Mapping the distribution and extent of *Quercus suber* habitats in Sardinia: a literature review and a proposed methodology

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ABSTRACT

The cork oak (*Quercus suber*) in Sardinia is an important tree since it contributes significantly to the local economy. Moreover, the habitats that support the species have been recognised as having both cultural as well as biodiversity value at a European level. These habitats are nowadays under ever increasing threat mainly due to anthropogenic activities (e.g. fires, intensification of agriculture) but also due to extensive insects' attacks. Despite the importance of the species in the island its distribution has not been adequately mapped. Different schemes have been used so far but these have not been integrated yet to provide a complete picture of the species and its habitats. The paper provides an account of the ecology of the species and reviews the available data sources and existing mapping schemes on the distribution of *Quercus suber* in the island of Sardinia, Italy. The paper argues that mapping the extent of the species in a conventional way in a time of rapid changes in the landscape is not adequate and that mapping efforts should focus on identifying the potential sites of cork oak habitats. The use of new techniques, such as landscape character mapping, and tools such as GIS and remote sensing, and their applicability for the development of a comprehensive mapping and monitoring system for cork oak in the island is discussed. Such techniques are vital components for the development of a detailed management strategy for Sardinia in order to assist other questions to be addressed on restoration activities and the economic assessment of the species' habitats.

INTRODUCTION

Worldwide, Mediterranean ecosystems rival tropical ecosystems in terms of biodiversity richness (Mooney 1988) and are the most biodiverse ecosystems in Europe (Council of Europe 1992). As a result they have received much attention in the scientific literature such as general surveys (e.g. Di Castri and Mooney 1973; Goodall *et al.* 1981; Blondel and Aronson 1999; Trabaud 2000) as well as more specialised publications dealing with plant responses to stress (Tenhunen *et al.* 1987), resource use (Miller 1981), plant-animal interactions (Arianoutsou and Groves 1994), plant conservation (Gomez-Campo 1985) and landscape degradation (Rundel *et al.* 1998).

Of the many reasons that make the Mediterranean Basin a high priority in biodiversity research and conservation Heywood (1995) has highlighted floristic richness, high endemism rates, high number of species found in unit areas and high degree of human interference. Within these ecosystems certain species, such as cork oak (*Quercus suber* L.), play key ecological and socio-economic roles. The international importance of the species is highlighted by the fact that *Quercus suber* is a target of the operating gene conservation network of the European Forest Genetic Resources Programme, which is coordinated by the International Plant Genetic Resources Institute (IPGRI) in conjunction with FAO. This is a collaborative programme among the European countries which aims at ensuring the effective conservation and the sustainable of genetic resources in Europe (IPGRI 2003).

The habitats that support cork oak include sclerophyllous forests and sclerophyllous grazed forests. In Europe sclerophyllous forests as defined under the CORINE project (Bossard *et al.* 2000) are characterized by the dominance of evergreen broad-leaved trees such as *Quercus ilex, Quercus suber, Quercus rotundifolia* forest and the presence of shrub understory. On the other hand scherophyllous grazed forests (cf CORINE, Commission of the European Communities 1991) are characterised by the dispersion of individual trees and groups of trees that may consist of chestnuts, cork and holm oaks as well as olives. Although particularly abundant in Spain and Portugal, where they are known as dehesas and montados respectively (Pinto-Correia, 1993), these open wooded landscapes can also be found in Greece, Italy and France (Grove and Rackham 2001).

These habitats have unique ecological roles since they host diverse animal and plant communities with many endangered species. Examples include birds of prey such as the booted eagle (*Hieraaetus pennatus*) (Suarez *et al* 2000), and the Black vulture, (*Aegyptius monachus)*, as well as the black stork (*Cicconia nigra*) (Tucker and Heath 1994), and passerine bird communities (Telleria 2001). They also include plant species such as the endangered *Drosophyllum lusitanicum* a west Mediterranean endemic carnivorous plant (Correia and Freitas 2002). Moreover, Ojeda *et al.* (2000) argue that the understory of the *Quercus suber* woodlands in southern Spain support higher species richness under intermediate conditions of disturbance, while Grove and Rackham (2001) support this argument by reporting 30 species of clover (*Trifolium* sp), medic (*Medicago* sp.) and other plants on as little as 20 m^2 in similar habitats in Spain.

The economic role of these habitats arises from direct benefits derived from cork exploitation and/or parallel activities carried out under cork canopies (e.g. cropping, grazing) which are of considerable social importance as they are associated with traditional agrosilvopastoral practices in Less Favoured Areas of the European Community where other sources of income and employment are limited (Commission of the European Communities, 1997). These traditional agro-silvopastoral systems of the Mediterranean Europe although relatively new, since they developed during the 18th and 19th century, they represent a sustainable balance between human activities and natural resources (*Joffre at al.* 1999). In the words of Naveh and Lieberman (1994) these agrosilvopastoral systems is the result of "management practices optimising the typical annual fluctuations in productivity without causing ecological degradation". These practices have created landscapes of high heterogeneity and cultural value. Therefore there is increasing recognition of the important contribution made by these agrosilvopastoral systems to the maintenance of valued semi-natural habitats and landscapes in Europe (Council of Europe, 1992, Council of Europe, UNEP & ECNC 1996)

Despite the fact that the appreciation of the important contribution made by these habitats to both biodiversity and "development" in Europe is growing, so do the concerns about their future. In general, habitats can be lost or deteriorate in quantitative and qualitative ways. In the first case the conversion of one use to another takes place while the second involves a degradation/change in the structure, function or composition of an ecosystem. Certainly in cork oak habitats in Europe both types of changes can be recognized. In the case of sclerophyllous grazed forests it has been often pointed out that the Common Agricultural Policy (CAP) has had a drastic effect on the quality and continuity of these ecosystems. As a result during recent decades these habitats have been subject to irreversible deterioration through intensification, extensification and land abandonment in Portugal (Pinto-Correia, 2000). These changes have resulted in turn in habitat loss, a decrease in landscape heterogeneity with a subsequent decrease of plant and animal diversity (Marañon, 1988; Gonzalez Bernaldez 1991). In addition to that, in other places such as Sardinia, cork oak habitats suffer from regular attacks of phytophagous insects (Barneschi 1971). Moreover apart from these threats, a recent report has also expressed concerns about the use of plastic cork stoppers and the threat this may impose in the long term to the local economy and ecological equilibrium of the areas (Goncalves, 2000).

Since the species and its habitats are so important it would be expected that detailed inventories and mapping would be available at a national and European level. However, a common problem highlighted by many researchers is that the true area that the species covers is not known since in many countries up to date inventories are not available, particularly with regard to age distribution and the density of the stands (Varela, 1999).

The island of Sardinia is the biggest producer of cork in Italy and, as in most South European areas, in recent decades the habitats that occupies have been subject to deterioration mainly through agricultural intensification, land abandonment, fire and development (Pinto-Correia 2000). Despite the cultural and biodiversity value of these habitats at a European level, and their importance for the local economy, little is known about the interaction of physical and cultural factors that have influenced their distribution on Sardinia. This information is vital for the protection of existing habitats and restoration of degraded habitats especially in designated protected areas of the European Community. The aim of this paper is to provide a review on the ecology and the extent of mapping in Sardinia and suggest a methodology for future mapping efforts.

BACKGROUND: Sardinia and the Cork Oak

Sardinia, is situated in a central position in the Mediterranean about 200 km from both the Italian coast and Tunisia and is the second largest island in the area after Sicily (Figure 1). It has a total surface 24.000 km^2 excluding the surrounding minor islands. The climate is typically Mediterranean with hot and dry summers and mild and rainy winters.

Geology

The variety of the landscapes that characterize the island of Sardinia is strongly linked to the geological history of the island from Precambrian until today. This complexity is demonstrated by the irregular distribution of numerous lithologies out cropping in the island. During the Palaeozoic the basement structure was defined by the early Caledonian and the Hercynian orogeny. This structure, consists mainly of granitic metamorphic rocks, covering about a third of the island in eroded low relief landscape (Marini *et al*. 2001). The erosion of the Palaeozoic reliefs, had even by the end of the Palaezoic, resulted in a low relief landscape which was repeatedly invaded by the sea during the Mezozoic. The outcrops of limestone and dolomite which appear in the central east and northwest coast (sometimes more than 800m in thickness), are proof of a substantial marine transgression.

During the Tertiary the Alpine orogeny delineated the actual configuration and the structural arrangement of the island. A complex system of semi-rift is created along a north south axis/line and affects the whole of Sardinia. This system is linked to the convergence of Africa and Europe, and is accompanied by a first alkaline volcanic cycle caused by the movement towards south-east of the Sardinian-Corsican complex, which separates the island from the European supercontinent and it displaces it to its present position. A second basaltic volcanic cycle came to an end less than 60.000 years ago. The associated lava flows filled the wide and shallow valleys of the time and helped preserving the valleys' features. Important movements of uplifting/raising gave way to a strong erosion that has determined the isolation in reversal of the basaltic relief, resulting in extended high plateaux having the characteristic profiles, called "giare" (singular giara) as for example in Gesturi and Serri. Sardinia was one on the most important mining regions in Italy. As early as the roman period extensive areas of the island such as Masua, Inglesias, Mantanai, and Fluminimaggiore were mined for barite, fluorite, and lead. At present all but one, at Carbonia, are closed and in most of the sites industrial archaeology is taking place.

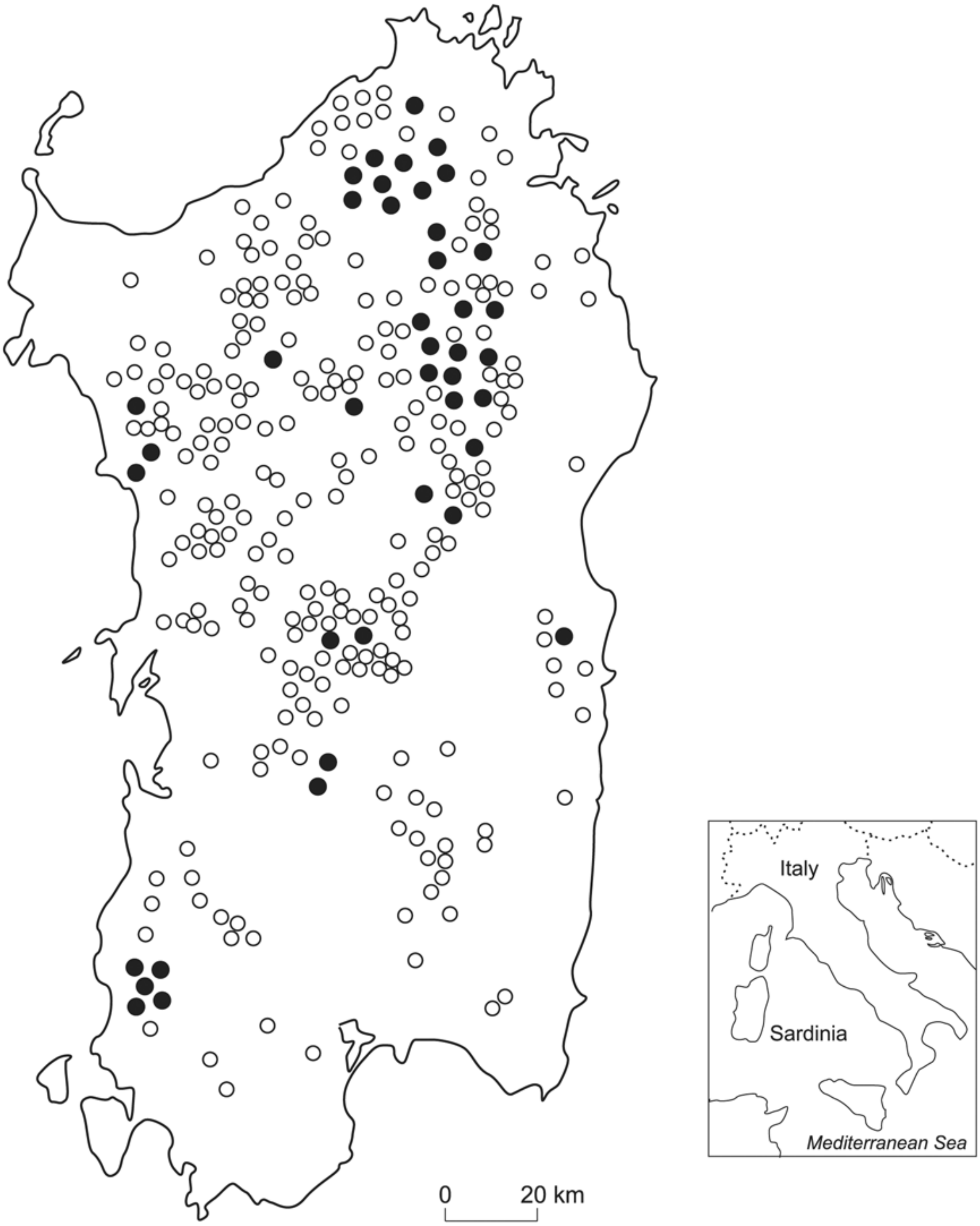

Figure 1 Distribution of cork oak forests in Sardinia according to Arigoni (1968)
○ areas up to 100ha ● areas c.1000 ha

Flora and Vegetation

The Mediterranean islands, have a rich and diverse flora due to their geographic position, geological history and insularity (see review in Greuter 1995) and Sardinia is no exception. The island's flora comprises around 2054 species 10% of which are endemic (Bocchieri, 1995). This includes species of recent formation others in the phase of evolution and species of ancient origin. According to Delanoë *et al.* (1996), 3 percent of the island's species belong to globally threatened taxa, while 8 percent of the total taxa are locally threatened (Table 1).

Table 1 The number of threatened plant taxa in Sardinia

IUCN Categories	Globally threatened taxa	Locally threatened taxa
Extinct	-	2
Endangered	11	33
Vulnerable	30	64
Rare	21	60
Insufficient documented	1	3
Total	63	162
% of taxa threatened	3	8

Source: Delanoë *et al.* (1996)

The vegetation of Sardinia is typical of the Mediterranean region. The principal formations include holm oak (*Quercus ilex*) forests, cork oak (*Quercus suber*) forests, broadleaved forests of downy oak (*Quercus pubescens)* and chestnut (*Castanea sativa*), pine forests mainly with aleppo pine (*Pinus halepensis)* and maritime pine (*Pinus pinaster)* as well as maquis and garrigue (Barneschi 1988; Chiappini 1985). Compared to other islands in the Mediterranean (e.g. Crete) Sardinia still retains extensive dune systems (Mayer 1995), which support formations *of Juniperus oxycedrus ssp. macrocarpa* at Scivu, Piscinas and Gemma Armidas (Todde 2002). These formations are unique for the endemic species they host and therefore are protected under the European Habitat Directive (Council of Europe, 1992). There are about 721000 ha in the island under protection in various schemes (RAS 2003a) with 114 sites proposed for the European network of protected areas Natura 2000 (Table 2).

Table 2 Protected areas and protected species in Sardinia

Designation	Number	Area (ha)
Sites of Community importance directive 92/43	114	462.000
Natural Parks (National and Regional	4	70.000
Marine Reserves	4	
Species of fauna protected under the directive 92/43	147	
Plant species protected under the directive 92/43	122	
Habitats protected under the directive 92/43	56 (14 of priority)	
Fauna sanctuaries established with regional decrees	85	120000
Zones for fauna breeding/repopulation	93	69000

(source: RAS 2003a)

Ecology and Distribution of Quercus suber

Quercus suber is an evergreen tree up to 20m with downy twigs, rather sparse leaf canopy, and a very thick and deeply ridged bark which sometimes reaches a diameter over 1.5m. The cork is a product of a secondary meristem and its extraction takes place when the individual tree reaches an age of 25-30 years (Pintus 1996). From that point onwards the bark is stripped every 10-15 years since the tree has the ability to reproduce a new meristem once the bark is removed (Figure 2). The main uses of the cork is as beverage sealant and insulation material (Concalves 2000).

The worldwide *distribution* of the cork oak *Quercus suber L.* is confined to the centre and western Mediterranean basin (Figure 3), including Spain, Portugal, countries of the North Africa, France and Italy (Table 3). Although present also in the tirrenian coast and Sicily, Sardinia is (probably) the most important cork oak producer in Italy (Boni, 1994). The main cork oak forest regions in Sardinia are Gallura, Iglesiente, Mandrolisai, Giara di Gesturi, Goceano, Planargia and the high planes of Buddusò, Alà, Bitti and Orune (Stazione Sperimental del Sughero (SSS) personal communication).

Detailed information about the important association of cork oak and humans in the Mediterranean during prehistoric and historic times can be found in Grove and Rackham (2001) and for Sardinia in particular in Pungetti (1996). However, there is a lack of

Figure 2. Typical *Quercus suber* wood pasture in Sardinia

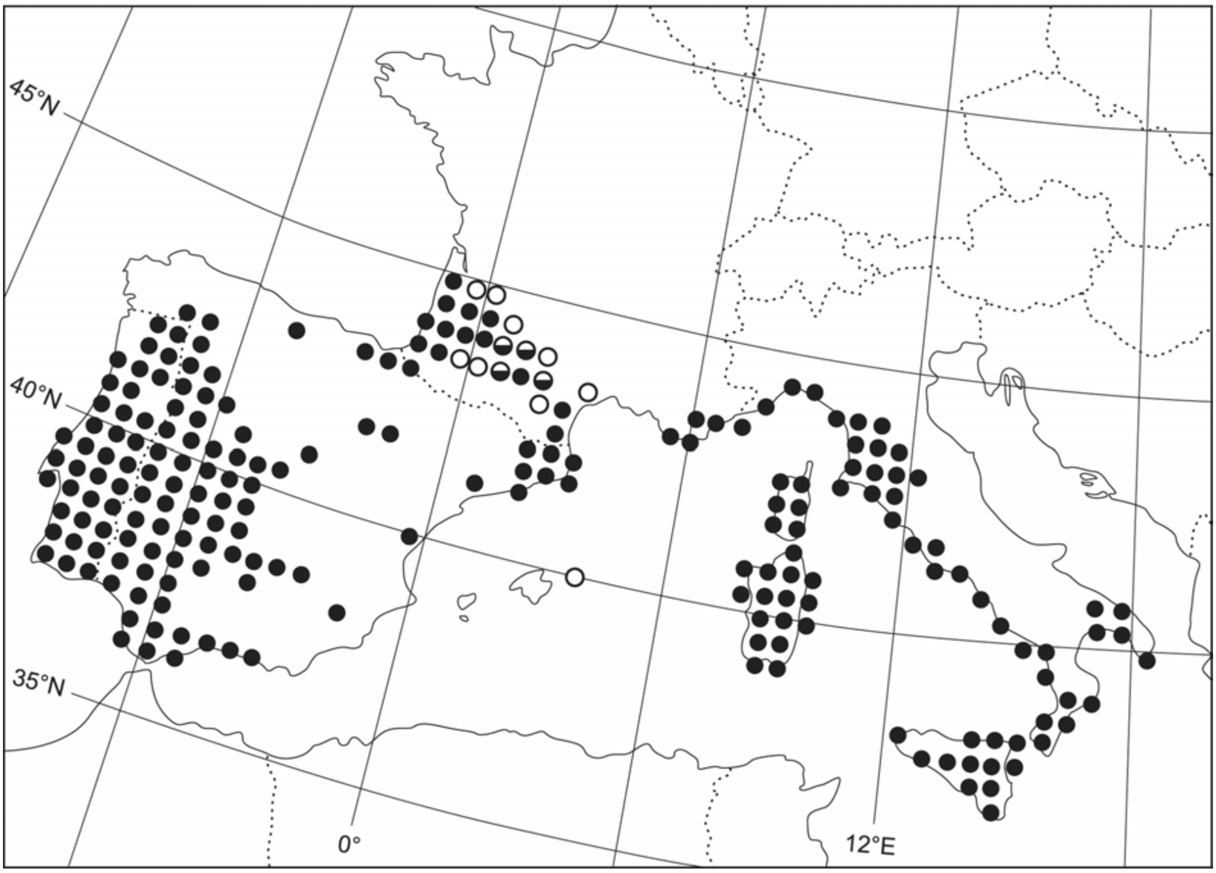

Figure 3. Distribution of *Quercus suber* in Europe (adapted from Jalas and Suominen 1972-1996)

information on the species distribution during the Pleistocene and the beginning of the Holocene. Since palaeoecological investigations in the Mediterranean basin are limited and unevenly distributed (Carrion *et al.* 2000; Grove and Rackham 2001) they cannot represent the complexity of the Mediterranean vegetation. In the case of the oak genus (*Quercus)* early accounts (e.g. Huntley and Birks 1983) make the distinction between the pollen of deciduous and evergreen oaks. The latter does not include *Quercus suber*. This is also the case with a study of quaternary deposits in the area of Montelargius Sardinia (Gulf of Cagliari) where no *Quercus suber* pollen was recorded (Pittau Demelia and Loi 1982). Despite the lack of pollen sites from Sardinia (Brewer *et al.* 2002) pollen analysis from other parts of the Mediterranean including Spain (Carrion *et al.* 2001) and Corsica (Grove and Rackham 2001) suggests that misidentification in the past might have been the reason for the absence or under-recording of cork oak pollen.

Table 3 Extent of pure dominant cork oak forest worldwide

Country	**Area of Pure Dominant Cork Oak Forest (ha)**	**% of world total**
Portugal	725,000	33
Spain	510,000	23
Algeria	460,000	21
Italy	225,000	10
Morocco	198,000	9
Tunisia	60,000	3
France	22,000	1
WORLD	2,200,000	100

Source: Goncalves (2000)

In Sardinia the distribution of *Quercus suber* is mainly confined to the North of the island (Figure 1), and is limited by precipitation and soils. In general, the species is neither drought nor frost tolerant. It prefers at least 600 mm of annual rainfall and an optimum temperature between 16-19^{o}C (Arigoni 1968). It grows preferably on siliceous substrates, particularly abundant in the island, with good water availability while very rarely it can be found on limestone. In terms of altitude it seems that although the majority of habitats are in the range of 300-600m the species can be found also above 600 and in some places up to 1000 m.

Broadly, the species can be found in two main types of habitats wooded pastures and forests. The Italian term "*Pascolo arborato*" that denotes a wooded pasture, is used for these habitats where *Quercus suber* can be the dominant tree or in mixture with for example *Quercus ilex* and *Olea europea.* Grazing is the main activity underneath as well as sowing of forage plants to improve pasture. However, cultivation under the tree canopy, as it takes place in the dehesas and montados of Spain and Portugal, is a rare phenomenon in Sardinia possibly due to a predominant pastoral culture in the North of the island (SSS personal communication).

The tree can be also found in pure stands or in mixed stands together with *Quercus ilex* or *Quercus pubescens*. Common species found in the understory of a 'sughereta' in Sardinia include *Cistus salvifolius L., Cistus monspeliensis L., Arbutus unedo L., Erica arborea L., Cytisus villosus Pourret, Ruscus aculeatus L., Rubus sp., Calycotome villosa (Poiret) Link* as well as*, Smilax aspera L. and Lonicera implexa Ait*. The management of the forest follows the uneven and even structure. Although the uneven forest structure results in lower production in terms of both quality and quantity, it encourages ecological balance resulting in disease and pests immunity and promotes natural regeneration.

The cork oak habitat *degradation* has been attributed in recent decades to fires, ploughing, overgrazing and insect/pest attacks. Summer fires are considered to have favoured the expansion of the plant on the island at the expense of *Quercus ilex* L. and *Quercus pubescens* Willd. (SSS personal communication). This is due to the plants thick bark which allows effective resistance against fire (Trabaud 1981; Margaris 1981), a property that is absent from the other two oak species. However, repetitive fires within short periods of short time render the trees susceptible to fungal attacks and destroy the understory leading to soil degradation and finally erosion phenomena. Moreover, it has to be noted that the cork oak forests, which endure damages as a result of fires, loose their economic value since the cork cannot be exploited.

The expansion of agriculture and the use of deep ploughing methods even on soils with a high content of rock and stone cover has resulted in the removal of the understory and consequent reduction of the organic matter leading eventually to the exposure of soil to erosive agents (Barneschi 1971). The increase of the number of animals with the usual effects of soil compaction and therefore reduction of water infiltration and increase run off. The above factors contribute to the susceptibility of these habitats to attacks by phytophagous lepidoptera/defoliators such as *Lymantria dispar*. The action of these insects is profound in areas which have been subject to frequent ploughing or where the understory is absent, which could indicate susceptibility due to a simpler structure and therefore resilience (Vogiatzakis personal observations). Moreover, this susceptibility increase after long periods of drought typical of the Mediterranean climate.

THE PROBLEM : The extent of *Quercus suber* mapping in the island

A detailed account of the distribution and extent of the species presupposes the mapping of all the habitats where the species is dominant or in mixture with other species. The inventory of the area covered by cork oak is not complete yet. According to *estimates t*he area covered by sugherete on the island is 90000 ha (120000 ha), a figure that increases significantly, i.e. a total surface area of 200,000 ha, if wooded pastures are included (Boni, 1994). To date the existing information has been fragmented in the sense that different habitats have been mapped but no consistent attempt has been made to bring this information together. This fact renders the mapping extent for a species of such importance on the island inadequate.

A careful examination of the available information on the species distribution reveals semantics being a source of confusion among land planners. The concepts of landuse, land cover and vegetation still mean different things to different people. As a result the same term i.e *garrigue* may appear in three maps with diversified context/meaning. This is certainly the case with *sughereta* a concept that in Italian denotes habitat where the cork oak is the prevailing element. Although the concept is based on tree density, its definition is still a controversial issue even between the Forest Service and the Experimental Station of Cork (SSS personal communication). For example in the recent forest map (Marini et al. 2002) tree density of 40% is used as a threshold to the forest map to discriminate between forest and non forest. However, in the land-use map released recently (described below), the threshold taken into account was only 20% (RAS 2003).

Since the management of the species on the island has been traditionally associated with the Forest Service (Pungetti 1996) forests have been historically accounted for in more detail than wooded pastures. This is probably the reason why, in some early accounts of the spatial extent of *Quercus suber* forests in Sardinia such as Arigoni (1968), only the forests are shown divided into two broad classes i.e. areas c. 1000 ha and areas up to 100ha (Figure 1).

In fact, an important source of information for the distribution of cork oak on the island was the vegetation map of the island produced by the Forest Service based on phytosociological, silvicultural and ecological components (Barneschi 1988). The vegetation map based on extensive fieldwork includes a detailed typology for the various vegetation formations where

Quercus suber is present. Nevertheless, since many changes have taken place in the island the last 40 years as a result of fires and land-use changes is inevitably out of date.

The landcover map of Sardinia produced by Marini *et al.* (1993) as part of the Co-ordination of the European Environment (CORINE) project, is another source of information. A priority application within the CORINE project was the assemblage of coherent information on the land cover of the European Community and the integration of this information within a GIS (Commission of the EC, 1991). Therefore the map produced for the island had a different, more general scope and inevitably is not a detailed picture of the species distribution on the island. For example although there are “up to date” information about the extent of the wooded pastures, an important cork oak habitat, this generic description is not enough to distinguish between the different types of wooded pastures which in the island of Sardinia may include apart from cork oak, other trees such holm oak, olive or a combination of these species (Barneschi 1988).

Using image interpretation of Landsat TM 7 Marini *et al.* (2002) realised a map of the forested areas of Sardinia for the Experimental Station for Cork and the Forest Service. This is essentially a refined piece of work if compared to the landcover map (Marini *et al.* 1993), with emphasis placed on the areas with forestry interest which are based on Landsat imagery of 1999 and 2000. This map makes a clear distinction between evergreen forests and open wooded pastures. Moreover, it provides information on degraded forest areas as well as burned areas of that year, still visible in the satellite images acquired during winter.

Fairly recently a land-use map was realised (RAS 2002) which also adds invaluable information in the distribution of the species on the island. This map was realized by interpretation of digital aerial photos in black and white and ancillary help from the vegetation map of Sardinia (Barneschi 1988), winter and summer LANDSAT TM images of 1998, and coloured orthophotos. This work is a synthesis of the so far published information to provide more detail on the existing land uses on the island with emphasis on these associated with semi-natural vegetation as well as agriculture. As such it has retained and modified or expanded the classes used by CORINE landcover map (Marini *et al* 1993). Figure 4 presents the results of three different mapping attempts and illustrates clearly some of problems described above. The figure shows the same area near Oschiri in the north of the island (Figure 1) as represented in the CORINE land cover map, the forest map and the vegetation map of Sardinia

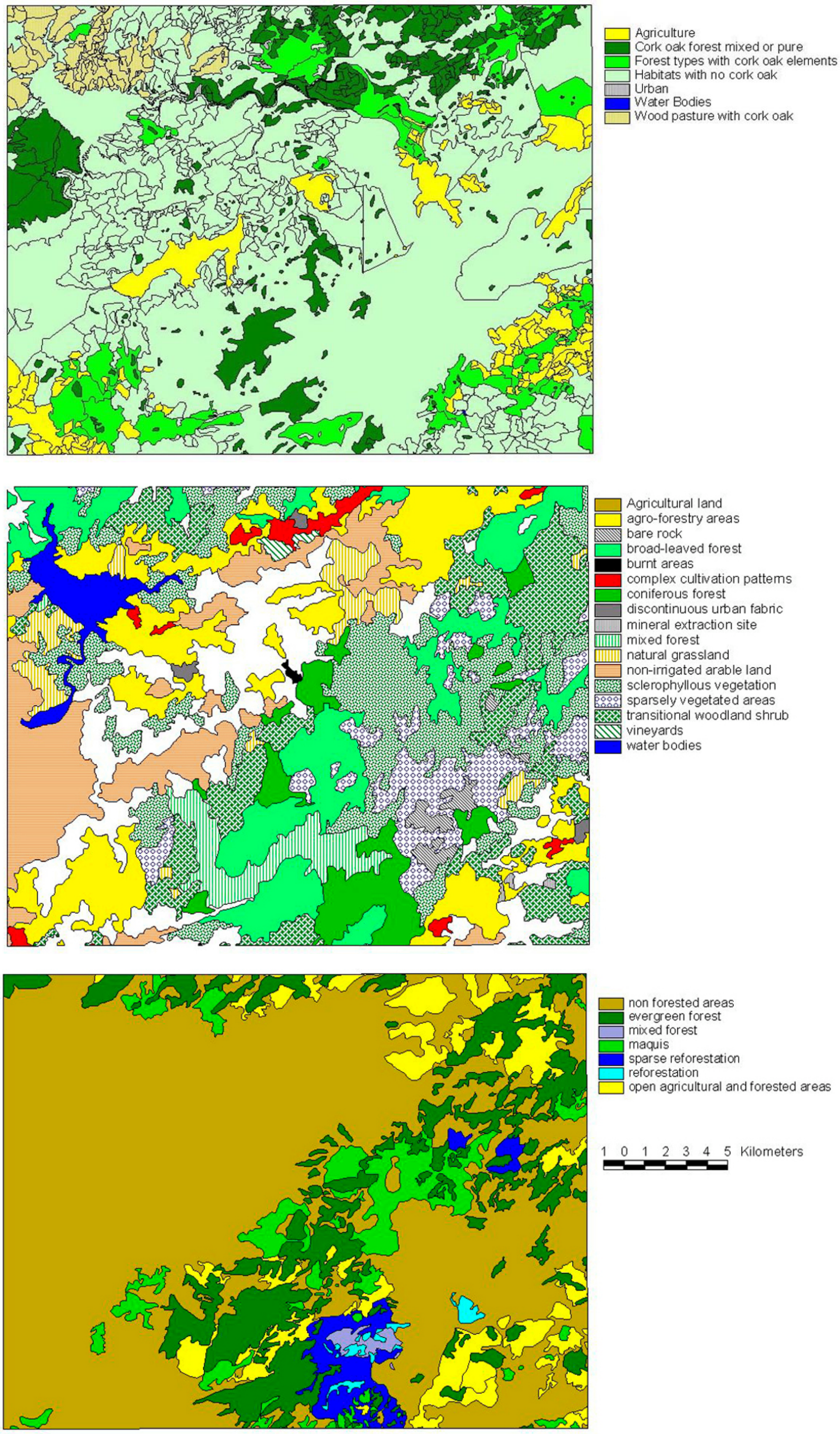

Figure 4. The same section of IGMI topographic sheet Oschiri Sardinia as shown in three different mapping schemes. From top to bottom: Vegetation map, CORINE map, Forest map (see text for details).

DEVELOPING A METHODOLOGY FOR HABITAT AND SPECIES MAPPING

The role of Remote Sensing

At present the tools to map the extent of the species on the island are available. For example, satellite remote sensing for vegetation mapping employs techniques based on the information that the satellite data provide on the spectral properties, spatial and temporal of the area under investigation and has been well documented for the Mediterranean area by Shoshany (2000). The actual availability of the sensors with acquisition ability that varies allows the right selection of data according to the level of detail and the classification method to be adopted. Vegetation mapping at a global and continental scale is based on a physiognomic classification extracted from datasets of low spatial resolution such as NOAA, AVHRR, MODIS (Lillesand and Kiefer 2000). Moreover, systems with increased spatial, spectral and temporal capacity, like LANDSAT ETM^+ and SPOT, are also available for the discrimination of classes with different cover densities at regional scales (Salvador and Pons 1998, Joffre and Lacaze 1993, Maselli, 2002).

Although these tools have already been used for landcover and forest mapping in Sardinia, the new generation sensors, with higher resolution, offer greater potential to advance scientific capability for vegetation and habitat mapping than previous systems, but have not yet been tested. For example, IKONOS, which was launched on 24 September 1999 with a width of scene 11km, is the first commercial satellite that acquires data with great spatial detail at a nominal resolution of between 1m (panchromatic) and 5m (multispectral). The orthorectified data allow applications in the field of mapping and monitoring of the natural resources which guarantee a high positional accuracy, therefore higher detail of the information handled (Maselli, 2002). The use of the radiometric information from these sensors for vegetation analysis can be supported by on site measurements acquired with portable spectroradiometers in order to characterise specific targets within the areas under investigation. Particularly in the case of *Quercus suber* the use of field spectroradiometers can provide useful information since the species' spectral response (as derived from satellite sensors) is quite similar to the one of *Quercus ilex.* The latter is also abundant in the island and in some cases found together with the species of interest.

Landscape Character Mapping

However, in times of rapid changes in the landscape the mapping of the species in conventional ways is not adequate since it will only give a snapshot in time. From the planning and management perspective what is more important is the *mapping of the potential sites* where the species may occur as well as possible *effects of habitat fragmentation* on species distribution. This will assist with the understanding of factors that influence its distribution as well as with future conservation and restoration – re-creation efforts. For example, looking at the section of the vegetation map of Sardinia (Barneschi 1988) near the area of Oschiri where only the cork oak habitats have been displayed (Figure 5) there are different degrees of habitat continuity which may be due to physical or cultural factors. Therefore there is a need to develop a framework to assist with habitat mapping and monitoring and a further detailed management strategy for Sardinia. Reducing the accelerating rate of species loss worldwide will require increased knowledge on the ecological processes and their interaction with human activities. There is increasing recognition that the spatial structure of landscape elements is a factor of critical significance in determining biodiversity (Turner and Gardner, 1991; Simmons *et al.* 1999). An approach that exhibits potential for biodiversity assessment is *Landscape Character Mapping.* This is based on a series of natural (e.g. landform, geology, soils) and cultural factors (e.g. land use, settlement pattern) that are used to describe the variability in the landscape at various spatial scales depending on the research scope (Warnock 2002). For example in a case study in the Chilterns UK where emphasis was upon parcel scale habitat restoration, mapping at the precision of local scale (1:25 000) was employed (Lee *et al.*2001)

As pointed out by Pungetti (1996) no consistent effort has been placed on developing a landscape assessment for the island. Previous attempts (e.g. Aru et al. 1991) resulted in a fairly descriptive typology of a regional scale mainly based on rock types with limited information on morphology and land cover (Table 4) and little emphasis placed on cultural elements. However, in Sardinia, as everywhere in the Mediterranean Basin, the long presence of human has been of vital importance in shaping the landscape. This is also evident for the existing cork oak habitats in Sardinia which reflect differences in physical (e.g. geology) and cultural (e.g. land-use) factors. Therefore a detailed typology need to be developed and tested which will also incorporate cultural elements. For example one important cultural change in the landscape during historical times has been the land reform known as the *"Law of chiudende"*. The *chiudende* or fencing of land not subject to rights (Makhzoumi and Pungetti 1999) was brought about by the

Savoy Royal family as part of their plan to link land property and land use and create a land-owing middle class. This led to the predominance of enclosed lands in the island visible even today.

Table 4 Classification of the Sardinian Landscape according to Aru *et al.* (1991)

1	Landscapes on limestones, dolomites and dolomitic limestones of the Palaezoic and Mesozoic
2	Landscapes on metamorphic rocks of the Palaeozoic
3	Landscapes on intrusive rocks of the Palaeozoic
4	Landscapes on acid and intermediate effusive rocks of the Cenozoic
5	Landscapes on basic effusive rocks of the Cenozoic and Neozoic
6	Landscapes on organogenous limestones, calcarenites, sandstones and conglomerates of the Cenozoic
7	Landscapes on marls, sandstones and marly sandstones of the Cenozoic
8	Landscapes on sedimentary formations of the Cenozoic of the Cixerri and Ussana
9	Landscapes on alluvial deposits and Aeolian cemented sandstones of the Cenozoic
10	Landscapes on alluvial sediments, conglomerates, Aeolian sandstones and calcareous crusts of the Neozoic
11	Landscapes on Aeolian sands of the Neozoic
12	Lanscapes on littoral sediments of the Neozoic
13	Urbanised landscapes: residential, industrial and tourist settlements

Predictive Mapping and GIS

The development of landscape character assessment/mapping has been facilitated by the use of GIS technology. This technology provides significantly increased opportunities for more detailed environmental resource inventory and analysis in space and time and show considerate promise for extensive use in nature conservation (Norton and Nix, 1991; Margules and Austin 1991;1994).

One of the objectives for which GIS systems are particularly valuable, is generating ideas and exploring relationships. For example, in the case of cork oak in Sardinia, another major task of any strategy for mapping the species and its habitats is establishing a baseline of current distribution patterns and a profound understanding of the environmental factors controlling these patterns. In that respect *predictive vegetation mapping* techniques using GIS can give some insight. Predictive vegetation mapping (cf. Franklin 1995) can be used to show the areas on the island where the species could be potentially found, based on mapped environmental variables within a GIS. The application of the range of techniques employed under predictive vegetation mapping has already been tested successfully in Mediterranean environments (Vogiatzakis 2000). Sardinia is fairly well mapped with many environmental datasets being available in digital format (RAS, 2003).

In fact, a first attempt on predicting the potential distribution of the species on the island has been carried out by Manca (2002). The approach was based on six environmental variables namely an aridity index (i.e. ratio of mean annual precipitation to mean annual evapotranspiration), Pavari's phytoclimatic index (based on a combination of vegetation and climatic characteristics), average rainfall, average temperature, soils, and aspect. Although a step towards the right direction the approach could be further improved. For example an important variable i.e altitude, that according to the Experimental Station of Cork Oak (SSS) influence the distribution of the species, is missing while there is no validation of the results. Finally the mapping follows an crisp/absolute way without allowing for the uncertainty inherent in the mapping process to be accounted for.

Barneschi (1971) has pointed out that in the past the species was found almost in every area on the island exhibiting tolerance to a wide range of physical conditions (geomorphology, soils, climate) and that only anthropogenic factors have reduced its extent. A way forward in order to refine the mapping could be achieved by reviewing the current knowledge on the distribution of cork oak and its habitats, surveying the published literature and especially in-house documentation. The environmental variables which influence the distribution of cork oak on the island taking into account the differences in landscape types and could be derived after consultation with local experts from the Universities of Cagliari and Sassari and particularly of the Experimental Station of Cork at Tempio Pausania (*Stazione Sperimentale del Sughero*). The factors to be used have to be mappable; therefore they should undergo a screening process for ensuring their validity in terms of accuracy, scale, completeness, extent, before finally employed for mapping within a GIS. The result/product map should be validated by integrating existing mapping information (e.g. land cover and forest maps, aerial photographs, satellite imagery) as well as fieldwork. Moreover fuzzy mapping techniques, a novel aspect in the field of GIS (Burrough *et al* 2001), can be used for representing uncertainty in the position of potential species distribution These techniques can be used in order to characterize geographical phenomena that do not have sharply defined boundaries including transitional areas between vegetation communities.

Habitat Creation and restoration

The identification of suitable sites for cork oak habitat creation and restoration on the island should be based on the principles of landscape ecology (Forman and Gordon 1986). This is particularly important when dealing with fragmentation since, as recent research indicates (Moilanen and Hanski 1998), biodiversity patterns cannot be fully understood without reference to both habitat and landscape attributes. This is also highlighted by recent European legislation (e.g. Birds and Habitats Directive) which now considers the conservation status of the wider countryside, including both its biological and landscape diversity. In order to identify parcels of land of potential for habitat creation a set of criteria can be employed to assess the suitability of land parcels for cork oak habitat creation of different habitat types according to the local interest. These criteria can include patch size, proximity, existing land use as well as the existing landscape type.

Even at this stage GIS can be employed for the development of a spatial decision model. Decision rule based models have been constructed in similar projects in order to identify the suitability of land parcels for conversion to different target habitat types (Griffiths *et al.* 2002). These models are usually flexible since they allow the end user to re-run with a different set of parameters and if necessary, changed decision rules. Thus, the model can be used to reflect local 'expert' opinion based upon a different vision for habitat creation under, for example, changed economic circumstances, new restoration targets or improved understanding of landscape ecological principles and biodiversity. Figure 6 provides a description of the proposed methodology, the tools used and in particular the role of GIS.

GIS can also assist in visualizing any changes brought by restoration efforts and model how a negative effect could be minimised to reduce a decline in the scenic quality of the landscape. For this reason novel approaches to the measurement and visualisation of changes in the landscape have been employed within a GIS using a combination of historical and current aerial photography and computer-aided design (McLure and Griffiths, 2000).

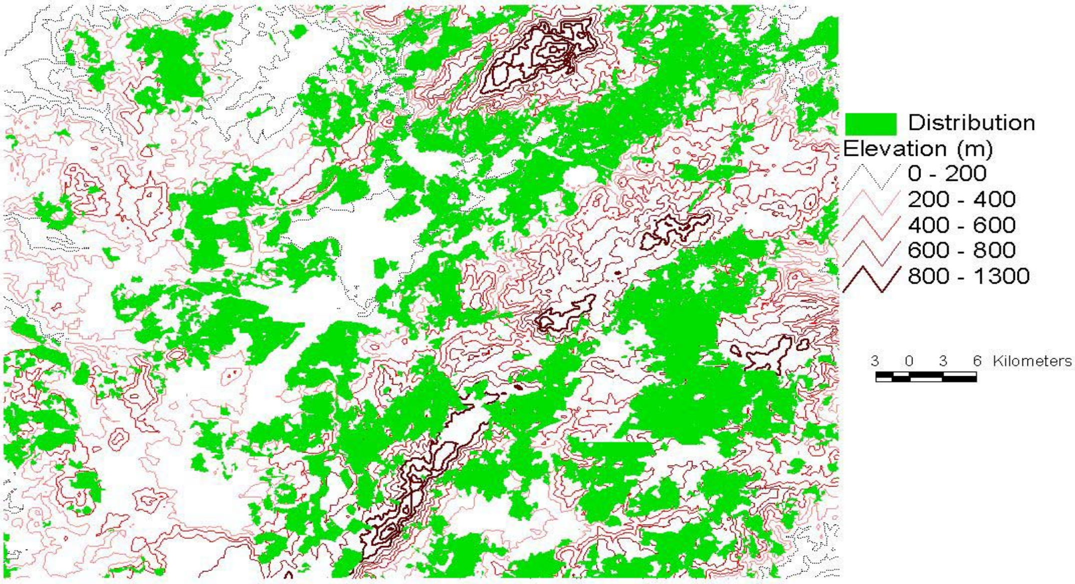

Figure 5. Distribution of cork oak habitats in the area of Oschiri, Sardinia

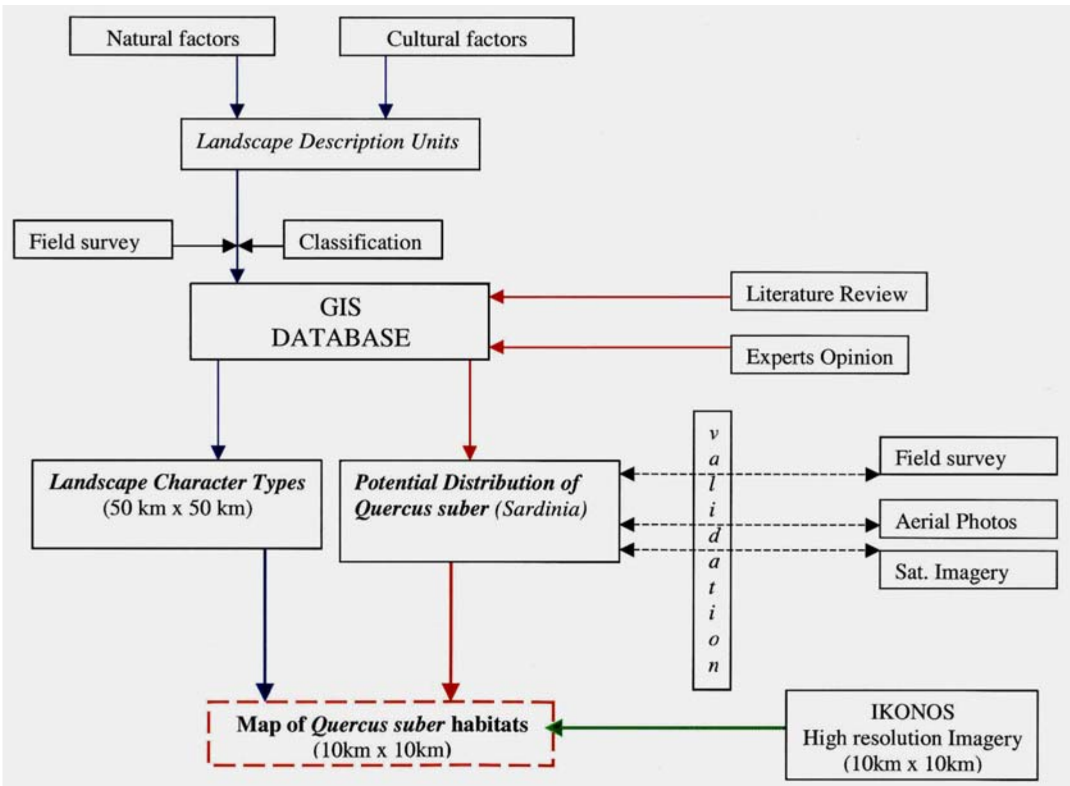

Figure 6. Flow diagram describing the proposed methodological steps

CONCLUSION

As demonstrated herein, a common strategy for the detailed mapping of cork oak on the island of Sardinia is lacking at present. This is partly to do with the different scope and agencies involved in the mapping of natural resources and is a very common phenomenon worldwide when there is no co-ordination of activities (Griffiths *et al*. 1999). This has impeded the development of a strategy that will enable the integration of the data sources mentioned above into a shared database.

Although mapping the actual and potential distribution of a species with ecological and economic significance such as cork oak is an important task it is only the first step/part of a detailed management strategy that should be developed for Sardinia. The development of a comprehensive monitoring system is vital to improve understanding of controls on biodiversity in these valuable landscapes of European significance undergoing rapid changes and to monitor protected areas effectively. This may assist further ecological and planning questions to be addressed.

The identification of suitable sites for expansion of cork oak habitat types on Sardinia may assist in the long term with evaluating the economic potential of the island in terms of cork production. Moreover it will give an insight to the consequences of past and future developments. For example is there any conflict between eucalyptus plantations and cork oak restoration? In other words could the extensive areas presently covered with *Eucalyptus* plantation be areas where successful cork oak restoration take place. Since habitat creation results in land use change any conflicts with other uses should be investigated (e.g. between habitat creation and agriculture) as dictated by other regional, national or EU policies (for example agri-environment schemes).

Another issue that may be addressed is the ecological quality of different habitats. In the past cork oak plantations have been established in the island as a result of subsidies given to the land owners by the Italian Ministry of Agriculture. Do these habitats value the same in terms of quality with existing semi-natural habitats or those potentially restored with ecological principles? And how do the semi-natural habitats compare between them? What would constitute indicators of good quality habitats (see Peco *et al.,* 1999) or indicators of habitat degradation (Groves, 1998)?

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