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Landscape Transformation under Global Environmental Change in Mediterranean Mountains: Agrarian Lands as a Guarantee for Maintaining Their Multifunctionality

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Received: 20 November 2017; Accepted: 9 January 2018; Published: 12 January 2018

Abstract: The analysis of past and present patterns of agrarian mountain areas allows researchers to characterize the influence of landscape heterogeneity on biodiversity, cultural heritage, and forest fire hazard. This process was mapped, quantified, and described through the use of digital mapping (GIS) and landscape indexes in a protected area in Alta Garrotxa (Catalonia, Spain). These areas require urgent management and modelling to provide alternative management scenarios, in order to maintain and recover habitats. A set of different scenarios have been designed using a multi-criteria evaluation and geospatial information available for the study area to identify the key areas for management action and to predict the potential effects on agricultural lands by prioritizing one or another management objective: biodiversity, landscape structure and perception, cultural heritage, fire hazard, and management cost. The observed progressive land abandonment of open areas with a small size and greater isolation will have a large impact on biodiversity and cultural heritage, and increase fire risk. Sustainable development will require planning objectives compatible with the conservation of biodiversity and the preservation of Mediterranean features with support for agricultural activities. This methodology can contribute to and be easily implemented by land managers, which could help to strengthen the link between managers and stakeholders.

Keywords: landscape homogeneity; farmlands; landscape metrics; multicriteria analysis; Mediterranean mountains; global change

1. Introduction

Landscapes are the result of generations of land use and management practices, along with political and agrarian pressured change, which have had both a direct and indirect impact on the landscape. Over the years, evolving management practices have created a number of culturally exceptional landscapes with high aesthetic, cultural, and ecological values [1,2]. Geometric elements on the Mediterranean landscape and a long history of land management and transformation, as well as the multifunctionality of Mediterranean agrarian landscapes, have been the driving forces behind the creation of regular regional patterns in land use and land cover, and have created a historical and cultural background [3]. Traditional rural landscapes are of immense diversity, versatility, and stability [4], where polyculture is a central element in recreating the original biodiversity of Mediterranean landscapes. The enormous socioeconomic transformations experienced in recent decades have radically altered the perception of agrarian mountain landscapes from being principally for agroforestry use to where they are now considered as multifunctional spaces which embrace alternative uses and roles such as providing recreation and tourism areas, protecting biodiversity, and providing ecosystem services [5].

In Europe, the mountainous Mediterranean countryside, in particular in the most marginal areas, has progressively been depopulated since the end of the 19th century, more so in the second half of the 20th century, as farmers left their land, attracted by the work opportunities in industry and services that the bigger towns and cities offered. In the study area, this trend continued for approximately 15 to 20 years, until an incipient tourist development and the arrival of new inhabitants put a stop to it [6,7]. In the Mediterranean uplands, the topography, the distance to houses, and the insufficient access to facilities also affect the spatial organization of these changes. When traditional agroforestry activities were abandoned, because they lacked economic profitability when compared to other areas with higher productivity and mechanization, this provoked notable changes in the region's countryside and environment and caused the accumulation of forest biomass [8,9].

This process has clearly led to the homogenization of mountain landscapes, especially in the case of the medium-sized Mediterranean mountains of Europe [10,11]. Landscape homogenization is a dynamic process characterized by increases in certain types of habitat at the expense of others. These mountainous Mediterranean landscapes are being increasingly dominated by forests, to the detriment of landscape diversity and the once varied agroforestry mosaics formed as a result of a thousand-year-old historical and cultural legacy [12,13]. These socioenvironmental dynamics increase the vulnerability of the landscapes to threats such as plagues, diseases, droughts, and severe forest fires [14].

Similarly, this homogenization is leading to a loss of biological and landscape diversity and causing a significant dissipation of historical and cultural identity [8,15]. The biological diversity linked to these Mediterranean mountain environments depends on the spatial heterogeneity resulting from human interaction with, and management of, the environment throughout time. Often, this biodiversity is greater than that of the largely natural landscapes which have experienced little human intervention [16]. The natural mosaics formed by cultivated fields and woodlands help to conserve natural and cultural diversity and decrease fire risk [17]. Some studies show that forest management can significantly reduce the economic costs related to forest fires (extinction and associated impacts) [18]. On the other hand, current afforestation has resulted in an ever-increasing vulnerability to forest fires [19,20]. Furthermore, factors such as holiday home sprawl in these forest zones, and the proliferation of road links and electrical networks, have also served to increase the risk of forest fires [21,22].

Another negative effect linked to the processes of depopulation and landscape homogenization is the loss of cultural heritage (e.g., country houses, archaeological sites, churches, and hiking paths), and the loss of local knowledge associated with traditional economic activities (traditional agriculture systems, making charcoal, hunting, collecting medicinal plants, and picking fruit, among others), as well as a decrease in the general appreciation of the landscape in abandoned areas. Until sixty years ago, most mountain villages were an important source of work and life in general.

Landscape dynamics and their possible effects on the region have become an important area for study in the past years [23]. Landscape dynamics and their potential effects have been widely studied on a regional scale over the past few decades [24–26]. Spatial and temporal knowledge concerning landscape patterns enables us to identify these dynamics; along with their environmental consequences [11,24,25]. This paper presents the results of a study carried out in the Hortmoier and Sant Aniol valleys in a mountain forest area included in the Nature 2000 network (Alta Garrotxa, Catalonia, Spain), with the aim of clarifying the relationship between the structural changes of agrarian lands. We have performed change analysis by photo interpretation of aerial photography of 1957 and 2009. Landscape metrics were also calculated to analyse the change in the degree of landscape homogeneity. Finally, a methodology was developed to determine the potential recovery of agrarian lands (crops, pastures, and open forests) using multi-criteria analysis and geographical information systems (GIS) to help management action.

2. Materials and Methods

2.1. Study Area

Alta Garrotxa is a rural area protected by the European Union's Natura 2000 network (32,000 ha) and an interesting example of an evolving landscape in the Mediterranean mountains (see Figure 1). The Alta Garrotxa area is a transitional region between the Mediterranean zone to the south-east, (temperature = 13–14 °C and precipitation = 850–900 mm) and the Pyrenean zone, whose conditions are comparable to sub-Atlantic regions (temperature = 11–12 °C and precipitation = 1100–1150 mm). Holm oak forests (*Quercetum ilicis galloprovinciale* and *Quercetum Mediterraneo-montanum*) dominate and, on the sunny mountainsides, extend up to 800–900 m above sea level, where they are then replaced by the pubescent oak (*Buxo-Quercetum pubescentis*) which has a potential domain that extends up to the highest peaks (e.g., Mont Comanegra 1580 m). The landscape mosaic is completed by the presence of scattered pastures; the most important of which are located on the southern slope of Mont Comanegra. The Hortmoier and Sant Aniol valleys (5000 ha) are regarded as the true 'heart' of Alta Garrotxa because of their geomorphological and biogeographical complexity and climate (temperature = 11–13 °C and precipitation = 1050–1150 mm). Regional socioeconomic dynamics are characterized by an almost total absence of human presence. Rapid depopulation has occurred since the nineteenth century (with 2000 inhabitants) and in particular since the middle of the twentieth century, when there was a decrease from 1302 inhabitants to 304 in the protected rural area.

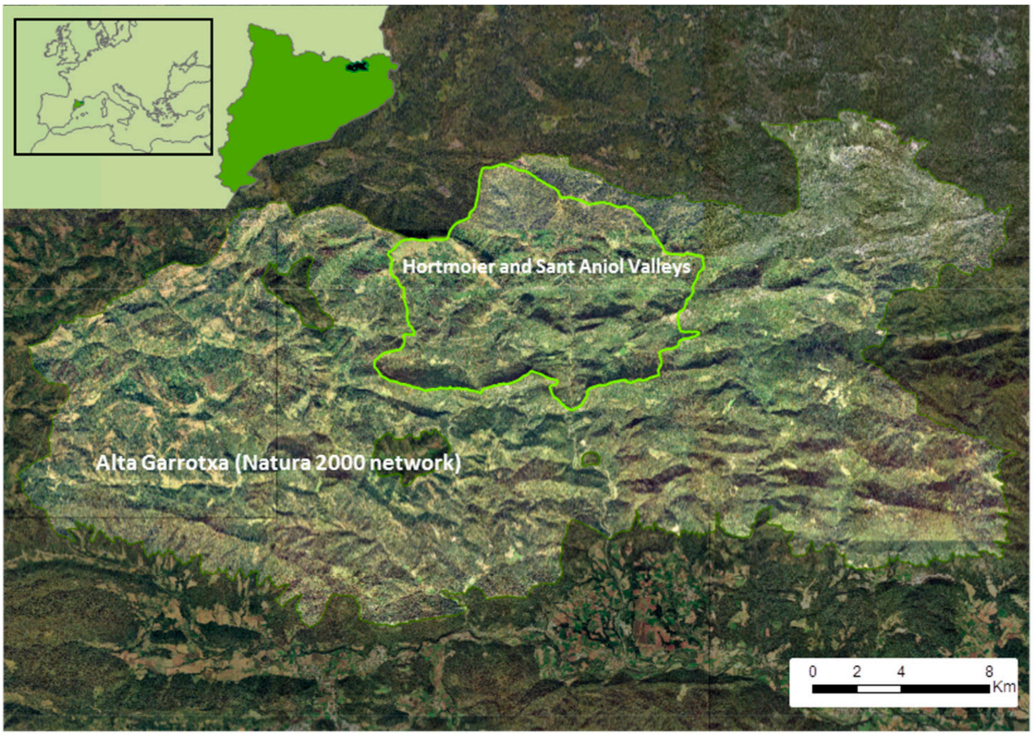

Figure 1. Location of the study area.

2.2. Composition and Landscape Configuration

To be able to quantify and value the different land use and land cover changes produced between 1957 and 2009 with a greater accuracy and certainty, detailed cartographic material was required. For the first period, we worked with black and white aerial photographs captured by the United States Army Map Service between 1956 and 1957 (known as the *American flight*) and available from the Spanish Army Geographical Service, and these were enlarged to an approximate scale of 1:7500. These aerial photographs had to be corrected using ERDAS IMAGINE (Orthobase module) and then, through photointerpretation, the different land uses and covers were digitalized. The polygons corresponding to the different classes were individualized following the criterion shown in Table 1 [27]. We have differentiated between 10 different types of land uses and covers (Figure 2). For the second period (2009), we used a black and white ICGC (Cartographic and Geological Institute of Catalonia) orthophotomap (scale 1:5000) from Cartographic and Geographic Institute of Catalonia. To verify the orthophoto map interpretation, the information for 2009 was complemented with 2013 fieldwork.

Table 1. Classes of land uses and covers.

Classes
Closed forest (>90%)
Dense forest (60–90%)
Open forest on pasture (10–60%)
Open forest on pan (10–60%)
Crops
Denuded
Building
Pasture
Track roads
Rivers

We have mapped, quantified, and described the composition and configuration of the landscape with a high accuracy (25 m pixel) through digital mapping and landscape indexes.

In ecology, the term 'landscape metrics' refers to the quantitative methods used to characterize classes of patches or entire landscape mosaics. The indexes of a landscape contribute interesting numerical information concerning the composition and the configuration of landscapes, the proportion of each land cover type, and the shape of the elements in the landscape. In addition, landscape indices allow useful and interesting comparisons to be made between different landscape configurations, for instance, the same area at different temporary moments or a definition of future scenes [28]. The indices used to characterize landscape patterns between 1957 and 2009 were the following (See Table 2): mean patch size (MPS), patch density (PD), edge density (ED), radius of gyration (GYRATE), perimeter-area fractal dimension (PAFRAC), Euclidean Nearest-Neighbour Distance (ENN), patch cohesion index (COHESION), and Shannon's evenness index (SHEI) [25,29].

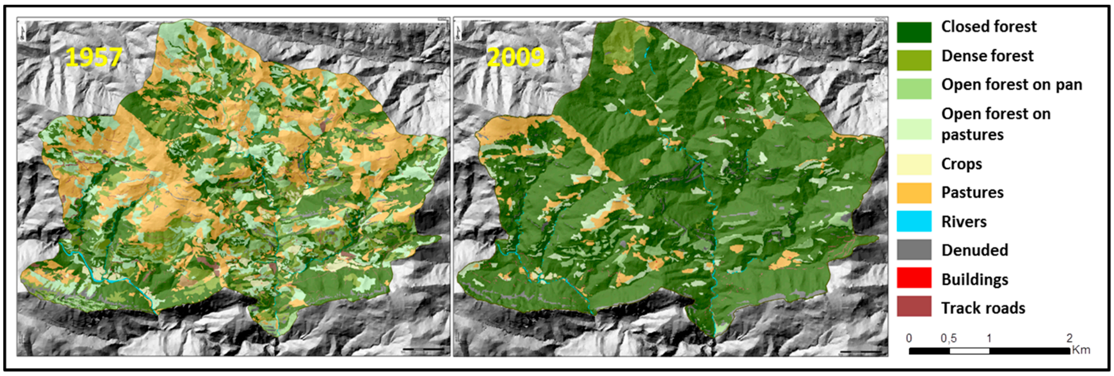

Figure 2. Land use and cover maps (1957–2009).

Table 2. Landscape metrics. MPS, mean patch size, PD, patch density, ED, edge density, GYRATE, radius of gyration, PAFRAC, perimeter-area fractal dimension, ENN, Euclidean Nearest-Neighbour Distanc, COHESION, patch cohesion index, SHEI, Shannon's evenness index.

Indices	Description	Units
MPS	Average patch size for a landscape	Hectares
PD	Number of patches per 100 ha for a landscape	Number per 100 hectares
ED	Length of edge per hectare for a landscape	Meters per hectare
GYRATE	Equals the mean distance (m) between each cell in the patch and the patch centroid. It is a measure of patch extent; thus, it is effected by both patch size and patch compaction	Meters
PAFRAC	Degree of complexity of patches based on a perimeter to-area ratio	None
ENN	Equals the distance (m) to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance	Meters
COHESION	Measures the physical connectedness of the corresponding patch type	None
SHEI	It is expressed such that an even distribution of area among patch types results in maximum evenness. As such, evenness is the complement of dominance	None

2.3. Creating New Agrarian Spaces Using Multi-Criteria Analysis and Geographic Information Systems (GIS)

Multi-criteria Analysis can be defined as a collection of procedures for structuring decision problems and designing, evaluating, and prioritizing alternative decisions [30–32]. Multi criteria Analysis can be defined as a collection of procedures for structuring decision problems and designing, evaluating, and prioritizing alternative decisions. Multi criteria suitability analysis has been used in this study. Multicriteria analysis (MCA) is the integration of attribute measures for criteria relevant to decision makers' objectives and measures of decision-makers' preferences. A common aggregation function that combines preference weights (w_i) and criterion scores (x_i) is known as the suitability index S. Weighted linear combination is a common means of calculating the suitability index [33]:

$$S = \sum w_i x_i \quad (1)$$

MCA includes formulating an evaluation matrix E consisting of $I*J$ standardized criterion scores (e) for I criteria across J alternatives and a group preference weight vector W consisting of preference weights (w) for each criterion i. The basic form of the weighted linear combination model can be expressed as equation 2. The weighted linear combination method is a straightforward application and can easily be spatially integrated in a geographic information system (GIS) by using raster-based map algebra.

$$\begin{bmatrix} s_1 \\ . \\ . \\ . \\ S_I \end{bmatrix} = \begin{bmatrix} e_{11} & \cdot & \cdot & \cdot & e_{1J} \\ . & \cdot & \cdot & \cdot & \cdot \\ . & \cdot & \cdot & \cdot & \cdot \\ . & \cdot & \cdot & \cdot & \cdot \\ e_{I1} & \cdot & \cdot & \cdot & e_{IJ} \end{bmatrix} * \begin{bmatrix} W_1 \\ . \\ . \\ . \\ W_I \end{bmatrix} \quad (2)$$

While different techniques for multi-criteria evaluation have been developed, the most commonly accepted method is Thomas Saaty's [34,35] Analytic Hierarchy Process (AHP), which has also been widely incorporated into different GIS applications to analyze aptitude [36,37]. The AHP first decomposes the decision problem into a hierarchy of subproblems. Then, the decision-maker evaluates the relative importance of its various elements by pairwise comparisons. The AHP converts these evaluations to numerical values (weights or priorities), which are used to calculate a score for each alternative (see Table 3). A consistency index measures the extent to which the decision-maker has been consistent in their responses. The Analytical Hierarchy Process (AHP) approach in the GIS-MCDA can handle such soft information (preferences, priorities, judgments . . .). The AHP extension developed by Marinoni in 2004 [38] was used with the Spatial Analyst extension of ArcGIS.

In our study, we established five types of criteria related to biodiversity, landscape structure and perception, cultural heritage, fire hazard, and management cost (see Figure 3). Different scenario maps were projected using multi criteria evaluation and geospatial information available for the study area. We classified each scenario map into seven suitability categories (1 low suitability and 7 high suitability for agrarian land recovery).

Table 3. Weights and criteria developed for local stakeholders for agrarian land recovery.

Criteria	Conservation Scenario	Neutral Scenario	Management Scenario
Biodiversity	45%	20%	4%
Lanscape configuration	28%	20%	7%
Cultural Heritage	16%	20%	16%
Fire risk	7%	20%	28%
Management cost	4%	20%	45%
Consistency Ratio ($CR < 0.1$)	0.0237	0	0.0237

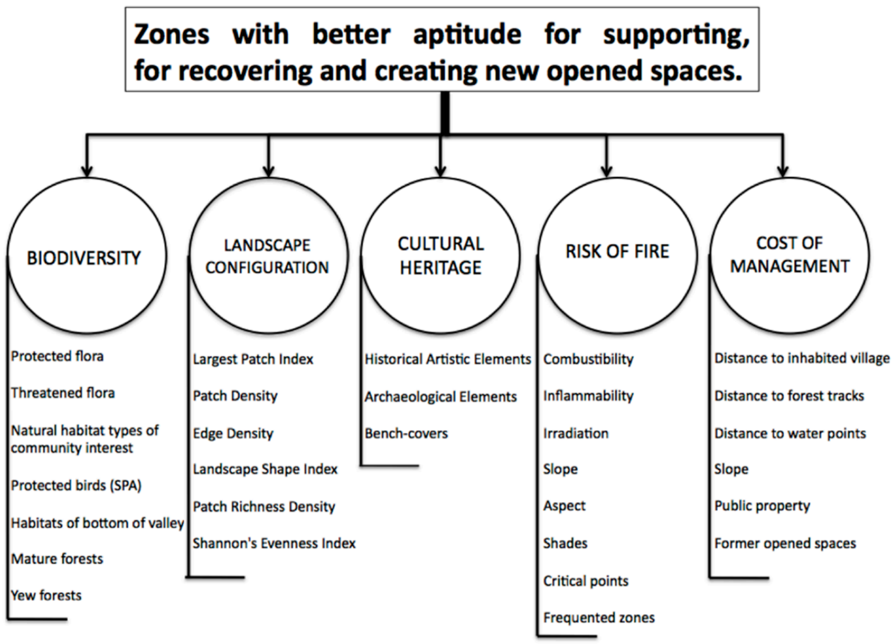

Figure 3. Multi-criteria analysis.

In the initial analysis, a first suitability map is developed in terms of biological biodiversity linked to agrarian lands (i.e., crops, livestock, bush, or open forests). In other words, we studied the zones that roughly contained "non-forest" diversity. To estimate this biodiversity, we used the available vectorial data layers relating to the key species and key habitats linked to these agrarian spaces, obtained from the Consortium of Alta Garrotxa, the local administration of the study area.

The perception and aesthetics of the landscapes reveal that, to a great extent, a number of structures are preferred over others [2,39,40]. According to Palmer [39], we can evaluate the perception of a landscape by calculating the ecological landscape indices [25,29] which refer to their configuration and composition. To carry out this analysis, six indices were chosen: ED (edge density), PD (patch density), LPI (large patch index), LSI (landscape shape index), PRD (patch richness density index), and SHDI (Shannon's diversity index). To calculate these metrics, the option "Moving window" from Fragstats® software (version 3.3, McGarigal and Marks, Oregon State University, Corvallis, OR, United

States) was used to create a raster map for each variable from the 2009 map of land uses and land covers. Finally, these raster layers were combined into one (reclassified into seven suitability categories).

Evidence that human activity had intensified in the area forming local cultures [40] includes the vast archaeological and architectural heritage that exists in the Alta Garrotxa today. Thus, to qualify and value the cultural heritage in the study zone, we used two recently conducted studies, which recorded two types of geographical information data: monumental heritage in the Alta Garrotxa [41] and archaeological heritage in the Alta Garrotxa, documentation obtained from Alta Garrotxa local administration. Espunya and Gallart [41] catalogued and georeferenced each monumental heritage element in the study area indicating its conservation status, while zones of archaeological interest were delimited based on the presence of archaeological remains.

Further to this, and in an attempt to prevent high-intensity fires, we identified areas of high fire risk where reducing the vegetation may help to contain fires. To assess potential fire hazards, a variety of information sources were used [42], along with the map of fuel models from the Fire Prevention Plan for the Alta Garrotxa (2006) [43], all of which were modified with the information concerning the evolution of woodlands during 1957–2009. The map models' flammability factor was developed by the Ecological and Forestry Applications Research Center in 2003 [44]. The global radiation data (annual average in MJ/m^2) came from the Climate Atlas of Catalonia [45], a collection of solar radiation data in Catalonia, which takes into account the variation in radiation depending on altitude and relief. The areas of greater affluence have been digitalized and a frequency map created by collecting information on crowded areas such as recreational areas, parking lots, the most popular visitor routes, or areas where people participate in adventure sports, as well as certain residential areas. We have used overlay analysis to combine the characteristics of several raster datasets into one raster layer [46].

Finally, we have classified the study area by taking into consideration the cost for a farmer to maintain the agrarian space that is to be regained in the future. Therefore, it is paramount to ensure that any new spaces recovered are in areas of low expenditure and are affordable to those farmers who want to cultivate them. Naturally, the most remote of the inhabited areas, water bodies, and roads which were on steep slopes on private property and in areas that were not agrarian lands in 1957, will have a much higher management cost.

Apart from the previously mentioned criteria, it was thought that including a restriction, understood as a set of relationships and limitations that certain types of criteria are delimited by, would be appropriate. These restrictions have been established with the intention of not recovering any open space within or in close proximity to a mature forest or a forest that has protected species (*Taxus baccata*). Once the criteria were established, the subsequent step was to consider them based on their degree of importance to different social agents. Depending on the degree of importance assigned to each of the criteria, we produced very different scenarios. The core of Saaty's process (1977) is the mechanism used to weight each of the criteria on each level of the hierarchy. This is done by making a comparison (pairwise), taking into account the contribution of each element to this hierarchy for each of the vertices immediately above that with which it is linked.

3. Results

3.1. Landscape Composition Changes Over the Last Fifty Years

In 1957, there was no change in the percentage of agroforestry habitats, even though there had been quite a lot of deforestation as a result of high levels of charcoal-related activity. Approximately 30% of the 1957 landscape corresponded to closed forest and pasture and around 15% to dense forest and open forest on pasture (see Table 4). Large areas of pasture and open forest indicate the importance of farming in the area at that time. Furthermore, 3% (155 ha) of the land is occupied by crops and the Alta Garrotxa terrain (known for being a low productivity land) has not helped in the area's development.

Table 4. Changes to different land use and covers between 1957 and 2009.

Classes	Δ ha. 2009–1957	Δ % 2009–1957
Closed forest (>90%)	2396.61	140.76
Dense forest (60–90%)	−580.30	−87
Open forest on pasture (10–60%)	−493.93	−62.68
Open forest on pan (10–60%)	2.45	1.59
Crops	−149.05	−96.38
Denuded	−0.67	−0.56
Building	−1.37	−55.75
Pasture	−1112.04	−76.87
Track roads	−63.93	−74.53
Rivers	−0.02	−0.06

The table above clearly shows the process of the aforementioned homogenization. Notably, closed forest has expanded by 140%, in step with the population decrease since the 1950s, and this has clearly led to progressive landscape uniformity. On the other hand, dense forest has decreased by 87%. The most likely cause for this decrease is the evolution of the dense forest into closed forest (See Table 5). The same process has occurred with open forest on pasture, which has been reduced by 62%. Finally, since 1957, pastures have been reduced by 74% and crops by 96%, and have mostly been transformed into closed forest.

Table 5. Transition matrix of land uses and cover classes (%) between 1957 and 2009.

1957	2009							
	Closed Forest	Dense Forest	Open Forest on Pasture	Open Forest on Pan	Crops	Denuded	Pastures	Others
Closed forest	89.6	2.21	2.92	2.32	0	0	2.67	0.28
Dense forest	82.69	3.53	4.42	6.57	0	0	2.66	0.13
Open forest on pasture	79.42	6.81	5.64	0	0	0	7.82	0.31
Open forest on pan	68.37	0	0	24.6	0	7.03	0	0
Crops	57.05	0	16.23	0	3.5	0	23.22	0
Pastures	73.34	1.97	11.74	0	0	1.21	11.74	0

By 2009, there was clear evidence of the homogenization process, with the greater part being dominated by closed forest and eventually occupying 80% of the study area to the detriment of the agricultural area (open forest, crops, and pasture) that covered 12% of the analysed territory (see Figure 4). The forest surface is not static but is changing in the Mediterranean basin; whereas in southern Europe, forests are currently expanding.

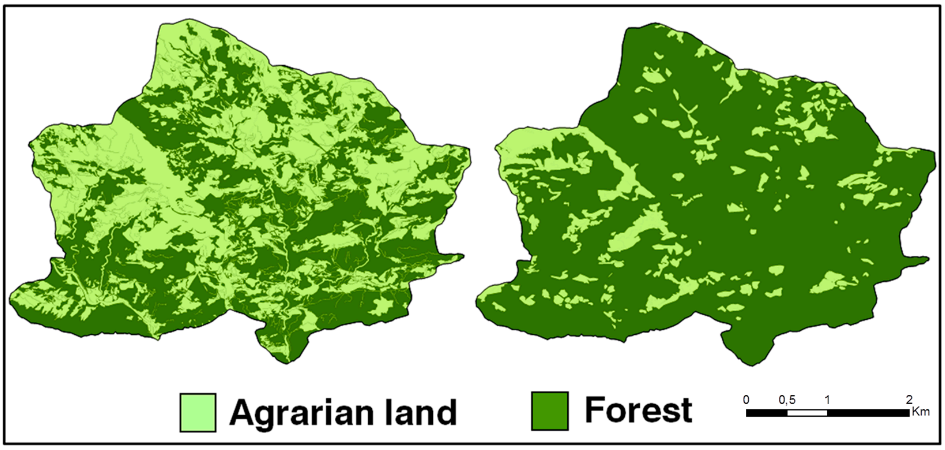

Figure 4. Forest vs. non-forest habitats.

3.2. Landscape Configuration Changes Over the Last Fifty years

Taking into account the MPS index, we can identify an increase in the average size of fragmented enclosed spaces such as closed forests (4085 ha) and, in 2009, this included approximately two hectares of dense forest (see Table 6). Moreover, there was a reduction in the average area of agrarian lands, including a 3.61 ha patch of open forest on a 4.28 ha grass pasture. Referring to the PD index, the categories closed forests and dense forests show a decrease, which indicates a reduction of fragments. Closed forests encompass a single patch covering 80% of the study area: a clear sign that the process of homogenization is widespread in the study area. Open forest on pan has increased its number of fragments, while the classes open forests on pasture, pasture, and crops have experienced a reduction in the average size of their fragments. All land use and cover classes show a reduction of the edge density (ED) throughout the study period.

Table 6. MPS, PD, ED, GYRATE, PAFRAC, ENN, and COHESION changes experienced by different land use and cover types between 1957 and 2009.

Classes	ΔMPS	ΔPD	ΔED	ΔGYRATE	ΔPAFRAC	ΔENN	ΔCOHESION
Closed forest (>90%)	4084.83	−3.6	−57.72	−40.53	−0.09	−19.13	0.41
Dense forest (60–90%)	1.8	−4.81	−79.05	4.49	0.01	921.52	−0.12
Open forest on pasture (10–60%)	−3.61	2.99	−59.24	−44.21	−0.02	58.83	−2.23
Open forest on pan (10–60%)	−1.31	1.08	−11.68	−57.25	0.08	−19.24	−5.47
Crops	−0.26	−2.41	−9.81	−9.76	0.14	466.84	−0.22
Pasture	−4.28	1.1	−54.01	−38.85	0.12	80.29	−1.58

Clear evidences of this fragmentation process can be observed in the values obtained for the remaining landscape metrics. The index of compactness of the fragments (GYRATE) has declined in the three open agrarian lands. The complexity index of form (PAFRAC) has increased in these three classes. Finally, the connectivity indexes (ENN and COHESION) have increased. In the case of Euclidean Nearest Neighbour (ENN), the distance between agrarian patches of the same class has increased, while cohesion (COHESION) between fragments has decreased. This fragmentation has favoured a breakup or dispersion of the patches for these open environments.

On the other hand, the class closed forest has displayed a distinctly converse behaviour, as reflected in the reduction of the complexity in the shapes of the fragments (PAFRAC), reducing the distance between the patches of closed forest and increasing cohesion and unity (COHESION) between forest fragments of this type, leading to a clear homogenization process.

From the year 1957, the result of this homogenization process has also resulted in a loss of landscape heterogeneity between the different classes/covers that make up the study area, as well as a loss of habitat edge, as was determined by calculating that the SHEI index (Shannon's evenness index) decreased from 0.72 in 1957 to 0.23 in 2009, which reflects a reduction of almost 50%.

3.3. Suitability Map Results for the Recovery of Agrarian Land

Three completely distinct scenarios have been created to examine the sensitivity and consistency of multi-criteria analysis: (1) a scenario in which a criterion of biodiversity basically prevails; (2) a neutral scenario in which each criterion is of equal importance; and (3) a scenario in which the criteria of management cost and fire risk prevention take maximum priority. Three pairwise comparison matrices [34] are thus obtained. As the result of a combination of the distinct criteria, Scenario 1, in which the criterion of biodiversity is prioritized (see Figure 5), defines the areas with a greater biodiversity in open environments (black) with respect to other areas in which biodiversity is of no importance (red). As expected, areas of ridge pastures and valley bottoms present rich biodiversity, as many habitats of Community Importance and bird species included in the Habitat's Directive can be found in these environments. A wide range of biodiversity for certain protected nesting bird species can also be found in risk areas.

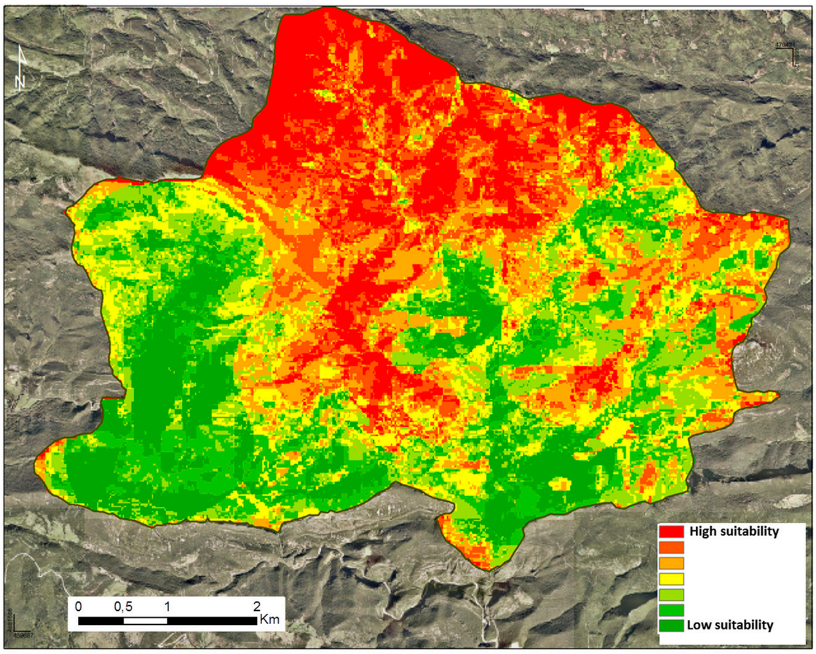

Figure 5. Suitability map according to the conservation matrix (Scenario 1).

The creation of Scenario 2, in which each one of the five criteria is of equal importance (see Figure 6), can be of great interest when managing and making decisions about nature protection areas when there is a lack of clear and specific administrative objectives. Unlike Scenario 1 and Scenario 3, this neutral scenario presents a smaller surface area with higher suitability values. These conditions are due to an equal prioritization of the different criteria, which therefore make it difficult to find areas where the five distinct criteria have simultaneously high values. Scenario 2 is, however, the scenario that gives a larger transition surface (with values between 3 and 5).

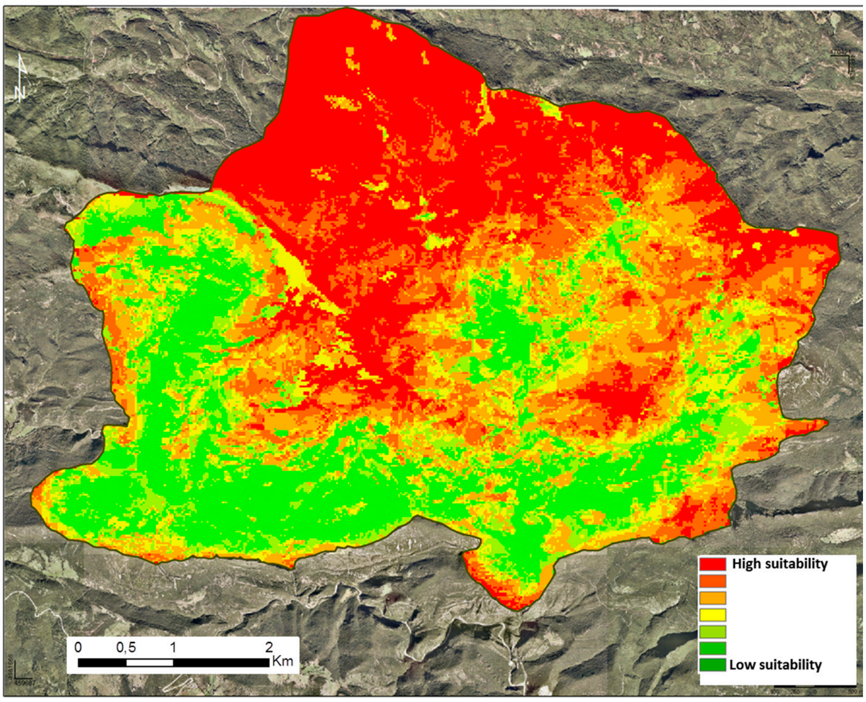

Figure 6. Suitability map according to the neutral matrix (Scenario 2).

Scenario 3 concentrates higher suitability zones in areas with gentle slopes (valley bottoms), which are easily accessible and close to water resources (see Figure 7). It can also be seen that high suitability areas are close to the few inhabited nuclei of the study area. The importance of this scenario is the role that the inhabitants within this study area have in maintaining the agricultural landscape. Difficulties in accessibility, as well as the costs that certain areas may incur for farmers that make these areas less attractive, are now reduced. These farmers and stock growers are therefore encouraged not to abandon farming. Consequently, management costs must be reduced to guarantee the recovery and maintenance of former agricultural areas.

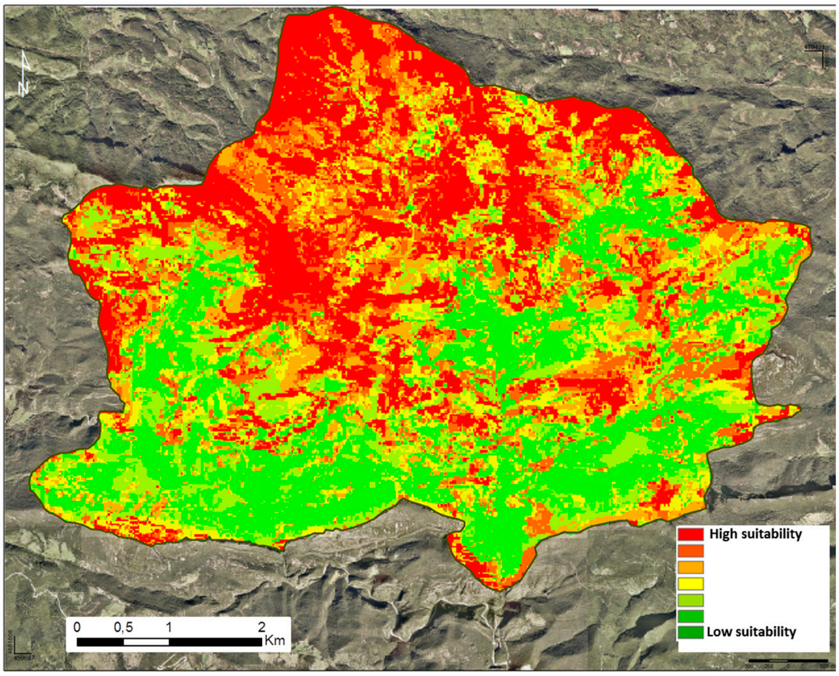

Figure 7. Suitability map according to the management matrix (Scenario 3).

4. Discussion

The evolution of land use and land cover from 1957 to 2009 shows a clear process of landscape homogenization characterized by a marked increase in the forest area, at the expense of agrarian lands such as pasture and croplands. This result is consistent with other case studies in the Mediterranean region [11,46]. These land use changes are directly related to the rural depopulation that the study area has undergone in recent decades. The population has declined, dividing by 4.5 during the past 50 years, causing a regression of agricultural activities. The number of farms divided by three during the past 20 years. The abandonment of charcoal production, as a result of its substitution by fossil fuels, resulted in a great descent of forest management practices, and caused the expansion and densification of forest in the study area. The final outcome is the establishment of a landscape pattern dominated almost exclusively by a single land cover: forest land.

An analysis of the landscape configuration shows that the agricultural areas are undergoing a clear fragmentation process. Fragmentation describes the appearance of discontinuities in a territory, in particular from the conversion of land uses and land cover types. Since 1957, agrarian patches have broken up into small pieces, due to the colonization of closed forest and the density of these spaces.

Large patch habitats are separated into small fragments and isolated from each other, as shown by the results obtained in mean patch size (MPS), patch density (PD), and edge density (ED). The progressive reduction in the density at the edges of all of land uses and cover classes is linked to the homogenization of closed forest from agrarian areas classes, and is due to reductions in area and in the number of patches of the different classes of open areas that have become part of a single dominant forest patch. This homogenization is a dynamic process of increasing a specific type of habitat at the expense of others.

The new shape of this landscape has direct biological and cultural consequences and also has consequences for the potential impact of natural hazards such as forest fires [19,22,47,48]. The loss of landscape heterogeneity and diversity implies the loss of ecological functionality [8,9,11]. The current trend generates a progressive trivialization of the landscape mosaic, which consequently involves a progressive loss of habitat heterogeneity [3,49]. Fragmentation and homogenization of agrarian lands are the main causes of the current high rates of species extinction. Certain groups of local organisms are particularly vulnerable to extinction because of homogenization (e.g., *Orchidaceae*), while other groups persist despite the high rates of habitat loss and homogenization (e.g., *Graminae*) [50]. Homogenization also decreases the relative amount of margin habitat, although it does, however, favour the increase of interior habitat in the landscape [19,51].

Forest fires are a major threat to Mediterranean forests, forming part of the dynamics of the Mediterranean forest as its floristic composition is rich in pyrophyte species that base their survival on the more or less recurrent presence of fire [14]. Landscapes where traditional activities have been abandoned contribute to the development of the vertical and horizontal growth of vegetation, to the emergence of woody areas, and to the accumulation of dead plant material [52]. Homogenous landscapes with high fuel loads and high connectivity are expected to favour fire intensity and spread. We recommend focusing on fire prevention by maintaining sufficient agrarian lands by preserving or promoting the traditional rural mosaic.

Mediterranean mountain areas require urgent management and modelling to provide alternative management scenarios, in order to maintain and recover habitats. The design of a model including a set of different scenarios and its evaluation using a multi-criteria evaluation analysis and geographic information systems has proved to enable the simple, quick, and efficient integration of an entire set of criteria (such as biodiversity, fire risk and management costs, landscape perception, and cultural heritage) that need to be considered when managing protected areas in this region. In addition, this type of analysis allows for simple updating of initial intelligence by adding more information regarding the existing criteria or by adding new criteria.

The results obtained for each Scenario show the importance of setting the different weightings (importance) of the criteria included in the analysis, according to the objectives, priorities, and needs of the protected area to be managed. Scenario 2 (neutral), unlike Scenario 1 (conservation) and Scenario 3 (management cost), presents a smaller surface area with higher suitability values for the recuperation of agrarian land. These conditions are due to an equal prioritization of the different criteria, which therefore make it difficult to find areas where the five distinct criteria have simultaneously high values. Scenario 2 is, however, the scenario that gives a larger transition surface, with several amounting to the medium suitability values.

Any sustainable development of this territory should prioritize conservation, biodiversity, landscape protection, and the preservation of Mediterranean features compatible with supporting agricultural activities that contribute to the area's biological diversity and cultural identity.

Managers should analyse and evaluate the repercussions on biodiversity, cultural heritage, or fire risk that may have resulted from the potential new agrarian lands for landscape structure.

5. Conclusions

Managers of Mediterranean regions have tried, not always successfully, to find a balance between the exploitation and conservation of natural resources. In the present time, despite some economic improvements, dramatic socio-economic, environmental, and land-use problems have emerged. Regional intervention and the management of rural mosaics should be the basic priorities in improving biological and landscape production and diversity in these natural areas [53], thus improving the perception of landscape and reducing fire risk at the same time.

Our analysis and multidisciplinary approach for characterizing the transformation of the landscape and the prospects for recovering agrarian lands, which take into account the impact on the morphology of the landscape, ecological and social processes, and the new relationships between local inhabitants and their environment, could then be applied more generally, (i.e., beyond the example of the Catalan pre-Pyrenees), in an attempt to better understand socio-ecological relationships and the challenges of landscape dynamics. This method attempts to contribute quantified changes and patterns in land use and their impact on the uniformity of the forest landscape. This kind of analysis helps to maintain and guarantee the agrarian land multifunctionality and makes the landscape more resilient.

This approach improves the availability of agrarian lands to reach 20% of the natural space and continues to maintain the forest vocation with 80% of the total area. This analysis contributes to the improvement of forest structure by designing three possible scenarios. This 20% would be enough to improve the quality of the landscape structure (forest in these areas are associated with a lack of management), increase the biodiversity, and considerably reduce the risk of fires.

Finaly, it is important to always consider the two main approaches (anthropocentric and ecocentric), which are often opposed. On the one hand, anthropocentric interpretation negatively views any major landscape changes resulting from the increase in forest cover, and stakeholders often associate these changes with a wilder, untamed nature, beyond human control; whereas, ecocentric interpretation views this evolution positively, and stakeholders say that it corresponds to the natural ecological dynamics. Participative processes for making decisions and reaching consensus must be implemented. The need to consider different views and perspectives and to obtain a broad consensus is even greater when bearing in mind that the amount of state funding dedicated to the management of protected natural areas is severely limited.

Acknowledgments: This work is carried out thanks to the financial support of Consorci of Alta Garrotxa and we thank the Consorci for help during the field work and access to documentation.

Author Contributions: All the authors have contributed significantly to the paper. The tasks were distributed in the following way. Diego Varga and Josep Vila Subirós conceived and designed the study. Diego Varga performed the acquisition of data. Diego Varga, Josep Vila Subirós, and Carles Barriocanal analysed and interpreted the data. Diego Varga, Josep Vila Subirós, Carles Barriocanal, and Josep Pujantell drafted the manuscript. Josep Pujantell performed a critical revision.

Conflicts of Interest: The authors declare no conflict of interest.

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