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Using chorographic sources to reconstruct past agro-forestry systems. A methodological approach based on the study case of the northern Apennines

Giovanna Pezzi ^{a*}, Davide Donati ^a, Enrico Muzzi ^b, Marco Conedera ^c and Patrik Krebs ^c

^aDepartment of Biological, Geological and Environmental Sciences, University of Bologna, Bologna, Italy; ^bDepartment of Agricultural and Food Sciences, University of Bologna, Bologna, Italy; ^cWSL Insubric Ecosystems Research Group, Cadenazzo, Switzerland

G. Pezzi (Corresponding author) Department of Biological, Geological and Environmental Sciences, University of Bologna, via Irnerio 42, I-40126 Bologna, Italy, Tel: +39 051 2091302; Fax: +39 051 242576, E-mail: giovanna.pezzi@unibo.it

ORCID

Giovanna Pezzi <http://orcid.org/0000-0001-9739-3530>

Davide Donati <http://orcid.org/0000-0003-3152-8951>

Enrico Muzzi <http://orcid.org/0000-0002-9912-3320>

Marco Conedera <http://orcid.org/0000-0003-3980-2142>

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Abstract Historical-geographical (chorographic) descriptions provide some of the earliest formal documentation about landscape. We propose a methodological approach aimed at reconstructing a spatial-explicit picture of the agro-forestry system of an 18th century landscape, detecting main land-use drivers, and

analysing existing legacies of past agro-forestry productivity in the present landscape. The study area was the Bologna Apennines and our data source was a chorographic dictionary from 1781-83. We obtained a matrix of 240 administrative units per 18 agro-forestry products with related productivity indices. Multivariate analysis showed that environmental constraints influenced products and productivity. Agricultural areas (and related products) mainly shaped the hillside, while forests and semi-natural areas (and related products) characterized the mountainside. Such former clustering is still recognizable: agricultural land mostly changed to artificial land-cover, whereas semi-natural areas and forests still exist. The proposed approach confirms that chorography can be a useful tool as a primary source in landscape research.

Using chorographic sources to reconstruct past agro-forestry systems. A methodological approach based on the study case of the northern Apennines (Italy)

Historical-geographical (chorographic) descriptions provide some of the earliest formal documentation about landscape. We propose a methodological approach aimed at reconstructing a spatial-explicit picture of the agro-forestry system of a 18th century landscape, detecting main land-use drivers, and analysing existing legacies of past agro-forestry productivity in the present landscape. The study area was the Bologna Apennines and our data source was a chorographic dictionary from 1781-83. We obtained a matrix of 240 administrative units per 18 agro-forestry products with related productivity indices. Multivariate analysis showed that environmental constraints influenced products and productivity. Agricultural areas (and related products) mainly shaped the hillside, while forests and semi-natural areas (and related products) characterized the mountainside. Such former clustering is still recognizable: agricultural land mostly changed to artificial land-cover, whereas semi-natural areas and forests still exist. The proposed approach confirms that chorography can be a useful tool as a primary source in landscape research.

Keywords: Land cover changes; Historical ecology; Landscape history; Provisioning ES; Geographical Weighted Regression (GWR)

Introduction

A retrospective knowledge of landscape evolution allows for a better understanding of its current structure, function and services (Szabó, 2010; Rick & Lockwood, 2012), as well as existing legacy effects (e.g., Foster et al., 2003; Rhemtulla & Mladenoff, 2007; Boucher et al., 2013; Thompson et al., 2013; Munteanu et al., 2015). Data sources for reconstructing historical landscapes are manifold and vary in their spatial and temporal resolutions (Swetnam et al., 1999). Topographic, historical and cadastral maps covering time spans preceding remote sensing imaging are of paramount importance in this

respect (e.g., Kienast, 1993; Skånes & Bunce, 1997; Cousins, 2001; Petit & Lambin, 2002; Bender et al., 2005; Gustavsson et al., 2007). However there are many other highly heterogeneous sources, ranging from censuses, forest inventories, diaries, printed books, chronicles, and historical-geographical (chorographic) descriptions, which might be considered. The latter are of particular importance as they represent one of the earliest formal georeferenced writings (Rohl, 2011). In recent times such information has not been confined to historical studies alone, but has become increasingly integrated with climatic, environmental, and demographic research in combination with other data sources (e.g., Rippon, 2001; Galloway, 2009; Xiangping et al., 2012; Griffiths & Salisbury, 2013; Hui et al., 2013; Scharf, 2014; Clavero & Hermoso, 2015).

In this paper we propose a methodological approach aimed at systematically collecting and analyzing in a geographic explicit way the information on demography, productive structures and related landscape as reported in historical documentation. To achieve this we used a chorographic dictionary of the Bologna Apennines dating back to the second half of the 18th century. From this we extracted data on agro-forestry production and demographic records at the administrative unit level in order to: provide a georeferenced picture of the agro-forestry system for the late 18th century; (ii) analyze which environmental and socio-economic factors influenced the richness, type and level of production; (iii) test existing legacies between past agricultural and silvicultural production systems and present land cover patterns.

Data and methods

Study area

The study area is represented by the hilly and mountainous Apennine territory of Bologna, which is located southwest from the Roman *via Aemilia* (Figure 1). The

Bologna Apennines cover about 2110 km² and are characterized by marked variations in terms of altitudinal range (40 to 1945 m asl), distance from the city of Bologna, as well as geological and soil constraints. The geological substrate mainly consists of marl, sandstone, clays and chaotic complexes of various rocks incorporated in a clay matrix (scaly clays; it.: *argille scagliose*, see also Table 1). The vegetation consists of mixed oak woods at the lower, hilly to submontane belt, *Fagus sylvatica* at the montane belt, and *Vaccinium myrtillus* and *V. microphyllum* heathlands at the subalpine level. Anthropogenic *Castanea sativa* woods are cultivated as coppices or orchards mostly in an elevation range between 300 and 1000 m asl (Blasi, 2010).

The present landscape is characterized by abandoned land at higher altitudes and in less accessible areas, and a land-use intensification and urbanization in particular at lower and more accessible sites. This is to a large extent the result of the industrialization process since the 1970s that attracted human migration from the Apennine reservoir, causing an anisotropic repartition of the population (Anderlini & Galligani, 1989).

The Calindri Dictionary and its historical context

The chorographic dictionary compiled by Serafino Calindri (*Perugia 1733- †Città della Pieve 1811) is a work conceived as a multi-volume encyclopedia illustrating the most diverse aspects of the Bologna province in the second half of the 18th century. The term 'chorography' literally refers to 'writing' (*graphia*) and a 'space or place' (*choros*) (Rohl, 2011). Under the influence of the Enlightenment and the Encyclopedism of the 18th and 19th centuries, such compilations and systematic listing of collected data resulted in the production of at least 15 Descriptions and Dictionaries throughout Italy between 1780 and 1835 (see Bordone, 1980 or Tosco, 2009, for a detailed list). The chorographic work of Calindri is of particular importance, as it is considered the first complete and

detailed description of a whole territory based on information personally obtained by the author (Fanti, 2003).

At the time of the Calindri dictionary, Bologna was a legation (province) of the Papal States, holding a strong functional control and influence over the countryside (e.g. Bignardi, 1964; Belfanti, 2001). Besides assuring the supply of primary goods (food and wood), the city also exerted a strong control on raw materials of primary industrial interest (Poni, 1990; Anderlini & Gallingani, 1989; Belfanti, 2001). The Calindri dictionary had its origin in the financial crisis of the Bolognese Papal state induced by a period of local wars combined with an iniquitous and preferential tax system (Giacomelli, 2009). Some authors have interpreted this work as a preliminary survey in preparation of a cadastre and its related tax reform, i.e. to tax landowners, including the previously exempt nobility and the Church (Fanti, 2003; Giacomelli, 2009).

Although the ambitious work remained unfinished, six volumes were published between 1781 and 1786, with the first five volumes (1781-1783) completely covering the hilly and mountainous sides of the Bologna hinterland (i.e. the area covered in our study). Its format is of an alphabetically ordered list of administrative units corresponding to a church, parish or municipality (hereafter referred to as units). The author personally collected information from local people and priests on the demographic and agricultural status as well as additional historical or anecdotal references, in order to provide a description of the administrative, physical, geographical, geological and ecclesiastical state of all the units he visited.

Data extraction and harmonization

We first selected the church, parish and municipalities for which Calindri provided detailed information on the type and the quantity of agricultural products and

demography. Single standard agricultural and forestry products were grouped into main product categories, whereas particular and seldom cited products were excluded from data handling (see Electronic appendix). For wheat and other cereals the annual yield was given, whereas for other products extremely heterogeneous descriptions and quantity assessments were provided. Data were thus first grouped into types of product, and the assessment of production level was harmonized and standardized onto a seven point scale (1 = almost nothing to 7 = a very great amount) with '4' set as the central production level, indicating a sufficient quantity of product for sustenance (in the following referred to as sufficient), while lower levels correspond to different degrees of scarcity (hereafter scarce) and higher levels represent the range of overabundance (hereafter abundant, see also Table 2). Starting from this seven point index we calculated different productivity indices at unit level. We first summed up the indices of all cited products for each unit, obtaining higher overall index-values for elevated product richness and/or related quantities. Following the same procedure, we calculated separate production indices for forests and semi-natural areas (*sensu* CORINE Land Cover, level1; European Environmental Agency, 2007) products on one side and agricultural area products on the other. As demographic data at unit level, we considered the number of hamlets; the highest number of families per hamlet; the number of families; and the number of individuals.

Data spatialization

To georeference and spatialize the data we relied on a coeval map of the Bologna Apennines. This valuable cartographic item is a watercolour drawing on paper, originally consisting of twelve rectangles glued on a linen canvas and is conserved in the Archiginnasio Municipal Library of Bologna (www.archiginnasio.it). It shows the main rivers, boundaries of the communes and related toponyms, location of the parish

churches and other features such as the road network. We additionally considered a Digital Elevation Model (DEM) with a resolution of 20 m provided by the Istituto Geografico Militare (www.igmi.org). By combining the information on available (old and present) maps and the present DEM, we defined 125 control points that were used to georeference the old map using the 'adjust' transformation option in ArcMap (Esri ArcGIS 10.1). Finally we spatially joined the information extracted from the *chorographic source* with related toponyms to the corresponding polygons in the shapefile of the units defined on the *Archiginnasio* map, including ancillary geological and geomorphological data. Elevation (min, max, and mean) and slope (percentage of slope $<15^{\circ}$ = low, 15° to 30° = medium, and $>30^{\circ}$ = high) were extracted from the DEM. The composition of rock types, soil thickness, calcareous and/or acid soil was retrieved from soil (1:250.000) and geological (1:25.000) maps available at <http://geo.regione.emilia-romagna.it/geocatalogo/>.

The present population was estimated at unit level by considering the basic geographic sections (*sezioni di censimento* = census sections) of the 2011 Italian population census provided by the Istituto Nazionale di Statistica (www.istat.it). In particular, we used the function transfer attributes of the ET GeoWizards GIS tool to calculate the population for every unit-polygon starting from the resident population in the related census sections, and by taking into account the ratio of spatial overlapping between the two categories of features.

Finally, in order to detect possible legacy and vestiges of past land-use in the present-day landscape, the Artificial surfaces, Agricultural areas, Forests and semi-natural areas categories (sensu CORINE Land Cover, level 1) were taken from the 2003 land cover map of the Emilia Romagna Region (scale 1:25.000). The percentages of these three land cover categories were then calculated for each unit (Table 1).

Data analysis

Units and related products were analysed by multivariate techniques using the software R 3.4.2 for statistical computing and graphics (R Core Team, 2017).

An Advanced Fuzzy Clustering (Package *advclust*; Achmad & Setia, 2016) was performed on the matrix of geographic-demographic data describing the characteristics of the units presented in the *chorographic source*. The number of clusters and the best fitting model were chosen on the basis of the available validation indices as calculated from the membership matrix or from the distance and membership matrix using the *validation.index* function of the R Package *advclust*. We then ran a Canonical Discriminant Analysis of the products provided at unit level. For this purpose we used the *candisc* Package (Friendly & Fox, 2017) for computing canonical scores and vectors, so as to transform the original variables into a canonical space of maximal differences for the targeted terms, whilst controlling the other model terms. Finally, productivity at unit level was tested by comparing the unit productivity indices for each cluster via ANOVA (both parametric and non-parametric).

Additionally, we explored possible patterns of non-stationarity in the relationship between geographic-demographic predictor variables and the productivity of forests and semi-natural area products and field products, respectively. For this purpose, we compared the performance of the Geographically Weighted Regression (GWR) best model over the Ordinary Least Square (OLS) best regression model. While the latter technique produces an equation that summarizes global relationships, the former generates spatial dependence that expresses local spatial variation (Fotheringham et al., 1998; Tu & Xia, 2008; Liu et al., 2011). Models with many parameters may have a very good fit to the data but few degrees of freedom (Kupfer & Farris, 2007). We therefore

did not consider the R^2 as the most suitable metric for selecting the best models or for comparing GWR and OLS regression models. Instead, a methodology that minimizes the corrected Akaike Information Criterion (AICc) was used to find the model with the lowest AICc that correctly explained the data. In fact, lower AICc values indicate a closer approximation of the model to reality and the best model is the one with the smallest AICc. We therefore selected the best GWR model by calculating GWR models of productivity using all possible combinations of geographic-demographic predictor variables, ranging from individual variable models to a model incorporating all predictors. With the aim of evaluating models that emerge from all possible combinations of individual variables, we selected the best OLS model by a model selection and a multi-model inference performed on the set of explanatory variables (see Rangel et al, 2010). Finally, results from OLS and GWR were compared, and one method was considered better than the other if the difference in AICc values between the best models was at least 3 (see Fotheringham et al., 1998; Liu et al., 2011). Significant non-stationarity of the localized regression coefficient was assumed if the GWR model described the relationship significantly better than a global model developed by using OLS regression. We also verified the autocorrelation coefficient (Moran's I) of the best method and model, in order to check for absence of autocorrelation (Moran's $I < 0.05$) (see Diniz-Filho et al., 2003 and 2008). OLS and GWR regressions were performed using Spatial Analysis in Macroecology software (SAM v4.0; Rangel et al., 2010).

To detect legacy and vestiges of past land-use in the present landscape, an additional generalized Canonical Discriminant Analysis was performed using the R Package candisc (Friendly and Fox 2017) to analyse possible land cover patterns on the retained unit clusters. By using the R Package vegan (Oksanen et al., 2018) a Canonical

Correlation Analysis (CCorA function) was performed between the present composition in land cover and the productivity and product richness, considering separately products of forests and semi-natural areas (hereafter forest) and field areas (hereafter field).

Finally, past and present demography were compared.

Results

General features

The final data set consists of a matrix of 240 units per 18 products (Tables 1 and 2). Most of the units (74%) are both parishes and communes, 25% are just parishes, and the remaining few are municipalities. Unit data and features can vary greatly in terms of population (range: 35-1997 inhabitants) and land area (range: 0.36-21 km²), related population density (range: 4-513 people/ km²), altitudinal gradient (range of the centroid mean values: 137-920 m asl), as well as lithological and soil conditions (Table 1). Products range from 7 to 13 per unit (Table 1). Ten out of eighteen are by-products of agricultural areas, whereas the remaining eight derive from the silvo-pastoral management (Table 2). These are mainly represented by food (9) and forage (3), followed by textile fibre (3) and fuel wood (3). Eleven products are recorded in at least 60% of the units (wheat, cereals, grape, fruit, raw silk cocoon, hemp, pasture, hay, nuts, acorn and wood). Overall, scarce to sufficient production levels prevail (about 65% of cases). In particular, the scarce level dominates for olive oil, silk, hemp and linen whereas hay, wheat and cereal levels range from scarce to sufficient. Grape and fruit may range from scarce to abundant while acorn, beech wood and timber are in general abundant. Two kinds of chestnut fruits are mentioned in the *chorographic source*: the *marroni* are the top quality, luxury, and high standard chestnut varieties growing on good soil and in a mild climate only, which are always mentioned as abundant where

cultivated; nuts, on the other hand, refer to the more ecologically unpretentious chestnut varieties used as staple food, including flour production, which may range from scarce to abundant.

Unit clusters and product types

All validation indices of the Advanced Fuzzy Clustering indicate in twos the number of clusters for the units (Table 3). The first grouping of 147 units forms the hilly part of the study area (hereafter referred to as cluster H) and the second includes the remaining 93 of the mountainous part (hereafter referred to as cluster M) (Figure 1). When looking at the centroid mean values of the variables considered in the analysis (Table 4) it becomes clear that the mountain cluster M includes units at higher elevation, greater in size, and characterized by shallow and acid soils. From a lithological standpoint these mountainous areas are characterized by a higher percentage of sandstone, rock, and scaly clays. By contrast, the hilly cluster (H) refers to areas with a higher content in calcareous soils, marl and sands. Interestingly, the two groups differ in numbers of inhabitants and families per unit, which are higher in the mountainous part (M), but not in terms of overall population density, which does not statistically differ between the two clusters (Figure 2).

The Canonical Discriminant Analysis performed on the two clusters also allowed us to detect differences in the product structure (Figure 3). In the H cluster, field products generally dominated with a significantly higher proportion of hemp, grape and olive oil, but with the exception of rye and cereals. The mountain units (M) are more suited to forest and open areas products, with a significant higher production of nuts, *marroni*, charcoal, beech wood and hay, with acorn representing the only exception.

On analyzing the productivity index with an ANOVA test, the two clusters do not show

any significant differences in overall productivity, but display significant (and opposing) differences when considering field and forest productivity separately (Table 5).

Effects of geographic-demographic factors on productivity

The relationship between the productivity of field products and geographic-demographic variables is not constant and shows spatial non-stationarity: the significantly lower AICc value of the best GWR model (753.990) with respect to that of the best OLS model (762.848) places it as the overall best. The best GWR model also displays a higher R^2 value ($R^2 = 0.578$; $R^2 \text{ Adj} = 0.529$) compared to the best OLS model ($R^2 = 0.456$; $R^2 \text{ Adj} = 0.449$). The autocorrelation is negligible (Moran's $I < 0.05$) at any distance for both best GWR and best OLS models. The best GWR model retains eight variables (number of families, number of hamlets, mean altitude, presence of thin soil, acidity of the soil, as well as surface covered by sandstone, marl, and rock, see Table 6) whereas the best OLS model has only four (mean altitude, acidity of the soil, number of families, and surface covered by clay, data not shown). Figure 4 shows the distributions of the regression coefficients and the p-values of the eight variables. The coefficients vary spatially and the local spatial dependence between field productivity and retained variables exhibit non-constant mean values and variance across the whole Bologna Apennines.

On the contrary, the relationship between the productivity of forest products and geographic-demographic variables is constant over space. The best OLS model displays a significantly smaller AICc value ($\text{AICc} = 852.412$) making it better with respect to the best GWR model ($\text{AICc} = 857.398$). However, the value of R^2 was slightly lower for the OLS model ($R^2 = 0.359$; $R^2 \text{ Adj} = 0.348$) than for the GWR model ($R^2 = 0.415$; R^2

Adj = 0.374). For both best models the autocorrelation is negligible (Moran's $I < 0.05$) at any distance (Figure 5). The best OLS model retains five variables (mean altitude, deep soil coverage, as well as surface covered by sandstone, clay, and rock (Table 7), which are very similar to the five retained by the best GWR model (mean altitude, presence of thin soil, surface covered by sandstone, clay and rock; data not shown).

Legacy of the past landscape

Figure 6 shows the relationships between the productivity and richness of field and forest products during the *chorographic source* time and the main current (2003) land cover categories (i.e., Artificial surfaces, Agricultural areas, Forests and semi-natural areas) resulting from the Canonical Correlation Analysis (CCorA). Regarding Cluster H (hill), the variance explained is 77.78 % for Axis 1 and 17.38% for Axis 2 (Figure 6a). Most of the former areas with good forest productivity became Forests and semi-natural areas, while units with high field productivity and richness mostly changed into Artificial surfaces. The variance explained in the mountainous Cluster M is 55.01% for Axis 1 and 37.51% for Axis 2 (Figure 6b). The former field richness is mostly linked to present Agricultural areas, whereas areas rich in forest products became today's Forests and semi-natural areas. Both field and forest productivity are on the contrary linked to present Artificial surfaces. When considering the results of Canonical Discriminant Analysis calculated at cluster level (Figure 7), the relationship between the hilly region cluster (H) and present Artificial surfaces becomes very clear, while the areas of the mountainous cluster (M) are more linked to current Forests and semi-natural areas.

Total population increases in both clusters, although with a higher rate and some peaks in number of inhabitants in the hilly region cluster (H), which makes the current population density significantly different between the two clusters, with the hilly region

displaying higher but more varying population densities (Figure 2). This is also confirmed by the representation of the population density data aggregated at the current municipality level for the same period (see periods 1781-83 vs 1811 in Figure 8). Figure 8 additionally shows the population evolution over the last two centuries, highlighting the general trend in population growth from the 19th to the beginning of the 20th century, a temporary collapse between the 1950s and 1970s, and a repopulation trend since the 1970s. Again, the evolution of the population is characterized by a marked divergence between the mountain (lower increase) and hilly region (higher increase and higher diversity in population densities among municipalities).

Discussion

The reconstructed landscape and productive structures

The proposed methodological approach allowed us to reconstruct the Provisioning Ecosystem Services (Millennium Ecosystem Assessment, 2005) in terms of nutrition (e.g., wheat, cereals, grape, fruit, nuts, acorn, hay and pasture), raw materials (e.g., wood, hemp, silk), and/or energy supply (e.g., wood) starting from a detailed chorographic description. The obtained landscape picture corresponds to two main land cover categories, which are agricultural areas (mostly organized as intermixed cropping producing wheat, cereals, grape, fruit, hemp, and silk) and forests and semi-natural areas (producing wood from *Quercus*, acorn, nuts, hay and pasture) as reported also by other coeval documents (e.g. Cantoni, 1787; Pedevilla, 1797).

The dominant administrative and organizational structure of the landscape mosaic described by the *chorographic source* is the parish church and its related territory. In fact, ninety-nine percent of the units coincide with a parish, which also mostly overlaps

(75%) with a municipality boundary. The greater importance attributed to the parish is not surprising, given the framework in which the chorographic source is inserted as well as the author's outlook (see *The Calindri Dictionary* section). Overall, the emerging picture highlights the importance of the parish and the priests in local society that goes far beyond religion, also involving social, civil and territorial aspects. As a result, the resident rural community and related territory, particularly in the mountainside, represented the administrative unit that mostly coincided also with the organisational religious unit (the parish), which allowed the religious and the civil community to coincide and to strengthen the sense of belonging of their members (Fanti, 1977; Giacomelli, 1985). Furthermore, records on such aspects as birth, marriage, death, demographic registers and chronicle annotations on the community life in general were kept by the priesthood. Here the priest holds a key role in obtaining and registering data, besides his function as a religious and cultural mediator. This is in line with the judgment of many historians, who consider that the parish represented the fundamental political-religious unit which structured the local and national landscape from medieval times until the 1930s (Foschi & Zagnoni, 1994; Belfanti, 2001; Tosco, 2009).

The products and productivity of each unit are highly influenced by environmental constraints, allowing us to clearly split the study area into two sectors: the mountainous areas (cluster M) and the hillside (cluster H). The two sectors obviously show distinct characteristics in terms of altitudinal gradient, but also of lithology and soil conditions (sandstone, rocks, and scaly clays in the mountains and limestone, marl and sands in the hillsides), and agro-forestry products (mostly related to forests and semi-natural areas in the mountains, preponderance of field products in the hilly areas). This results in a significantly higher proportion of hemp, grape, and olive oil in the hillside and a significantly higher production of nuts, *marroni*, beech wood and hay in the

mountainside.

Overall, the territory appears mainly poorly productive (with only a few exceptions such as nuts, fruit and grape) and without any significant differences in terms of overall productivity between the two clusters, which points to a sound specialization and adaptation of the productive structures to the environmental constraints. Nevertheless, overall environmental conditions in the study area seem to be better with respect to the plain to the north of Bologna, where the abundance of swamps and the frequent flood events result in an increased risk of malaria (Anderlini & Galligani, 1989). When considering productivity in forests and semi-natural areas from field productivity separately, the former display a constant relationship with topographic and pedological variables of the mountain environment. By contrast, field productivity displays different interaction intensities and directions in function of the location (i.e., hill or mountainside) within the study area. Possible reasons for this anisotropy may be the climate and pedology (the hillside is generally warmer and drier compared to the mountainside (Antolini et al., 2015), but is also icy during winter, with very drained soil), the lithology (acidic soils could increase the number of field products in the hilly side, but are usually linked to chestnut cultivation in the mountainside (Corticelli et al., 2004) and geology (the asphyctic, clayish hills unsuitable for building and crops are particularly widespread in the hillsides of the north-eastern corner of the study area).

Furthermore, there is a significant amount of additional and valuable information in the form of anecdotal records (see Electronic appendix), which cannot be treated statistically, but may be valuable in understanding the local socio-economic and cultural framework. For instance, the general reference to ecosystem degradation due to overgrazing and forest over-exploitation, including log driving activities on local torrents and rivers. Worthy of particular note are the records about the niche products

(beech oil, saffron cultivation), local forms of economic integration (straw industry, transhumance, seasonal/temporal migration) and complex land ownership (e.g. sharecropping, farm hand, civic uses). Reports on mulberry and olive tree mortality give an indirect but very precious confirmation of the impact of the adverse climatic conditions during the Little Ice Age.

How did the production structure and the related landscape evolve?

The two main clusters we defined based on the 18th century landscape are still recognizable at present. The hillside is now highly linked to artificial surfaces. As a general rule, the most valuable sites experienced an extreme land use intensification, producing the well-known modern trend of soil sealing, to the detriment of agricultural land and the regulating ecosystem services (Millennium Ecosystem Assessment, 2005). The mountainside, on the contrary, displays a higher resistance to changes, with a significant forest cover increase since the post-World War II period, former field richness being strongly linked to current agricultural areas. In both cases, the typical former multifunctionality of intermixed land usage became completely lost in favour of specialized cultivation such as vineyards or orchards (Farinelli, 2003; Agnoletti, 2007), while most related products and ecosystem services vanished as well (Bürgi et al., 2015).

When following the evolution of single crops, some interesting patterns can be discerned. For instance, in the 18th century chestnut fruit cultivation displayed two very distinct product lines: nut production as a source of staple food, especially in the mountains, and *marroni* production as a luxury food for the wealthy upper-classes (Cantoni, 1787; Conedera & Krebs, 2008). Starting from the 19th century the nut production in the traditional chestnut orchards declined due to various interacting

factors, such as socio-economic changes, the decrease in the importance of chestnut fruits as a staple food, and the spread of diseases such as ink disease (*Phytophthora cambivora*) and chestnut blight (*Cryphonectria parasitica*) (Petri, 1918; Biraghi, 1955; Conedera et al., 2004; Turchetti et al., 2008; Pezzi et al., 2011). The *marroni* cultivation on the contrary partially survived the crisis due to the high added value of the products and subsequently benefitted from a renewed interest in chestnut tree cultivation from the late 1980s. Since then the number of chestnut orchards devoted to *marroni* production has increased, thanks also to specific quality trade-mark and promotion initiatives (Krebs & Conedera, 2008). The restoration of traditional chestnut groves also took place, but these were more closely linked to local tradition and cultural heritage than to income (Pezzi et al., 2017).

Another case of cultivation resurgence is represented by the olive tree. At the time of the *chorographic source*, olive tree cultivation was reduced by unfavourable climatic conditions related to the Little Ice Age (Calindri, 1781-83) and by competition from olive products from Tuscany. Today, favourable climatic conditions have renewed interest in olive tree cultivation (Rotondi et al., 2018), whereas there is no longer any hemp and silk cultivation in the study area. The last references to such cultivation date back to the 1930s in the Italian Census (Istituto Centrale di Statistica del Regno d'Italia, 1935). Currently, remnants of hemp and silk cultivation tend to be associated with cultural and touristic activities as attractions in heritage museums or along specific hiking tracks.

Regarding population density, it is interesting to note that at Calindri's time the socio-economic structure of the study area allowed for a balanced distribution of the population density between hilly and mountainous areas. Past economic structure and agro-forestry techniques made it possible to exploit the entire resources of the territory

and thus to adapt the cultivations to the geographical context. As a consequence, the territory was able to support a certain number of people regardless of the location, while access to missing products was granted by local trades. Starting from the 1920s, population densities in the hilly region experienced a marked increase, a trend that became more apparent and statistically significant with the post-World War II socioeconomic changes (i.e., economic growth, agricultural mechanization, industrialization, expansion of the traffic routes). The socio-economic transformations led to the depopulation of marginal areas (i.e. mountain areas) and to a population shift towards the lowlands. As in other western European contexts, such post-war socio-economic transformations differently impacted on the landscape according to their topography (and the altitudinal gradient in particular) and accessibility (Antrop, 2005). As a consequence, a pronounced land abandonment occurred in the mostly infrastructure-poor mountainous areas, giving rise to a strong forest transition (Falcucci et al., 2006), while the lowlands experienced a strong urbanization and the hillsides represented transition zones with partially contrasting trends in landscape evolution (Anderlini & Galligani, 1989).

From the study case to an over-regional perspective

The historical-geographical (chorographic) work analysed in this study represents one of the earliest formal written documents about the landscape in question. As with many other similar and coeval studies at the time of the Enlightenment and Encyclopedism, it describes the locations in alphabetical order (Bordone, 1980). Thanks to the systematic recording of the economic and statistical aspects as well as the variety of first-hand data collected by compilers, such chorographic works represent a highly valuable source of information about the historical landscapes of the 18th and 19th centuries. Recent local studies dealing with this type of chorographic resource are correspondingly high in

number (e.g., Rohl, 2011; Fanti, 2003; Tosco, 2012; Clavero & Hermoso, 2015).

This paper shows that information derived from historical-geographical descriptions are reliable and can be helpful in establishing guidelines to better understand how the agro-forestry systems and the related landscape came into being before World War II (Antrop, 2005; Agnoletti, 2007). In addition, clear legacies with the current landscape have been documented, thus adding further value to the proposed approach, which could be extended to other territories and landscapes in the future. Historical-geographical descriptions are in fact increasingly available as online sources (Beslagic et al., 2013; Clavero & Hermoso, 2015).

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Caption of figures

Figure 1. Location of the Bolognese Apennines (Italy) and of the considered units of the *chorographic source*. The two colours refer to the unit groups as derived from cluster analysis. Light green = 147 units of cluster H (hill); Pink = 93 units of cluster M (mountain).

Figure 2. Population density among clusters (H= hill, M=mountain) in the late 1700s and 2011. Statistical significance according to the Kruskal-Wallis test: * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

Figure 3. Results of the Canonical Discriminant Analysis among clusters (H= hill, M=mountain) and product types. Level of significance: * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

Figure 4. Geographic distribution of coefficients (left side) and p-values (right side) of the variables of the GWR model of the productivity of field products as function of the geographic-demographic variables (see Table 6 for abbreviations).

Figure 5. Moran's I of the residuals of OLS model of the productivity of forest products as function of the geographic-demographic variables.

Figure 6. Plots of the Canonical Correlation Analysis (CCorA) indicating late 18th century productivity (field and forest) and product richness (field and forest), and 2003 land cover (Artificial surfaces, Agricultural areas, Forests and semi-natural areas). a) Cluster H (hill); b) Cluster M (mountain).

Figure 7. Results of Canonical Discriminant Analysis among clusters (H= hill, M=mountain) and present landscape features (Artificial surfaces, Agricultural areas, Forests and semi-natural areas). Level of significance: * = $P < 0.05$, *** = $P < 0.001$.

Figure 8. Evolution of the population density in the hilly (pale grey) and mountainous (dark grey) cluster over the last two centuries. 1781-83 data refer to the *chorographic source*, records for 1811 and 1853 derive from Anderlini and Galligani (1989), whereas the remaining data are taken from the ISTAT population census (www.istat.it).

Table 1. General features of variables considered in the analysis of the *chorographic source* units.

Variable		Unit n.	Min	Max	Mean	SD
Unit features	Unit area (km ²)	240	0.358	21.340	6.900	4.022
	Min altitude (m)	240	40.880	691.100	237.877	152.187
	Max altitude (m)	240	105.500	1942.540	645.093	303.326
	Mean altitude (m)	240	74.990	1158.570	414.073	223.964
	Slope ($\leq 15^\circ$)	240	1.950	99.930	51.835	20.033
	Slope ($> 15^\circ, \leq 30^\circ$)	240	0.070	64.810	39.534	13.971
	Slope ($> 30^\circ$)	240	0	80.260	8.631	11.888
Lithology	Sandstone (%)	212	0.002	100	29	29
	Sands (%)	134	0.003	100	23	25
	Rocks (%)	130	0.049	100	20	27
	Clay (%)	130	0.010	100	25	26
	Scaly Clays (%)	147	0.005	100	39	29
	Marl (%)	139	0.000	75	16	18
	Conglomerate and breccia (%)	60	0.004	86	15	20
	Gypsum (%)	16	0.046	31	8	10
	Ultramaphic rocks (%)	7	0.383	2	1	1
Soil conditions	Calcareous (%)	202	0.101	100	70	30
	Acid (%)	21	0.018	56	27	18
	Deep (%)	203	0.016	100	65	33
	Thin (%)	49	0.069	100	40	33
Demography	Inhabitants (n.)	240	35	1997	329.338	249.046
	Families (n.)	240	6	312	62.454	45.750
	Population density (people/ km ²)	240	4.391	512.845	58.437	53.187
	Hamlets (n.)	240	0	22	3.271	3.667
	Families per hamlet (n.)	240	0	62	10.529	11.219
Production	Total product richness (n.)	240	7	13	10.433	1.276
	Forest product richness (n.)	240	1	8	4.742	1.063
	Field product richness (n.)	240	2	8	5.692	0.975
	Total productivity	240	5.250	17.500	10.536	2.174

Forest productivity	240	0.750	10.750	5.295	1.735
Field productivity	240	1.500	9.750	5.242	1.570

Table 2. List of products derived from the *chorographic source*, and count of units in which they are recorded. Percentage of units in which they are scarce, sufficient or/and abundant is provided. Scarcity includes levels 1 to 3 (1=*quasi niente*; 2= *penuria, pochissimo, scarseggia di più*; 3 = *scarso, poco*); sufficient (4= *non poco, sufficiente, non molto*); abundant (5=*abbonda*; 6= *molto*; 7= *moltissimo*).

Land use/cover system	Category of product	Product	Unit n.	Scarce %	Sufficient %	Abundant %
Agricultural areas	Food (human)	Wheat	240	45	37	18
		Cereals	239	59	24	18
		Rye	12	25	25	50
		Grape (wine)	229	40	18	42
		Fruit	227	40	14	46
		Olive oil	27	74	13	13
		Vegetables	21	0	0	100
	Fibre	Silk	221	72	9	19
		Hemp	147	94	5	1
		Linen	18	100	0	0
Forest and semi-natural areas	Food (animals)	Hay	225	39	39	22
		Pasture	197	35	11	54
	Food (human)	Nuts from chestnut	185	45	13	42
		<i>Marroni</i>	41	24	8	68
	Food (animals)	Acorn (pig)	212	18	16	67
	Fuelwood	Oak wood	224	39	10	52
		Beech wood	21	6	6	88
		Charcoal	49	56	9	36

Table 3. Validation index result of the Fuzzy Clustering. As the validation index fitness decreases with the increase of the number of clusters, results of more than three are not shown.

Validation Index	Value	
	<i>2 cluster</i>	<i>3 cluster</i>
Partition Coefficient	0.895	0.840
Modified Partition Coefficient	0.789	0.760
Classification Entropy	0.180	0.286
Xie Beni	0.239	0.368
Separation	0.207	0.292
Kwon	58.360	92.968
Tang	58.360	90.632

Table 4. Centroid mean values of the listed variables in each group (H= hill; M= mountain) obtained by the Fuzzy Clustering. The number of units for each cluster is provided. Level of significance (according to U Mann-Whitney) is provided: * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

Variable		Value/cluster		P value	Significance
		Cluster H (n.=147)	Cluster M (n.=93)		
Unit features	Unit area (km ²)	6.314	7.567	0.014	*
	Minimum altitude (m)	136.791	383.652	<0.001	***
	Maximum altitude (m)	444.727	919.977	<0.001	***
	Mean altitude (m)	259.611	632.563	<0.001	***
	Slope ($\leq 15^\circ$)	52.491	50.723	0.681	
	Slope ($> 15^\circ, \leq 30^\circ$)	40.486	38.655	0.230	
	Slope ($> 30^\circ$)	7.023	10.621	0.062	
Lithology	Sandstone (%)	0.195	0.349	<0.001	***
	Sands (%)	0.186	0.037	<0.001	***
	Rock (%)	0.042	0.209	<0.001	***
	Clay (%)	0.210	0.039	<0.001	***
	Scaly Clays (%)	0.176	0.310	0.013	*
	Marl (%)	0.123	0.048	0.002	**
	Conglomerate and breccia (%)	0.059	0.007	<0.001	***
	Gypsum (%)	0.009	0.000	0.001	**
	Ultramafic rocks (%)	0.000	0.001	0.313	
Soil conditions	Calcareous (%)	0.738	0.388	<0.001	***
	Acid (%)	0.014	0.030	0.023	*
	Deep (%)	0.545	0.542	0.896	
	Thin (%)	0.067	0.111	0.920	
Demography	Inhabitants (n.)	296.871	350.586	0.044	*
	Families (n.)	53.587	70.761	<0.001	***
	Hamlets (n.)	1.828	5.220	<0.001	***
	Families per hamlet (n.)	7.745	13.918	<0.001	***

Table 5. ANOVA of the two groups of clusters (H= hill; M= mountain) on the basis of the productivity index.

Parametric and non-parametric ANOVA

Effect	Productivity					
	Total		Forest		Field	
	F	p(F)	F	p(F)	F	p(F)
Cluster (H/M)	0.297	0.586	50.799	0.000	49.621	0.000
Levene's test	12.347	0.001	2.067	0.152	0.442	0.507
U Mann-Whitney	0.970					

Descriptive Statistics

Effect	Unit	Productivity					
	Total			Forest		Field	
	n.	Mean	SD	Mean	SD	Mean	SD
Total	240	10.547	2.172	5.299	1.738	5.248	1.570
Cluster H	147	10.486	1.921	4.723	1.472	5.764	1.465
Cluster M	93	10.644	2.530	6.220	1.741	4.424	1.374

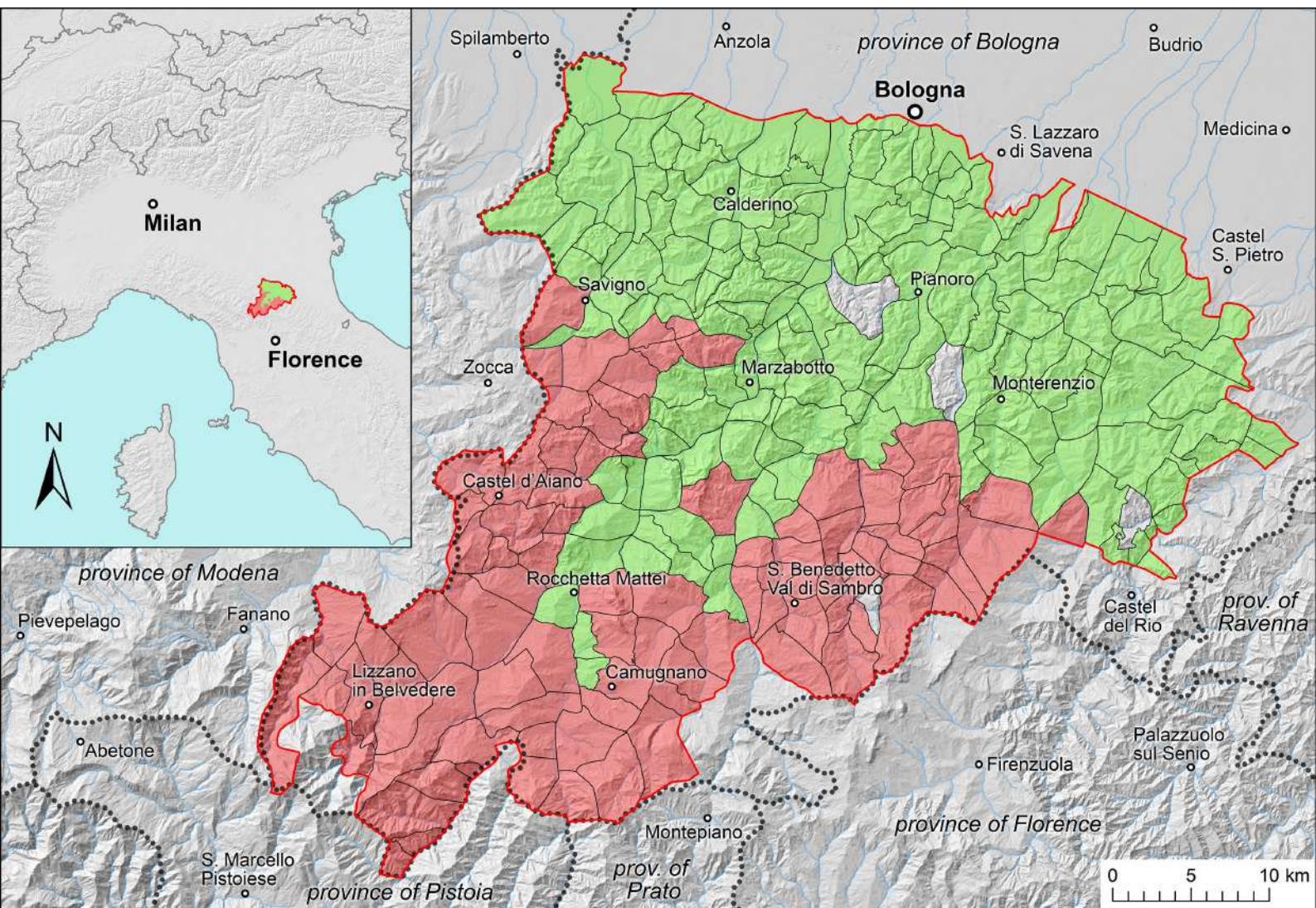
Table 6. Parameter estimates of the best GWR model of the productivity of field products as function of the geographic-demographic predictor variables.

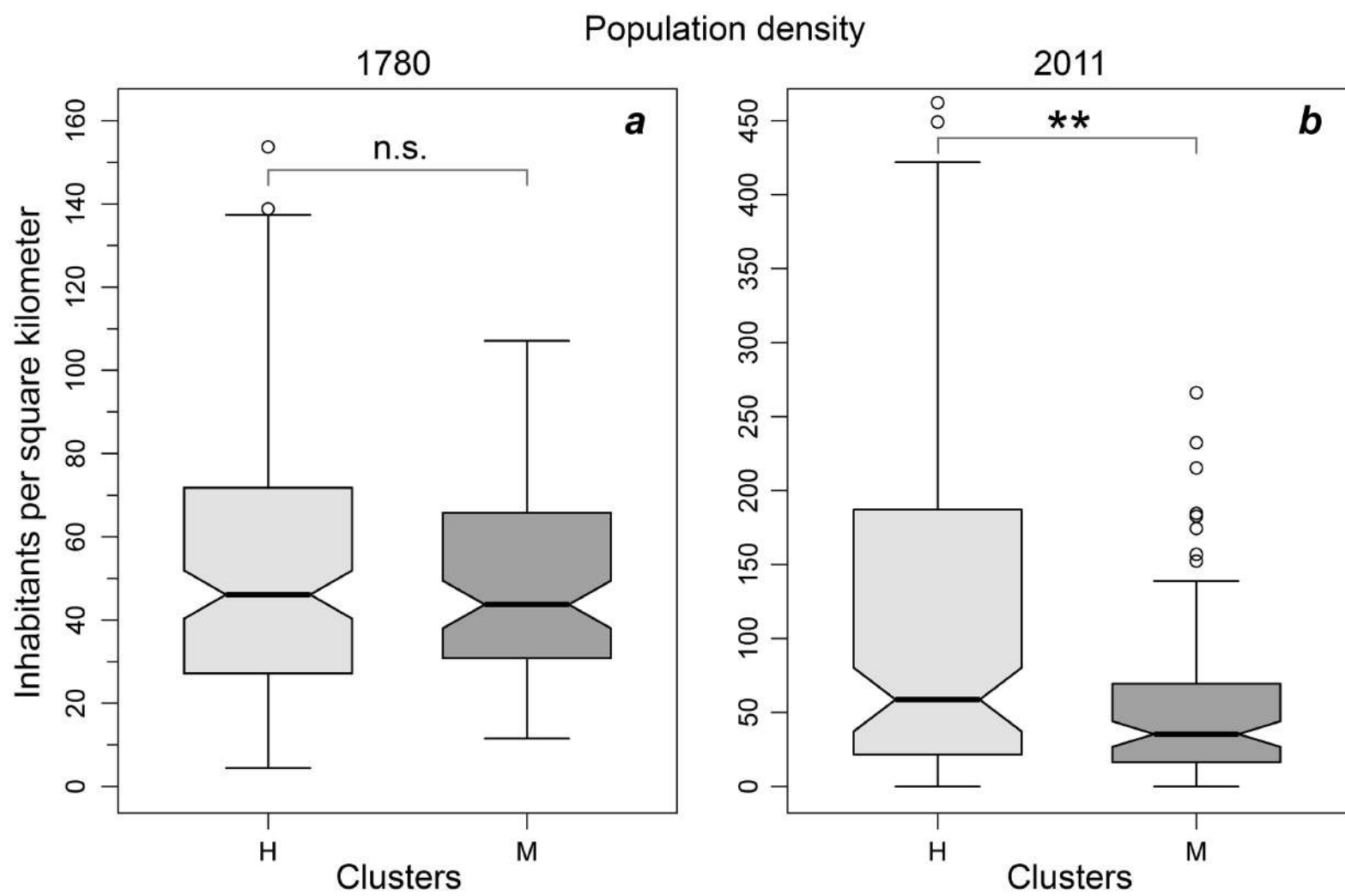
Variable	Minimum	Lwr Quartile	Median	Upr Quartile	Maximum
Constant	5.658	5.900	6.078	6.208	6.458
Mean altitude (ALTMEAN)	-0.006	-0.005	-0.005	-0.004	-0.003
Thin soil (THIN)	-3.068	-2.453	-1.684	-0.609	-0.260
Acid soil (ACID)	0.455	1.935	2.889	3.308	3.593
Marl (MAR)	0.328	0.703	0.931	1.802	2.517
Sandstone (SAND)	-0.968	-0.447	-0.200	0.357	1.886
Rock (ROCK)	-0.745	0.152	0.941	1.765	2.254
Families (n.) (FAM)	0.006	0.011	0.014	0.019	0.024
Hamlets (n.) (HAM)	-0.183	-0.108	-0.028	-0.034	-0.098

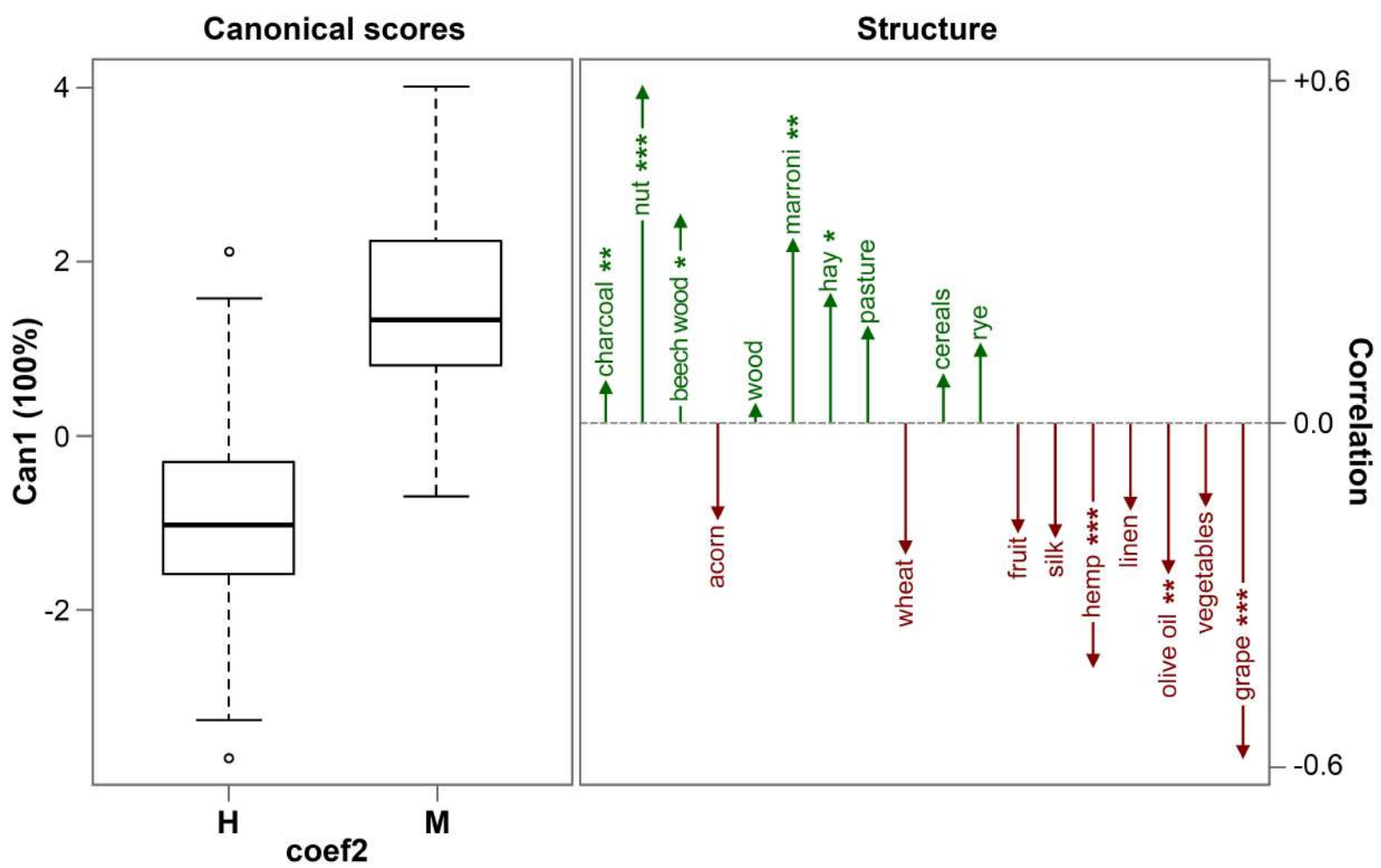
Table 7. Statistical summary of the OLS best model of the productivity of forest products as function of the geographic-demographic variables. Significance codes: * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

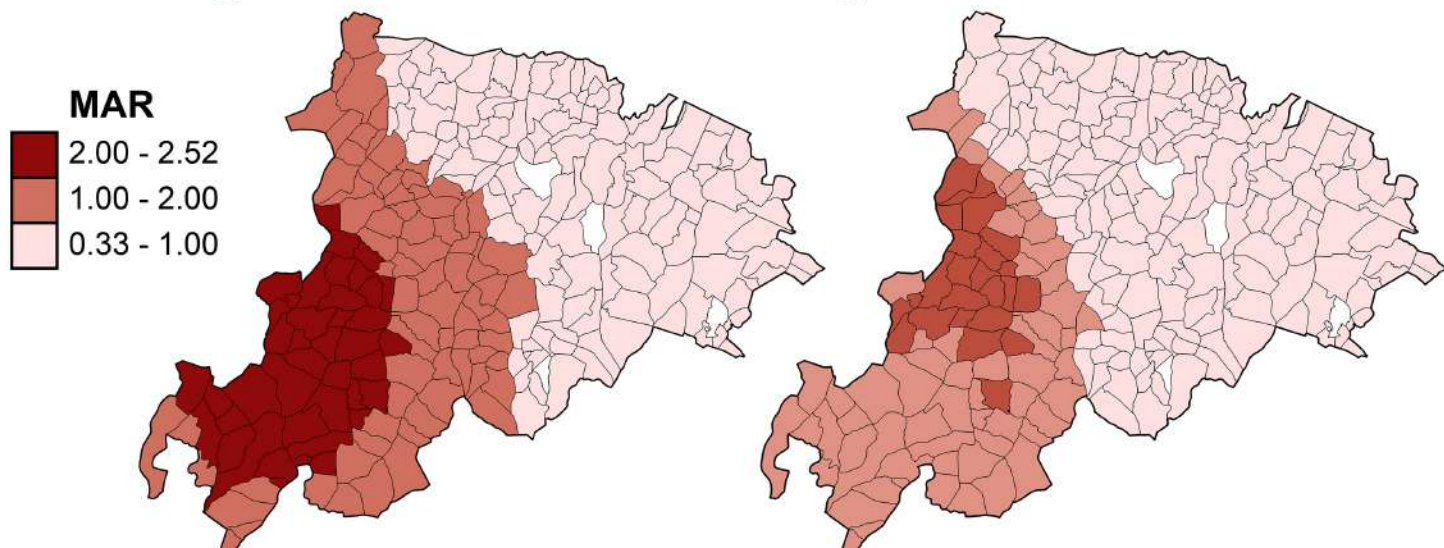
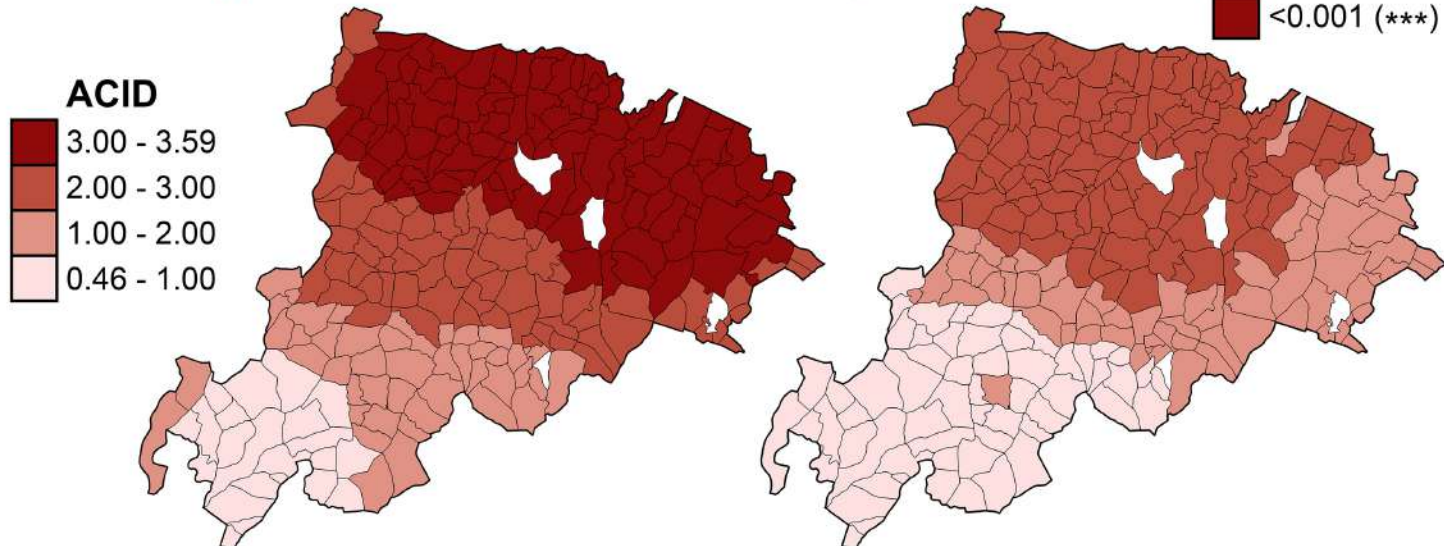
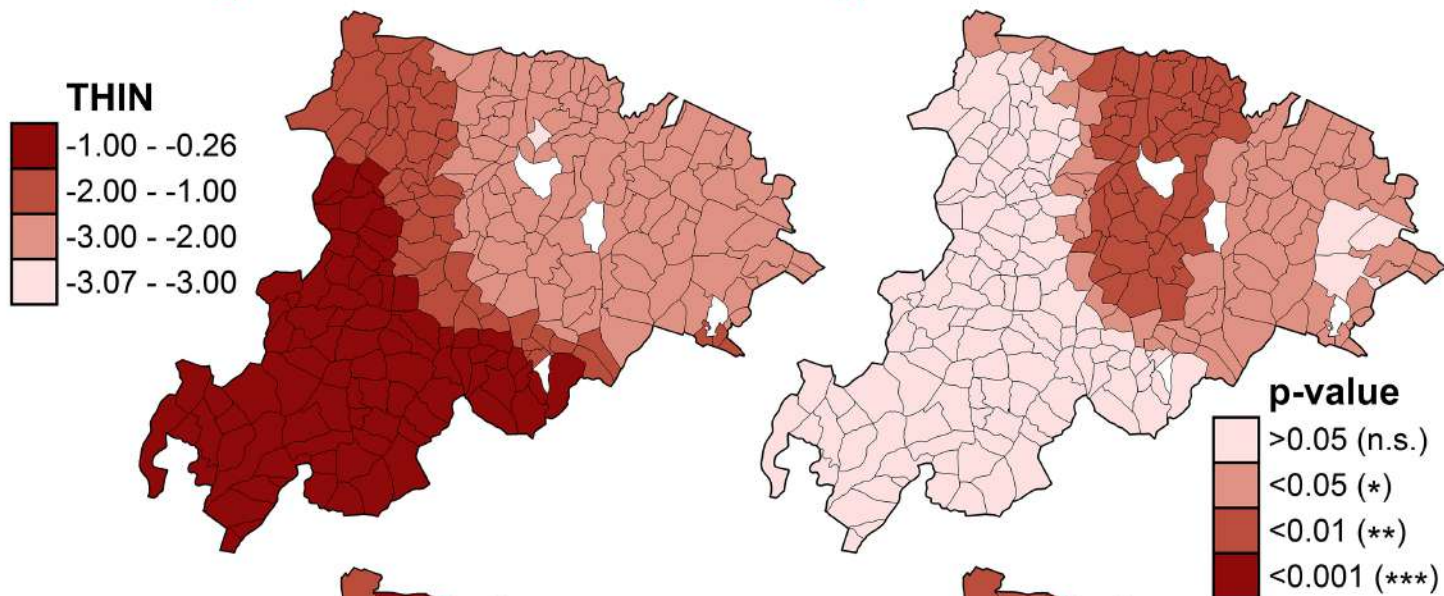
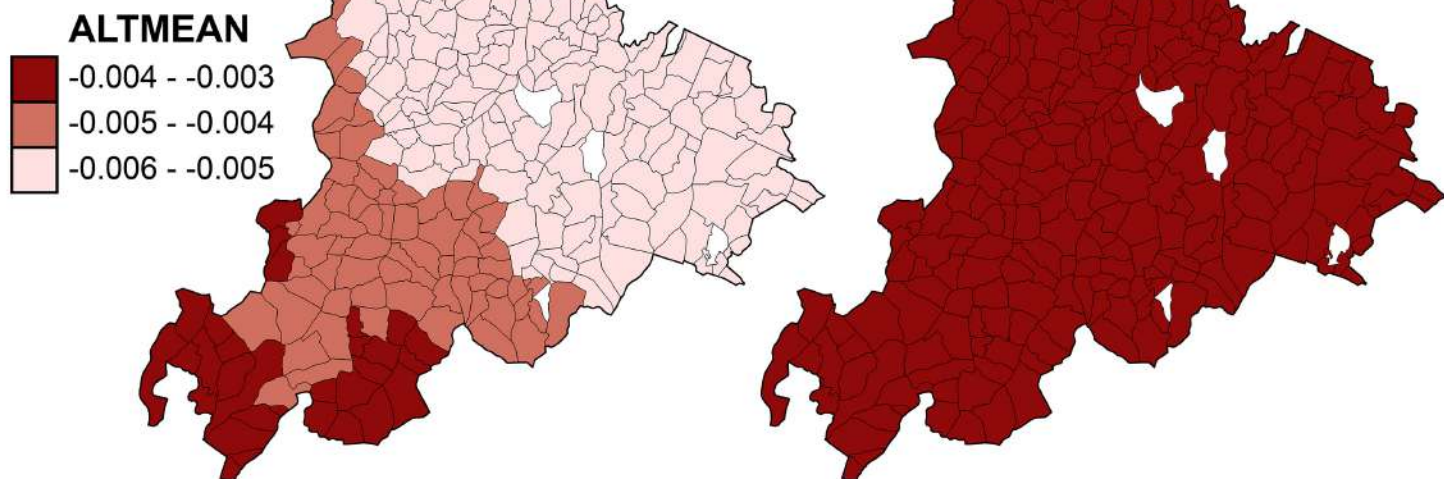
Variable	Coefficient	Std Error	t	P Value	Significance
Constant	4.465	0.301	14.851	<0.001	***
Mean altitude	0.005	<0.001	9.635	<0.001	***
Sandstone	-1.787	0.378	- 4.727	<0.001	***
Rock	-2.265	0.557	- 4.063	<0.001	***
Clay	-1.376	0.453	- 3.035	0.003	**
Deep soil	-0.613	0.271	- 2.265	0.024	*

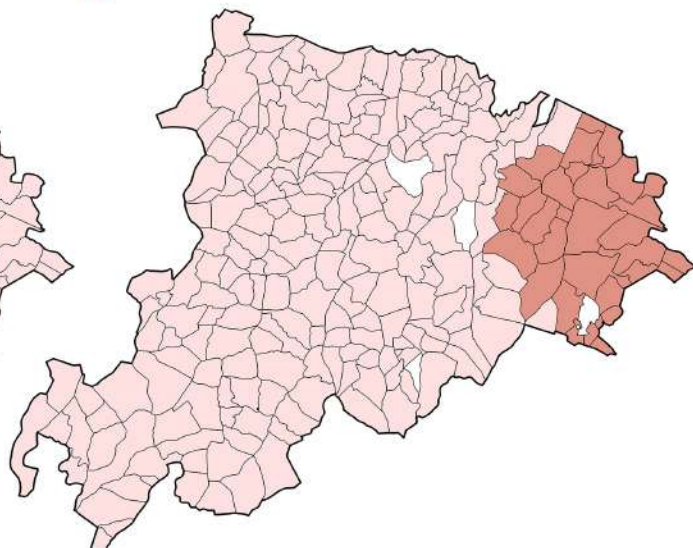
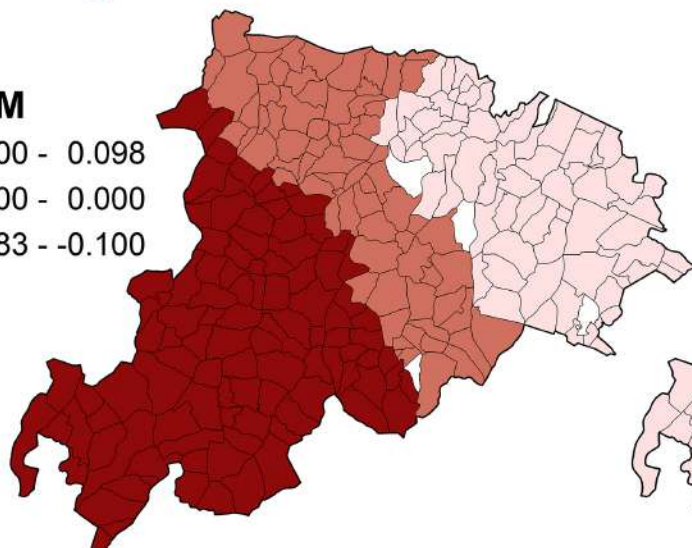
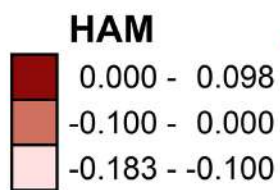
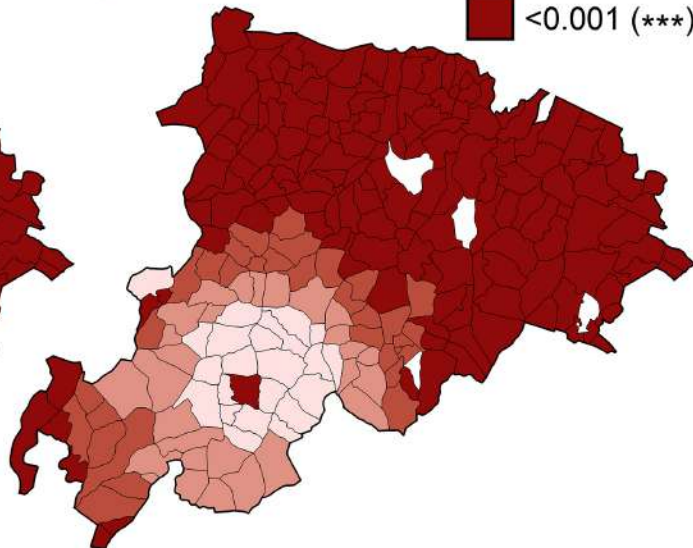
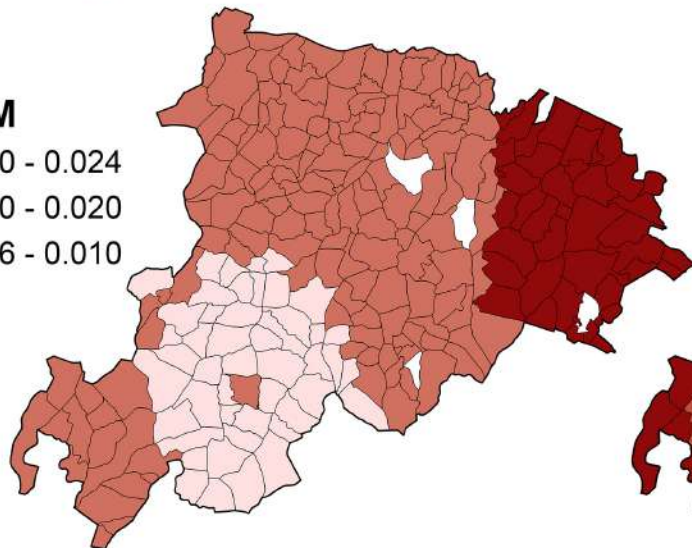
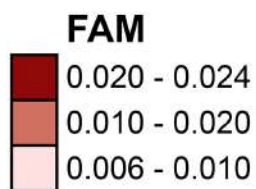
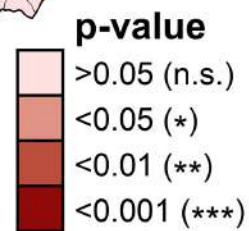
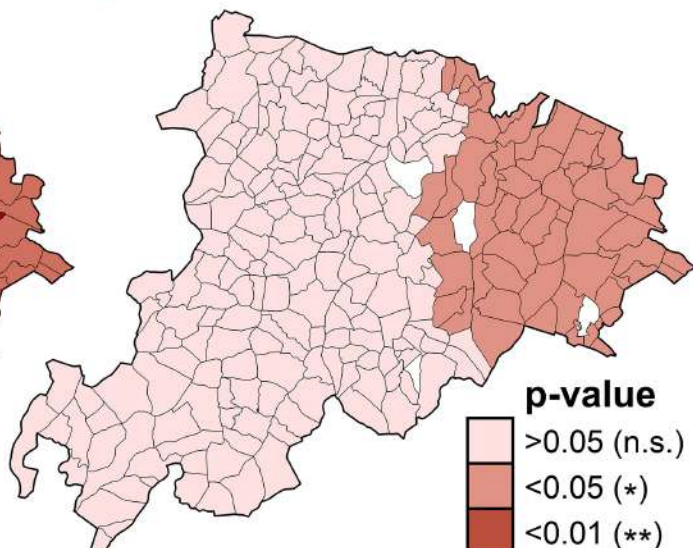
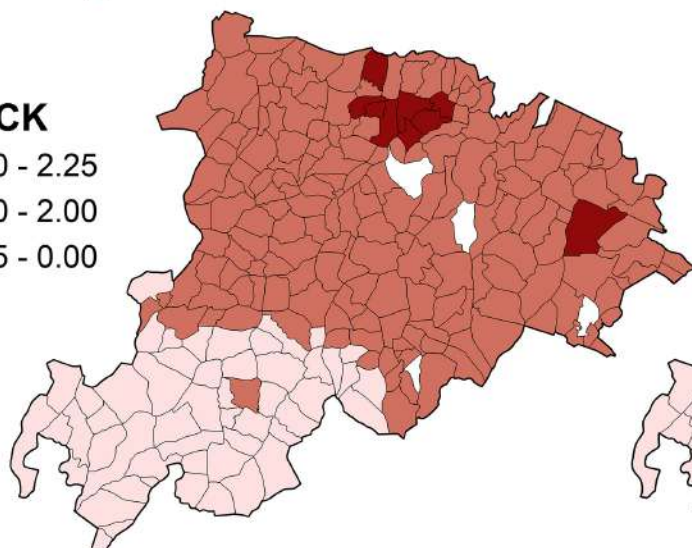
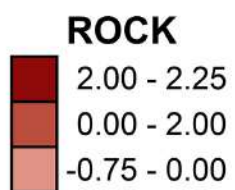
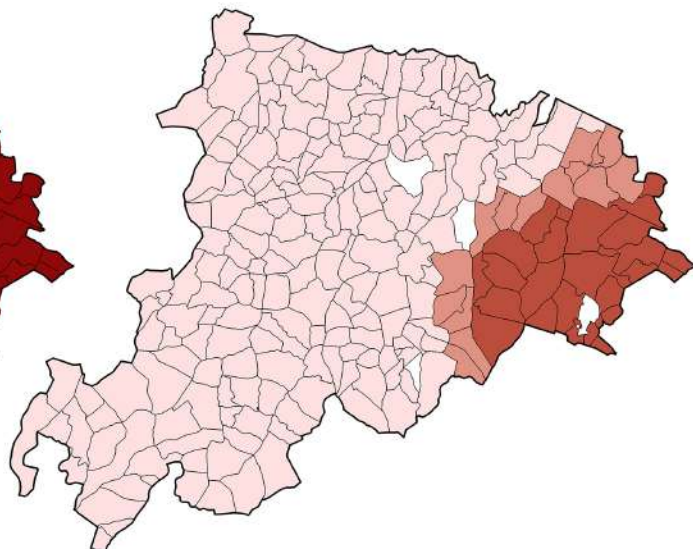
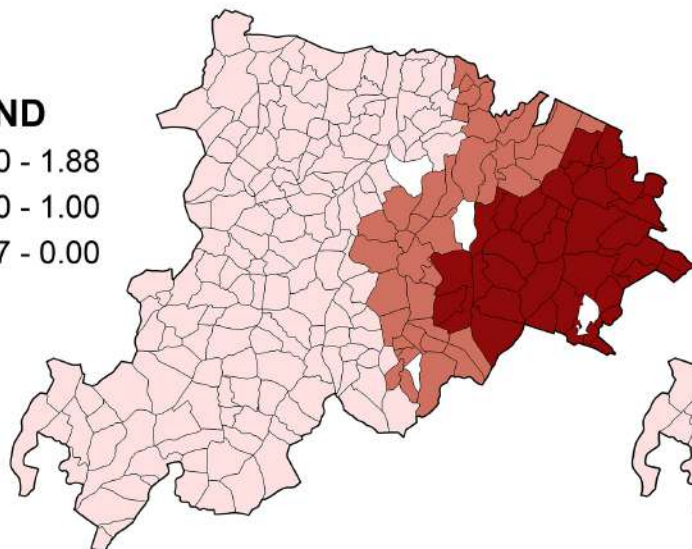
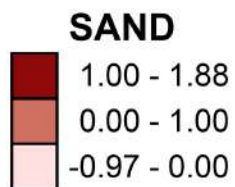
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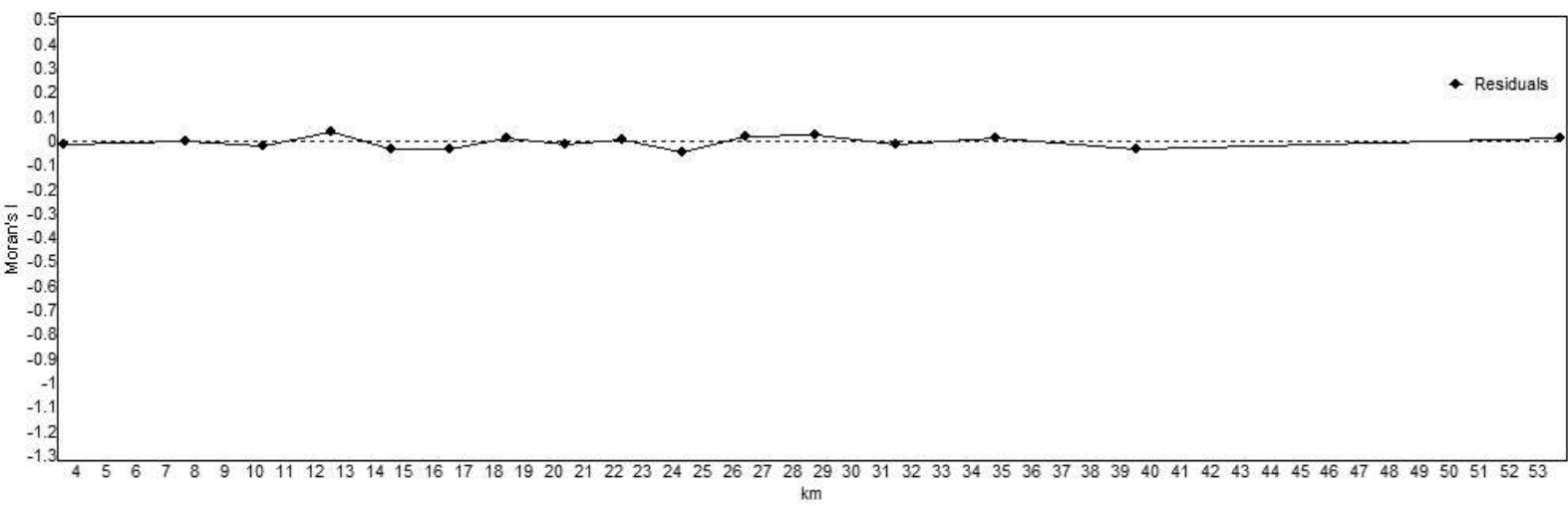


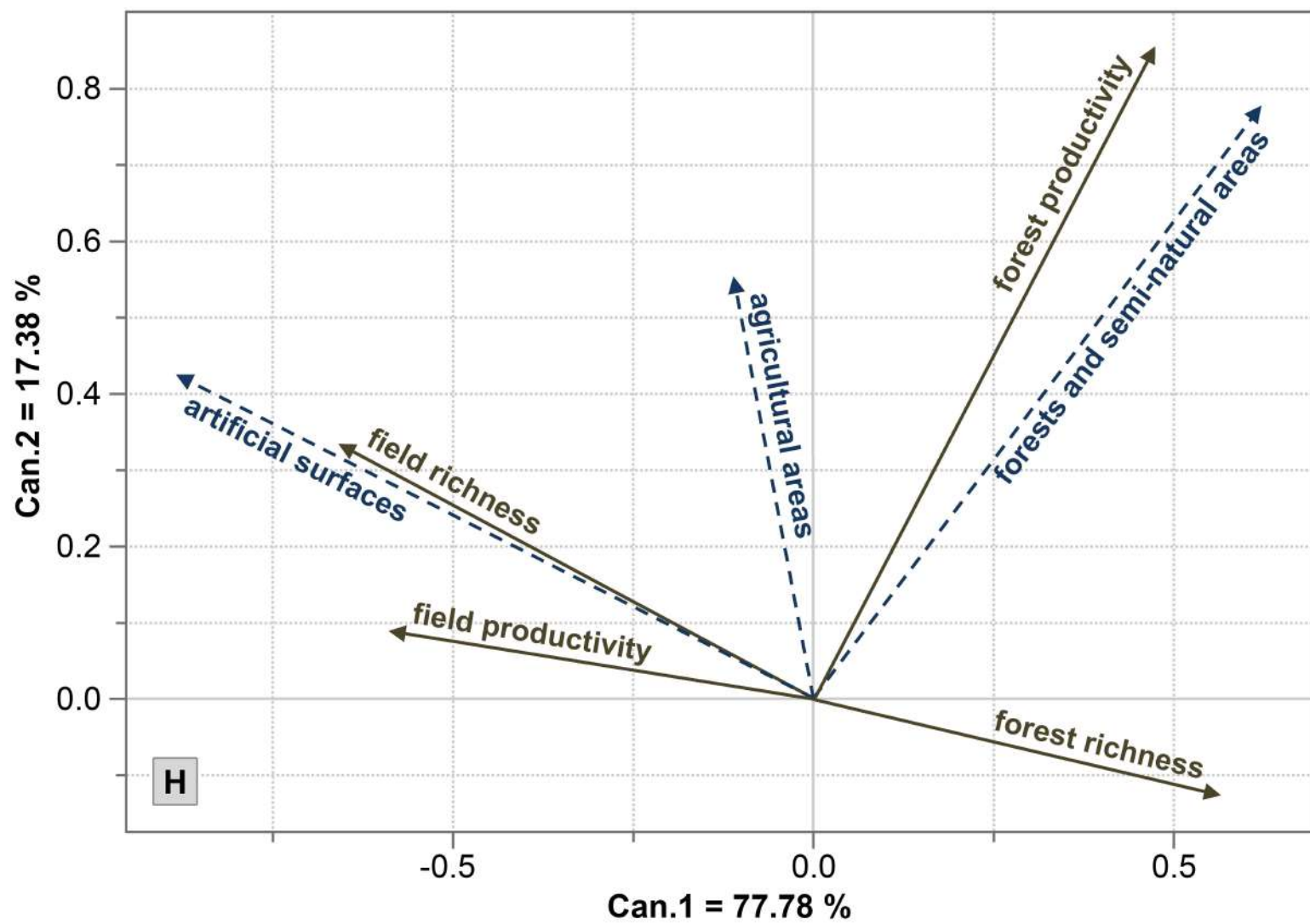


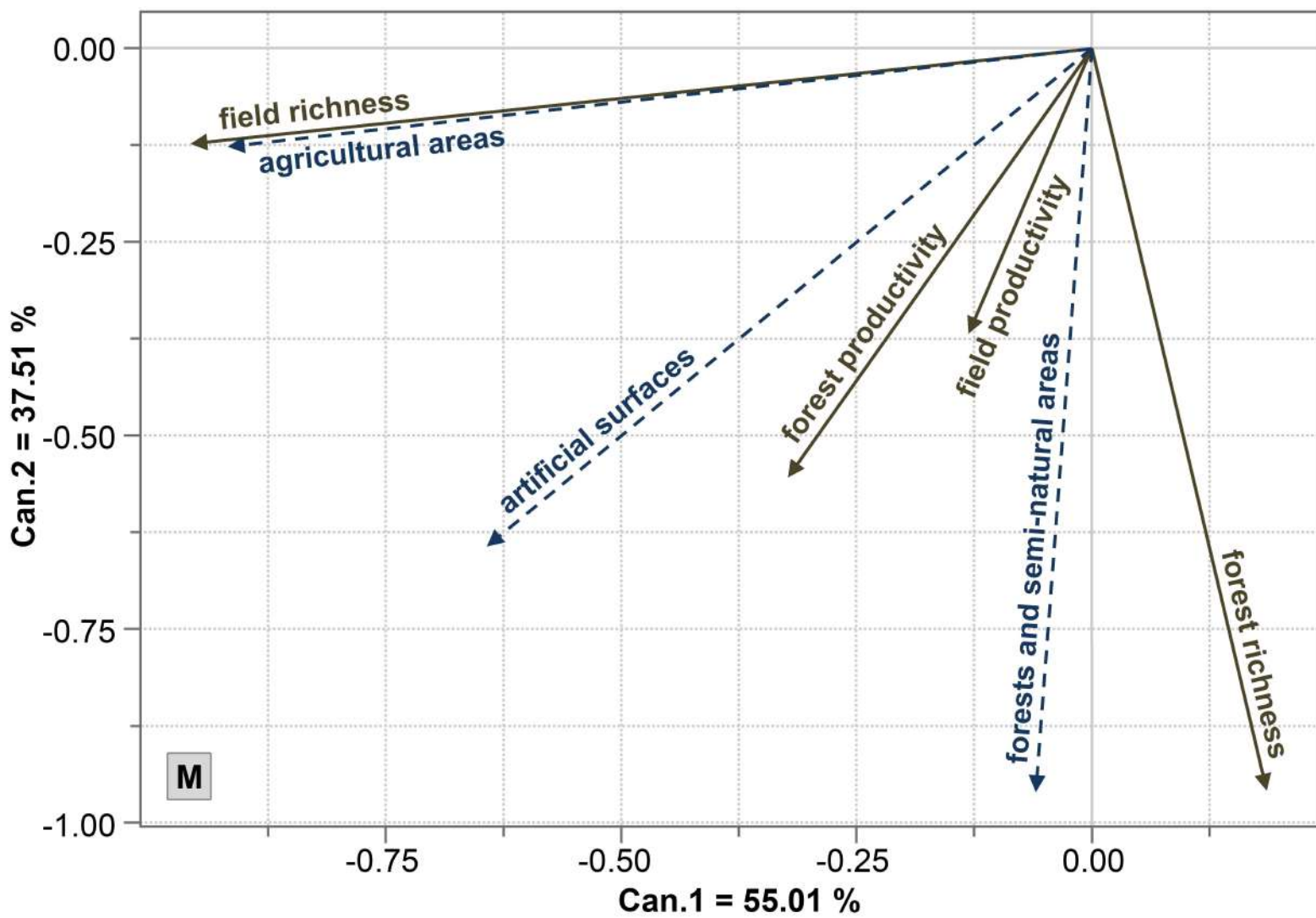


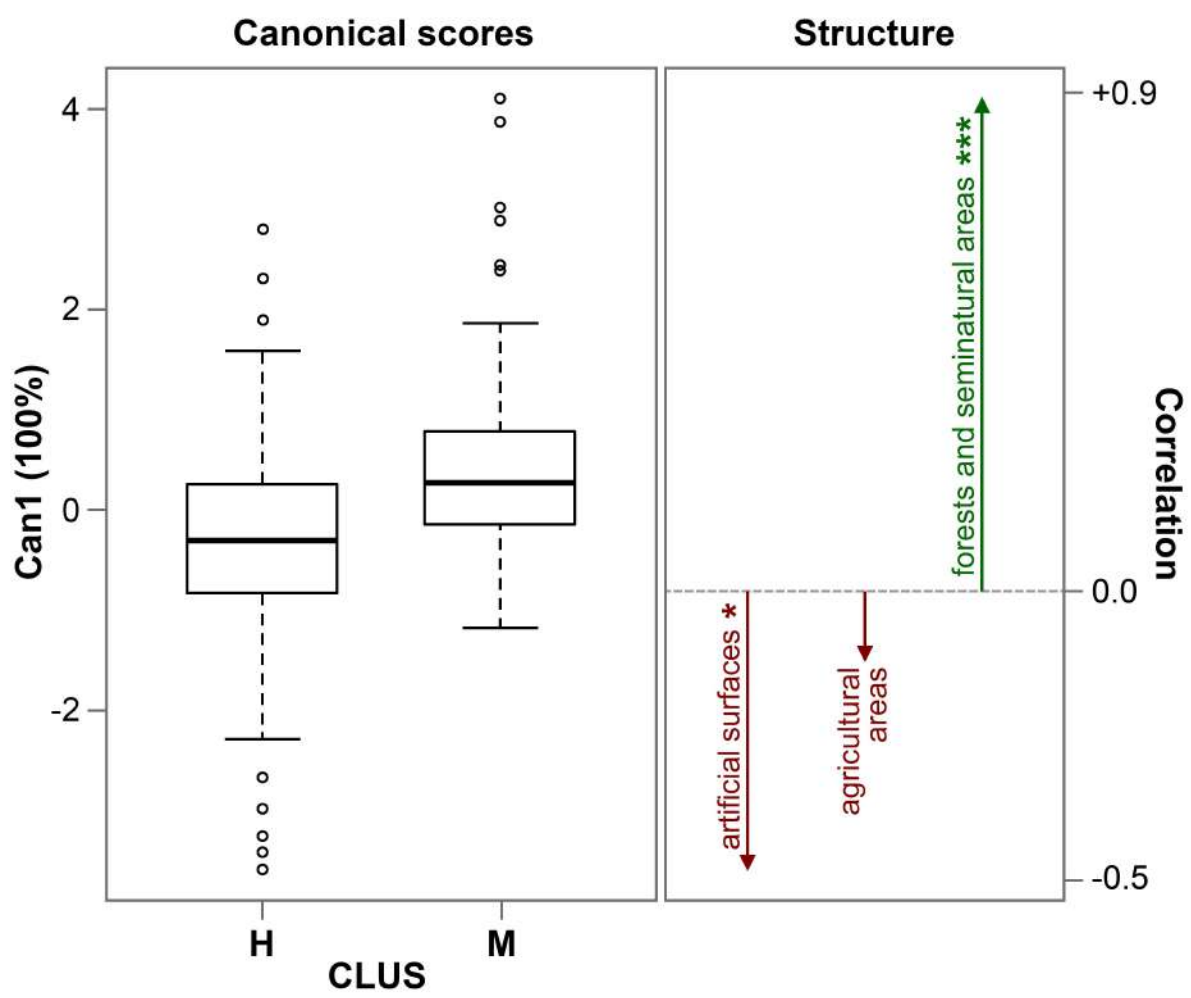


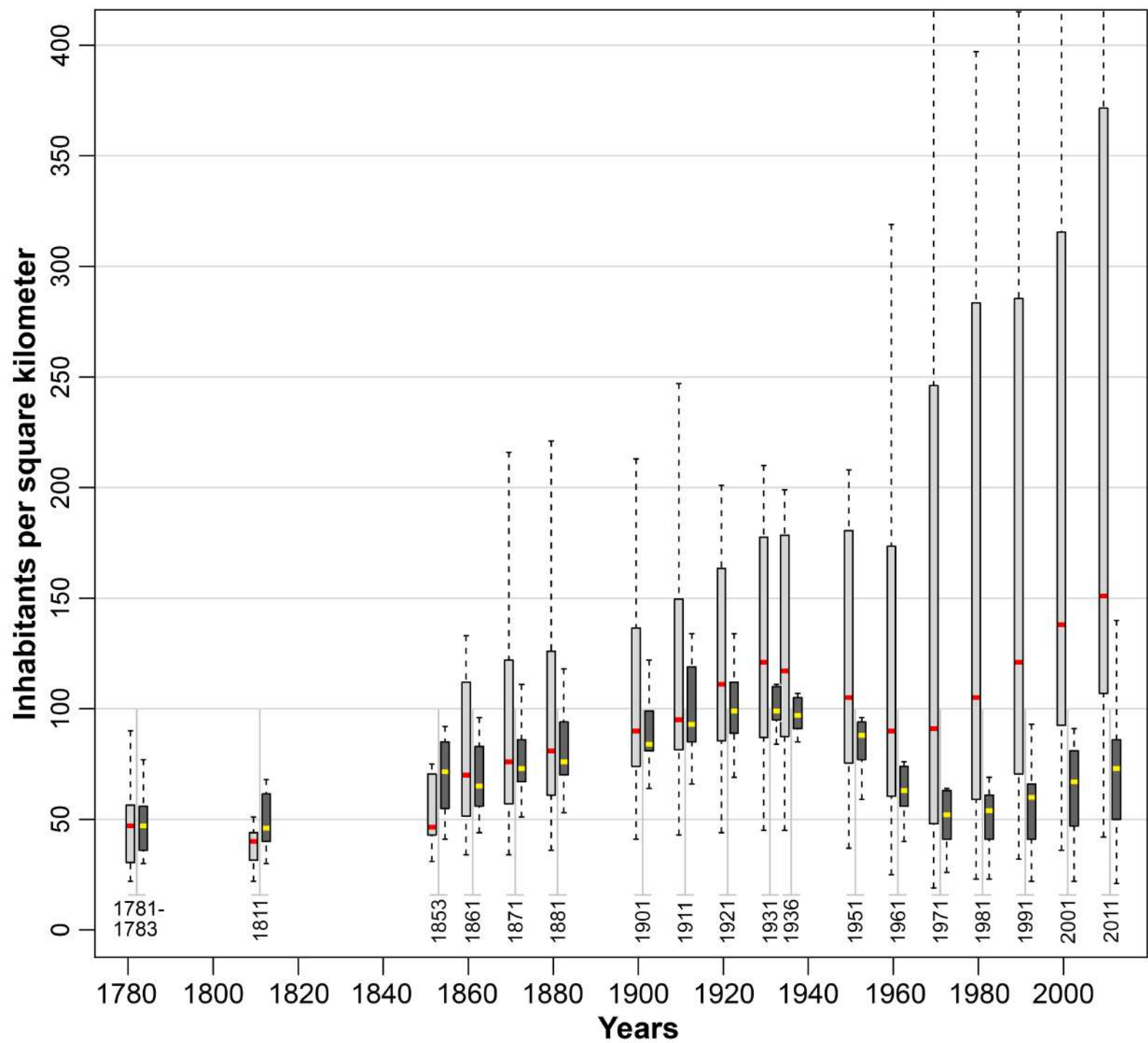












Electronic Appendix. Anecdotal records not included in data analysis. (*) For details see Laghi L., 1803. Dell'utilità delle faggete e delle qualità e proprietà dell'olio di faggiuola. Bologna.

Category		Record type and count (n)		Volume & Unit name
1. Detail of a product	1.1. Wheat & Cereals	Maize	2	I (Boschi di Granaglione), V (Vergiano)
	1.2. Fruit	Fig	15	II (Casalecchio dei Conti), III (Liano, S. Lorenzo in Collina, S. Maria della Cappella, Misericordia, Monte Cavalloro), IV (Ozzano, Pitigliano, Rastignano), V (Sabbione, Savignano, Savigno, Stifonte, Varignana, Vedriano)
		Walnut	11	I (S. Apollinare), II (Calvenzano), III (Gaggio, Medelana, Monte Acuto Ragazza), IV (Monte Maggiore, Rasiglio), V (Samoggia, Sperticano, Vegegheto, Venola)
		Peach	11	I (S. Apollinare, Bazzano), II (Castel del Vescovo S. Pietro), III (Gugliara, Macerato, Montasico), IV (S. Rofillo), V (Savignano, Scanello, Serravalle, Venola)
		Cherry	8	I (Biagioni, Boschi di Granaglione), II (Castelluccio), III (Monte Acuto delle Alpi), IV (Monte Renzio, Pitigliano), V (Savignano, Viticciano)
		Pear	7	I (Biagioni, Boschi di Granaglione), II (Castel de' Britti, Castel del Vescovo S. Pietro), III (Montasico), IV (Pietra Colora), V (Serravalle)
		Apple	6	I (Biagioni, Boschi di Granaglione), II

			(Calvenzano), III (Medelana), V (Sperticano, S. Silverio)
	Plum	3	I (Biagioni, Boschi di Granaglione), V (Serravalle)
	Mulberry	3	I (Bargi, Burzanella), II (Calvenzano), III (Lizzano)
	Almond	1	II (Castel del Vescovo S. Pietro)
	Azarole	1	II (Capanne)
	Sour cherry	1	II (Capanne)
1.3. Grape	Vineyard	19	I (Baigno, Bargi, Bisano), II (Campeggio, Camugnano, Capanne, Capugnano, Caprara, Carpineta, Casola di Casio), III (Gaggio, Grecchia, Ignano, Lizzano), IV (Rocca Corneta, Roncizio), V (Sassuno, Villiana, Viticciano)
	Wine	9	I (Badalo, Battidizzo), II (Castel del Vescovo, Caprara, Casaglia di Gaibola, Croara, Varignana S. Giorgio), III (Macerato, Misericordia)
	<i>Piantata</i>	6	I (Bisano, Bargi), II (Carpineta, Casola di Casio, Campeggio), III (Gaggio)
1.4 Vegetables	Artichoke	8	II (Croara, Casaglia di Gaibola), III (Gaibola), IV (Roncizio, S. Rofillo, Savignano), Vol. V (S. Silverio, Valle in Pietra)
	Cauliflower	2	V (S. Silverio, Toletto)
	Peas	2	III (Gaibola), V (Valle in Pietra)
	Pumpkin	2	I (Amola, S. Ansano)
	Cardoon	1	V (S. Silverio)
	Capers	1	I (Bazzano)
	Salad	1	II (Capanne)
	Alfalfa	1	III (Moglio)

	Potato	1	III (Moglio)
	Saffron	1	V (Savignano)
1.5 Pasture	Sheep	20	II (Bargi, Biagioni), III (Capuccioli, Castel dell'Alpi, S. Cierlo, Farneto), IV (Gavignano, Lizzano, Monte Acuto delle Alpi, Monte Pastore), V (Monte Severo, Piano di Setta, Rocca Corneta, Rocca Pitigliana, Ronca, Verzone, Vignola De Conti, Vignale, Vigo, Viticciatico)
	Goat	4	II (Capuccioli, Castel Dell'Alpi), III (Monte Acuto delle Alpi), IV (Piano di Setta)
	Lamb	1	II (Farneto)
	Horse	3	II (Farneto), III (Lizzano, Monte Acuto delle Alpi)
	Cheese	37	I (Baigno, Barbarolo, Bargi, Battidizzo, Bombiana, Boschi di Granaglione, Brigola, Burzanella), II (Campeggio, Castello D'Ajano, Castelluccio, S. Cierlo, S. Damiano, Farneto), III (Gavignano, Gragnano, Grecchia, Labbante di Sopra, Mogne, Monte Cavalloro), IV (Monte Pastore, Monte Severo, Musiolo, Rocca Pitigliana, Ronca), V (Sambro, Savignano, Scanello, Stagno, Tavernola, Trasasso, Toletto, Verzone, Vignola De Conti, Vignale, Vigo, Viticciatico)
	Milk	2	I (Boschi di Granaglione), III (Grecchia)
1.6. Hay	Cattle	1	II (Castel Dell'Alpi)
1.7. Acorn	Pig	1	I (Boschi di Granaglione)
1.8. Beech wood	Beech oil (*)	1	V (Viticciatico)
	Timber wood	2	II (Farneto), III (Mogne)
1.9. Oak wood	Oak bark	1	III (Livergnano)

	Truffle	2	III (Montasico), V (Venola)
	Mushroom	1	III (Montasico)
Other	<i>Pinus</i> spp. for pine nuts	2	I (Battidizzo), III (Montasico)
	Laurel	1	V (Villa D'Aiano)
	Raspberry	2	I (Boschi di Granaglione), III (Granaglione)
	Bluberry	3	II (Capanne, Farneto), IV (Rocca Corneta)
	Strawberry	1	I (Boschi di Granaglione)
	<i>Acer</i> and <i>Carpinus</i> woods for timber	1	V (Salvaro)
	Alder for timber	1	III (Monghidoro)
2. Ecosystem degradation and its causes	Badlands and unstable areas	33	I (Amola, S. Andrea, Barbarolo, Bisano, Bombiana), II (Casola Canina, Ciagnano, Croara, Fiagnano), III (Gaibola, Gesso, Liserna, Majola, Monte Acuto Ragazza, Monte Armato, Monte Calderaro, Monte Calvo), IV (Monte Maggiore, Monte Veglio, Pizzano, Roffeno), V (Sabbione, Samoggia, Savigno S. Prospero, Savigno S. Croce, Savigno, Sesto, Stanzano, Stifonte, Stiolo, Tiola, Vedriano)
	Overexploited woods	3	I (Bisano), II (Capuccioli), V (Varignana S. Giorgio)
3. Effect of adverse climatic conditions	Mulberry death	2	I (Bargi, Burzanella)
	Frost causing olive tree death (years 1708 and 1716)	2	II (Frassineta), IV (Oliveto)
4. Local forms of economic integration	Straw (for hats)	20	I (S. Andrea Valle di Sambro, S. Andrea Valle di Savena, Barbarolo, Bibolano,

			Brigola), II (Campeggio, Castel Novo di Bisano, Fradusto), III (Gabbiano, Gragnano, Lognola, Lojano, Monghidore), IV (Monzone, Querceto, Roncastaldo), V (Scanello, Valle, Valle di Sambro S. Benedetto, Vergiano)
	Seasonal migration	3	I (Biagioni, Boschi di Granaglione), III (Lizzano)
5. Rural-urban dependence on food stuffs and raw materials provision	Food stuff from town	1	I (Casaglia di Gaibola)
	Transport of wood by river	3	II (S. Damiano), IV (Rastignano, Rodiano)
	Sheep transhumance from plain	1	III (M. Severo)
6. Land ownership	Sharecropping (<i>mezzadria</i>)	27	I (S. Ansano, Baigno, Bargi, Bombiana, Brigola), II (Cassano, Cedrecchia, Frassineta), III (Gabbiano, Gavignano, Gesso di Bologna, Gugliara, Jano, Lizzano, Moglio, Mongardino, Monghidore, Monte Acuto delle Alpi, Monte Chiaro), IV (Piano di Setta, Pizzocalvo, Rasiglio, Roncastaldo, Sassuno, Savigno S. Prospero), V (Vergiano, Zena)
	Small owners	3	I (Biagioni, Boschi di Granaglione), III (Lizzano)
	Land owners	31	I (S. Andrea di Coriano, S. Andrea Valle di Savena, Bibolano, Burzanella), II (Calvenzano, Campiano, Capignano, Casaglia di Gaibola, Casalecchio di Reno, Casale Fiumanese, Castel dell'Alpi, Creda, S. Damiano, Fagnano), III (Gaibola, S. Lorenzo in Collina, Lustrola, Malfolle, Misericordia), IV

(Monte Maggiore, Monte Rumici,
Pedriolo, Pradalbino, Qualto, Rocca
Corneta), V (Sasso Molare, Sasso Nero,
Stanzano, Stifonte, Trasasso, Villa
D'Aiano)

Farm hands 1 IV (Oliveto)
(pigionenti)