7 | 4 | 580 | 564.3 |
| | Pastures | 3 | 1628 | 1432.1 | 4 | 660 | 817.8 |
| | Grasses | 1 | 467 | 262.3 | 3 | 86 | 69.7 |
| | Unproductive or barren lands | 2 | 711 | 514.1 | 1 | 849 | 72.1 |
| PLANTATIONS | Vineyards | 1 | 325 | 271.4 | 1 | 208 | 130.8 |
| | Olive groves | 1 | 28 | 22.1 | 1 | 147 | 153.4 |
| AGROFORESTRY SYSTEMS | Wood pastures | 6 | 1137 | 1343.4 | 0 | 0 | 0 |
| | Grasses with trees | 2 | 30 | 24.2 | 0 | 0 | 0 |
| | Vineyards with other trees | 3 | 3 | 1.4 | 0 | 0 | 0 |
| | Olive groves with other trees | 1 | 1 | 0.7 | 0 | 0 | 0 |
| | Crops with trees | 1 | 3114 | 4899.8 | 0 | 0 | 0 |
| PERMANENT CROPS | Arable lands | 1 | 1552 | 2415.4 | 1 | 5541 | 5406.5 |
| PRODUCTIVE / RECREATIONAL GREEN AREAS | Forest nursery | 1 | 17 | 0.4 | 1 | 0 | 0 |
| | Gardens | 1 | 11 | 6.4 | 1 | 9790 | 484.3 |
| | Vegetable gardens | 1 | 129 | 14.4 | 1 | 39 | 11.9 |
| WETLANDS | Wetlands | 1 | 58 | 314 | 1 | 8 | 36.5 |
| MAN-MADE INFRASTRUCTURES | Buildings and courtyards | 15 | 4704 | 86.7 | 19 | 32114 | 464 |
| BODIES OF WATER | Lakes and ponds | 1 | 12 | 174.6 | 1 | 3 | 103.4 |
| | Rivers | 1 | 183 | 330.8 | 3 | 179 | 76 |
| ROADS | Roads | 1 | 329 | 275.4 | 4 | 4404 | 627.8 |

A comparison of the number of parcels and surfaces (ha) occupied by each land use is given.

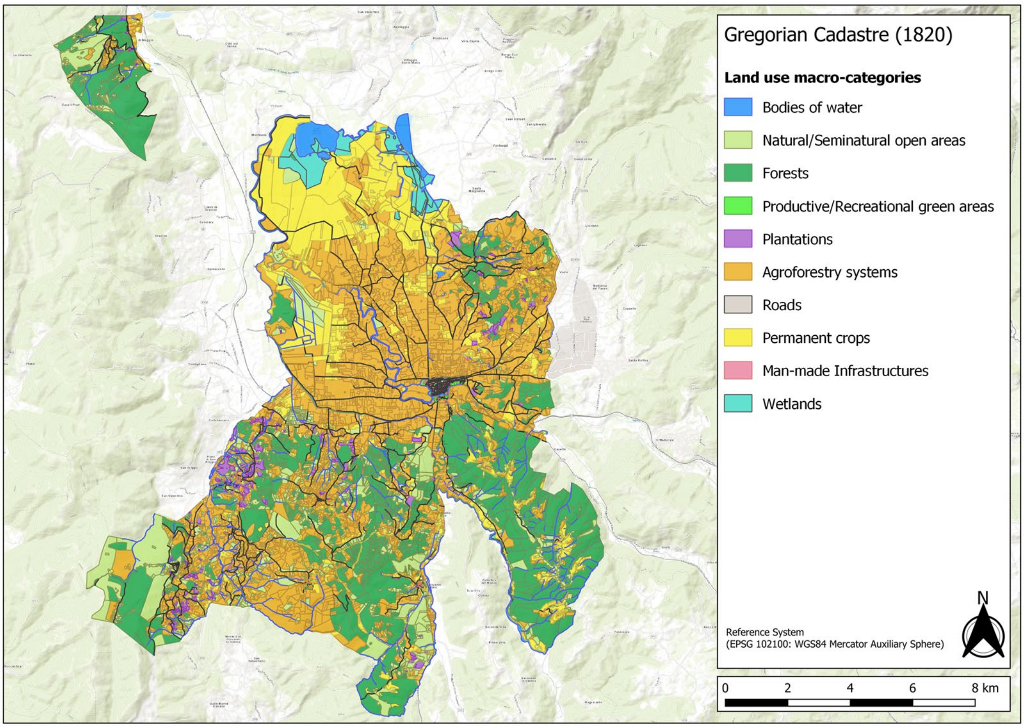


**Figure 2.** Vectorised version of the land use map of the Municipality of Rieti as derived from the Gregorian Cadastre (1819). The colours in the legend show the macro-categories of Table 1.

plantations have reduced their presence in the southwest while they increase in the northeast; finally, roads and infrastructures networks have become more complex following the urban expansion in the Valley.

A quantitative overview of the diversity in landscapes (Table 1) allows getting the distribution of the land use categories in terms of occupied surface. The comparison, between the two investigated time slices, evidence that many changes occurred, and the landscape varied significantly; variations are spread on the whole study area, with less impact in the north, south-east and the exclave of Moggio (Figure 4).

In particular, the actual mosaic of landscapes shows the introduction of conifers in reforestation programs (185.9 hectares of pine and fir forests), the intensification of oak, beech, willow and deciduous forests (almost doubled than in 1820), olive groves (from 22.1 to 153.4 hectares), monocultures (from 2415.2 to 5406.5 hectares) and an increase of shrublands and grasses (from 245.7 to 564.3 hectares). Other categories show significant variations because of the socioeconomic evolution of the Rieti Municipality, notably after the industrialisation process. Urban areas have increased five times, and the roads three times; urbanisation has led to the coverage or drainage of several ditches, the creation of many artificial canals in rural areas, and the exploitation of lakes and ponds (with a global reduction of 65% in surface).

Conversely, the agroforestry systems disappeared (6269.5 hectares converted mainly into arable crops and residential areas), pastures and grasses reduced in surface (43% and 74% respectively), as well as vineyards (46% less), wetlands (89% less) and unproductive lands (86% less). The latter data, crossed with the abovementioned increase of shrublands and grasses might reveal a partial process of evolution towards natural ecosystems. About vineyards, the Gregorian Cadastre registered 4658.8 hectares of arable lands occupied by rows of vines without specifying their coverage, but it is interesting to note that the plantation is often mixed with crops, wheat in particular. Other species recorded in 1819 and worthy of note are the canvas

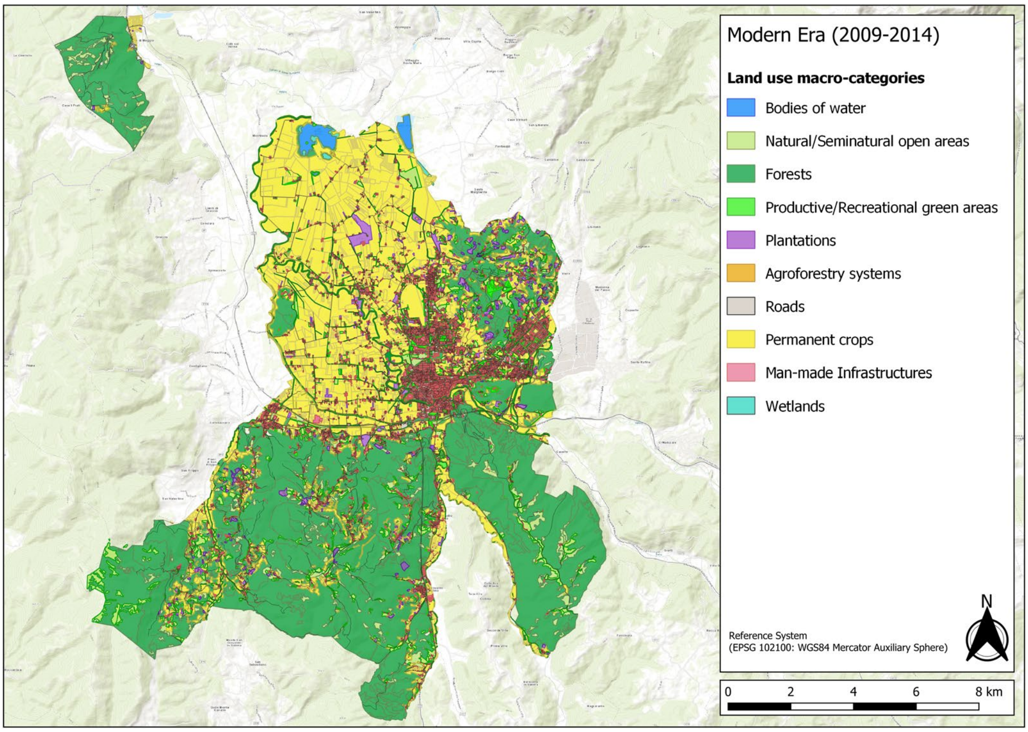


**Figure 3.** Land use map of present time (2009-2014). The colours in the legend show the macro-categories of Table 1.

(*Cannabis sativa* L., even mixed with vineyard, with a surface of 2.4 hectares), the junipers (*Juniperus* spp., 55.8 hectares), the maples (*Acer* spp., scattered in unproductive areas with a surface of 5.8 hectares), the mulberry (*Morus alba* L., occurring in 0.3 hectares of crops) and the broom (*Cytisus scoparius* (L.) Link, 29.8 hectares). A summary matrix of changes in land use is given in Table 2; this is the result of an intersection function in QGIS, between the Gregorian land use map (Figure 2) and the modern one (Figure 3); the graphical overview is shown in Figure 4, while Table 2 returns the surfaces in numbers. Each row shows the surface in hectares of a given macro-category in 1820 converted into another macro-category in 2014. Conversely, it is possible to check the composition of modern macro-categories by reading the matrix by columns, with the grey cells that indicate the unchanged surfaces after 200 years. For example, the present forests account of 7659,7 hectares, 3673.9 of which match with the forests of 1820, thus representing the unaltered surface after 200 years; the remaining hectares observed in 2014 are the result of a landscape conversion from other old macro-categories to forest (values given in the white cells).

Figure 5 shows three different areas of the Municipality of Rieti where changes occurred at different magnitudes: Map 8 (Belvedere, mountainous), Map 7 (Prato Lungo, flat with lakes), and Map 2 (Campo Reatino, flat and bordering the city). In the first example, the Belvedere area has not undergone serious changes in the composition of the landscape, because of its topographical features and its location: it is a mountainous area, already covered by forests in 1820, sparsely populated with few possibilities of urbanisation. This 'inaccessibility' has mostly preserved ancient landscapes, with forests expanding their range at the expense of abandoned agroforestry systems and open areas. Prato Lungo is a flat area, characterised by the presence of lakes and marshes in the northern part, rather marginal compared to the axes of urban expansion of the city of Rieti and still today it is a typical rural area of the Rieti Valley. Here the main changes are linked to the transition from agroforestry systems to monocultures, from

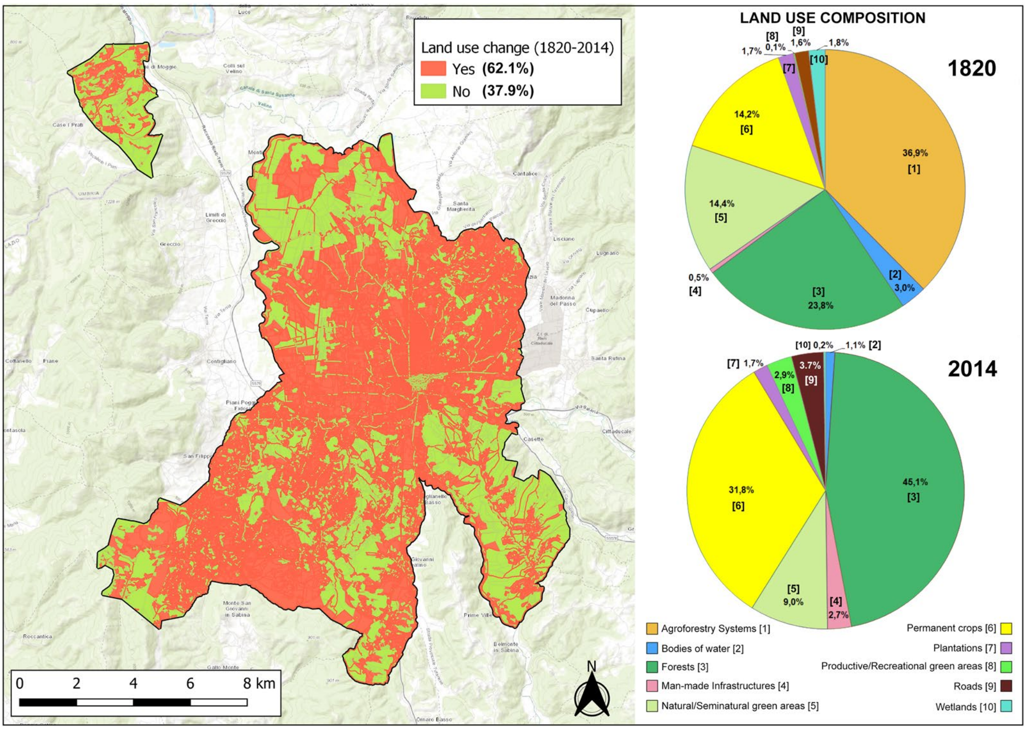


**Figure 4.** Land use changes in the Municipality of Rieti (left panel). Red areas have changed from 1820 to the present time, green areas kept land use unaltered. Pie charts (right panel) show the land use composition in percentage for the time slices considered. The numbers in square brackets within the charts refer to the below macro-classes.

the reduction of wetlands and lakes in favour of new lands to cultivate, which explains about 50% of the changed surface. The last example, Campo Reatino, shares the same orographic characteristics as Prato Lungo, but it is close to the city of Rieti. The eastern part underwent a significant process of urbanisation, while the rural part shows the same evolution as Prato Lungo, i.e. the change from agroforestry systems to permanent crops. As a result, the area has been deeply modified by human activities.

Concerning the forest use in 1820, a specific focus reveals that coppice is 46% of the total forests (1848.8 out of 4042.8 hectares), a value that notably increases at present time (94%, i.e. 7232 out of 7659.6 hectares). Other 123.5 hectares of agrosystem surfaces were interested in coppices, but it is not possible to estimate the real area covered by those plants, because of coverage data missing in the Gregorian Cadastre. High forests pass from 217.5 hectares in 1820 (5.8% of the total forested area) to 181.1 hectares in 2009-2014 (2.4% of the total); other high trees were present in wood pastures and crops, recorded in the land registries, for a total of 35.7 hectares. In some cases, land registers specify the oak species, although they do not give an exhaustive framework of their real distribution. Specimens recorded are holm oak (*Quercus ilex* L.), sessile oak (*Quercus petraea* (Matt.) Liebl.), and turkey oak (*Quercus cerris* L.), while the nomenclature 'fruit oaks' might be traced back to the downy oak (*Quercus pubescens* Willd.) due to its wide distribution in the area (details in Table 3).

## Discussion

Historical cartography shows a great variety of features of cardinal importance to investigate the landscape evolution of territory; in particular, the geometric parcel-based cadastres gained

**Table 2.** Matrix of land use changes from 1820 to 2014.

| 1820 \ 2014 | Bodies of water | Forests | Man-made Infrastructures | Natural/ Seminatural open areas | Permanent crops | Plantations | Productive/ Recreational green areas | Roads | Wetlands | TOTAL SURFACE (ha) 1820 |
|---|---|---|---|---|---|---|---|---|---|---|
| Agroforestry | 19.9 | 1852.0 | 308.2 | 528.9 | 2673.6 | 168.8 | 339.9 | 378.2 | 0.0 | 6269.5 |
| Bodies of water | 146.2 | 135.7 | 3.7 | 19.1 | 149.8 | 1.7 | 5.3 | 9.7 | 34.1 | 505.3 |
| Forests | 0.1 | 3673.9 | 7.9 | 220.3 | 64.0 | 22.3 | 19.2 | 35.2 | 0.0 | 4042.9 |
| Man-made Infrastructures | 0.3 | 6.8 | 43.2 | 4.6 | 10.8 | 0.4 | 8.3 | 12.3 | 0.0 | 86.7 |
| Natural/Seminatural open areas | 1.6 | 1501.3 | 23.1 | 464.2 | 342.5 | 30.6 | 38.1 | 52.8 | 0.0 | 2454.2 |
| Permanent crops | 6.9 | 271.6 | 45.4 | 194.6 | 1733.8 | 41.7 | 54.8 | 66.7 | 0.0 | 2415.5 |
| Plantations | 0.0 | 135.8 | 7.4 | 44.1 | 70.6 | 12.5 | 11.4 | 11.8 | 0.0 | 293.6 |
| Productive/Recreational green areas | 0.5 | 0.8 | 7.5 | 0.0 | 3.2 | 0.3 | 3.4 | 5.6 | 0.0 | 21.3 |
| Roads | 1.6 | 77.4 | 17.1 | 27.6 | 75.9 | 5.8 | 15.4 | 54.6 | 0.0 | 275.4 |
| Wetlands | 2.3 | 4.4 | 0.4 | 20.6 | 282.3 | 0.1 | 0.4 | 1.1 | 2.4 | 314 |
| TOTAL SURFACE (ha) 2014 | 179.4 | 7659.7 | 463.9 | 1524 | 5406.5 | 284.2 | 496.2 | 628 | 36.5 | |

Each row shows the surfaces converted from the macro-category of 1820 to the new ones in 2014. Each column shows the macro-categories of 2014 and the surfaces subtracted from those of 1820. Bold-bordered grey cells give the values of unchanged surfaces after 200 years. Agroforestry systems fully disappeared at present, as mentioned in the text. Values in the cells are given in hectares.

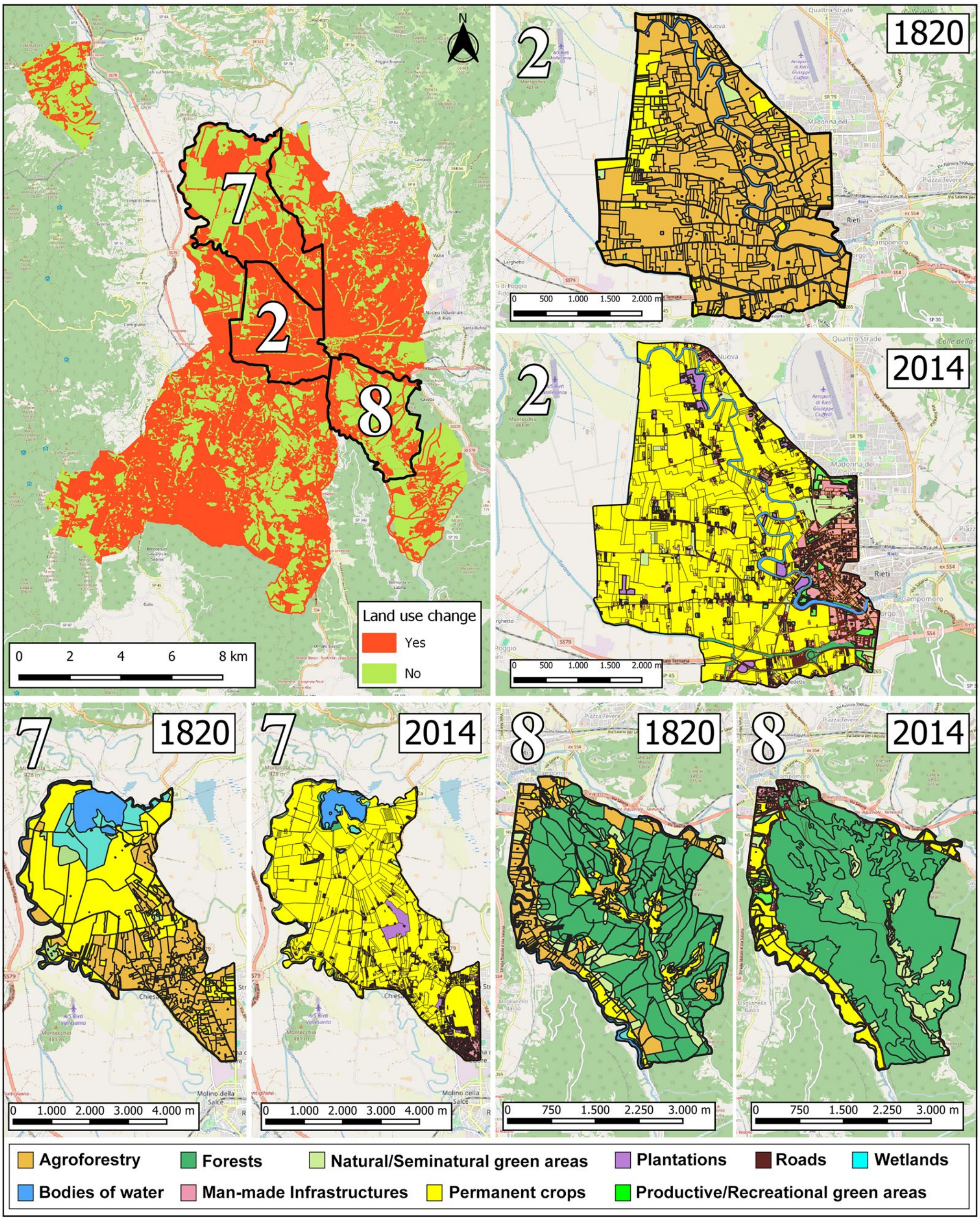


**Figure 5.** Detailed comparison of three vectorised Maps (Campo Reatino, n.2; Prato Lungo, n.7; Belvedere, n.8) in 1820 and 2014. The upper-left box shows the location of the Maps within the 'land use changes map' of Figure 4.

the attention of the researchers because couple spatial (maps) and non-spatial (land registers) data (Agnoletti, 2007; Bender, Boehmer, Jens, & Schumacher, 2005a, 2005b; Dolejš & Forejt, 2019; Forejt, Dolejš, & Raška, 2018; Harvey, Kaim, & Gajda, 2014; Sobala, 2024). Georeferencing and vectorising old maps in a GIS environment is crucial to getting a territorial information system of a past time slice (Cousins, 2001). Because of this, it is important the quality of historical data (cartographic and not). Once a digital version is obtained, and non-spatial data are joined to the cartographic one, it is easy to analyse and infer useful information, measuring

Table 3. Tree species and their forest-use systems in 1820 with surfaces given in hectares.

| Type | Coppice (ha) | High forest (ha) | Not specified (ha) |
|---|---|---|---|
| Deciduous spp. | 1619.4 | 25.4 | 517.3 |
| Generic oak spp. | 30.0 | 35.1 | 340.0 |
| Turkey oak | n/a | 130.0 | 253.7 |
| Holm oak | n/a | n/a | 80.1 |
| Sessile oak | n/a | n/a | 17.9 |
| Downey oak | n/a | n/a | 361.7 |
| Chestnut | 97.9 | 10.1 | 7.4 |
| Beech | 3.5 | 16.6 | 207.8 |
| Willow | n/a | n/a | 12.8 |
| Unspecified spp. | 98.0 | 0.3 | 177.8 |

land changes towards a direct comparison with contemporary data. In this study, the Gregorian Cadastre of the Papal State for the Municipality of Rieti has been tested, and the results showed the effectiveness of those old maps in getting a detailed framework about the landscape diversity at the beginning of the 19th century. A comparison with the landscapes of the 21st century is possible after a process of land use class harmonisation as described in this study.

The main evidence tells a local story, but recoverable in many other contexts, of significant changes in the so-called 'cultural landscape' (Antrop, 2005) over two centuries, characterised by the transition from a rural to an industrialised world (Bruno et al., 2021; Lasanta et al., 2017). Those transformations reflect the rapid socio-economic evolution that involved Europe in the last century, especially after WWII when historical rural landscapes started facing significant changes and threats (Agnoletti, Emanueli, Corrieri, Venturi, & Santoro, 2019; Lasanta et al., 2017; Salvati et al., 2017).

The Rieti Valley is a peculiar case study because it includes a core flat area, rich in water, surrounded by mountains in the middle of the Apennines so it was possible to evaluate the different landscape change dynamics occurring both in plain and in mountainous environments, as exemplified by the three sample areas of Figure 5. In the last years, particular attention has been paid to mountain ecosystems and the drivers responsible for their changes (Malandra, Vitali, Urbinati, Weisberg, & Garbarino, 2019). For example, the hard deforestation practices done in the past to gain lands for grazing and agriculture, and the land abandonment of the same areas after the second half of the 20th century that lead to a gradual increase of natural forest re-growth, is a commonly observed phenomenon in the Mediterranean countries (Abadie et al., 2018; Foster, 1992; Gellrich, Baur, Koch, & Zimmermann, 2007; Malavasi, Carranza, Moravec, & Cutini, 2018; Rocchini, Perry, Salerno, Maccherini, & Chiarucci, 2006). In the southern part of the Rieti Valley, the results depict the abovementioned scenario, with many hectares of agroforestry systems and open areas re-occupied by forests. Comparing the numbers of the forest parcels and their extension, there was a major fragmentation in 1820 (many parcels with small surfaces), while the global area has been increased in 2014 but parcels have reduced in numbers (Tables 1 and 2), indicating greater continuity in the forest cover (see Map 8 in Figure 5 to have an example). Despite those ecosystems can promote recolonisation by the vertebrate fauna and may cause soil erosion and water flow (Falcucci, Maiorano, & Boitani, 2007; Tasser, Mader, & Tappeiner, 2003), the forest recolonisation is accompanied by a simplification of those landscapes with a consequent decrease in biodiversity (Lasanta et al., 2017).

The abandonment of agroforestry systems and extensive pastures, in favour of monocultures and intensive breeding, is another significant landscape change, especially in the flat areas. Here it can be observed the transition from a system of large latifundia in 1820 to a parcellisation in 2014, a phenomenon occurred after the 1960s (see Table 1, Table 2, Maps 2 and 7 of Figure 5) (Fanfani & Spinelli, 2012). The main drivers are the increase in population (the city of Rieti accounted for 11,000 inhabitants in 1816, 21,000 in 1900 and 47,500 in 2017; statistical data available at http://dati.istat.it/Index.aspx), the affirmation of family farms, for the direct and indirect effects of agrarian reform and the application of the law for the development of small peasant property, and the agricultural mechanisation of the mid-20th century (Kay et al., 2019; MacDonald, 1963). The latter promotes the abandonment of treelines above the crops, to facilitate the movements of the machinery. The wetlands reclamation in the northern part of the Rieti Valley is a further consequence of the need for more lands to be cultivated to achieve the population demand for food (Stäuble, Martin, & Reynard, 2008; Stein et al., 2010). The increase of urbanised areas, especially during the Italian economic miracle (1950s-1960s), and the construction of a dense network of artificial channels for irrigation caused a strong exploitation of water resources (García-Ruiz, López-Moreno, Vicente-Serrano, Lasanta–Martínez, & Beguería, 2011). Finally, the obtained results allowed us to map past species occurrence referred to in literature but currently disappeared (e.g. canvas and mulberry; see De Felice, 1965 and Silvestrini, 2012), to notice ancient agricultural practices presently abandoned (e.g. vineyard mixed with wheat) and to depict the old hydrographic network (among other things).

This information might be useful both to researchers for academic studies and to professionals for historical investigations and conservation-oriented land management projects. Popular issues could be the evaluation of flooding risks, the hydrogeological analysis, the identification of reforestation areas with species selection to use, the biodiversity conservation study, the natural landscape restoration, the evaluation of vulnerability of historical-cultural landscapes, and the urban studies. All of them might be topics for which WebGis applications, or Territorial Information Systems, based on historical and present data in a single platform, might help the decision makers to select the best management strategies (Belli et al., 2021; Bender et al., 2005a; Brigante & Radicioni, 2014; Dolejš & Forejt, 2019; Madonna et al., 2022; Magaudda & Vacca, 2019; Orciani, Frazzica, Colosi, & Galletti, 2007; Taffetani, 2008).

In conclusion, the added value of processing historical maps towards a GIS approach relies on the possibility of quantifying the landscape evolution after appropriate methodological measures. However, some critical issues might still arise, for example, if the compared maps (ancient and modern) do not have the same original purpose. This study case analysed an old parcel-based cadastral map (first, designed to be a fiscal instrument) and two complementary modern maps (conceived under an ecosystemic approach as a Corine Land Cover map). Unfortunately, access to the modern cadastre is strictly regulated and many data are protected and cost-demanding, so it was not possible to directly compare two cadastral maps. Another point of criticism might be the effectiveness of doing similar studies in other areas, because of the lack of historical maps and quantitative data for reconstructing land uses.

Further improvements would include a complete analysis of the continuity/change of the landscape structures using a chronological sampling made of as many time horizons as possible, retrievable from other available cadastres, documents, b/w aerial photos, remote sensing analysis, etc., especially in environments strongly anthropized in time (Brown de Colstoun, DeFries, & Townshend, 2006; Piastra, 2011; Picuno, Cillis, & Statuto, 2019; Sobala, 2024; Statuto, Cillis, & Picuno, 2016).

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The author reports there are no competing interests to declare.

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## Data availability statement

Part of the data that support the findings of this study were derived from the following resources available in the public domain: https://dati.lazio.it/catalog/it/dataset/carta-forestale-su-base-tipologica-della-regione-lazio; https://dati.lazio.it/catalog/it/dataset/2014-carta-tecnica-regionale-numerica-scala-1-5-000-provincia-di-rieti. The data about the vectorised version of the Gregorian Cadastre of Rieti is available from the corresponding author, FV, upon reasonable request.

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