Forty-Four Years of Land Use Changes in a Sardinian Cork Oak Agro-Silvopastoral System: A Qualitative Analysis

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Abstract: The island of Sardinia is the biggest producer of natural cork in Italy. In this study, cork oak cover change is investigated in a typical agro-silvopastoral system where the main activities are cereal fodder and wheat cultivation, sheep rearing and cork exploitation.

The research method is based on the comparison of two land use maps produced by photo-interpretation of digitised aerial photographs taken in 1954 and 1998, combined with interviews with local farmers, field surveys, and data collected from literature, administrative documentation and decadal censuses (at council level).

The results show that the cork oak woodland surface decreased (-29%). It was substituted by other forest, ploughed land, and mixed grassland and shrubland. Apart from the transformation of the cork oak woodland to other forest, other changes have happened probably because of an increase in agricultural and pastoral activities as described by the documental material available for the same area.

Keywords: Cork oak, multi-temporal analysis, aerial photography classification, forest cover, land use, Sardinia, agro-forestry.

1. INTRODUCTION

Cork oak forests are semi-natural systems in which human agricultural and pastoral activities are implemented (the so-called agro-silvopastoral or agroforestry system). The economic significance of these habitats lies in direct benefits derived from cork exploitation and the parallel activities usually carried out under tree canopies (i.e. cropping, grazing, hunting, mushroom-collecting), which are of considerable social importance since they are associated with traditional agricultural, silvicultural and pastoral activities [1]. Moreover, the habitats that support the species have been recognised as having both cultural and biodiversity value at European level [2, 3].

According to the most recent land use map of Sardinia [4], the pure stands of cork oak forest, in which the trees are mainly cork oaks (*Quercus suber* L.), cover 84,763 ha; a second typology, low-density cork oak populations, usually associated with tilled land, is estimated at 53,178 ha. Both systems can be considered productive in terms of cork extraction and contribute significantly to the local economy. They correspond to 83% of national cork oak surface and 10% of the world coverage [5]. About 80% of the Sardinian pure cork oak forests are privately owned and characterised by high fragmentation and small average size (between 10 and 20 ha) [6]. A third typology, the protective cork oak forest, is a mixed forest composed of cork oak, other oaks and Mediterranean shrubs of no economic interest (in terms of cork production) but with a relevant covered area of 355,411 ha. Therefore, in Sardinia the total area of natural cork oak trees (pure and mixed) is 493,352 ha or about 20% of the Sardinian surface. Most of the productive cork oak forests and cork farms are concentrated in the north of the island [7], and contribute 150,000,000 euros per annum through the production of cork bottle stoppers [8].

Cork oak habitats are threatened by over-grazing, deep ploughing, extreme exploitation of cork oak plants and unskilled cork stripping [9, 10]. Fires are also responsible for a reduction in regeneration and in the area covered by these systems [11]. In addition, extreme climate events (e.g. long drought) can contribute to a general vegetation stress ('cork oak decline') [12]. The resulting spatial macro-effects are forest regression, forest density reduction, and an increase in the number and dimension of gaps [13]. The contraction of cork oak ecosystems has a negative effect on industry (reduction in cork production), biodiversity (e.g. bird community [14]), and the quality of the environment (e.g. reduction in capacity of carbon storage).

Analysing changing landscape patterns is one approach to understanding ecological dynamics and the influence of natural and human disturbances [15-18] and supporting decision-making for reciprocal protection of vegetation and human activities. Few studies have analysed the spatio-temporal changes in Mediterranean cork oak forests. For a small area in Spain (~1,200 ha), it was estimated a reduction of 6.2% of the original cork oak cover from 1977 to 1998 [19]. A more complete analysis (that considers imagery data as well as topographic information), applied in Southern Portugal on 6,224 ha from 1956 to 2005, has shown that cork oak area regression rate was slightly larger than its extension

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rate [20]. While, an expansion of cork oak forest was estimated on 40,000 ha in Southern Spain for the last 100 years [21]. In all these studies the cork oak changes are due to human factors such as land use changes or forest management.

Following the remote sensing techniques applied in similar analysis [19-22], and consisting in photo interpretation and field investigation, this study analyse the changes in cork oak cover in relation to forty four years of agricultural activities, human population and socio-economic dynamics, by studying the differences between two series of aerial photography and other documental material (decadal demographic, forestry, and agricultural statistical censuses from 1960 to 2000). Whereas today satellite imageries are detailed enough to map vegetation structures, historical analysis of landscape patterns usually uses different sources of information such as aerial photographs [23-25] (no satellite imageries are available for 1950s) that do not allow a finer vegetation classification [26]. This is one of the reasons why only a qualitative analysis based on unsupervised and supervised methods for imagery classification combined with literature research and field surveys is recognised as a good compromise in analysis of historical changes in complex vegetation systems [26-28].

2. A BRIEF DESCRIPTION OF THE CORK OAK FOREST ECOLOGY AND MANAGEMENT

The cork oak vegetation area responds to the oceanic Mediterranean climate (humid and subhumid). This climate is characterised by high summer temperatures, mild winters, copious rainfall (optimal 600-800 mm) and short periods of drought [29]. The presence of cork oak in dry areas is related to the mitigating effect of high atmospheric humidity [30]. It grows commonly in low-calcium soils, whose main constituent is silica [31]. Thus, on the basis of its ecological requirements cork oak may be defined as a thermophilous, hygrophilous, drought-tolerant, heliophilous species [32]. Winter cold is the most limiting factor for its spreading to the more continental interior zones [33].

The pure stands of cork oak forest are managed as high forest, with low levels of intervention and, when possible, seed regeneration [34]. These systems are called *dehesa* in Spanish and *montado* in Portuguese; despite the name, they are very similar in forest structure and management to the rest of the Mediterranean cork oak forest.

The estimated life of a cork oak tree is 300 to 400 years and trees are economically viable for fewer than 150 [6]. Cork exploitation, on the same plant, occurs every ten years, when the bark has a sufficient width for industrial processing. It is not necessary to cut the plant but simply remove the tree bark; it demands, however, a masterly touch to protect the cork generation tissue [6]. The cork of the first harvest has a hard and irregular structure and is usually used for low-quality products. Only cork obtained from the third and following debarking of trees reaches perfect quality. A mature cork oak tree can produce more than 50 kg of cork in a single stripping, worth 50 to 250 euros/q depending on its quality [7].

3. STUDY AREA

The investigated area is called Sa Serra (latitude 9°15', longitude 40°20') and is located in Nuoro Province, central Sardinia (Italy). It is considered a dynamic area owing to population growth, land use changes and the high pressure of grazing; with regard to the latter, the Forestry Commission in 1985 extended the protection limits to almost its whole surface. The town of Nuoro (population in 2001: 36,320), capital of its province, is situated on the plains near the border of the south-eastern section of the study area.

Sa Serra (10,050 hectares) is a mountainous area with an average elevation of 500 m and moderate slopes (often lower than 15%). The annual rainfall is on average 850 mm and the mean annual temperature is 13.5°C, and 9.5°C is the mean annual minimum temperature [35]. These climate parameters follow the optimal climate range for cork oak [6].

The land-cover is a mixture of agricultural, forested and suburban land. The forest is primarily composed of cork oak and rarely other Mediterranean oaks. Land use is dominated by extensive and intensive agriculture and grazing, in most cases associated with cork production (5-1.5t/ha) which is considered as secondary income [36], because of its medium quality and the higher and continuous earnings obtained from the products of sheep farming.

4. METHODOLOGY

The approach included: (1) definition of the area and data collection (imageries, documents etc…); (2) photo-treatment; (3) unsupervised and supervised classification and overlaying land use maps (1954 and 1998) to reveal changed land; (4) validation.

4.1. Area Delimitation and Data Collection

The Sa Serra site was delimited with the help of topographic maps at the scale of 1:25,000 provided by the Military Geographic Institute (IGM, sheets 481-sect II, 482-sect III, 499-sect I; 1989). These maps contained county and municipality borders, approximate land cover types, watercourses, road networks and contours.

Information on land use was obtained from large-scale aerial photographs for 1954 and 1998 (Table **1**). The aerial photographs of 1998 were supplied orthorectified with 1.0 m resolution by the Environmental Department of the Sardinian Government [4]. The 1954 photographs were provided in paper prints by the ICCD institute [37] and then digitalised by an A3 scanner at 600dpi, 8 bits. This value was chosen because it guarantees a good picture quality with high geometric definition and manageable dimension in terms of bytes (50 MB).

Each series of photographs was related to the spring season in order to guarantee comparable sun angle and vegetative phenology.

Other heterogeneous material included a land use map of Sardinia (based on Corine classification), at a scale of 1:25,000; a digital elevation model of the area [4]; the

Table 1. Characteristics of the Airborne Remote Sensing Data

Year	Sensor	Date	Mode	Camera Focal Length (mm)	Scale/Ground Resolution	Ground Resolution (m)
1954	Aerial Photographic Camera	March-May	Black & white	152.3	1:33,000	0.5
1998	Digital Camera	March-April	Black & white	14	1:10,000	0.3

decadal census about agriculture, forest and population, literature; official documentation and farms data p; all provided an estimable source of information about land use changes.

4.2. Photo-Treatment

Orthorectification [23] was carried out with the tool *Orthoengine* (performing a thin plate spline math model) of *PCI* software using the digitalised photographs of 1954 and the digital elevation model (10m resolution). The final orthorectification error was 1.6 m.

During this procedure tonal adjustments of the photographs were made to ensure the mosaic would look as seamless as possible. Such a process results in adjustments to tonal response from objects on the photograph that have to be taken into account when comparisons are made with the same area taken at a different time with a different optical system [24].

4.3. Classification

Definiens eCognition [38] was used to classify the land use in macro-classes using the object-oriented approach [39]: from the photographs it was extracted homogeneous regions with unique semantic meanings (based on the pixel values) and sufficient geometric accuracy [40]. In other words, the software aggregated the pixels, according to their value, until the final object satisfied various indexes of spectral and geometrical homogeneity (segmentation).

The object-based method requires the prior definition of several parameters: scale, colour, shape, smoothness and compactness (see [38] for a complete definition of them). The five parameters were chosen after several trials of a small portion of the area by comparison of the classes produced in the process of segmentation with the true classes delimited and verified on the ground. The comparison took into account the classes, area and perimeter of each polygon. The authors used 100, 0.4, 0.6, 0.7 and 0.3 for scale, colour, shape, smoothness and compactness respectively, giving greater weight to shape and contour than to colour (black and white aerial photographs are poor in colour information) and compactness. These values allowed an error in perimeter and area of less than 10% (estimated from a field sample).

The object-based segmentation resulted in four macro-classes: forest/shrub cover (forest), roads and building (urban), ploughed land (agricultural), and water. The difficulties of splitting polygons into more detailed classes, as explained above, made it necessary to export the layers produced into an administrative geographic information system (*ArcGis-ArcInfo* [41]) for supervised classification (photo interpretation) [42]. Field surveys were carried out to acquire familiarity with land use types present in the area and with their photographic characteristics, and to collect several digital pictures that could be used as reference during photo-interpretation. Local recent vegetation maps were also used [43]. At the end of the classification process thirteen types of land use were mapped. The principal photographic characteristics of each land use adopted in the supervised classification are reported in Table **2**. For instance, cork oak can be distinguished in aerial photographs by its darker colour and larger crown size than the other Mediterranean tree species. A forest cover of 20% was adopted to distinguish between pure cork oak forest (>20%) and agro-forestry systems (<20%). The value of 20% was chosen in accordance with the definition of forest given by Food and Agricultural Organisation [44] and the value of canopy cover used in the former National Forest Inventory for Italy. When the canopy cover is less than 5%, the term forest or forestry is replaced by 'trees' (Table **2**).

The tree/forest cover is estimated visually using a point grid superimposed on the vegetation, and counting the number of points included in the tree/forest crown.

The products of unsupervised and supervised classification of both the imageries of 1998 and 1954 were two land use maps.

4.4. Validation

Photo-interpretation validation consisted of a survey on the field to verify ground truth (present land use cover) and the past uses through interviews with the owners or looking at the residuals of past uses or operations. It was carried out on 20% of the area.

The validation steps were as follows:

(a) Identification of the area to be considered for validation. The polygons to be validated were taken randomly and were not necessarily spatially continuous.

(b) Verification of the actual land use.

(c) Verification of past land use.

  a. Interviews. The interviews were carried out with the owners of the farmland. The questions were designed to discover the past land use and the causes of its changes.

  b. Past land use residuals analysis. The selected polygon was investigated in order to find signs of previous vegetation (coppice, regeneration, distribution and composition of the present vegetation), agricultural uses (passed cultivation, abandoned land, road and path network system, type of rural

Table 2. Classification Legend for Sa Serra. The First Column is the Official Class of CORINE Classification (European Environmental Agency). The Second Column Refers to the Classes Used in this Analysis

Corine Code Level	Classes	Cork Oak Cover (%)	Other Tree Cover (%)	Photographic Characteristics for Manual Interpretation
1	Roads and rail networks	0	0	Uniform colour: white or grey. Irregular shape
1	Industrial farm and military areas	0	0	Uniform colour (various) and regular shape. They have a large patch size.
1	Rural habitation	0	0	Uniform colour (various) and regular shape. They are dispersed in the area and characterised by the presence of collector roads.
2	Pure ploughed land	0	0	Fine texture, uniform colour (grey - dark grey), presence of tillage patterns (regular lines). Regular shape and absence of trees.
2	Ploughed land with trees	<5	<5	Fine texture, uniform colour (grey - dark grey), presence of tillage patterns (regular lines). Regular shape and presence of sporadic trees.
2	Ploughed land with group of trees	<5	5-20	Fine texture, uniform colour (grey - dark grey), presence of tillage patterns (regular lines). Regular shape and presence of trees.
2	Cork oak with pasture or ploughed land	5-20	<5	Dark trees (cork oak) associated with ploughed land (fine texture, uniform colour, presence of tillage patterns) or pasture (coarse texture, varied colours).
3	Cork oak forest	>20	variable	Open forest with major component of dark trees. The other vegetation (brighter) comprising a mixture of shrubs and trees. Irregular shape.
3	Other forest	5-20	≥20	Close forest with varied colour. Irregular shape.
3	Afforestation and reforestation	variable	variable	Regular pattern and texture. Rows of small trees in parallel lines.
3	Fire screen	0	0	Large white borders of the forests. Uniform colour and regular shape. Fine texture.
3	Mixed grassland and shrubland	<5	<5	It has a mixed texture and varied colour owing to the presence of vegetated parts, stones and nude soil.
4-5	Natural and artificial water storage and rivers			Water has black colour and regular shape (artificial) or irregular but continuous (natural). Rivers have characteristic shape.

house), and fires (evidence in the tree trunk, rootstock, bark and branches).

The validation of the 1998 and 1954 maps was done for the same 50 polygons. Interviews and field investigation were the only methods available to verify the past land use. In fact, for the study area there were no historical maps or detailed reports. They were carried out during spring 2003.

5. RESULTS

The analysis of the historical documentation allowed in build a general description of the Sa Serra macro-dynamics in the last 100 years [36,45-51].

During the fascism of the 1930s and 1940s, large parts of Sa Serra were converted to ploughed land to respond to food demand. The maximum surface was reached around 1957 [44], with large portions of the natural vegetation replaced by wheat cultivation.

Between 1960 and 1980, the process of industrialisation determined human emigration from the countryside to the neighbouring city of Nuoro with a progressive increment of abandoned land [44], reduction in agriculture surface and number of active farms [46-47] (Table **3**). From 1950/1960 it started a generalised conversion of the bovine farms in sheep farms because of the associated lower cost of management [45]. A large proportion of abandoned land was acquired at low cost by neighbouring farm determining the increase of the average farm dimension. The prevalent farm management was based on extensive grazing [48], associated with expansion of cultivated pasture even in areas occupied by natural mixed grassland and shrubland [46-49].

The industrial crisis in the 1980s and the expansion of the cities in the neighbouring countryside contributed to the return of intensive agricultural (increase in number of farms and agriculture surface) and intensive pastoral activities: wheat cultivation decreased, often replaced by pastures and fodder lands [49]. The number of sheep per hectare increased from two to three [46].

The final decade is characterised by a new regression of agricultural land (Table **3**) in part for the transformation of agricultural land in forest land promoted by European founding given to promote re-forestation or afforestation in farm land (EEC Regulation 2080/92 on forestry measure in agriculture) [36]. By interviews, it was ascertained that the application of EEC Regulation 2080/92 contributed to the cork oak reforestation of 2% of the total area.

According to the census [46], the years associated with a reduction in number of active farms are always associated with years with an expansion of mixed grassland and shrubland.

During the qualitative field survey, it was found several cases where the vegetation renovation had been destroyed by human intervention and illegal cutting of trees, usually realised in order to increase the agricultural and/or pasture

Table 3. Decadal Agricultural and Population Census [54-55] for the Municipalities Sharing Sa Serra Area. The Categories are Not Referred to Sa Serra But to the Overall Area Contained by the Municipalities (48,700 ha). Some Categories were Not Reported in the Early Census (NR)

	1960-1970	1970-1980	1980-1990	1990-2000
Total number of farms	1,095	983	1,062	1,196
Number of mechanised farms	NR	427	680	642
Cultivated pasture(ha)	2,626	3,272	5,766	7,838
Agriculture (ha)	1,734	1,633	1,789	1,212
Mixed grassland and shrubland (ha)	33,391	13,019	24,373	16,797
Afforestation and reforestation (ha)	NR	NR	4	1,695
Forest	5,506	10,609	10,654	6,562
Cattle (number of individuals)	6,500	6,094	5,974	4,685
Pigs (number of individuals)	NR	3,188	3,845	3,292
Sheep (number of individuals)	NR	94,005	99,020	106,844
Goat (number of individuals)	NR	NR	3,728	5,091
Horse (number of individuals)	NR	NR	571	707
Chicken (number of individuals)	NR	NR	21,642	5,682
Population	39810	43908	45021	42446

surface (farm mechanisation). This problem has been investigated in Spain and Portugal, where agro-pastoral activities are the principal cause of the absence of cork regeneration in all the agroforestry systems such as *dehesas* and *montados* [50]. This phenomenon is greater in areas where the cork market is not able to participate in the global cork business [51-52].

The summary table (Table **4**) was obtained from the intersection of the two land use maps and gives an approximate (and not statistical) quantification of the land use changes (Fig. **1**). The changes influenced 36% of the total surface area where 60% of the transformed surface was cork oak forest. Whereas ploughed land with groups of trees was relatively unchanged, the areas of cork oak with pasture or ploughed land, other forest and pure ploughed land increased with values between 6 and 10% of their starting surfaces. The largest surface increments, however, were estimated for the, mixed grassland and shrubland (66%) and the ploughed land with trees (66%) classes. The large percentages for afforestation and reforestation, fire screen, rural habitation and natural and artificial water storage and rivers categories were because of their near-absence in 1954.

A total of 5,205 ha (51%) of the study area was cork oak forest in 1954 (61% with the surface of cork oak with pasture or ploughed land). This surface was severely decreased after forty-four years by 29%.

Figs. (**1-3**) are maps of the area at the two different temporal moments, 1954 (left) and 1998 (right), and specific to the main land use categories considered in this work: cork oak forest, ploughed land, mixed grassland and shrubland and other forest. Fig. (**1**) shows that the cork oak forest

Table 4. Land Use Change Between 1954 and 1998 in the Study Area

	1954 (ha)	1998 (ha)	Difference Between 1954 and 1998 (ha)
Other forest	1,440	1,590	+150
Cork oak forest	5,205	3,682	-1,523
Cork oak with pasture or ploughed land	859	908	+49
Mixed grassland and shrubland	599	997	+398
Ploughed land with trees	688	1,150	+462
Pure ploughed land	603	654	+51
Ploughed land with groups of trees	545	536	-9
Afforestation and reforestation	2	185	+183
Fire screen	0	14	+14
Rural habitations	1	13	+12
Industrial farms and military areas	61	232	+171
Roads and rail networks	46	83	+37
Natural and artificial water storage and rivers	1	6	+5

erosion interested almost the entire area, especially in its centre, apart from the extreme South-West corner. In part, this is due to the diffusion of small parcels of ploughed land in the centre, in the North and North-East of Sa Serra (Fig. **2**). The centre of the area is probably the main area interested

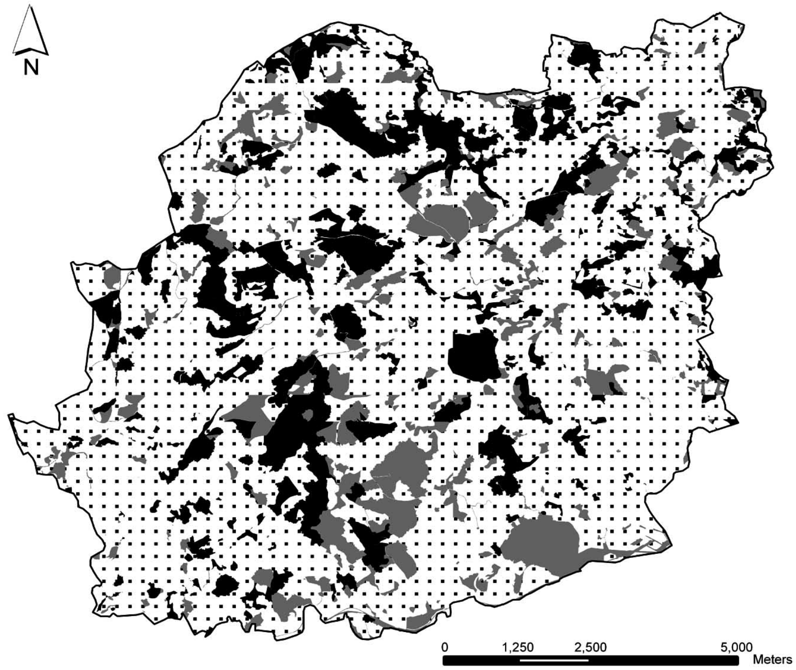

Fig. (1). General land use dynamics in Sa Serra: 'cork oak woodland' regression (black), changes not involving 'cork oak woodland' (grey) and unchanged areas (stippled).

Table 5. Matrix of the Changes (Values in % of the Total Area). * Cork oak Forest + Cork Oak with Pasture or Ploughed Land

1954 \ 1998	Cork Oak Woodland	Other forest, Afforestation, Fire Screen	Ploughed Land (Pure, with Trees, with Groups of Trees)	Mixed Grassland and Shrubland	Other Land Uses	% in 1954
Cork oak woodland*	44	8	6	3		61
Other forest, Afforestation, Fire screen	2	9	2	1		14
Ploughed land (pure, with trees, with groups of trees)			16	2		18
Mixed grassland and shrubland		1		5		6
Other land uses					1	1
% in 1998	46	18	24	11	1	

by land use change, in fact, the increasing in ploughed land is associated with the increasing in grassland and shrubland (Fig. **3**). The extension of mixed grassland and shrubland is usually the effect of reduction in forest cover (Table **5**).

Table **5** shows the transactions between the main classes in terms of percentage of the overall area. The sum of the rows is the proportion of the classes with respect to the overall area in 1954 and the sum of the columns is the proportion in 1998. The main transactions are all referred to as cork oak woodland (the sum of the cork oak forest and cork oak with pasture or ploughed land surfaces), characterised by a degradation in other forest, afforestation and fire screen (8%), ploughed land (6%) and mixed grassland and shrubland (3%). This was because of loess in cork oak density with the gaps occupied by other Mediterranean trees (other forest), shrub species (mixed grassland and shrubland) or cultivations (ploughed land).

The results of the validation are reported in Tables **6a** and **6b**. The accuracy of the 1998 land use map was estimated at 88% (Table **6a**), mainly because of misleading forest composition and or forest height (well-developed mixed grassland and shrubland can easily be confused with other forest or degraded afforestation).

The validation process for the land use map of 1954 gave an accuracy of 70% (Table **6b**), an order of accuracy much smaller than for 1998. In fact, the 1954 photographic material resulted in more darkness, which made it difficult to distinguish forest with a low degree of cover crown from mixed grassland and shrubland, which were underestimated. The same problem was found in afforestation and reforestation because of the different method of reforestation applied at that time, with less shrub-cutting and soil movements, resulting in a mixed system of shrubs and individual plants that gives an overall forest appearance.

6. DISCUSSION

The unsupervised classification had the advantage of precisely defining the macro-classes of land cover, in a large area, for easier recognition of the sub-classes during the

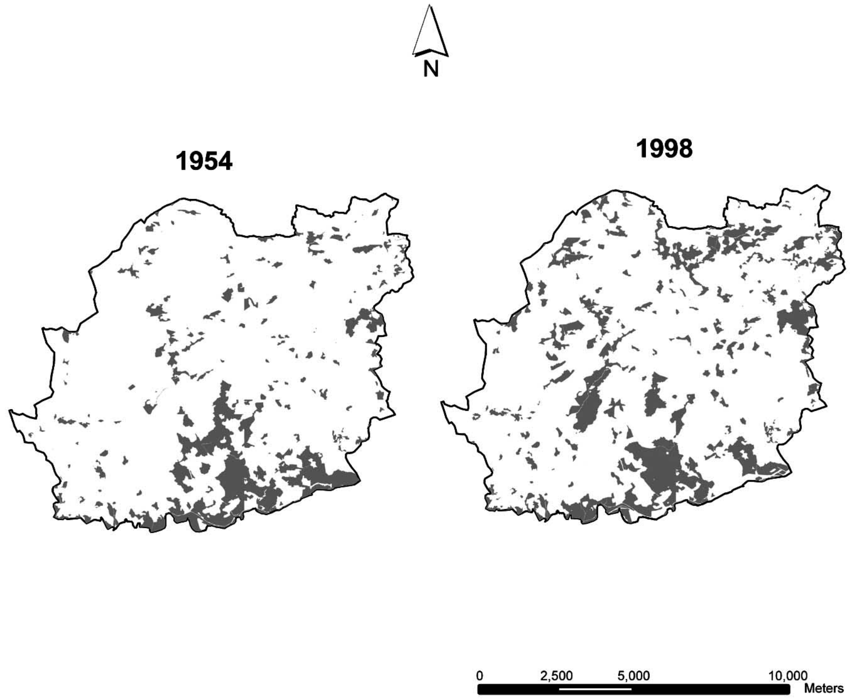

Fig. (2). The spatial differences in the area of 'Ploughed land' (grey) between 1954 (left) to 1998 (right).

successive supervised classification [54-58]. With regard to high-spatial resolution imagery [53], the black and white photo provides poor information and does not allow the direct unsupervised classification of the sub-classes, especially when the vegetation is composed of species with similar optical behaviour (i.e. cork oak and holm oak). On the other hand, the supervised classification (manual) distinguished the different sub-classes by the use of imageries, maps and information gathered during the field surveys. However, the success of the supervised classification is due to the use of local experts during the phase of photo-interpretation as shown elsewhere.

The trends in the census data (considering only 1960/70 and 1990/00) and in the results from the analysis of land use change by aerial photography are in agreement for the classes of cultivated pasture (as defined in the census) and ploughed land (as defined in the cork oak change map, containing ploughed land with trees and pure ploughed land); and afforestation and reforestation (Tables **3** and **4**). The disagreement between the two investigation is due to a different definition of forest. In fact, in the census the class forest is defined as a minimum surface of 0.5 ha with tree cover of 50%. This definition probably excludes a great part of cork oak forest, which usually is composed by sparse trees with low cover. And in fact, the trend in the class forest is similar to the one of the class other forest.

The mixed grassland and shrubland category considered by the census is manly composed by natural pasture land. The main difference with the class used in the imagery classification, is that the census consider the natural pasture as mixed grassland and shrubland if they are grazed for at least 5 years. In the case of abandoned land, this category is included in forest. This can be another reason explaining the increase in forest and the reduction in mixed grassland and shrubland. in the census

The imagery comparison describe an increase in agro-pastoral activities characterised by four processes: an expansion in cultivations - increase in ploughed land with trees and pure ploughed land (Table **4**); transformation of other forest and cork oak woodland in ploughed land (Table **5**); a progressive conversion from agricultural to pastoral management - increase in mixed grassland and shrubland (Table **4**); transformation of cork oak woodland, other forest and ploughed land in mixed grassland and shrubland (Table **5**). The transition from ploughed land to mixed grassland and shrubland (Table **5**) relates to the land abandonment [20]. The result is the regression of the cork oak forest and the expansion of the other categories (Figs. **2**, **3**).

During field survey and interviews (realised for the validation analysis) the authors confirmed the presence of the changes in land use, particularly in cork oak forest. Often, owners admitted the reduction of cork oak by fires, and climate change and diseases were other causative factors. These factors may have contributed to the transformation of the cork oak woodland in other forest by reducing the capacity of cork oak regeneration [22]. Quantification of the damages arising from exceptional drought, entomological attacks and diseases is not achievable with the method applied. Other studies confirm the presence of several pathogens related to cork oak decline [59], but there is no evidence of a direct relation between disease and cork oak forest regression. Repeated fires are almost certainly the causes of forest regression and forest cover losses, but in the study area few fires were recorded that were large enough to reduce the cork oak forest on the present scale.

7. CONCLUSIONS

This research presents a change map for loss of cork oak forest over a period of 44 years obtained through a digital

Table 6a. Validation Results for 1998

Classes	Number of Polygons Validated	Correct	Incorrect	Incorrect Classes
Other forest	6	4	2	1 Cork oak forest; 1 mixed grassland and shrubland
Cork oak forest	6	5	1	1 Other forest
Cork oak with pasture of ploughed land	6	6	0	
Mixed grassland and shrubland	4	3	1	1 Afforestation
Ploughed land with trees	6	6	0	
Pure ploughed land	6	6	0	
Ploughed land with groups of trees	6	5	1	1 Mixed grassland and shrubland
Afforestation and reforestation	3	2	1	1 Other forest
Fire screen	2	2	0	
Rural habitations	1	1	0	
Industrial farms and military areas	1	1	0	
Roads and rail network	1	1	0	
Natural and artificial water storage and rivers	2	2	0	

Table 6b. Validation Results for 1954. *No Validation for 1954 Because Absent. ** Validation Polygons Reduced Because Not Enough

Classes	Number of Polygons Validated	Correct	Incorrect	Incorrect Classes
Other forest	6	2	4	1 Cork oak forest; 1 mixed grassland and shrubland; 2 afforestation
Cork oak forest	6	4	2	2 Other forest
Cork oak with pasture of ploughed land	6	5	1	1 Ploughed land with trees
Mixed grassland and shrubland	4	2	2	1 Pure ploughed land, 1 cork oak forest
Ploughed land with trees	6	4	2	2 Mixed grassland and shrubland
Pure ploughed land	6	6	0	
Ploughed land with groups of trees	6	3	3	2 Mixed grassland and shrubland; 1 afforestation
Afforestation and reforestation**	1	1	0	
Fire screen*	0	0	0	
Rural habitations	1	1	0	
Industrial farms and military areas	1	1	0	
Roads and rail network	1	1	0	
Natural and artificial water storage and rivers**	1	1	0	

analysis of aerial photographs (and overlay analysis of the two land use maps produced), and information from field surveys, literature (reports and official documents from local and central Sardinian Government) and the analysis of census and farm data. The latter is drawn from interviews with farm managers and/or owners and field survey.

In particular, census data and farm analysis significantly supported the present research. In fact, there are substantial differences between photo data and the ascertaining of a trend when observation is confined to two time periods.

The cross-analysis of the land use changes drawn from field investigation and historical documentation indicates that human intervention is a possible cause of the remarkable decrease in cork oak area and crown tree cover.

The present national and regional policies (L.N. 991/1952; L.N. 759/56; L.N. 431/85; L.R. 4/94) are not adequate for cork oak protection because of the lack of clear terminology and definition of cork oak forest. The inclusion of cork oak forests in Annex I of the Habitat Directive [60] is one of the necessary tools to protect cork oak habitat. From a management point of view, it is important to define an

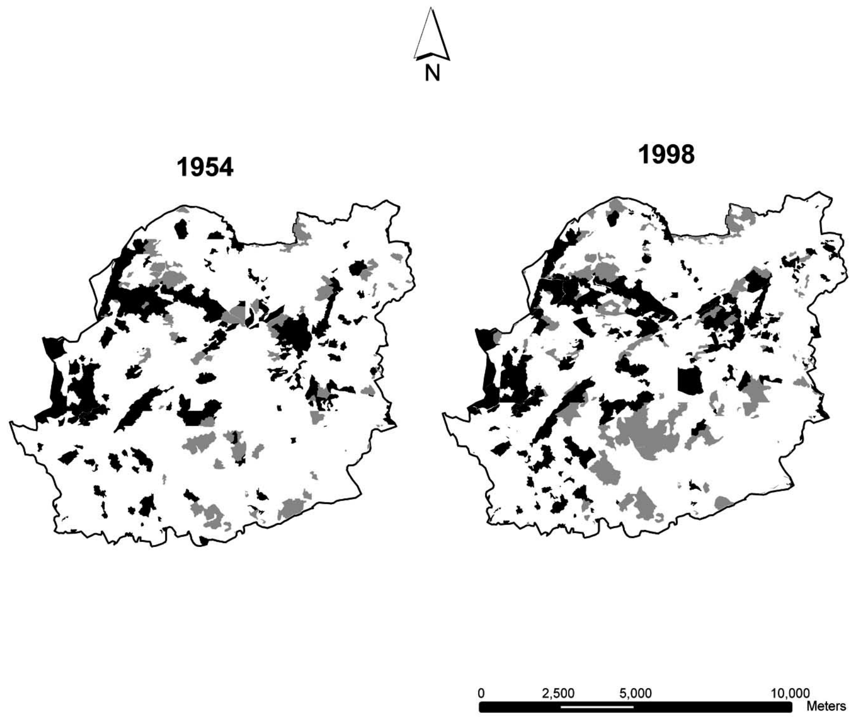

Fig. (3). The spatial differences in the area of 'Other forest' (black) and 'mixed grassland and shrubland' (grey) between 1954 (left) to 1998 (right).

optimal management system which links livestock, crops and forest [52,61] in order to reach a continuous economic yield (cork can only be extracted every ten years) and the permanent presence of cork oaks by planning and selecting their regeneration [62].

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