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Land use changes, landscape ecology and their socioeconomic driving forces in the Spanish Mediterranean coast (the Maresme County, 1850-2005)

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RESUM: Utilitzem un conjunt de mètriques del paisatge per estudiar l'evolució a llarg termini seguida en una típica zona costanera del Mediterrani des de 1850 fins a 2005, que mostren una greu deterioració del medi ambient entre 1950 i 2005. Les principals forces motores d'aquesta degradació del paisatge han estat el creixement urbà experimentat a les antigues zones agrícoles situades a les planes litorals, juntament amb l'abandonament i la reforestació dels vessants dels pujols interceptats per àrees residencials de baixa densitat, carreteres i altres infraestructures lineals. Duem a terme una anàlisi estadística de redundància (RDA) amb la finalitat d'identificar els que considerem com alguns agents rectors socioeconòmics i polítics d'última instància d'aquests impactes ambientals. Els resultats confirmen les nostres hipòtesis interpretatives, que són que: 1) els canvis en les cobertes i usos del sòl determinen canvis en les propietats dels paisatge, tant estructurals com funcionals; 2) aquests canvis no es produeixen per atzar, sinó que estan relacionats amb factors geogràfics i forces socioeconòmiques i polítiques.

ABSTRACT: We use a set of landscape metrics to study the long-term environmental transformation of a typical coastal Mediterranean area from 1850 to 2005. Our figures show a dramatic environmental deterioration between 1950 and 2005. The main proximate drivers of this landscape degradation are the effects of urban sprawl on former agricultural areas located in the coastal plains, together with the abandonment and reforestation of hilly slopes intercepted by low-density residential areas, highways, and other linear infrastructures. We carry out a statistical redundancy analysis (RDA) to identify certain ultimate socioeconomic and political drivers of these environmental impacts. The results confirm our interpretive hypothesis that: 1) land cover changes determine changes in landscape properties, both structural and functional; 2) these changes are not at random, but related to geographical endowments and socioeconomic or political drivers.

J.E.L.: N53, N54, O18, Q15, Q56, R14.

KEYWORDS: Land-use change, ecological connectivity, statistical redundancy analysis (RDA), socioeconomic drivers, Mediterranean landscapes.

1. Introduction

Land use change is an important component of the transformation that has taken place in areas with a long history of human occupation. Recent work has highlighted the dramatic changes in landscape over the last 50 years in Mediterranean Europe. In general, the relatively small area of fertile plains of the Mediterranean region has experienced accelerated processes of agricultural intensification, industrialization and urbanization, while the larger rural mountain area has been abandoned and reforested (Gerard *et al*., 2010). These land cover changes are an expression of the socioeconomic transformations which have had such a profound impact on the ecological patterns and processes of landscapes in recent times (Potschin and Haines-Young, 2006). In order to identify the driving forces behind them, the main turning points in their development, and the specific impacts on the ecological structure and dynamics of landscapes, it is very useful to adopt a historical perspective (Grove and Rackham, 2001; Marull et al., 2008).

Land cover changes have been led by a set of socio-ecological driving forces, and conditioned by different natural endowments (Farina, 2000). Due to the multidimensional character of these factors, different studies have tended to focus on different variables: demography, economic structures and trends, economic geography, institutional arrangements, or environmental features have all been explored. Which variables to include or omit, and how to relate them to each other in order to explain the prevailing landscape changes, remain open questions (Lambin et al., 2000; Moran and Ostrom, 2005; Lambin and Geist, 2006). The selection is context-specific, as it depends on the question raised, the scale and boundaries of the system analyzed, and the historical period considered.

When this socio-ecological and co-evolutionary standpoint is adopted, three main interpretive factors stand out: context, agency, and outcome. By combining them, we try to explain: 1) why people take land-use decisions based on the limited number of options offered by the context in which they act; 2) what the environmental consequences of their decisions are; and 3) how these changes alter the context in which new options arise and new decisions may be adopted (Moran and Ostrom, 2005). Land cover changes affect both the structural patterns and the ecological processes of landscapes, which in turn may enhance or degrade their suitability for hosting different species (Steiner et al., 2000; Stoms et al., 2002) and the environmental services they are able to perform (Forman, 1995; Gustafson, 1998).

Recent land cover changes have usually entailed a reduction in grain size and fragmentation of agrarian units[1], thus entailing the ecological isolation of these units (e.g. through infrastructures accumulation) which can clearly compromise landscape permeability and, then, its ability to provide habitat and ecological connectivity for different species (Fahrig, 2003; Turner, 2005). In a situation in which the conservation of natural systems is at stake, the co-evolutionary and socio-ecological approach we advocate is a useful tool for assessing the sustainability of any decision-making process (Haberl et al., 2004, Marull et al., 2010). We need to handle this complex set of factors from a holistic standpoint within a dynamic interpretation built on multidimensional datasets (Naveh and Lieberman, 1984; Naveh, 2000). Our approach requires working in

[1] Concerning forest and urban areas the process is usually the opposite, since grain size has increased, while fragmentation of these landscape units has decreased, due to urbanization and reforestation processes, as it was the case in the area we study here.

large teams to carry out a research that is «*multidisciplinary, multiscalar, multitemporal, spatially explicit, and policy relevant*» (Moran and Ostrom, 2005:13).

The aim of this paper is to test our main hypothesis, which are: 1) land cover changes determine changes in landscape properties, both structural and functional; 2) these changes are not at random, but related to geographical endowments and socioeconomic or political drivers. In section 2 the study area is presented together with some of its main socio-economic and political drivers across time. Our sources and methodology are explained in section 3. In section 4 we present the landscape's spatial attributes and the ecological connectivity indices obtained from land-use maps. Then, we attempt to link some social and environmental variables with the landscape attributes and composition using a multivariate statistical model. Finally, we present in section 6 a brief socio-ecological interpretation of the main driving forces behind these historical landscape changes.

2. Introduction to the studied area

With an area of 398.9 square km, the Maresme County is located northeast of Barcelona following the coastline. Their municipalities are historically split into two types along the slope line that goes down perpendicular to the sea: those on the mountain range or near the sea, connected each other through irregular water creeks and local roads (Fig. 1).

Two or three hundred years ago the Maresme had a very high population density, especially in the coastal towns closest to Barcelona. At the beginning of the eighteenth century, the Lower Maresme had 65 inhabitants per square km, equivalent to

1.5 hectares per capita, the figure considered by Ester Boserup (1981) to be the upper limit that any European organic-based agricultural economy could stand. In the mid-nineteenth century this threshold was comfortably exceeded in almost all the municipalities (Table 1), and in fact some of them reached truly spectacular densities of over 600 inhabitants per square km, which were matched only by industrialized and urban societies. These striking figures can partly be explained by the early location of commercial and industrial activities in the area, thanks to the connection with Barcelona by sea and then from 1848 onwards by railway.

This high population pressure and the limited land availability existing in the coastal municipalities circa 1850 were accompanied by a relatively even distribution of land ownership among a large number of smallholders. Although this was a general feature of agricultural development in Catalonia (Tello and Badia, 2011), the fragmentation of land ownership was especially high in many coastal municipalities of the Maresme County. Table 2 shows this fact, and also shows that this situation changed little between 1850 and 1954 in the cases in which data are available. These smallholder communities maintained or even strengthened their position through the creation of agricultural cooperatives in the period between the end of the nineteenth century and the Spanish Civil War (1936-1939). As their lands were mainly located in coastal towns, near the aquifers, small peasants also transformed the prevailing rain-fed cultivation into new irrigated plots to sell the fresh vegetable produce demanded by the growing markets of Barcelona and other European cities.

Both the context and agency changed dramatically during the second half of the twentieth century. The loss of demographic weight and economic power of these communities of peasant smallholders were key factors in the progressive degradation of the landscape in the Maresme County in this period. Whereas the Catalan Autonomous Government had attempted to introduce innovative Regional Planning during the Second Spanish Republic (1931-1939), under the Francoist dictatorship (1939-1975) urban developers, tourist investors and finance corporations took control of the decision-making processes regarding land allocation amid a virtual vacuum of public policy. After Franco's death, the political transition towards a new autonomous government for Catalonia in 1977 and the restoration of democratic city councils in 1979 ushered in a party system, but few of the parties were interested in putting an end to real estate speculation (Naredo, 1996; Carpintero and Marcos, 2008).

3. Sources and methods

By means of digital photographs taken from the cadastral maps in the historical archives, we drew 36 GIS land cover maps for twelve municipalities in the Maresme County for the years 1850, 1954 and 2005 (Parcerisas, forthcoming). Although the county is formed by 30 townships, we had to limit our study to those 12 municipalities, as they are the only ones whose cadastral maps drawn around 1850 are available in good condition at present. Then these digital maps have been used to calculate a set of landscape metrics representative for the major landscape properties namely grain size, fragmentation, land cover diversity and connectivity, by using the programs FRAGSTATS, MiraMon and ArcGIS scripts generated *ad hoc*:

- *Largest Patch Index:* (LPI): Measure of the largest polygon in each municipality as an indicator of the grain thickness of the landscape;

- *Edge Density* (ED): Total length of perimeters (of the polygons of each land cover) in relation to the surface area of the municipality. This measures the potential exchanges between land covers and land uses;

- *Effective Mesh Size* (EffMesh): This is the inverse of the extent of fragmentation proposed by Jaeger (2000), which is now commonly used in the European Union:

For. 1: $EffMesh = \Sigma(A_i^2)*1000/\Sigma(A_i)$

Where A_i is the area of each polygon;

- *Polygon density* (PolD): the number of polygons (of all the covers taken together) as a very simple measure of fragmentation.

- *Shannon Index* (*Shannon*): This measures the land cover diversity:

For. 2: $Shannon = \Sigma(Pi*\ln Pi)$

Where P_i is the proportion of land matrix occupied by each type of cover.

- The *Ecological Connectivity Index* (ECI) assesses the functionality of the land matrix according to its ability and to host and connect the horizontal flows of energy, matter and information which sustain biodiversity (Opdam et al., 2001; Burel and Baudry, 2002; Mallarach and Marull, 2006; Marull et al., 2007). This functional analysis of ecological connectivity uses new parametric methods which require continuous information available for the whole area studied, margins included (Marull et al., 2006, Marull et al., 2010). As this information is not available before mid-20th century for the whole area, the study had to limit the evolution of ecological connectivity indices to the years 1956, 1993 and 2005. However, it has been possible to trace this analysis back to 1850 in a specific area that encompasses the municipalities of Palafolls and Tordera.

The following socio-geographical variables were also calculated (as fixed between years) by using analytical procedures to combine GIS layers:

- Average altitude of each municipality (ALT), from a Digital Altitude Model (DAM) of 30 pixel meters.

- Average slope of each municipality (AVGSLOPE).

- Average distance from the coast of each municipality (D_Cost), using an algorithm to calculate GIS distances.

- Average distance from the city of Barcelona (D_BCN), an algorithm to calculate GIS distances.

- Municipal area (Area), obtained directly from the GIS layer.

The following socioeconomic variables were also obtained in each municipality and year, in order to carry out two multivariate statistical redundancy analyses (RDA) using the CANOCO 4.5 software (Lepš and Šmilauer, 2003):

- Total population registered in each municipality (Population), obtained from past and present censuses.

- Number of landowners per inhabitant in each municipality (LANDOWN/INHAB), obtained from past cadastral records and censuses (access to cadastral lists of landowners is currently prohibited).

- Number of landowners per unit area in each municipality (LANDOWN/AREA), obtained from the sources mentioned above.

The lack of data for some socioeconomic variables for the present day (such as landownership), or for earlier times (e.g. the county's GDP in 1850), prevents an analysis that includes all the variables selected for the entire period studied. With this limitation in mind, we conducted a first RDA analysis for the entire period from 1850 to 2005 by combining data from a total of 12 municipalities in three years, i.e., 36 observations for each variable. Landscape attributes (composition, landscape metrics and ECI) were considered as dependent variables, social and environmental data and years as independent variables, and the population as a covariate. Landscape attributes (composition, landscape metrics and ECI) were considered as dependent variables, social and environmental data and years as independent variables, and the population as a covariate. All variables were standardized in order to avoid problems of scale.

4. Results found in land-use change and landscape metrics

4.1. Land-use changes of the Maresme County from 1850 to 2005

Circa 1850 the landscape of the Maresme County was primarily agricultural and remained poly-cultural, in spite of the specialization in winegrowing (Garrabou et al., 2009). Cropland extended over more than half the land matrix, while about 40% of total area was woodland comprising pine, oak and shrubs that provided firewood and timber. There was a predominance of vineyards in the coastal plains and the initial slopes, while woodland was located further up in the mountain range, with many cereal plots scattered throughout the area, especially along the valley of the Tordera River (Fig. 2).

The main change experienced between the 1850s and 1950s was a significant expansion of irrigated orchards in the coastal plains by pumping of underground water. The area of woodland in the higher inland area also increased slightly. After the Phylloxera plague of the 1880s, both irrigated land and woodland expanded at the expense of vineyards (Badia-Miró et al., 2010). Cereal crops remained scattered in rain-fed plots either in the plains or on the slopes. The urban area doubled during this period. However, although the polarization of land-use along the slope line started to reduce the land cover diversity, agricultural mosaics remained in place and the biodiversity was not very affected.

In contrast, during the latter period from 1950 to 2005, agricultural activity lost much of its economic importance as large amounts of land were given over to industrialization, tourism, and, last but not least, residential conurbations. The entire land matrix underwent rapid environmental degradation mainly due to the fast-growing urbanization triggered by private urban developers in the absence of any appropriate or enforced land-use planning. The urban sprawl became a continuous conurbation along the coast, and also invaded some upland areas (Paül and Tonts, 2005). Developed land grew at a rate of 8% a year between 1950 and 2005, and it currently occupies over 23% of the total area. Initially a tourist destination or a second-home area for weekends, the county became an area of dormitory towns within the metropolitan region of Barcelona.

4.2. Landscape properties

Landscape patterns have experienced two opposite trends of change, depending on previous land covers and geographic context: In woodland-dominated areas of the Upper Maresme, both Polygon Density and Effective Mesh Size decreased during the last 50 years due to the impact of the construction of the network of roads and highways, and also due to the urban development of low-density scattered suburbs. Roads and urban development broke up the potential exchanges between landscape units (Trombulak and Frissell, 1999; Forman, 2000). In contrast, the coastal municipalities of the Lower Maresme recorded increases in the average size of patches and in grain size, mainly due to the extent of urban sprawl in the lower lands and the reforestation of slopes (Fig. 3).

Ecological connectivity indices showed a sharp decline almost everywhere between 1956 and 2005. Despite the beginning of industrialization and urbanization, in 1956 the Maresme County still enjoyed fairly high ecological connectivity thanks to the predominance of agricultural patches with agro-forest mosaics[2] throughout the land matrix, and the key role played by creeks as the main ecological corridors between the mountain range and the sea (Fig. 4). Then, from 1956 onwards, a set of new barriers were introduced due to the construction of additional roads and highways and the real estate boom. The new urban developments were located either in scattered low-density residential areas mainly on hilly slopes, or in apartment blocks along the coastline. In addition to disturbing ecological processes everywhere, this urban sprawl destroyed the role played by agro-forest mosaics in maintaining biodiversity (Pino et al., 2000; Santos et al., 2008), and interrupted the function of the creeks as geological and ecological corridors (Beier and Noss, 1998; Chetkiewicz et al., 2006).

Figure 4 shows the sharp reduction in ecological connectivity experienced not only during the Francoist dictatorship (1939-1975), but unfortunately since the restoration of parliamentary democracy in 1978 as well. It is striking to see how over the last 50 years the remaining agricultural and forest covers which endured the attack of suburban developments in the inner upland areas have become increasingly isolated from each other, and also from the coastline, where urban sprawl has invaded almost all the interstices. Figure 5 shows the evolution of ecological connectivity in a section of the Tordera Valley, extending the time horizon from 1850 to the present. To a large

[2] In that case, land cover fragmentation would be clearly positive, as it would allow ecological processes occurring within its territory.

extent, the high ecological connectivity of the mid-nineteenth century was still in place a century later, but today acceptable levels of connectivity are found only in some hilly woodland areas and along the narrow bed of the Tordera River. Although there is more woodland today than there was a century and a half ago, these forest lands have become highly fragmented due to urban sprawl and the associate transport infrastructures. Therefore, the land matrix's capacity to sustain naturalness and biodiversity has dramatically declined (Saunders et al., 1991; Fischer and Lindenmayer, 2006 and 2007).

5. RDA analysis of landscape attributes and socio-ecological drivers

In the resulting ordering of canonical axes shown in Figure 6 the distribution of the arrows reflects the degree of correlation between variables, while the length of the arrows reflects their contribution to explaining the total variance. The dependent variables are represented in italics, the independent variables in bold, and covariates in blue. The first two canonical axes in Figure 6 show an interesting ordering among the factors analyzed. As expected, the vectors of the percentages of agricultural, forest and urban usages (PERC_A, PERC_F, PERC_U) appear divided almost equally in the plane between the two axes. Landscape change over time is reflected in the changing situation of the red triangles, which show that from 1850 to 2005 the predominant landscapes have migrated from an agricultural axis to an urban-forest one, via an intermediate agro-forest stage in the 1950s.

The statistical relationships between landscape composition attributes and socio-environmental variables shown in Figure 6 are consistent with the interpretation suggested above, and also with the results of our earlier study (Marull et al., 2010).

Forest landscape is predominantly concentrated in larger, higher and steeper townships located farther from the coast and Barcelona. Urban areas acquire greater weight in the coastal plains located in smaller municipalities and closer to Barcelona. Agricultural areas appear halfway to both previous cases. Total population is related to these mainly urban places and not with the township area. However, the small size of the population arrow indicates that this variable has a lesser significance in explaining the landscape structure and its evolution from 1850 to 2005.

The distribution of landscape metrics on this space-time plane becomes less clear, as one would expect, given the complexity of ecological processes in different landscape patterns (Wu and Hobbs, 2002; Li and Wu, 2004). Forest landscapes show higher ecological connectivity indices (ECI), while agricultural mosaics appear to be more diverse. Nevertheless, the landscapes with higher edge density (ED) appear to be mainly forest areas associated with a certain amount of agricultural covers, which increase the number of ecotones. Landscapes with higher grain size (LPI) and greater effective mesh size (EffMesh), which are less fragmented, can be of two types: either mainly forest or urban, or a combination of both, as we see from the intermediate position of these metrics between the two composition variables. As expected, larger townships (Area) show higher values for the number of polygons and for the sum of their perimeter (PolD). The variance explained by these first two canonical axes is high, up to 45%. As indicated by the results of the Monte Carlo test shown in Table 3 (first axis eigenvalue = 0.293 canonical, F = 11,685, P = 0.002, 499 permutations), the relationships analyzed can be considered highly significant.

The aim of the second RDA is to include some additional socioeconomic variables which are only available for the period between the mid-nineteenth and mid-twentieth centuries. The dependent variables were the landscape attributes (composition and metrics), while the independent variables included the ones used in the first RDA together with the new ones (geographical variables, socioeconomic variables and years). Thus, we have only 20 observations, and the results of this second RDA must be interpreted with caution as the very limited number of data may produce unwanted effects and spurious correlations. This statistical analysis does not detect any association linked to temporal changes, probably because we have only two dates. Nonetheless, the proportion of variance explained (73.6%) is high.

This second analysis confirms that the largest grain size (PolD) and effective mesh size (EffMesh) appear in the least fragmented forest landscapes located in high, steep areas far away from the coast and Barcelona. The novelty here is the relationship of this pattern with the socioeconomic variables related to land ownership. Indeed, Figure 7 confirms that less fragmented landscapes (often forests or agro-forest mosaics) were maintained in townships in which a greater proportion of the active population was involved in agriculture, i.e. where the number of landowners per inhabitant was higher. In more industrialized and urbanized areas, where farming is no longer the main economic activity, the number of landowners per unit area increases. For their part, large municipalities with mainly forest use have lower ratios of landowner per unit area than smaller coastal townships with higher levels of agricultural or urban land use.

This statistical association reflects the greater abundance of smallholders engaging in intensive agricultural or horticultural land uses in coastal municipalities, and the least unequal distribution of landownership in these areas (Table 2). It is also interesting that in this second analysis the population variable seems to have greater significance, and appears to be associated with agro-forest landscapes characterized by a high cover density (Shannon) and edge density (ED). This result stresses the fact that maintaining these landscape mosaics required a certain level of agrarian labour force and population density (Marull et al., 2008).

6. Conclusions

We have presented a body of cartographic evidence, landscape metrics and statistical analysis which confirm our hypotheses expressed above. Firstly, the data provided show clearly that land cover changes which took place during the period studied have entailed some other changes in landscape properties, both structural and functional. Despite the significant changes in agricultural land uses between 1850 and 1950, in the mid-twentieth century the agro-forest landscapes still held a relatively high cover diversity associated with edge ecotones, and a fairly good ecological connectivity in the Maresme County. However, our evidence also highlights the environmental deterioration experienced between 1950 and 2005, as a result of accelerated urban sprawl and the retreat of agricultural activity in the coastal plains, together with the abandonment and reforestation of hilly slopes intercepted here and there by low-density residential areas, highways, and linear infrastructures. The lack of adequate land-use planning during much of this period increased the chaotic nature of these land-cover changes which led to a very severe loss of ecological connectivity.

Our second hypothesis is that these land use changes, and the corresponding alteration in landscape properties, are related ultimately to some specific driving forces and ruling agencies. We are still far from offering a complete agency-based model of these long-term landscape changes, and even further from being able to empirically test it with a large database (Evans et al., 2005). More information is needed on some important variables that we have omitted, such as per capita energy consumption, GDP, land rents and travel costs, which we intend to include in future research. However, we believe that these two RDA statistical analyses carried out with the variables available have provided some significant results.

We find that over the past 150 years the landscape of the Maresme County has been transformed from a predominantly agricultural model in the 1850s to a basically metropolitan one in 2005, via an intermediate model in place until 1950, still based on agro-forest mosaics. Until the mid-twentieth century the agro-forest mosaic occupied most of the land matrix and played a key role in maintaining connectivity between landscape units. Over the last 50 years the decline of agricultural cover, as well as the interposition of barriers in reforested areas, has had a highly negative impact on ecological connectivity.

Underlying these landscape changes is a profound socio-metabolic transition from a mainly solar energy system towards another one based mainly on fossil fuels (Fischer-Kowalski and Haberl, 2007; Marull et al., 2008). The old solar energy system was areal-based, in that it relied on the photosynthetic flows in the local territory to provide most of the energy carriers needed for local consumption. In contrast, the fossil energy system that fuelled the urban-industrial economy has globalized its ecological footprint, at the same time freeing up a large share of local landscapes from the pressures exerted by the consumption needs of the local population (Marull et al., 2010).

These underlying forces may explain how, seen from a human-nature interaction perspective at a local or regional scale, the landscape outcome of this socio-metabolic transition was a combination of overpressure (urban sprawl) and abandonment (reforestation). They can also help us to understand the changing role played by population growth as a driver of this landscape transformation. Indeed, an interesting result obtained with our redundancy analysis is the very low explanatory capacity found for the population variable when all our three dates are taken into account, compared with the length acquired by the population arrow when only the years in the 1850s and 1950s are included in the multivariate RDA. This clearly suggests that the increase in population densities led to a set of increasingly intensive land-use patterns, but only as long as the whole economy remained mainly agricultural and solar-based (Fischer-Kowalski and Haberl, 2007).

Under a fossil-fuelled social metabolism and a globalized economy, the population density increased by turning a great deal of the land into derelict reforested areas. In contrast, whereas a great deal of the prevailing land matrix was maintained as agro-forest mosaics, between 1850 and 1950, the long population arrow of our second RDA test clearly indicates an intermediate position between agricultural and forest land-covers, associated with the arrows of Shannon and Edge Density indices. This may suggest that the maintenance of these landscape mosaics, able to sustain high biological diversity, also needed the high labour intensity provided by a still mainly agricultural population.

Therefore, there appear to be some critical thresholds of human disturbance of natural systems that either increase species richness (by maintaining agro-forest mosaics) or decrease it (by destroying these mosaics either through intensification or abandonment). This result is in agreement with the intermediate disturbance hypothesis (With and Crist, 1995; Wrbka et al., 2004). Applying the Shannon index to land-cover diversity provides a rather similar result. While maintaining a clear meaning in the still mainly agrarian landscapes up to the mid-twentieth century, the Shannon index becomes increasingly ambiguous when it has to account for cover diversity in a territory where landscape units are polarized between urban sprawl and derelict reforested areas, as has happened in the last fifty years. Therefore, the Ecological Connectivity Index emerges as a useful alternative metric to assess the ecological functioning of landscapes from a long-term historical perspective.

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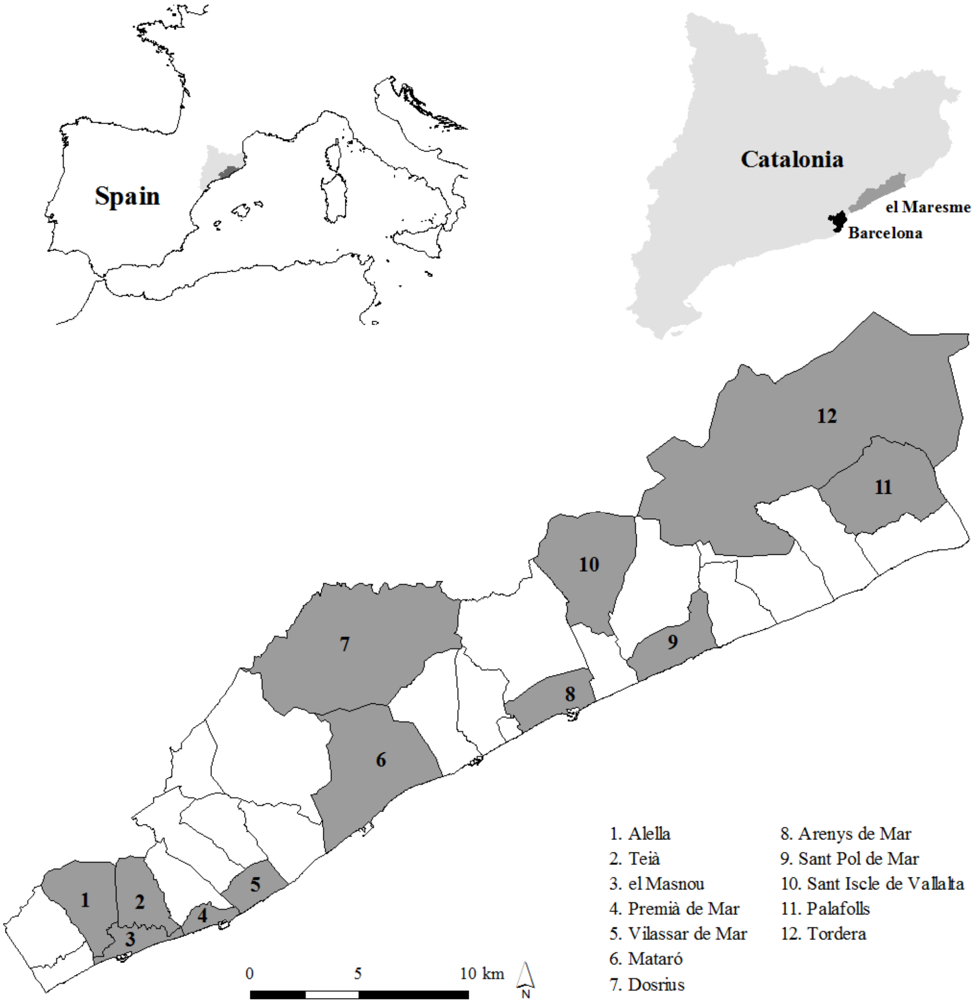
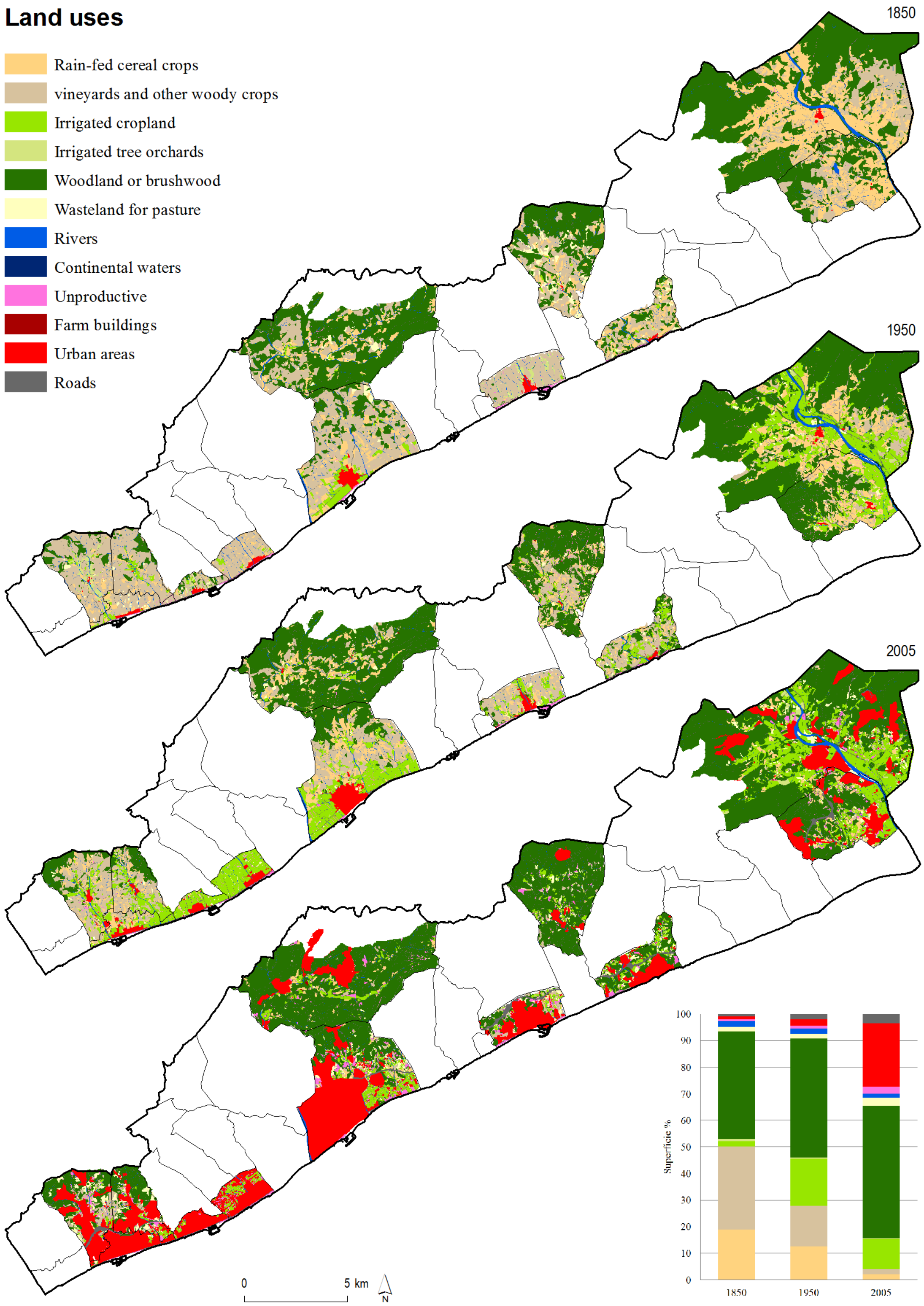
Appendix

Figure 1. Map of the 12 municipalities studied in the Maresme County, Catalonia (Spain).



Source: our own data.

Figure 2. Land use in the 12 municipalities of the Maresme in 1850, 1954 and 2005.



Source: our own data, using ArcGIS and MiraMon software from the cadastral maps in the corresponding municipalities and years.

Table 1. Population density in the Maresme County, 1719-2001.

Year	Lower Maresme	Upper Maresme	Maresme	Catalonia
1719	65.1	37.0	50.1	12.5
1787	113.1	93.5	102.6	25.8
1857	231.8	133.1	178.9	51.5
1900	239.1	126.0	178.4	61.2
1930	321.7	172.4	241.6	86.9
1950	353.7	177.1	259.0	100.9
1975	880.2	310.5	574.5	159.5
2001	1,326.1	484.3	874.5	192.3

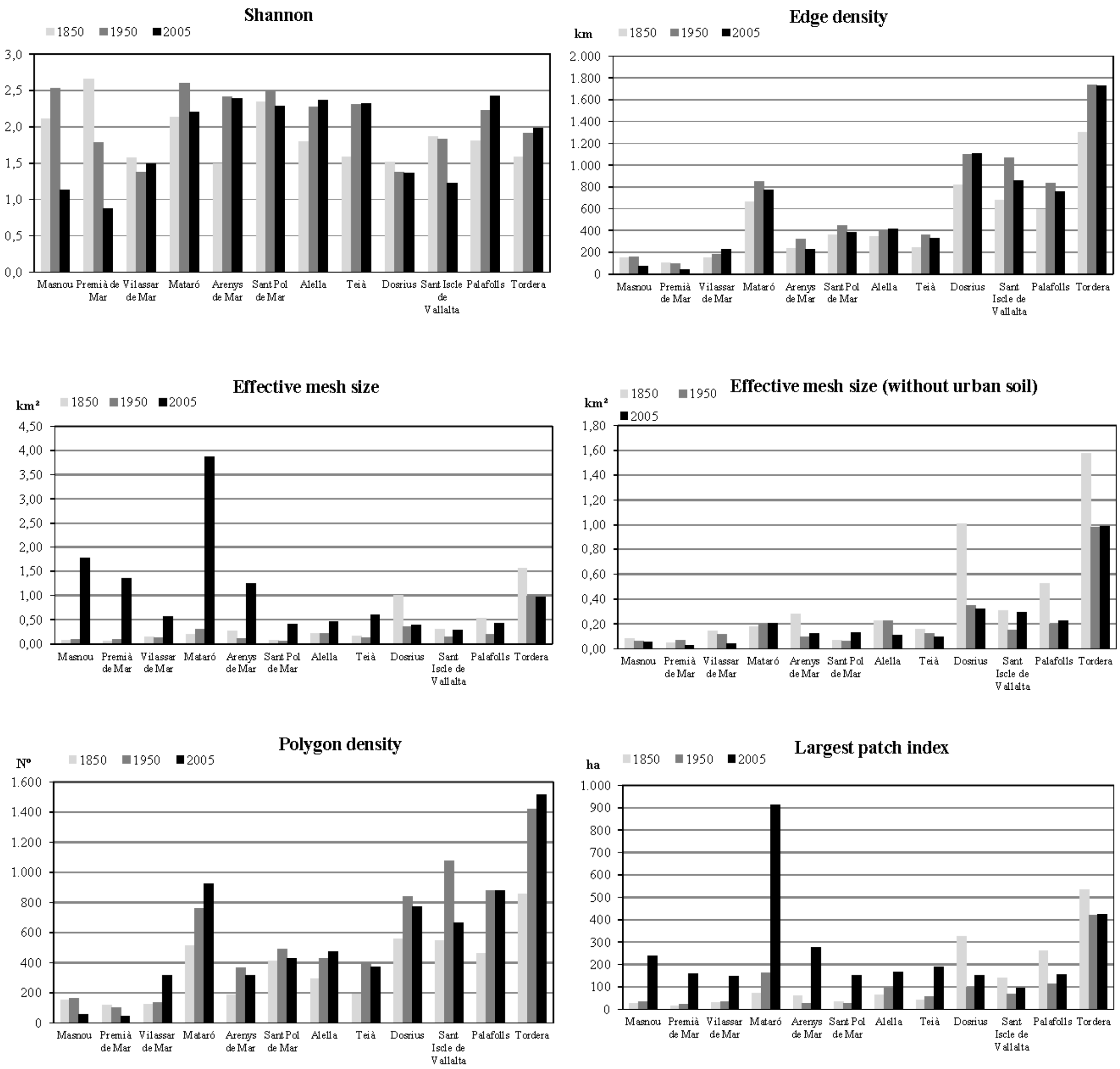
Source: Idescat and Centre d’Estudis Demogràfics datasets.

Table 2. Population density and land ownership distribution in the municipalities of the Maresme County from 1850 to 1954.

Municipalitiy	Pop. density 1857	Pop. density 1955	Landown. per inhab. 1850	Hectares per landowner 1850	Gini land-ownership 1850	Landown. per inhab. 1954	Hectares per landowner 1954	Gini land-ownership 1954
Alella	167.2	174.5	0.08	6.7	0.71	0.12	4.5	0.74
Arenys de Mar	791.9	950.1	n.a.	n.a.	n.a.	0.03	2.8	0.50
Dosrius	28.3	22.5	n.a.	n.a.	n.a.	0.19	20.0	0.79
Masnou,	624.3	870.2	n.a.	n.a.	n.a.	0.03	1.4	0.60
Mataró	737.6	1,523.9	0.02	5.0	0.65	0.01	3.2	0.66
Palafolls	62.2	74.9	0.48	2.9	0.76	0.29	4.0	0.73
Premià de Mar	614.3	2,149.0	n.a	n.a.	n.a.	0.02	1.4	0.47
Sant Iscle de Vallalta	50.8	42.4	0.19	6.7	0.80	0.22	10.0	0.77
Sant Pol de Mar	197.7	238.5	n.a.	n.a.	n.a.	0.10	3.8	0.61
Teià	208.0	229.5	0.08	5.0	0.70	0.11	3.7	0.70
Tordera	46.0	45.9	0.22	6.3	0.79	0.17	12.5	0.81
Vilassar de Mar	775.5	1,040.5	0.07	1.5	0.51	0.06	1.4	0.47
Barcelona province	92.4	288.8	n.a	23.9	0.70	n.a.	n.a.	n.a.

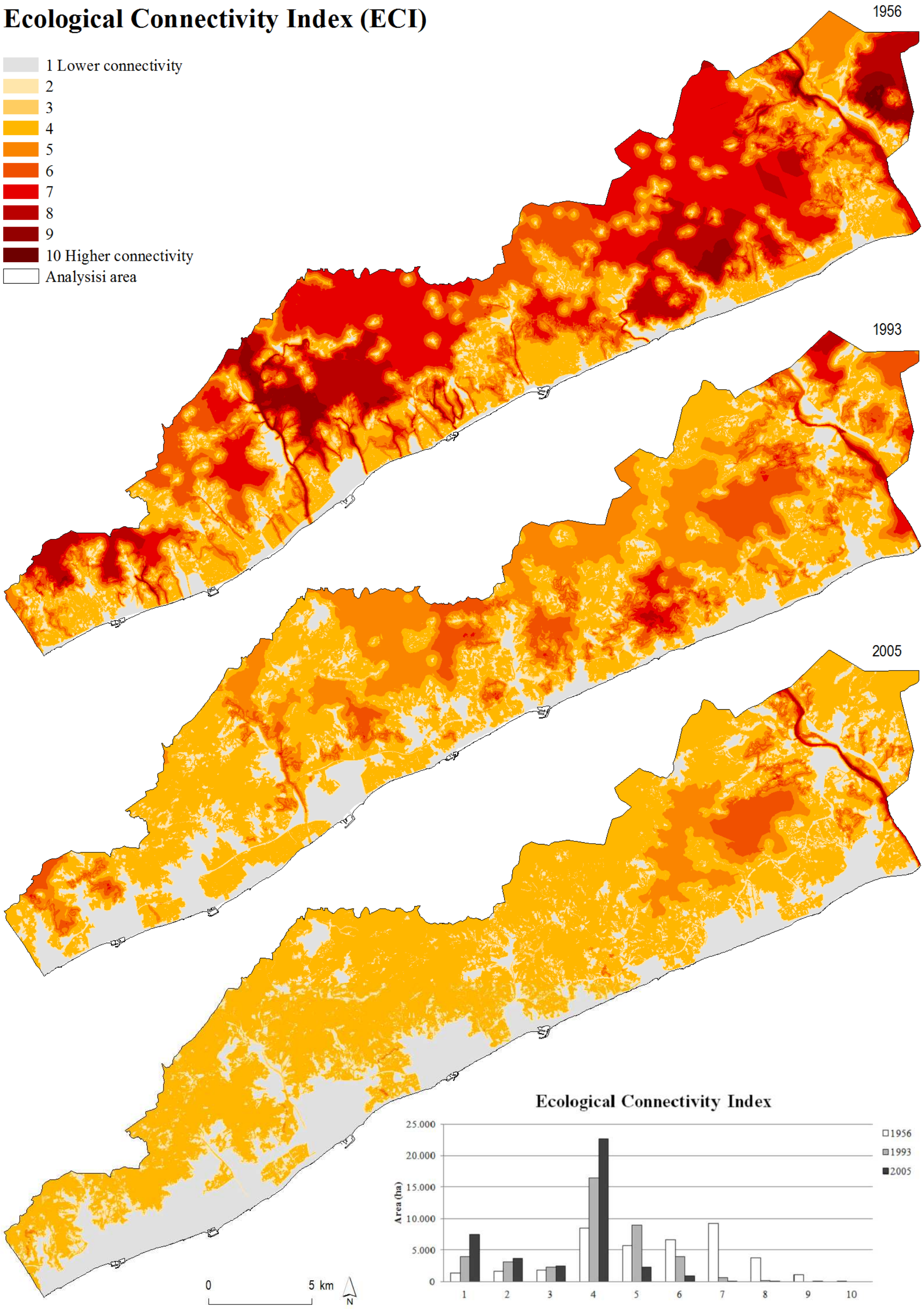
Source: Idescat and Centre d'Estudis Demogràfics datasets, the cadastral maps and registers from the corresponding municpalities, the *Repartimiento Personal de la Riqueza Territorial* of 1852 and the *Estadística Territorial de la Provincia de Barcelona* made by the cartographer Pedro Moreno Ramírez in 1858.

Figure 3. Landscape attributes in the municipalities of the Maresme County in 1850, 1954 and 2005



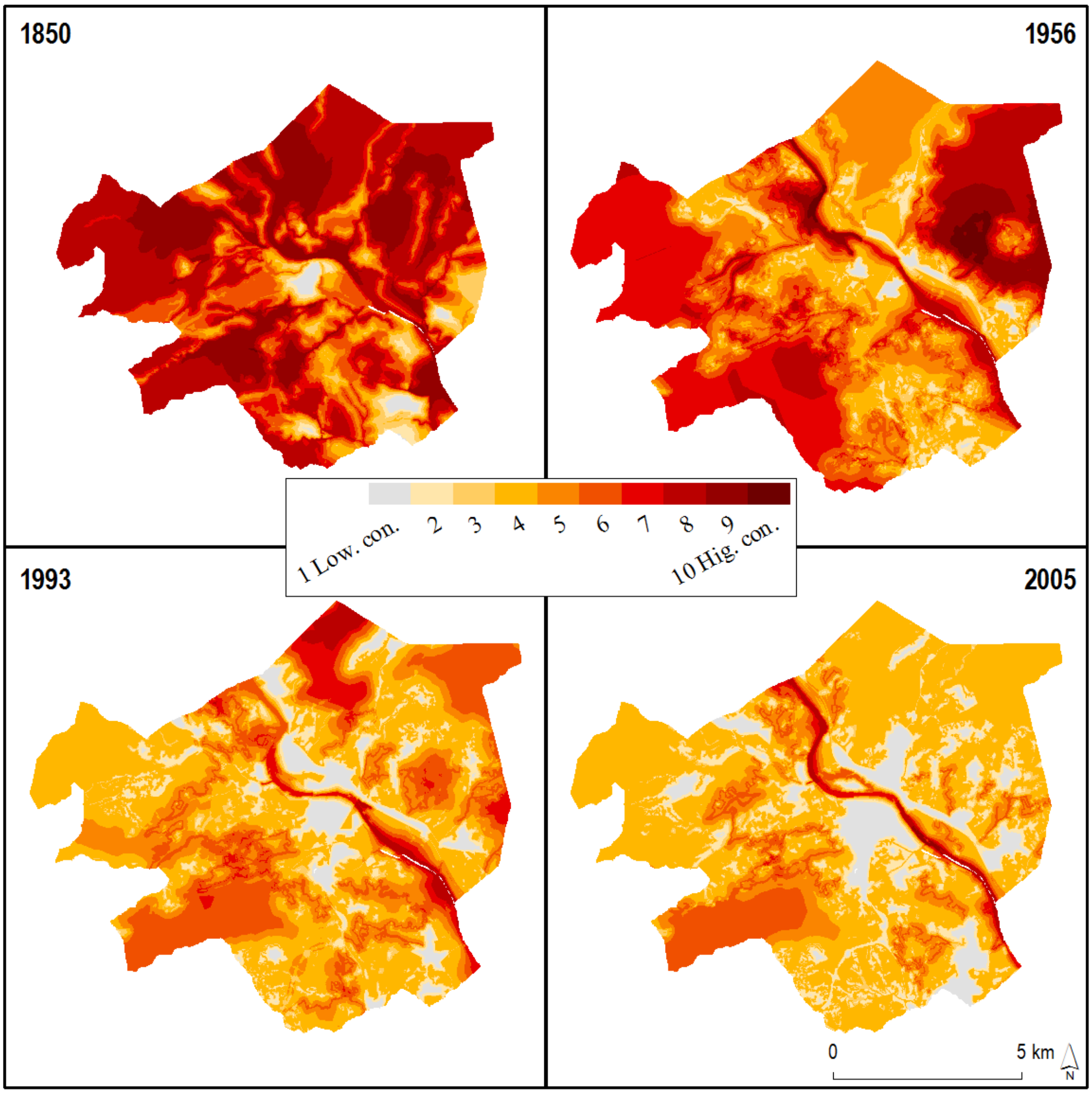
Source: our own data, using ArcGIS and MiraMon software from the land cover maps of Figure 2 in the corresponding municipalities and years.

Figure 4. Ecological Connectivity Indices in the Maresme County (1956, 1993 and 2005).



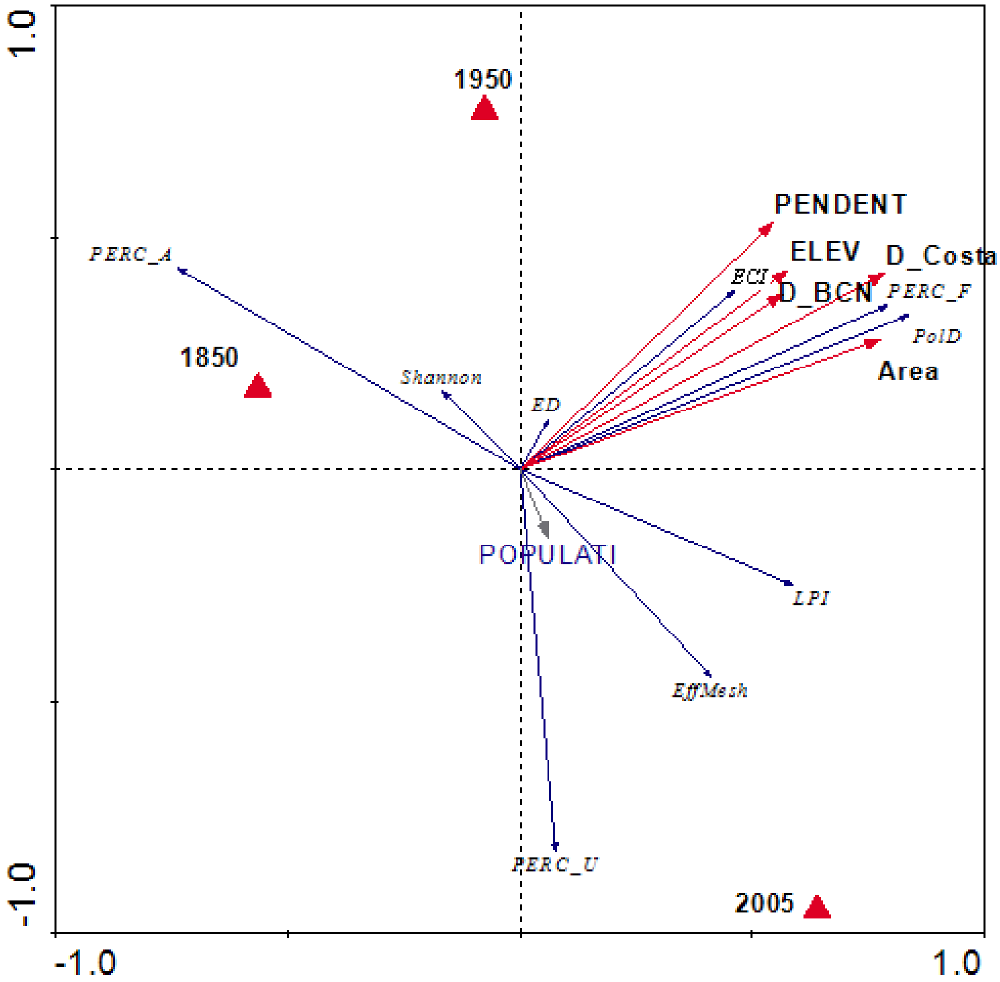
Source: our own data using with ArcGIS and MiraMon software from the photo-interpretation of the aerial photos taken by the US army in 1956, together with the land cover maps in 1993 and 2005 taken from digitized satellite images.

Figure 5. Ecological Connectivity Indices in Palafolls and Tordera municipalities, 1850-2005.



Source: our own data, using ArcGIS and MiraMon software from the photo-interpretation of the aerial photos taken by the US army in 1956, together with the land cover maps in 1993 and 2005 taken from digitized satellite images.

Figure 6. First two canonical axes of the RDA multivariate statistical relationship between landscape attributes, land cover composition and socio-environmental variables between 1850 and 2005.



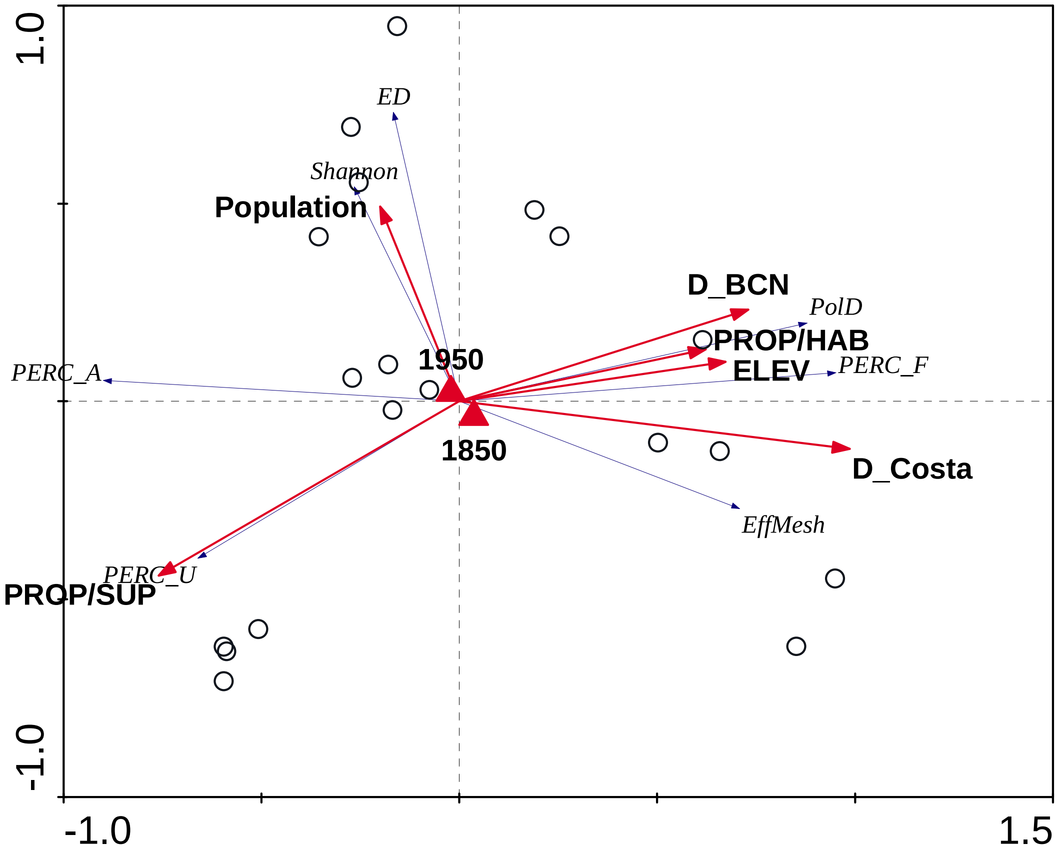
Source: our own data, calculated with CANOCO 4.5 software (Lepš & Šmilauer, 2003) from the dataset assembled with the historical sources mentioned in the above figures and tables.

Table 3. Summary of statistical results of the redundancy analysis (RDA) made in Figure 6.

Canonical axes	1	2	3	4	Total variance
Eigenvalues	0.293	0.173	0.093	0.063	1.000
Correlations between independent variables and metrics	0.944	0.831	0.939	0.777	
Cumulative percentage of metrics variance	29.3	46.5	55.8	62.1	
Cumulative percentage of predictor variables variance	43.8	69.6	83.5	92.8	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.669

Source: our own data, calculated with CANOCO 4.5 software (Lepš & Šmilauer, 2003) with the same dataset used in Figure 6.

Figure 7. First two canonical axes of the RDA multivariate statistical relationship between landscape attributes, land cover composition and socioeconomic variables between 1850 and 1950.



Source: our own data, calculated with CANOCO 4.5 software (Lepš & Šmilauer, 2003) from the dataset assembled with the historical sources mentioned in the figures and tables above.

Table 4. Summary of statistical results of the redundancy analysis (RDA) made in Figure 7.

Canonical axes	1	2	3	4	Total variance
Eigenvalues	0.508	0.208	0.097	0.085	1.000
Cumulative percentage of metrics variance	0.996	0.964	0.946	0.986	
Cumulative percentage of metrics variance	50.8	71.7	81.4	89.8	50.8
Cumulative percentage of predictor variables variance	54.1	76.3	86.6	95.6	54.1
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.939

Source: our own data, calculated with CANOCO 4.5 software (Lepš & Šmilauer, 2003) with the same dataset used in Figure 7.