UNIVERSITÀ DEGLI STUDI DI SASSARI

SCUOLA DI DOTTORATO DI RICERCA
Scienze e Biotecnologie
dei Sistemi Agrari e Forestali
e delle Produzioni Alimentari

Indirizzo Monitoraggio e Controllo degli Ecosistemi Forestali in Ambiente Mediterraneo

Ciclo XXVIII

Biodiversity, grazing, wildfires and management of *Quercus suber* forest in the mountain of Bitti-Buddusò (NE Sardinia)

Dr. Vernal Makdissi

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Anno accademico 2014- 2015

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A.D. MDLXII

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ABSTRACT

Quercus suber species grows in a narrow region bordering the western Mediterranean. The importance of cork oak lies in the fact that cork material constitutes a valuable sustainable source of income. Nevertheless, anthropic activities have strongly affected these landscapes i.e. fires, overgrazing and inappropriate cork harvesting. This thesis describes cork oak forest situation in the Mountain of Bitti-Buddusò, using data from five different floristic composition studies and the economical plan of silvo-pastoral goods of Buddusò, in addition to the phytosociological study that we conducted in 2015. Overall, 362 species were encountered with the dominance of therophytes (44.5%) followed by hemicryptophytes (32%), which presence indicates a high period of summer aridity and the inclusion of areas related to grazing. The chorological spectrum showed the prevalence of Steno and Euri-Mediterranean species (34.1 and 26.9%, respectively) revealing thus the Mediterranean character in which cork oak forests insure an optimum vegetative growth. Moreover, we gathered data from two wildfires that occurred between 2012 and 2014 to examine the post-fire tree responses. The most common response type was crown and basal resprouting (71.8%). Vulnerability to fire was higher in older and stripped trees. Additionally, stocking rate registered a lower density (0.62 heads/ha) than that observed 50 years earlier, which shows the importance of grazing management in multi-ownerhip lands.

Key words: Mediterranean, floristic composition, cork extraction, regeneration.

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1. INTRODUCTION

1.1. Background information and problem statement

Quercus suber is a species with native range in the western Mediterranean and represents in Sardinia one of the most common trees of *Quercus* (Camarda & Valsecchi, 2008). This species constitutes a characteristic ecosystem of woodlands, which have been considered a fundamental component of landscapes in the western Mediterranean. This is the result not solely of the biological features of the trees (i.e. tree health, tree height, bark thickness) (McHugh & Kolb, 2003) and their longevity, but also their profitability to humans, such as cork production and grazing.

The area occupied by present cork oak forests is not known with exactitude. However, by using the existing data for national forest inventories, the total area can be estimated currently around 1.44 millions hectares in Europe and 0.70 million hectares in northern Africa (APCOR, 2013).

In the most recent Nature map of Sardinia (Camarda et al., 2015), habitat mapping refers to an accurate symbology for the national territory organized particularly for the Carta della Natura project, based on the CORINE Biotopes System Classification and EUNIS (APAT, 2003; ISPRA, 2009). Indeed, these classification systems are connected with Natura 2000 codes used as reference for the habitats of common interest as defined by Habitats Directive Dir. 92/43CE. Accordingly, in Sardinia Q. *suber* species is encountered in two types of habitats; Tyrrhenian Cork-Oak Forests (45.21) and the *Dehesa* (84.6). Indeed, these habitats are as overall estimated at a total of 103,597.47 ha. Both systems can be considered productive in terms of cork oak extraction and contribute to the local economy.

Cork oak forests are associated with a remarkable biodiversity, constituting one of the best examples of sustainable forest environment and a unique ecosystem recognized for their ecological value (Fumi et al., 2014). In consequence, emerges the need of implementing forest policies and programs, which can be able to develop sustainable forest management practices that allow not solely an exploitation of goods and services, but tend particularly to preserve structural and functional attributes of forest ecosystems.

Cork oak bark is the primary source of industrial cork. These agro-forestry systems, besides contributing to different environmental services (i.e. carbon storage, biodiversity preservation, hydrology regulation) (Aronson et al., 2009), are an economical essential element as the cork oak bark is extracted in great quantities. Cork is hence the most valuable product, making it the main source of income from these forests (Campos et al., 2008). When considering the potential value of the cork oak forests as producers of cork, Portugal occupies the most important producer registering around 100,000 tons covering by that 49.6% of the world production (FAO, 2010b). Italy cork production represents 6,161 tons, with only 3.1% of the world production (APCOR, 2012), out of which almost 80.6% are provided by Sardinia (Ruiu & Pintus, 2013), which makes the Island the most important cork oak producer in Italy (Boni, 1994; Dettori et al., 2006).

Despite of their economical value, cork oak forests are threatened by several stresses, both anthropogenic and natural such as pests and diseases, over-harvesting, over-grazing and land use changes. Moreover, climate change is affecting tree health and increasing their vulnerability to wildfires (WWF, 2007).

Therefore, we recognize the need of improving cork oak forest landscape management techniques, in particular the management of understory vegetation to reduce fire hazards, to promote moreover the exploitation of secondary forest resources and the biodiversity conservation.

The traditional land management systems, involving a combination of agro-forestry and animal husbandry, produce the least amounts of overland flow and the lowest soil erosion rates. Cork oak forests seem to be one of the most conservative land uses compared to pastures and cultivated areas (Laouina et al., 2010).

The secular cork oak forests land use and the threats of degradation, which many cork-oak populations are facing, require the application of flexible and adaptive management systems, which are able to mediate between the need of protecting the landscape and the financial policies. Management systems adopted in cork oak forests are arboriculture, agro- forestry, silvopasture and integrated forest productivity (Dettori et al., 2001). In Sardinia, most of the cork oak forests are subjected to agro-livestock activities, which involve the formation of coppice forests.

1.2. State of art

A first indication on the importance of the Italian cork oak heritage goes back to surveys carried out in 1934 during the Proceedings of the National Conference on Cork in Sassari. In these surveys, the highest concentration of *Q. suber* trees is quoted to be present in Sardinia, with a total of approximately 5 million trees.

Precisely, a communication published in 1922 in the Italian Forest Journal "*Alpe*", indicates that Sardinian cork oak is on a usable condition of about 42 thousand hectares of which 18 thousands are sufficiently covered with a dense formation to recall the presence of real cork oak forest, as for the rest cork oak forests is mostly scattered to constitute wooded pastures or "*pascoli arborati*[1]".

The *Ex-Azienda Speciale* in Buddusò implemented a detailed economical plan of silvo-pastoral goods in the Municipality of Buddusò in the period 1967-1976. The study, after a detailed description of the ecological and socio-economic characteristics of the territory, outlines important historical information regarding the utilization and exploitation of cork oak, indicating useful data, guidelines and procedures for grazing. In this plan, the study of pastures constitutes the most important and efficient part, and indeed the extent and the crucial role played by both communal pastures and wooded lands in the economy of Buddusò, justify largely the implementation of this work.

The experimental cork producing area (Stazione Sperimentale del Sughero, hereafter S.S.S.) named "Cusseddu-Miali-Parapinta", located in Tempio Pausania, NE Sardinia, represents the first example of cork oak forest certified (FSC) n° SA FM/COC-1436 in the world. S.S.S. is extended on a total area of 67 ha and is constituted of a cork oak forest covering around 70% of its total area. In this station, several testing programs regarding cork oak multifunctional management are conducted, in particular with respect to uneven-aged forests with natural regeneration. Indeed, a study aiming at quantifying the natural regeneration of *Q. suber* and the other *Quercus* species was conducted in 1994 in Tempio Pausania, and the overall analysis showed a sufficient natural regeneration capacity of oak species with various values of number and diameter of seedlings. The lowest values were found in the pastured parcel, showing a negative influence of livestock on the regeneration whereas shrub clearance seems to favor the

[1] An Italian term denoting a wooded pasture, *Dehesa* in Spanish and *Montado* in Portoghese

increase of seedlings number and thus to positively influence their growth (Ruiu et al., 1996).

Various studies on the post-fire recovery of cork oak are especially followed in the S.S.S., which offer two examples of intervention of recovery on two different types of cork oak forests. The first typology concerns both artificial young seedlings (almost 15 years) and young seedlings deriving from natural regeneration. On the other hand, the second typology concerns cork oak forest, which assists already to a regeneration (27.7% of total trees) and has been burned one year after the harvesting process (Pintus, 2003). Moreover, studies on the application of methodologies for the optimization of artificial regeneration are carried out, depending on the reforestation plan whether is implemented on lowland or hills (Piazzetta et al., 2014).

1.3. Research objectives

The following specific objectives were established for the thesis:

- To explore the compositional biodiversity of a cork oak forest.
- To shed light on the extraction processing of *Q. suber* trees in the Municipality of Buddusò.
- To explore the role of tree size and cork harvesting in determining post-fire *Q. suber* vegetative response across a cork oak forest in the Municipality of Buddusò.
- To draw general findings/conclusions in the context of the dynamics of cork oak forest after wildfires and the management practices of private and public ownership landscape.

2. OVERVIEW

2.1. Mediterranean climate

The Mediterranean Basin stretches 3,800 km east to west from the tip of Portugal to the shores of Lebanon and 1,000 km north to south from Italy to Morocco and Libya (Natura 2000, 2009), situated between parallels of 30 to 40 North and South (Di Capri & Mooney, 1973) (Fig. 1).

Figure 1. Geographical map of the western Mediterranean Basin (*source*: DEMIS images).

It has what is called a 'Mediterranean climate', which describes the distinct, subtropical climate shared by five regions around the world, the western United States (California) and Mexico (northwest Baja), central Chile, the cape region of South Africa, south and southwestern Australia, and the Mediterranean Basin which is the largest (Bolle, 2003). The Mediterranean climate is interposed between the temperature maritime type and the arid subtropical desert climate (Barry & Chorley, 1998), and is defined as a transitional regime between temperate and dry tropical climates, with a concentration of rainfall in winter and the occurrence of summer drought of variable length (Di Castri, 1981). The climate gradient across the Mediterranean Basin is extreme, and the temperature and rainfall can vary greatly throughout the region. It ranges from the cold mountainous areas of the Alps with annual mean temperature below zero (-2 °C at 2500 m elevation) to the hot plains of Africa with annual mean temperatures up to around 22 °C even near the coast and monthly average summer maximum annual temperatures of 26 °C near the coast and 32.5 °C inland (Bolle, 2003).

2.2. Mediterranean-climate vegetation

The five Mediterranean-climate regions of the world occupy less than 5% of the Earth's surface yet harbor about 48,250 vascular plant species, which represent around 20% of the world flora (Cowling et al., 1996). This has led to the Mediterranean being one of the first 25 Global Biodiversity Hotspots (Myers et al., 2000). The vegetation is characterized by the dominance of woody shrubs with evergreen leaves that are broad and small, stiff and sticky (sclerophyllous), but also with some thermophilous deciduous (e.g. *Anagyris foetida*, *Euphorbia dendroides*). An overstory cover of small trees might sometimes be present as well as an understory of annuals and herbaceous perennials (Di Castri, 1991). Several typical members of the shrub flora are aromatic (i.e. rosemary, oregano, thyme) and contain highly flammable oils. The dominant trees in the Mediterranean area are evergreen oaks and pines. Four species of pine are native to the Mediterranean region; they are *Pinus pinea*, *P. pinaster*, *P. halepensis* and *P. brutia* (Gitas, 1999).

2.3. *Quercus suber* L. - the tree

2.3.1. Botanical description

Quercus suber belongs to the family of *Fagaceae* and order of *Fagales*. This species was described by Linneo in 1753. Countinho and Pereira (1939), Natividade (1950) and Vicioso (1950) stated that the species contains more than 40 varieties, which were grouped in four: genuine, subcrinita, macrocarpa and occidentalis. When in fact, 21 varieties of *Q. suber* are reported to be present in Sardinia (Chiappini & Palmas, 1975; Camarda & Valsecchi, 2008). A large variation between trees in the same population is found in several characteristics, such as cork quality. The evolutionary importance of introgressive hybridization involving *Q. suber* with other *Quercus* lineages (i.e. *Q. suber* x *Q. cerris* = *Q. crenata*, *Q. suber* x *Q. ilex* = *Quercus morini*) has been detected by numerous studies, which has led in consequence to high levels of morphological and phenotypic diversity between cork oak and other species of the Mediterranean oaks.

Cork oak is a low-spreading evergreen oak tree with thick, twisted branches and a short stem (Fig. 2). The trees may reach up to 20 m high, but usually do not attain heights greater than 14-16 m. Nevertheless, open-grown trees might have large crown dimensions, e.g. 500 m² of crown projection in some mature trees with 150-200 years of age (Pausas & Pereira, 2009). Due to its extensive and deep root systems, cork oak trees are able to extract water from deep lying aquifers to maintain high leaf hydration (Nardini et al., 1999), helping therefore the tree to maintain water status and xylem conductance above lethal levels throughout the summer drought period (Pausas et al., 2009).

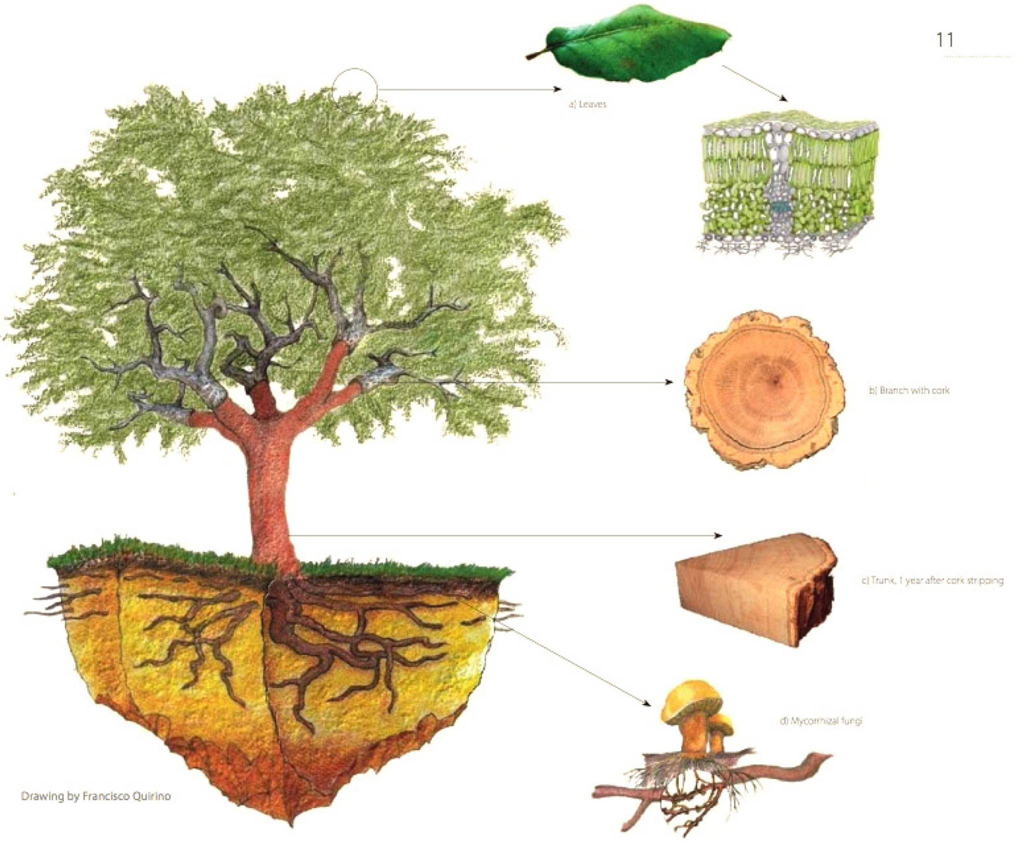

Figure 2. The cork oak: leaves, bark, roots (*source*: Pereira et al., 2008).

Leaves are dark green above, very fuzzy and whitened below, with spiny-ended lobes, and a size varying in the range of 3-3.5 cm of length and 3-5 cm of width (Camarda & Valsecchi, 2008) (Fig. 3). The average leaf life expectancy is only around 1 year, much shorter than in other evergreen oaks, such as *Q. coccifera* whose leaves can last 5-6 years (Pausas et al., 2009), thus, leaves fall occur in spring. This seasonality of leaf falling is the reason why cork oak trees do not look at their best in spring time, as the crown is still dominated by the fading color of the previous year leaves (Pereira, 2007), appearing thus unhealthy. Cork oak leaves are well designed to cope with unpredictable climates. They are sclerophyllous, which means hard, tough, stiff and leathery (Schimper, 1903; Seddon, 1974; Turner, 1994). These properties can be used to characterize sclerophyllous leaves in terms of structural integrity, such as the capacity of the structure to resist deformation and fracture, and are indeed properties that are influenced by a sub-surface as well as surface characteristics (Edwards et al., 2000). Sclerophylly is often considered as an adaptive trait of woody plants in areas with a Mediterranean climate such as the Mediterranean Region, with strong seasonal water deficits. Nonetheless, this characteristic does not automatically confer greater tolerance to drought, and it may have evolved since it provides protection from many different types of stress (Read & Stokes, 2006), such as poor mineral nutrition or attacks by defoliators (Salleo & Nardini, 2000).

Cork oak is a monoecious species with flowers emerging from April to May and produces fruits in October-November (Camarda & Valsecchi, 2008). The flowering season may sometimes be longer, with flowers emerging in autumn (Pereira & Tomé, 2004), and that may occur only in limited extent in some years and in a scarce number of individuals (Machado, 1935; Boavida et al., 1999; Diaz-Fernandez et al., 2004). Flowering and fructification begin at a tree age around 10-15 years. Pollination occurs in spring with male and female flowers on the same plant. The vector for pollination is wind, and the ovaries of fertilized flowers mature into acorns.

Cork oak trees produce both annual and biennial acorns, which vary largely in form and size, with a length of between 2 and 4 cm (Camarda & Valsecchi, 2008) (Fig. 3).

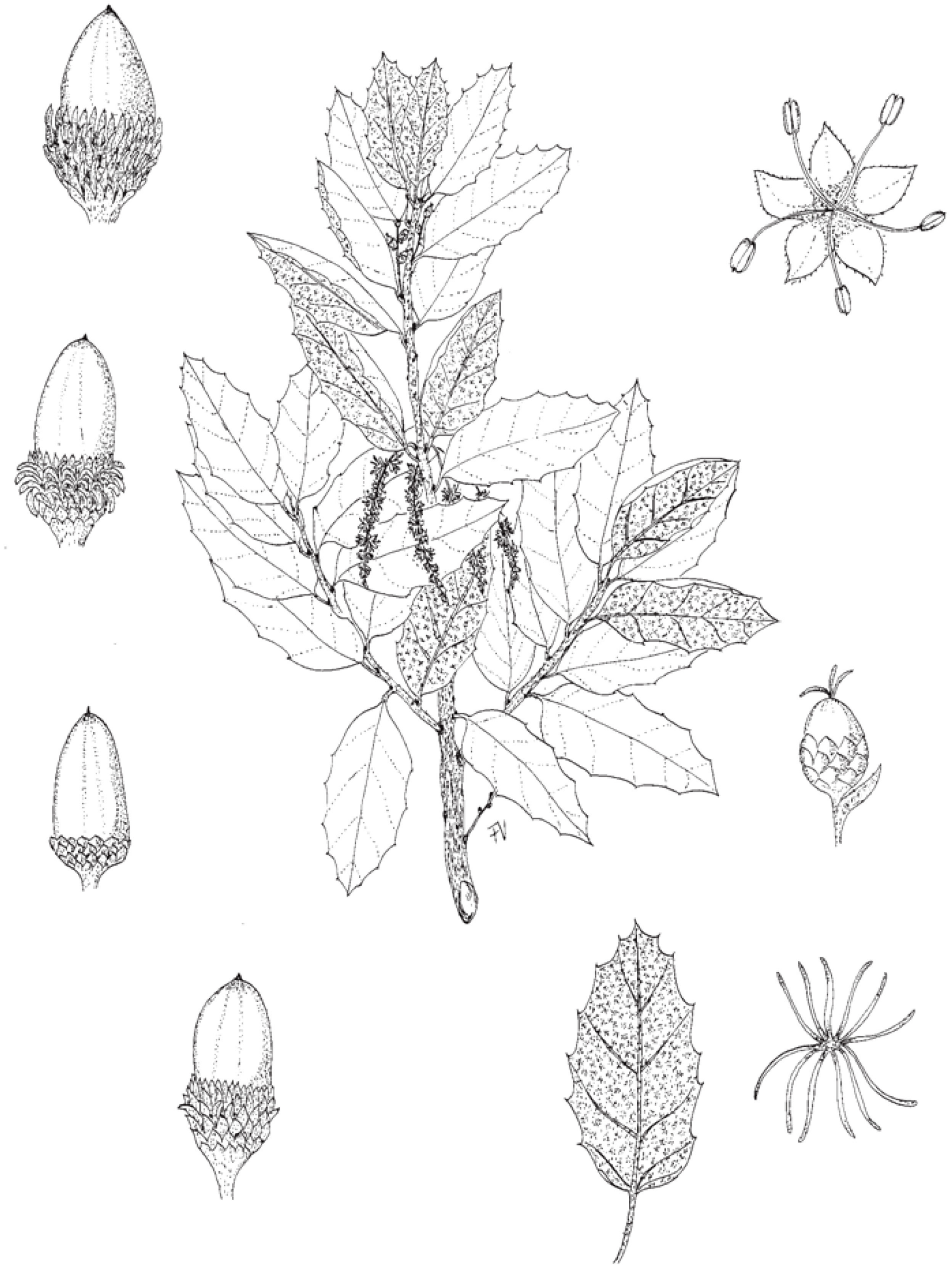

Figure 3. *Quercus suber*: flowers, leaves and acorns (*source:* Camarda & Valsecchi, 2008).

The annual maturation is more common in the southern cork oak woodlands, and the acorns grow mainly in late summer and autumn with a complete maturation occurring in November (Merouani et al., 2003). In contrast, biennial maturation is more common in northern populations, and the acorns do not experiment a growth during the first vegetative period but mature in the autumn of the next year. Biennial frequency may be related to short plant growth periods, limited by cold or drought (Pereira & Tomé, 2004). Cork oak acorn produced by a single tree has large variation among years. Furthermore, within a population, there can be high variability of acorn production between individual trees for no obvious reasons. As a matter of fact, fruit production is usually favored in warmer temperatures and abundance of photosynthetic assimilates (Pausas et al., 2009).

The habit of *Q. suber* tree is strongly affected by cork harvesting, which determines the selection of secondary stems and in particular the modification of the main trunk (Camarda & Valsecchi, 2008).

2.3.2. Ecology

The cork oak is a semi-tolerant species, well adapted to mild climates namely to the Mediterranean climates with Atlantic influences, mild winters, and hot and dry summers. It grows in warm humid and sub-humid conditions from sea level up to 2000 m, with optimum growth occurring up to 600 m altitude (Pereira, 2007). In Italy, the maximum altitude for the growth of *Q. suber* occurs in Sicily and reaches 1200 m, while in Sardinia it reaches 950 m (Camarda & Valsecchi, 2008).

The optimum mean annual temperature and precipitation regimes experienced by *Q. suber* are 600-1000 mm. Similarly, cork oak trees still survive with precipitation under

400 mm (Pereira, 2007). The minimum annual rainfall for a balanced tree development must be 500 mm, with reference to the stations of Morocco (De Philipps, 1935), characterized by high humidity and average temperatures, which are mitigated by the influence of the Atlantic Ocean. In Sardinia, in the areas in which *Q. suber* trees is highly spread, precipitations reach nearly 800-1000 mm (Camarda & Valsechhi, 2008).

Cork oak trees occur in regions with optimum average temperature in the range 13-16 °C (Blanco et al., 1997), but could still survive until 19 °C. These trees could resist high temperatures due to the confinement in some areas where there is a high availability of water in the ground, or a high level of atmospheric humidity (Pignatti, 1998). Accordingly, at temperatures below 4-5 °C, the leaves of cork oak have a freezing tolerance allowing them to withstand the frequent mild freezing events in the Mediterranean areas (Cavender-Bares et al., 2004). In Sardinia, the highest spread of cork oak trees lies in areas with mean annual temperature ranging from a maximum of 18 °C and a minimum of 13.3 °C (Camarda & Valsechhi, 2008).

The species can grow on poor and shallow soils, and occur in acidic soils on granite, schist or sandy substrates. *Quercus suber* prefers deep, well-aerated, drained soils with a pH range between 4.8 and 7.0 (Pereira, 2007). As regards soils, the main limiting factors for the growth of the species are a requirement for siliceous soils, although it can exist on decalcified limestone (Blanco et al., 1997). As a matter of fact, previous results (Dettori et al., 2001; Corona et al., 2005) confirmed that better cork quality was found at altitudes higher than 650 m and on sandy soils with high phosphorus content. Moreover, the best cork quality on Sardinian hills can be explained by the lower growth rate of cork tissue and by a higher uniformity in the annual ring thickness, due to the lower temperatures and the consequent shorter growth season (Bullitta et al., 2011).

An individual cork oak can survive for 250-300 years, but according to Pereira (2007), 200 years seem to be the limit for an industrially valuable cork production, thus each tree could be harvested between 12-20 times during its productive lifetime (Natividade, 1950). According to (Amorim, n.d.) the oldest and most productive cork oak in the world is the Whistler Tree, planted in 1783 in Alentejo, and harvested over twenty times since 1820. In 1991, the Whistler harvest produced 1,200 kg of bark, good for more than 100,000 wine bottle corks.

Species of *Q. suber* are frequently associated with *Q. ilex*, and more rarely, with other tree species (i.e. *P. pinaster*, *P. nigra*, *P. pinea*) (Bugalho et al., 2011). In Sardinia, *Q. suber* is sometimes associated with holm oak (*Q. ilex)* or pubescent oak (Q. *pubescens)*. The understory vegetation of Sardinian cork oak forests includes a variety of small species of trees and large shrubs, in particular *Arbutus unedo* and *Erica arborea*. In more open forests subjected to wildfires, *Cytisus villosus*, *Cistus monspeliensis* and *C. salvaefolius* appear in the areas between (300)-500 m and 900 m (Camarda & Carta, 2006). Phylogenetically, cork oak is considered to be closely related to three Asian oak species, (*Q. cerris*, *Q. acutissima* and *Q. variabilis*) (Manos & Stanford, 2001).

2.3.3. Geographic distribution

Cork oak trees show a high ecological plasticity. This species is spread in the west Mediterranean Basin, and extends to the western coastal Mediterranean adjoining Atlantic areas between 33 N and 45 N latitude. Cork oak trees occur in the coastal regions of southwest Europe and northwest Africa, including France, Portugal, Spain, the islands of Corsica, and some coastal plains and hilly regions of Morocco, Algeria and Tunisia (Pereira & Tomé, 2004) (Fig. 4).

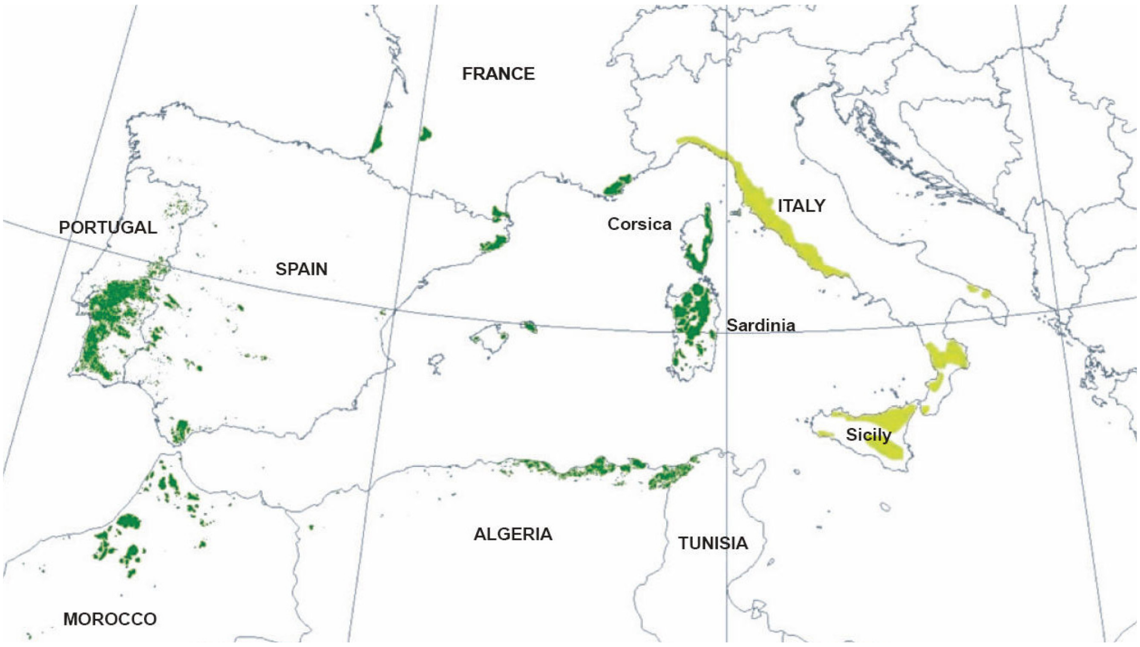

Figure 4. Geographic distribution map of cork oak forest (*source:* CEFE, 2005, modified).

In Italy, cork oak forests cover considerable areas in Sardinia, Sicily and on the Italian coasts of Liguria, Tuscany and Calabria (Jalas et al., 1996), and are also present in Apulia on the Adriatic coast (Crivellari, 1950; Ruiu & Pintus, 2006) (Fig. 5).

At present, the area occupied by cork oak forests and cork oak based agro-forestry systems is not known with exactitude, and the real value is somehow lower. Cork oak landscapes are estimated to occupy nearly 2.14 million hectares of worldwide area (Table 1), and about 201,428 tons of raw cork are harvested annually, 49.6% of which is from Portugal, where 850 million Euros contribute to the economy of the country (APCOR, 2013). Using the existing data for national forest inventories, the total cork oak area can be referred as 61% in the Iberian Peninsula (Portugal 34% and Spain 27%), three countries in North Africa have 33% (Morocco 18%, Algeria 11% and Tunisia 4%, and Italy and France have in total the remaining 6% of the total area of worldwide cork oak (APCOR, 2013) (Table 1). Conversely, cork oak distribution in

Italy is contradictory with the results of the most recent Nature Map (Camarda et al., 2015), which reported that a total of 103,597.47 ha of *Q. suber* forests cover the Island of Sardinia without taking in consideration the other Italian Regions.

Figure 5. Cork oak forest distribution in Italy.

Table 1. Worldwide distribution of cork oak forest (*source*: APCOR, 2013) and cork production (*source*: APCOR, 2012).

Country	Surface (ha)	Surface (%)	Production (t)	Production (%)
Portugal	736,775	34.4	100,000	49.6
Spain	574,248	26.8	61,504	30.5
Morocco	383,120	17.9	11,686	5.8
Algeria	230,000	10.7	9,915	4.9
Tunisia	85,771	4.0	6,962	3.5
France	65,228	3.0	5,200	2.6
Italy	64,800	3.0	6,161	3.1
Total	**2,139,942**	**100.0**	**201,428**	**100.0**

Cork oak was introduced to some countries outside the Mediterranean Basin (i.e. Bulgaria, California, Chile, New Zealand, southern Australia and Turkey) in the twentieth century, as an ornamental plant or with the aim of producing cork products, achieving some satisfactory results but no successful developed industries were registered (FAO, 2013).

Most of the present distribution of *Q. suber* forests is the result of an ancient anthropogenic alteration by clearance, coppicing, fires and overgrazing, but also reforestation (Pereira, 2007).

2.3.4. Economic value

Cork oak has a wide range of traditional applications and uses. Cork oak bark is the primary source of industrial cork making very high the contribution of *Q. suber* forest to the economy. Indeed, cork stoppers, ensuring the most effective closure for wine bottles (Silva et al., 2005) remain the gold standard of cork applications representing the largest market. Each ton of thick cork plank can provide, on average, 66,700 cork stoppers. A total of around 18 billion cork stoppers are produced annually worldwide (Amorim, n.d.), 14 billion of which are produced in Portugal (MTSS, 2008).

Within the cork stopper segment, natural cork stoppers rise in first place, with 590 million Euros, followed by building materials with about 177 million Euros (Cork world, n.d.). According to the Portuguese Cork Association (APCOR, 2013), the main target sector of cork products is the wine industry, which absorbs 68.4% of what is produced, followed by the construction sector with 31.6% including floors, insulation and coatings, blocks, sheets and also other products. (Fig. 6).

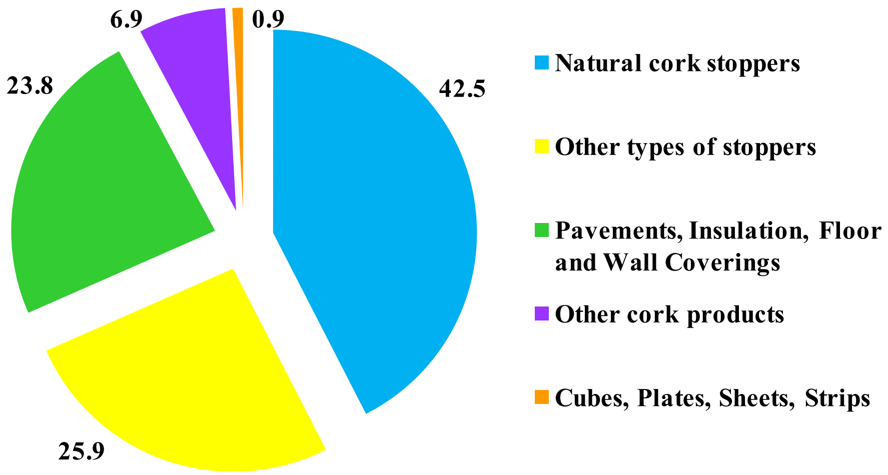

Figure 6. Structure of cork sales by type of product (*source:* INE and APCOR, 2012).

In 2015, Corticeira Amorim reported a turnover of 147.4 million Euros for the first quarter of 2015, an increase of 6.3% compared to the first quarter of 2014, largely due to cork stoppers business (Amorim, 2015).

During production, unsuitable cork is mainly used for rubber composites and agglomerates for wall and floor coverings (Silva et al., 2005), representing 23.8% of total cork products (APCOR, 2012). Only second reproduction cork, called *amedia*[2], is used for cork stopper production since it shows a continuous and a uniform thickness (Pereira & Tomé, 2004), while all types of cork can be used for agglomerates (Silva et al., 2005). The tannins and natural acids contained within the cork are used in chemical and beauty products. Cork material is used also in motor gaskets, handbags, insoles of shoes and skirts.

[2] Second crop called "secondary cork"

2.3.5. Intrinsic characteristics of extracted cork

It is usually assumed that, even if at present there is not enough data to confirm this empirical rule, the minimum rotation period of cork between successive extractions after the first cork debarking is 10 years in Sardinia (Regione Autonoma della Sardegna, 1994), whereas in Portugal is 9 (Pereira & Tomé, 2004).

In the early 1950, Natividade (1950) showed in his work that cork extraction is extremely traumatic for cork oak trees, as it exposes a considerable part of live tissues and causes an extensive wound. Indeed, stripping occurs during the summer season, which generates an excessive loss from the exposed surface (Pinto & Torres-Pereira, 2006), leading thus to a decrease in stomatal activity (Fialho et al., 2001; Costa et al., 2003) and the death of the newly exposed inner bark tissues with subsequent formation of a traumatic periderm starting approximately 30 days after cork extraction (Silva et al., 2005). Moreover, injuries caused by cork harvesting operations can also be associated to the loss of tree vigor (Costa et al., 2004). In fact, wounded trees are more vulnerable since bark is usually absent or much thinner near wounds making the trunk more heat-sensitive and more vulnerable to the other external agents (Miller, 2000). In addition, the ability of the trees to defend themselves from insect and fungi attacks is reduced (Wargo, 1996). In fact, Ruiu and Pintus (2006) monitored the phytosanitary conditions of cork oak trees in 42 sites all over Sardinia. Their research revealed a higher mass of weakening and withering diseases in the trees that have already been debarked than that in unharvested trees. P.A Ruiu (2015, personal communication) highlighted the importance of correct harvesting and the rotation cycles of *Q. suber* trees to maximize the good survival conditions of the species.

In their studies, Catry et al. (2009) and Moreira et al., (2009) indicated that larger trees are more vulnerable to fire damages than smaller trees, and that can be explained by the fact that older individuals were debarked more times in their lifetime. Indeed, in Sardinia cork oaks stripped more often were reported to have higher post-fire mortality (40%) than trees debarked only once (17%) (Barberis et al., 2003). Another study in Sardinia outlined that, after a fire, the percentage of mortality and irrecoverability in debarked *Q. suber* trees (35.2 and 31.8% respectively) was higher than that in unharvested trees (30.2 and 25.4% respectively%) (Ruiu & Pintus, 2014). One possible explanation for this, is that the insulating properties of bark are particularly effective on unstripped cork oaks, due to a different bark structure (Moreira et al., 2007).

Rives et al. (2012) stated in their paper that cork extraction is carried out without causing any harm to the tree, so that these forests can be exploited sustainably.

3. CORK OAK FORESTS IN SARDINIA

3.1. Spatial distribution

At present, forests in Sardinia cover 19.21% of the habitats of the island (Camarda et al., 2015), and is ranked in the first place by the extension of woods and forests among the other Italian Regions, recording a total area of 1,241,409 ha and an increase of around 54 thousands ha more with respect to the inventory of 2005 (Mulas, 2014). According to the data elaborated by the Regional Forest Service and Fire Brigades CFVA (1995-1998), Sardinia registered a total area of 1,095,847 ha (with a Forest Index of 45.49%), out of which 34.06% belonged to cork oak forests. According to Camarda et al. (2015), the area covered by cork oak forest, is estimated at a total of 103,597.47 ha, representing 4.3% of the total area of the habitats in Sardinia. The spread of *Q. suber* forests in the island interests particularly the areas of Gallura, Sulcis Iglesiente, Mandrolisai, Giara di Gesturi, Goceano, Planargia and the high planes of Buddusò, Alà dei Sardi, Bitti and Orune (Camarda & Carta, 2006) (Fig 7).

The Ecological Value (E.V.) represents an estimation of the quality level of cork oak habitat and is subdivided in numerical values of five classes (ISPRA, 2009). In Sardinia, about 78.70% of cork oak forest falls within the "very high" class (Table 2), which shows a high quality level of *Q. suber* biotope in terms of potential presence of fauna and flora on the basis of ecological fitness criteria of specie-habitat, the rarity, the extent and the shape of the plant, and other indicators transposing the Communitarian Directives. As for the Ecological Sensibility of cork oak biotope, which expresses the intrinsic susceptibility of a biotope to the risk of biodiversity loss or ecological integrity regardless the anthropogenic threats, the index shows that 99.93% of cork oak forests in Sardinia falls in the "average" class (Camarda et al., 2015). The Anthropic Pressure provides a summary index of the man-made disturbance degree, which consists on the fragmentation caused by road networks, adjacency with industrial areas, quarries, urban areas and agricultural areas, and the spread of human disturbance. This indicator was derived using the data of solely resident population excluding thus the touristic pressures during summer. In Sardinia, 55.78% of cork oak habitat falls within the “low” class and 42.55% is attributed to the “very low” class.

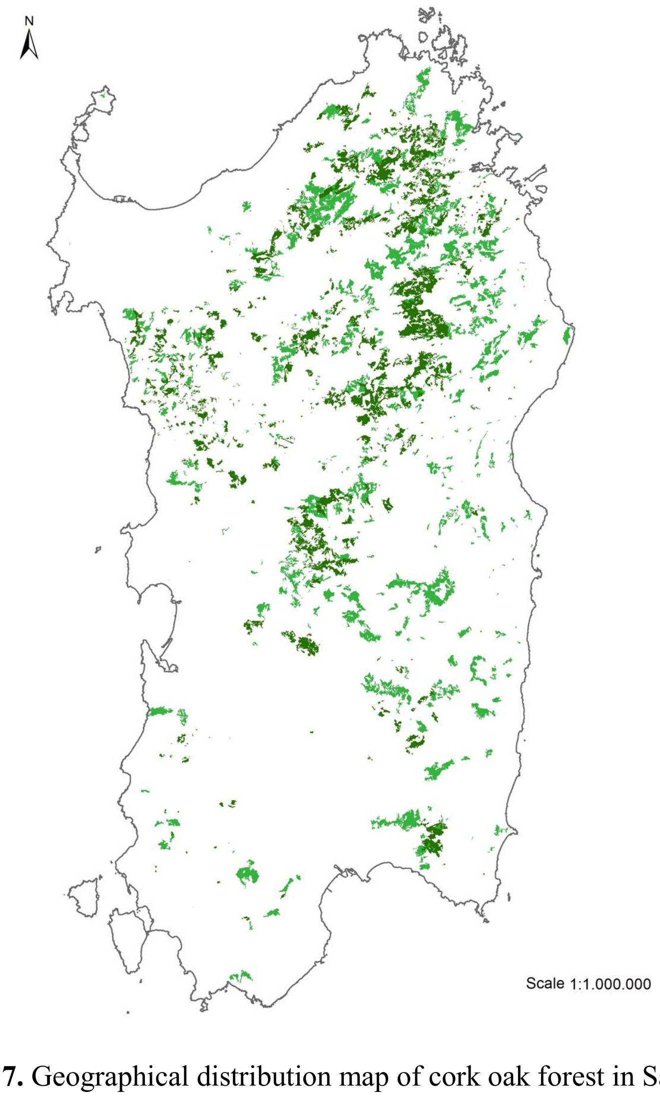

Figure 7. Geographical distribution map of cork oak forest in Sardinia.

Table 2. Quality indicators of cork oak forests in Sardinia (*source:* Camarda et al., 2015).

Indicator	Class				
	Very low	Low	Average	High	Very high
Ecological value				21.30	78.70
Ecological sensibility			99.90	0.10	
Anthropic pressure	42.55	55.78	1.62	0.05	
Environmental fragility	42.53	55.75	1.67	0.05	

3.2. Biodiversity of *Quercus suber*

3.2.1. Types

Cork oak forests, in lowland habitats with low rockiness, are often plowed regularly, and shrub layer is consistently cleared for the benefit of an herbaceous cover more favorable to grazing (Camarda et al., 2015).

In the territory of Buddusò, and according to the sites' specific composition, we distinguish one pure formation and seven mixed formations dominated by *Q. suber* (Camarda & Carta, 2006).

We recognize the natural types of *Q. suber* as below:

1) pure cork oak forests without understory, similar to "*pascolo arborato*", with a cover ranging from 20 to 50%;
2) mixed forests of cork oak occasionally plowed or subjected to fires, with an understory of *Lavandula stoechas*, *C. monspeliensis* and/or *C. salvaefolius*;
3) mixed forests of cork oak subjected to overgrazing;
4) mixed forests of cork oak with an understory of *C. villosus*;

5) *Quercus suber* forests with a rich understory of evergreen sclerophyllous species or thermophilic desiduous species, which constitute a cork oak layer and a layer of bush species (*Pistacia lentiscus*, *E. arborea*, *A. unedo*, *Phillyrea latifolia*, *Myrtus communis* and *Calycotome spinosa*), with a full cover classified mainly as matorral;
6) mixed forests of cork oak and holm oak;
7) mixed forests of cork oak and pubescent oak;
8) mixed forests of cork oak with *Q. congesta*, which represents thermophile aspects (up to 400-500m above sea level), or *Q. pubescens* with mesophilic characteristics (up to 900 m above sea level).

3.2.2. Forms

Regarding the forms of *Q. suber*, the research of Chiappini and Palmas (1972a) highlighted the presence of 15 different forms of *Q. suber* in the territory of Bitti, an adjacent area to the sites being studied in our research. Other 6 forms were added by Camarda and Valsecchi (2008). The following forms of *Q. suber* are those encountered in Sardinia till the date:

Quercus suber f. *genuina* Cout.

Quercus suber f. *stenocalix* Chi. & Palm.

Quercus suber f. *substenocalix* Chi. & Palm.

Quercus suber f. *clavata* Cout.

Quercus suber f. *subocculata* Cout.

Quercus suber f. *brevisquama* Batt. & Trab.

Quercus suber f. *dulcis* Batt. & Trab.

Quercus suber f. *paterocalix* Chi. & Palm.

Quercus suber f. *anulata* Chi. & Palm.

Quercus suber f. *longicalix* Camus

Quercus suber f. *brevicupulata* Batt. & Trab.

Quercus suber f. *dolichocarpa* Camus

Quercus suber f. *microcarpa* Batt. & Trab.

Quercus suber f. *crinita* Guss.

Quercus suber f. *subcrinita* Cout.

Quercus suber f. *fusiocarpa* Vals.

Quercus suber f. *poliisoquama* Vals.

Quercus suber f. *kraspedata* Vals.

Quercus suber f. *marcocarpa* Willk. & Lange

Quercus suber f. *radisquama* Mihi

Quercus suber f. *brevicupulata* Batt. & Trab.

3.3. Plant diversity in cork oak forest

Cork oak forest is an open formation both for the form of foliage and for the fact that this forest is of anthropic origins for the extraction of cork, firewood and grazing. Being a forest of secondary origin with great natural conditions, this woodland has tend, through evolutionary processes, to form mixed forests with other oak forests, whereas the understory vegetation of a "*sughereta*[3]" includes species of the Mediterranean bush,

[3] A "*sughereta*" an Italian concept that denotes habitat where the *Quercus suber* is the prevailing element

in particular, *A. unedo*, *E. arborea*, and *C. villosus* in the range (300)-500 and 900 m above sea level, favored after fires (Camarda et al., 2015).

The use of cork requires continuous and effective silvicultural treatments, indicating how the structure and the floristic composition of the understory vegetation depend on the type of interventions.

Under high natural conditions, species such as *A. unedo, E. arborea*, *P. lentiscus*, *P. latifolia*, *C. monspeliensis*, *C. salvaefolius* and *Daphne gnidium* are encountered, as for shrub species the "*sughereta*" include among others *Holcus lanatus*, *Carex distachya*, *Galium scabrum*, *Pulicaria odora* and *Leontodon tuberosus.*

When cork oak forest assumes the character of "*pascolo arborato*" or *dehesas* in Spain, *montado* in Portugal (*meriagos* in Sardinia[4]) (Pilla & Pulina, 2014) without the shrub component, the floristic composition is that of the anthropic grassland of the herbaceous formations and is implemented by the contribution of cultivated forage species (Camarda et al., 2015).

3.4. Pasture

Silvo-pastoralism is a system of land management in which tree and shrub species are growing in association with herbaceous species and in which animal husbandry coexist. In lands where agro-pastoral activities play a crucial role in the socio-economic development, the silvo-pastoral management of woodlands in particular those of *Q. suber* and *Q. ilex* being for centuries the only source of income for local population, represent today a balanced and sustainable productive system. Indeed, many studies

[4] In Sardinian language

have documented the importance of trees and shrubs as a source of forage in arid and marginal areas with predominantly pastoral management. These may in fact serve as food during the long and dry summers of the Mediterranean when graminaceous and other herbaceous species are in dormancy during this period of the year (Papanastasis, 1999).

There are several technical considerations that may enhance damages from grazing. In fact, the damage caused by livestock varies with animal species and the intensity of land utilization. Cattle tend to ravenously tear leaves and tender branches up to plucking young plants from the ground when the grass in soil is abundant. Conversely, goats would rather prefer new shoots of grass and would climb trees or assume the bipedal stance increasing thus the height of grazing, which results as the most damaging technique for pasture (Fig. 8). Finally, sheep are less voracious and are considerably less harmful since their diet consists on young shoots of trees and sprouts of shrub essences when hungry. In general, livestock consume around 2-3 pounds of dry weight forage per day per 100 pounds of body weight after they are weaned (Bullitta et al., 1976).

In cork oak forests associated to pasture for cow grazing (Fig. 9), the regeneration of plants is mainly reduced and young plants are seriously damaged due to the "eating behaviour" of grazing cow such as biting and bite size. Indeed, seedlings show a retarded growth and, in the few cases in which these manage to succeed, those seedlings give rise to individuals with significant defects affecting in particular cork production (Carta, 2000).

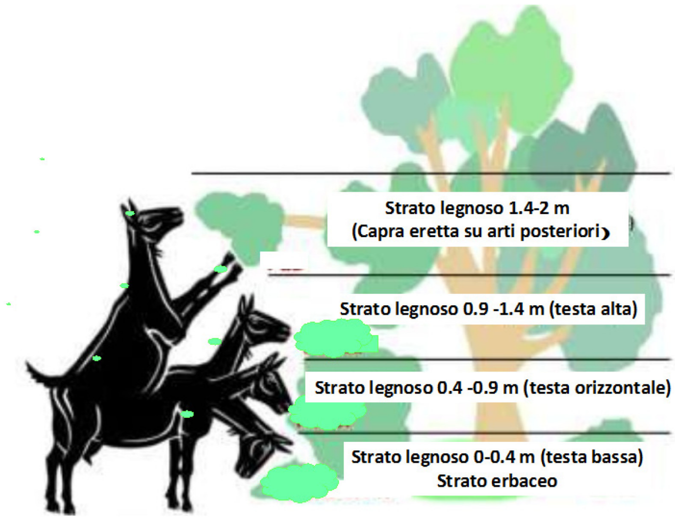

Figure 8. Bipedal stance of goat increasing the height of grazing in shrub-forest (*source*: Molle & Decandia, 2005).

Figure 9. Grazing in a cork oak forest in Buddusò.

It is obvious that a sparse system as the cork oak forest, in which understory vegetation and shrub cover are abundant, is highly associated with pasture. Clearings of the forest are therefore a form of rational land use and reconciliation of grazing and woodland. The presence of clearings ensure a considerable advantage to livestock through high productive forage (Capelli, 1982), enabling a load reduction in the dense areas (Maltoni, 2005) and consumption of biomass contributes hence to the reduction of fire risk (Franca et al., 2002).

In order to render forest and pasture production in close and compatible harmony, it is therefore fundamental to consider the real potentials of the forest that meet the nutritive needs of grazing animals without incurring irreversible deterioration enhancing the land cover loss and soil erosion.

3.5. Management practices

Quercus suber is the most important forest species in Sardinia both in terms of regional forest area and forest industry product. This western Mediterranean species contributes indeed to the financial rentability of Sardinia agro-silvo-pastoral systems, thus comes the necessity of functional ecosystem conservation.

Cork is usually exploited in pure stands of cork oak, mixed more or less degraded and also in areas of scattered trees distribution over coppices of holm oak or other tree species of pastures and arable lands (Carta, 2000).

For pure cork oak stands, silviculture interventions offer two types of stands; even- and uneven-aged forest structure. However, for the cork production, coppice stands cannot be used since require shorter cycles, which could not be well adapted to the cork oak, not having the cork as the main product. Having said that, emerges the necessity of determining previously our primary management objective for the stand, whether for cork production or fire prevention.

The most proposed management model is that of even-aged high forests, which are indeed the most encountered in a cork oak forest, and are more suitable for the development of cork that is produced in larger quantities. Thus, this model fits the best as is more productive. In uneven-aged structure, which is closer to the state of naturalness, the crown is spread over several layers. Here, the model requires much more attention and experience from the extractor, yet best results are provided both in terms of cork ecology and qualitative production (Carta, 2000).

In Sardinia, we distinguish two approaches of artificial regeneration of cork oak forests, depending on the reforestation plan whether is implemented on lowland or hills (Piazzatta et al., 2014). In general, lowland reforestation involves lands with degraded vegetation or former farmer lands, and may present some limitations with respect to seedling mortality caused by wind and/or excessive exposure. As for reforestation plans in hills, these plantations are executed under the supervision of the Sardinian Forest Administration[5], and are characterized by the use of bulldozer to create terraces separated by 4 m with a total elimination of shrub vegetation. Henceforth, these plantations are implanted by the use of bucket (Kamo), which enhances the preservation of the existing vegetation and reduces the erosion caused by rainwater (Piazzetta et al., 2014).

In the factories of Alta Gallura area specialized in cork production, cork arboriculture is the most adopted management model with a high productivity and profitability to the island, in which cork production provides up to 100% of the income (P.A Ruiu, 2015, personal communication).

Agroforestry and silvo-pastoral interventions are widespread in Sardinia where most of cork is subjected to agro-zootechnical activities; in this case cork loses its ability to auto-renewal potential.

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[5] *Ente Foreste*

According to Barneschi (1975) the integrated forestry productivity is the most appropriate management system for cork oak forests, in which the concept of pure *Q. suber* stands is mostly found in association with other species, mainly *Q. ilex* and *Q. pubescens*. This management model contributes to the maintenance of the natural equilibrium of the ecosystem, and facilitates the adaptation to extreme climatic conditions in the Mediterranean (P.A. Ruiu, 2015, personal communication).

3.6. Biotic factors affecting cork oak trees

The productivity of cork oak forests is affected by various biotic factors such as phytophagous insects and fungal pathogens, whose incidence is often enhanced by irrational silvicultural practices and improper management strategies (Luciano & Lentini, 2006).

Phytosanitary conditions of these ecosystems have gradually worsened in the recent decades due to the resurgence of pest attacks and in particular to the increasing incidence of the forest decline, which is caused by an interaction of multiple biotic and abiotic factors. The intensity of these factors depends on the anthropogenic activities, such as overgrazing and land abandonment.

In addition, climate change seems to have strongly contributed to the recent trend with the increase of both temperatures and rainfall in winter as well as long periods of aridity in spring and summer, causing the reduction of forest productivity.

3.6.1. Insect pests

Cork oak formations are exposed to severe infestations of lepidopteran defoliators such as *Tortrix viridana*, *Malacosoma neustrium* and, above all, the gypsy moth *Lymantria* *dispar*. In cork oak forests, damage concerns mainly the reduction of cork production in the year of complete defoliation (60%), which determines damage comparable to the loss of one year of cork production, and in the following year (32%). In case of a defoliation of 50%, the cork production is reduced by 42% (Cambini, 1971).

In different forest areas of Sardinia, the gypsy moth exhibits three distinct outbreak intervals (i.e. 5-6 years, 8-9 years and over 10 years), depending on the forest type and management strategy (i.e. mixed or pure stands, complexity of the understory vegetation and pasture management) (Luciano et al., 2002).

Both biotic and abiotic factors can influence gypsy moth gradations, such as natural enemies, food quality, climate and forest management (Prota et al., 1992; Luciano et al., 2003). Studies in homogenous forest areas revealed higher frequency of outbreaks in degraded forest ecosystems in which anthropic activities (i.e. fires, plowing, inappropriate cork harvesting and pruning) have weakened the environment, thereby exposing it to more frequent insect attacks (Fig. 10). Nevertheless, areas that retain a greater complexity, due to the presence of the typical Mediterranean understory vegetation are less subject to pest infestations. These ecosystems are characterized by a high biodiversity and a great ability to resist to stress factors such as moth defoliators, attempting to alter the ecosystem balance. This situation is particularly evident in a number of areas of cork oak forest (i.e. Monti, Berchidda, Buddusò) characterized by a rational management in the 70-80s, with defoliations occurring every 8-9 years. The progressive degeneration of forests has caused a drastic increase in the frequency of infestations starting from the 90s (Luciano et al., 2002).

Figure 10. Infestations of *Lymantria dispar* on a burned *Quercus suber* trunk.

Since the 70s, a monitoring network has been extended throughout the Island in order to detect annually the areas exposed to infestations of *L. dispar* (Luciano et al., 2002; Cocco et al., 2010). Studies on effective biological control methods have long been carried out in Sardinia and have developed a technique based on the use of *Bacillus thuringiensis kurstaki* applied against young larvae by the means of aircraft (Luciano & Lentini, 2002). This technique has been applied since 2001, and has enabled preserving more than 100,000 hectares of forests in Sardinia (Luciano & Franceschini, 2013).

Climate change has enhanced in recent years the emergence of secondary insect infestations such as *Platypus cylindrus.* A close relationship was found between the infestations of this species and the reduction of rainfall in spring. Therefore, it is crucial to evaluate whether to proceed or not on stripping during dry years, as the insect is able to attack and grow on plants stressed from debarking and water needs (Cao & Luciano, 2005). Attacks caused serious damage to the bark that would be formed in the following years (Fig. 11), and in addition several pathogenic fungi would penetrate inside the trunks affecting the viability of the plants in the long term (Luciano et al., 2006).

Various species of ants, including *Lasius brunneus* and *Crematogaster scutellaris*, are able to nest under the cork bark, disrupting the production of gentle cork (Loi et al., 2012; Verdinelli et al., 2012). Major damages are represented by excavations, which enhance the disintegration of cork planks (Fig. 12).

Figure 11. Adult *Platypus cylindrus* (A) and damage on cork oak trunk (B) (*source*: P. Luciano).

Figure 12. Damage on cork planks by *Lasius brunneus* (*source*: P. Luciano).

3.6.2. Fungi

The cork oak decline is the main pathological problem in Sardinian forests due to its complex aetiology and the resulting difficulties in defining suitable control strategies (Maddau et al., 2009; Solla et al., 2009). Among the biotic causes, fungal pathogens such as *Biscogniauxia mediterranea*, a canker-causing agent of *Quercus* species, has been associated with declining cork oak trees (Maddau et al., 2011) (Fig. 13). In Sardinia, this species causes major damages to *Q. suber* trees, in which completes its biological cycle producing a considerable quantity of inoculum (Franceschini et al., 2002). In addition, *Diplodia corticola* is also responsible of weakening cork oak trees, attacking young plants and mature trees causing the withering of branches from the distal parts, together with the occurrence of cankers on main branches and fresh exudates (Luciano & Franceschini, 2013). *Diplodia corticola* causes economic damages on *Q. suber,* as infections affect the regeneration of cork and the quality of planks (Fig. 14).

Figure 13. Symptoms of "charcoal disease" caused by *Biscogniauxia mediterranea* on *Quercus* species (*source*: B. Linaldeddu).

Figure 14. Trunk canker caused by *Diplodia corticola* on *Quercus suber* tree (*source*: B. Linaldeddu).

In *Q. suber* tree, discolored bark, which is difficult to detect, is the first disease symptom, appearing 2-3 months after cork removal. Bark in summer comes off of the trunk easily and the tree dies usually between one and three years after symptoms are first noted (Luque & Girbal, 1989). According to Luciano and Franceschini (2013), the strategic actions aiming at reducing the infections of the pathogen must be adopted by removing infected twigs and branches and burning the pruned wood.

Recently, the root pathogen *Phytophthora cinnamomi* has been a considerable cause of decline and mortality of *Q. suber* trees in several forests in northern Sardinia threatening the biodiversity of those cork oak ecosystems (Scanu et al., 2013) (Fig. 15-16). Nonetheless, so far only *Phytophthora quercina* was proven to be the pathogen species significantly associated with the decline of cork oak trees (Vetraino et al., 2002). The interventions adopted to mitigate the infections are as follow: a) prevent the spread of spores present in the soil; b) eradicate the disease by reducing the concentration of inoculum; c) favor the discharge of precipitations in order to avoid root rot; and d) enhance favorable conditions for the tree growth. The critical situation of cork oak forest imposes to ensure the sanity of young plants. Therefore, a thorough re-organization of nurseries and sanity control system should be carefully considered (Luciano & Franceschini, 2013).

Figure 15. Bleeding cankers of *Phytophthora cinnamomi* on the collar of cork oak trunk (*source*: B. Scanu).

Figure 16. *Quercus suber* tree sudden death caused by *Phytophthora cinnamomi* (*source*: B. Scanu).

4. CORK OAK EXTRACTION IN SARDINIA

4.1. Outline and legal status

The exploitation of the cork starts with the extraction of the raw material. At this early stage, the study of the characteristics of the cork oak plays a major role. *Quercus suber* is a typical Mediterranean plant whose wide regional spread, is linked to some of its peculiarities such as adaptation to drought and fire resistance.

This species is distinguished by a remarkable species variability, which sometimes makes the accurate identification of the plant typology a problematic task. The latter characteristic renders more difficult sorting optimal acorns for sowing, on which depends the future extraction of cork oak with a high production capacity. To overcome this problem, the acorns are selected in autumn from highly selected cork trees. If planted immediately, they would be able to maintain the integrity of the germination capacity that can reach even up to 80% (Camillo del Bono, 1993).

From the physiological point of view, cork could be exploited when growth is at its highest, (mid-May to the beginning of August), when the phellogen is in full meristematic activity allowing easy separation of the cork layers (Silva et al., 2005). Cork stripping is carried out manually using an axe, and the extractor makes long cuts in the cork, first horizontal then vertical, allowing the detachment of large cork planks. The cork is then loaded into tractors and transported from the field to the storage place.

In Sardinia, according to the Regional Law of May 27, 1955, N. 22 (published in the Official Bulletin of R.A.S in February 28, 1956) the exploitation of cork oak is possible between May 1 and August 31 of each year. This Regional Law, which as mentioned earlier, was intended to regulate only cork extraction, and was followed by the National Law of July 18, 1956, N. 759 (published in July 31, 1956) related to the cultivation, protection and cork exploitation, in which indicates the annual extraction period from May 15 to August 31. This latter Law is currently valid in Italy and has not been replaced or overlapped with other regional regulations.

Following that, the National Legislation introduces more accurate series of articles with respect to the cork oak defence and promoting thus the establishment of a cork oak map at the Chambers of Commerce, Industry and Agriculture, in which cork oak forests are distributed.

According to the Art. 20 of the Regional Law of February 9, 1994, N. 4, the first cork extraction, called *demaschiatura*[6], must be practiced in such a way that does not exceed two times the outer circumference measured at 130 cm (average person's breast height) from the ground and of a minimum of 60 cm. Moreover, the same law prohibits any further intervention for the following extraction on those plants measuring three times the outer circumference previously specified. The product of the first decortication is called virgin cork, *sughero maschio* or *vergine* or *sugherone*. Virgin cork is irregular in structure, thickness and density, and is hard rough (Cumbre et al., 2000). It has a low commercial value, as it has deep fractures due to tissue failure upon the tangential stresses of the tree radial growth (Pereira & Tomé, 2004), and is mostly used for the production of asphalt (Del Bono, 1993).

According to the Art. 22 of the same Law, the second decortication occurs after 10 years (Regione Autonoma della Sardegna, 1994), and the first reproduction cork is called *sughero gentile* or *femmina*, whereas in Portugal occurs after 9 years (Pereira & Tomé, 2004) and in Morocco between 8 and 12 years (WWF, 2007). However, and under the same Art. of the Regional Law, the second extraction of cork below 10 years

[6] stripping of first cork-planks

might be authorized for particular physiological motivations aiming at the recovery of the plants such as a pre-management or a restoration plan or even after a fire. The second cork obtained in the following extraction is more regular than virgin cork, but still have numerous longitudinal running cracks (Pereira & Tomé, 2004).

4.2. Cork industry: between past and present

Contradictory and different reports trace the history of cork oak exploitation in Sardinia. One thing on this regard is confirmed that cork oak transformation was already present at the beginnings of XIX century, limited to the first processing of raw cork such as boiling and roughing (Idda & Gutierrez, 1984). However, cork was already used in the Nuragic Age, as planks were found inside the *nuraghi*[7] and were probably used for insulation. Greeks and Romans used cork as well, in particular for fishing floats, barrel stoppers and women footwear in winter. In fact, cork stoppers were found intact in the jars of a Roman ship that sank in the Island of Spargi in the Arcipelago di La Maddalena, and is kept today in the Naval Museum of the city (Camarda & Valsecchi, 2008).

The first trades and processing of raw cork in Sardinia date from the first half of the nineteenth century by the French through establishing factories in Gallura, Sassari and Nuoro, and later on by local merchants through establishing oak enterprise processing in Tempio and Calangianus, (Beccu, 2000). In the early years of the twentieth century, Sardinian cork acquired a genuine industrial relevance reaching an extraction of around 2,500 tons/year, 40% of which dedicated for export and the remaining part processed on

[7] Ancient megalithic edifice found in Sardinia and developed during the Nuragic Age between 1900 and 730 BCE.

site (Camillo del Bono, 1993). Sardinian cork was recognized as an important commercial resource, thus the importance of protecting this species from which it was extracted emerges, and in consequence first legislations on the cork extraction and its exportation started to gain attention and interest.

According to a statement of the province of Nuoro (ASC, 1840), a total of 106,800 trees of *Q. suber* covered the area (Table 3), out of which one-third of the total number of trees were subjected to harvesting. As for the south-occidental area of Sardinia, Iglesiente, in Fulmini and Gessa, the number of trees of *Q. suber* was around 208,378 in 1837 (ASC, 1837). We notice in the table below that Garofai occupies the highest number of *Q. suber* trees (50,000). In fact, this village was in past included in the Municipality of Bitti and depicts indeed the importance of cork oak forest in the studied area.

According to "*Notizie intorno ai boschi e terreni soggetti al vincolo forestale*", the average annual cork production in Sardinia, for the period 1879-1883 was around 1,332 tons representing 74.20% of the national corresponding data (Beccu, 2000).

Cork oak habitats adopt an efficient industrial transformation process concentrated mainly in Alta Gallura, and handmade activities in Nuoro and Oristano (N. Solinas, 2015, personal communication), and according to Corona et al (2005), the production of cork stoppers is the most remunerative industrial product of cork oak in Sardinia. The Island is the Italian Region that occupies the highest concentration of cork oak forest area (103,597.47 ha) (Camarda et al., 2015), and cork oak forests in Sardinia produce around 50 % of the needs of processing companies (Dettori et al., 2006), and the remaining 50% are exported mainly from Portugal (Deplano et al., 2006). No available data for Sardinia, but on the national level, in 2014 Italy imported 10.1% of the cork produced worldwide for a sum of around 137 thousands Euro (Table 4). Italy's share from the export reached only 3.2% for a total cost of 42,629 thousands Euro (ITC, 2014) (Table 5).

Table 3. Number of existing cork oak in the province of Nuoro in 1840 (*source*: ASC, 1840).

Municipality or village	***Q. suber* tree (no.)**	**Municipality or village**	***Q. suber* tree (no.)**
Nuoro	10,000	Ovodda	4,000
Oliena	500	Mamoiada	1,000
Lollove	1,000	Orgosolo	2,000
Garofai	50,000	Galtellì	2,000
Lula	3,000	Dorgali	500
Orune	10,000	Orosei	30
Bono	1,000	Onifai	50
Anela	30	Irgoli	200
Bultei	2,000	Loculi	100
Burgos	30	Orani	8,500
Bottidda	500	Oniferi	2,200
Esporlatu	100	Orotelli	2,200
Bolotana	40	Ottana	1,000
Benetutti	400	Sarule	500
Fonni	200	Siniscola	250
Gavoi	1,000	Posada	60
Olzai	100	Lodè	140
Illorai	2,000	Torpè	170
		Total	**106,800**

Table 4. World imports of cork in 2014 (*source*: ITC, 2015).

Importing country	Import (Million Euro)	Country share (%)
France	221,233	16.3
USA	203,410	15.0
Italy	137,022	10.1
Portugal	127,846	9.4
Spain	102,024	7.5
Germany	92,602	6.8
Russia	38,898	2.9
United Kingdom	32,729	2.4
Argentina	31,154	2.3
China	30,965	2.3
Other	340,394	25.0
Total	**1,358,277**	**100.0**

During the last five years, cork articles imported and exported by Italy (393,007 and 33,113 million Euro, respectively) (Table 6 and 7), making Portugal the largest importer of cork in the world, which uses it for proceeding and subsequently for export in the form of consumer end products). As a matter of fact, the following listings include samples of the main cork suppliers of cork and cork articles. Specifically, these include natural raw cork, waste cork, crushed, granulated or ground cork, debarked or squared cork pieces, cork stoppers, disks, wall coverings and many other items. For instance, regardless the absence of cork oak forests in Germany, the country's share from the export reached 2.1% of the total exports worldwide. That would be explained by the important development of cork products and specifically shoe components.

Table 5. World exports of cork in 2014 (*source*: ITC, 2015).

Exporting country	Export (Million Euro)	Country share (%)
Portugal	844,957	62.8
Spain	223,582	16.6
France	63,573	4.7
Italy	42,629	3.2
Germany	27,616	2.1
USA	22,999	1.7
Morocco	16,222	1.2
China	14,784	1.1
Belgium	9,409	0.7
Chile	9,284	0.6
Other	70,748	5.3
Total	**1,345,803**	**100.0**

Table 6. Value of supplying markets for cork articles imported by Italy for 2010-2014 (*source*: ITC, 2015).

Exporting country	Imported value (Million Euro)				
	2010	**2011**	**2012**	**2013**	**2014**
Portugal	67,827	76,070	85,902	79,918	83,290
France	12,658	15,447	16,997	19,907	25,042
Spain	21,873	22,184	31,233	21,215	19,158
Morocco	1,674	1,422	2,113	2,665	4,330
Tunisia	2,777	2,311	1,527	2,297	1,926
China	802	817	795	762	1,132
Germany	960	880	794	751	869
Austria	563	528	517	361	327
Algeria	538	365	64	82	138
Netherlands	51	52	21	20	111
Other	2,283	1,541	844	1,283	699
Total	**112,006**	**121,617**	**140,807**	**129,261**	**137,022**

Table 7. Value of importing markets for cork products exported by Italy for 2010-2014 (*source*: ITC, 2015).

Importing country	Exported value (Million Euro)				
	2010	**2011**	**2012**	**2013**	**2014**
Portugal	4,259	8,356	5,015	7,797	7,686
USA	6,385	6,100	8,551	7,503	7,185
France	10,938	12,273	9,851	8,561	6,877
China	2,014	4,230	3,882	3,712	5,004
Spain	4,432	4,143	3,705	3,321	3,002
Argentina	1,799	2,417	2,528	2,098	2,061
Germany	2,260	1,644	1,554	1,494	1,231
Switzerland	1,810	1,775	1,261	1,227	1,127
Australia	410	559	725	759	708
Slovenia	820	867	702	650	664
Other	6,738	7,208	7,655	8,406	7,084
Total	**41,865**	**49,572**	**45,429**	**45,528**	**42,629**

According to the FAO (2010b), the total cork production in Italy is around 6 thousand tons, out of which 80.6% are provided by Sardinia (Ruiu & Pintus, 2006) (Fig. 17). Approximately 180 companies are operating in cork sector, employing around three thousand workers. According to the data of the Portuguese Statistics Institute, around twelve thousands workers operate in 800 companies (Ranking Brothers & Sons, 2012).

As for the distribution by district, the ex-district of Sassari, - today recognized as partly district of Olbia-Tempio constitutes the most devoted cork oak forest in terms of production process and transformation.

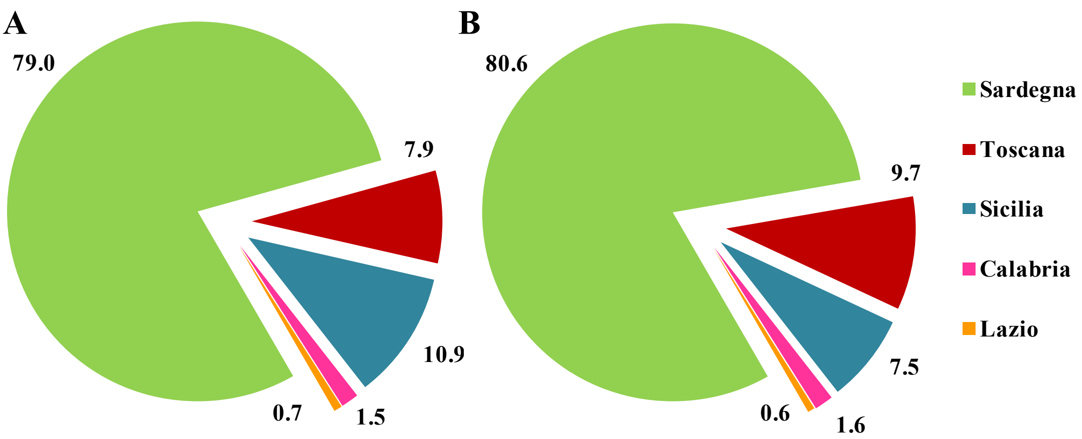

Figure 17. Percentage of cork oak surface (A) and cork oak production (B) (*source*: Ruiu & Pintus, 2006).

5. FOREST FIRES

5.1. Forest fires in the Mediterranean Basin

The Mediterranean Basin is identified as one of the highest biodiversity hotspots of the world. Mediterranean forests are highly diverse in topography, soil, hydrology, land use and geography. It is estimated that about 25,000 plant species inhabit the region (Myers et al., 2000), of which around 60 percent are endemic (Thompson et al., 2005).

Fire is one of the most significant elements influencing the Mediterranean landscapes and ecosystems, shaping the composition and the structure of forest ecosystems. However, in recent decades, the general trend of fires in terms of number, intensity and size in the Mediterranean Region has widely increased. The average surface of burned areas in the Mediterranean countries is estimated to reach 600,000-800,000 hectares per year (WWF, 2000). This phenomenon is mainly due to land use changes, increase of ignition sources and extreme meteorological events. Therefore, responding to such increase in the occurrence of forest fires, several methods of investigation are being developed to optimize successful prevention efforts and fire fighting phases. Furthermore, several policies and forest fuel management strategies are being adopted to reduce wildfires risks, and promoting the sustainable use of forest ecosystems goods and services (Lehmkul et al., 2007).

The Mediterranean is characterized by warm and dry summers, which increase the fire risk making the Mediterranean areas prone to the occurrence of a larger number of fire events. The estimated forest area in Mediterranean countries was over 85 million hectares in 2010, representing 2% of the world's forest area (FAO, 2010b), and there is a growing global awareness of the importance and vulnerability of this region with respect to rapid land-use changes, socio-economic conflicts, increasing anthropogenic pressure and interests. Mediterranean-type climates are typical of regions where precipitation exceeds potential evapotranspiration during the rainy season, resulting thus in sufficient plant growth that becomes highly flammable during summer dry season. These regions are dominated by fire-prone ecosystems and are dominated by fire-adapted vegetation resulting from a long evolutionary association with fire (Pausas & Keeley, 2009). In the same paper, authors pointed that fire is not a new ecosystem process but rather one that has been part of land plant evolution since the Palaeozoic. Bradshaw et al (2011) analysed the different flaws of fire adaptations. One is the misconception that fire is a recent Neogene (23 million years ago) phenomenon, whereas fire has been part of Earth system since the Silurian origin of land plants 443 Ma (Pausas & Keeley, 2009).

5.2. Forest fires in Sardinia

5.2.1. Outline

The phenomenon of forest fires is one of the greatest threats to the Mediterranean Basin and is one of the underlying causes of the spread of desertification processes. Knowledge of historical forest fire data is an efficient tool to analyse the phenomenon in order to implement the best strategies to reducing the number of ignitions and mitigate damages. Although the occurrence of events appears to decrease slightly in the last years, wooded lands are facing an increase in the trend of fires (CFVA, 2014).

The analysis of fire data statistics is conducted on the basis of relative data, absolute values and percentages registered in a period of time sufficiently enough to provide a representative trend of the phenomenon, with respect to the various parameters. In Sardinia, the systematic collection of statistical historical forest fire data starts since

1971 through the compilation of specific paper forms called INCE (CFVA, 2014). On these paper forms, nearly 60 entries of elementary information i.e. geography, climate, presumed causes, burned area estimated, vegetation typology, land ownership, terrestrial/aerial interventions, are defined for each fire event. The detection of fires in Sardinia during both summer campaign and winter covers all events occurring in the Island regardless of the size or the typology of the affected area whether wooded or not (M. Bazzoni, 2015, personal communication).

5.2.2. Fire history in numbers

The yearly trends in terms of number of fires and total burned areas in Sardinia for the period 1971-2014 are shown in Figure 18. The number of fires registered in this period is 146,832.

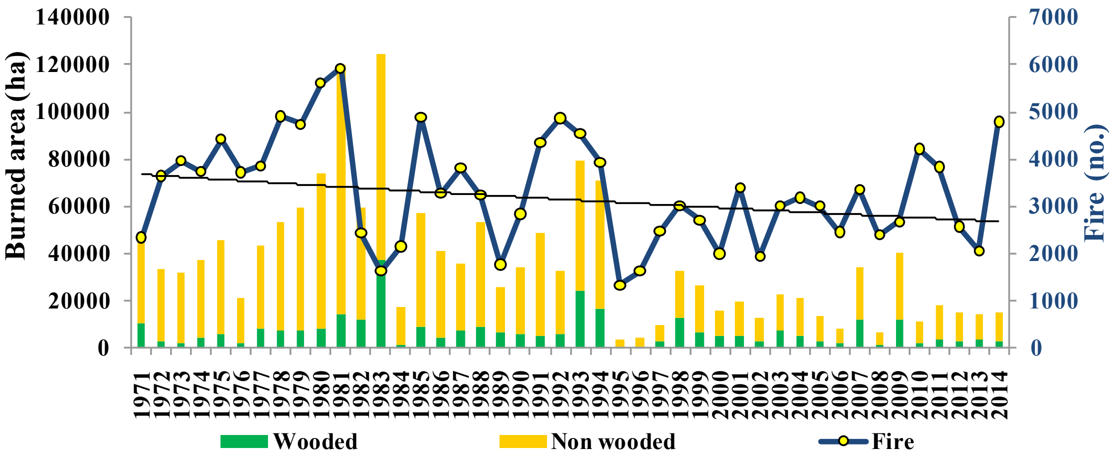

Figure 18. Trend of number of fires, wooded and non-wooded burned areas for the period 1971-2014 in Sardinia.

The subdivision of long series of registered fires in Sardinia, in three sub-categories, enables us to underline three different trends:

- the period 1971-1981 shows an exponential increase of the number of fire events registering a total of 4,260 fires/year;
- in the period 1982-1994, we observe mainly an inversion of the tendency of the number of fires recording 3,337 fires/year;
- in the period 1995-2013, the number of fires (except some slight increase) tends to stabilize with an average of 2,705 fires, to reach again a peak of 4,797 fires in 2014.

The lower trend of fire occurrence over the last period is largely due to the improvements of fire protection services, the surveillance of suspicious and negligent activities, the early detection of forest fires and the timely development of initial attack actions. Overall, between 1971 and 2014, statistics indicate that approximately 1,597,006 ha of lands were recorded as affected by fires, of which 320,931 ha of forests (Fig. 18). We can observe that the year 2009 registered the highest burned area in the last years (40,729 ha). Moreover, the same graph shows that fires in 2008 burned a total area of 6,681 ha, which is the lowest in the last 20 years, registering 2,400 fires. During the period 1990-2011, the 80 stations of CFVA distributed in the 8 provinces Cagliari, Carbonia-Iglesias, Medio Campidanno, Nuoro, Ogliastra, Olbia-Tempio, Oristano and Sassari, recorded a total of 67,303 fires (Fig. 19).

According to the existing regional legislation, Sardinia contributes through conventions and program agreements to prevention, preparedness, coordination in the operation rooms and in surveying burned areas, and the Regional Service of Fire Brigades to active fire-fighting and coordination in the operation rooms of municipalities. Regarding identifying ignition causes over the territory, a highly specialized staff carry out investigation and law enforcements, which may be considered satisfactory given the multiplicity of causes and motives characterizing the phenomenon.

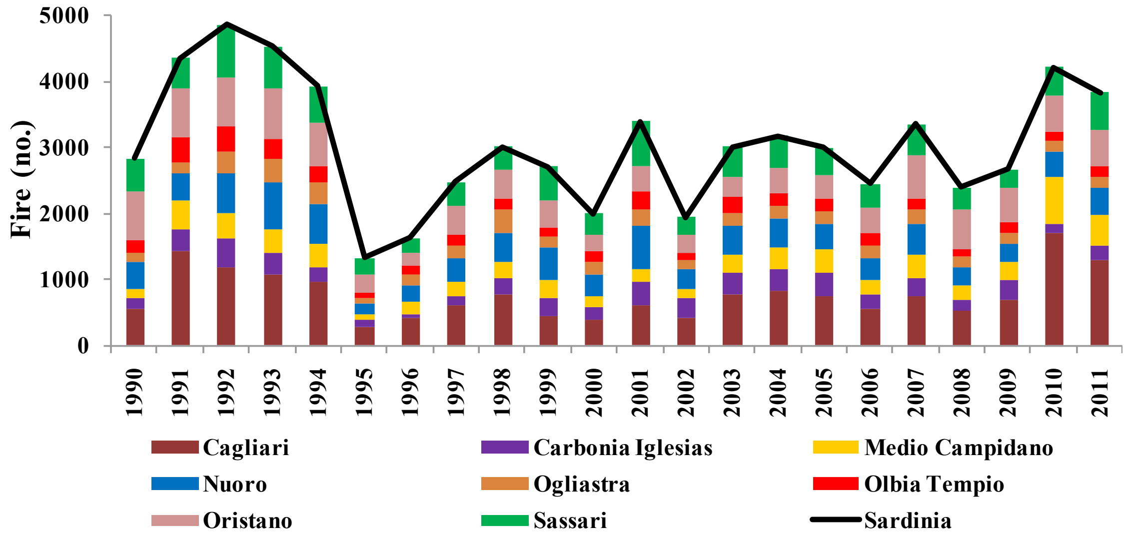

Figure 19. Trend of number of fires in Sardinia Provinces for the period 1990-2011.

6. CASE STUDY

6.1. Selection of the study area

In Sardinia, vegetation surveys and studies reveal a lack of information at management strategies level. As such, the first economical plan analyzing the management strategies of *Q. suber* forest is assigned to the *Ex Azienda Speciale per la Gestione dei Beni Silvopastorali* of the Municipality of Buddusò. Accordingly, nearly 50 years later, we have decided to study the current situation of cork oak forest of the same area in terms of plant diversity, grazing and fires and thus draw general and specific findings and considerations of the management practices of this human-induced landscape.

6.2. Geographical characteristics

Buddusò is located in the southwestern border of the province of Olbia-Tempio, in NE of Sardinia (Fig. 20). The municipality is bounded in the northwest by Oschiri, northeast by Berchidda, east by Alà dei Sardi, southeast by Bitti, southwest by Osidda and west by Pattada. The total area of the municipality is 176.84 km^2 and is populated by 3,908 people (density of 22.1 hab/km^2) (ISTAT, 2014) (Table 8).

The topography of the area is characterized by undulating hills and valleys alternating with flat stretches of land ("Punta Sa Jone", 1,003 m, represents the highest peak). On the border with Bitti, the river Tirso is born, flowing for about 152 km, representing thus the longest river in Sardinia.

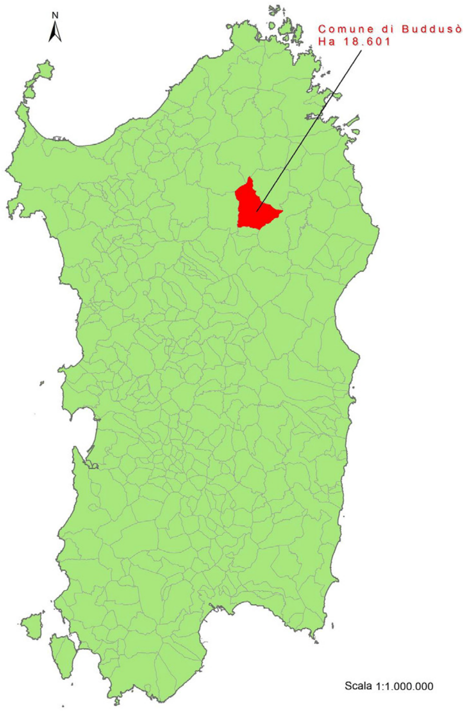

Figure 20. Localisation of the municipality of Buddusò at regional level.

The area is particularly known for the several quarries of white granite, which for decades has been a source of a flourishing mining activity and used worldwide for the construction of several architectural complexes and skyscrapers.

Table 8. Geographic characteristics of the Municipality of Buddusò.

Altitude (m)	Lower altitude (m)	Higher altitude (m)	Latitude	Longitude	Total area (km^2)
700	98	1003	40°34'44"76 N	09°15'32"76 E	176.84

6.3. Abiotic characteristics

6.3.1. Climate

Climatic data was collected by the Meteorological Stations of Buddusò, for the periods 1971-1980, 1985-2000 for rainfall and Sos Canales reservoir for the periods 1971-1978, 1981-1992 for air temperature (Fig. 21). Bagnouls-Gaussen's diagrams were used to report the monthly averages of air temperatures and precipitation. The length and intensity of the drought period are identified by the intersection of the precipitation curve with the average temperatures (Bagnouls & Gaussen, 1957).

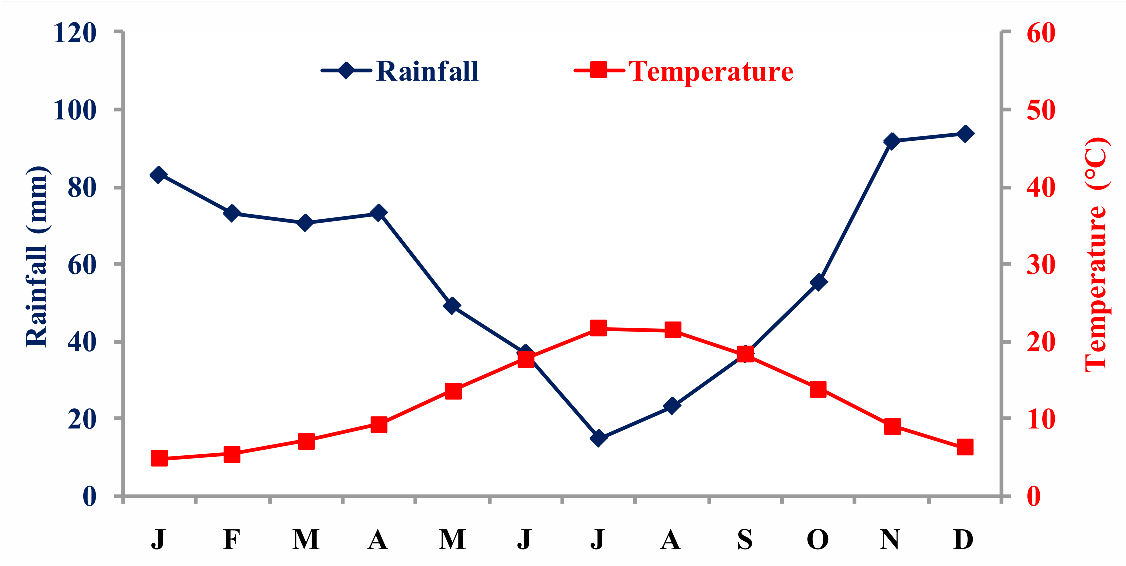

Figure 21. Bagnoul-Gaussen's diagram of the meteorological station of Sos Canales for the periods 1971-1980, 1985-2000 for rainfall and 1971-1978, 1981-1992 for air temperature.

Mean monthly temperatures of the site ranged between a minimum of 4.8 and a maximum of 21.6 °C. A maximum value of 38.4 °C reached in August and minimum of -8.3 °C. Drought period started in July and ended in September. Annual mean rainfall were 684 mm, rainfall events were concentrated in autumn and winter, with low monthly rainfall in summer (July-August period).

6.3.2. Pedology

Soils constitute the memory of the Earth, which plays a pivotal role in the structure and dynamic of ecological communities (Blondel et al., 2010). According to *Carta dei suoli della Sardegna* (Aru et al., 1991) the principal characteristics of pedological typologies are as follow (Fig. 22):

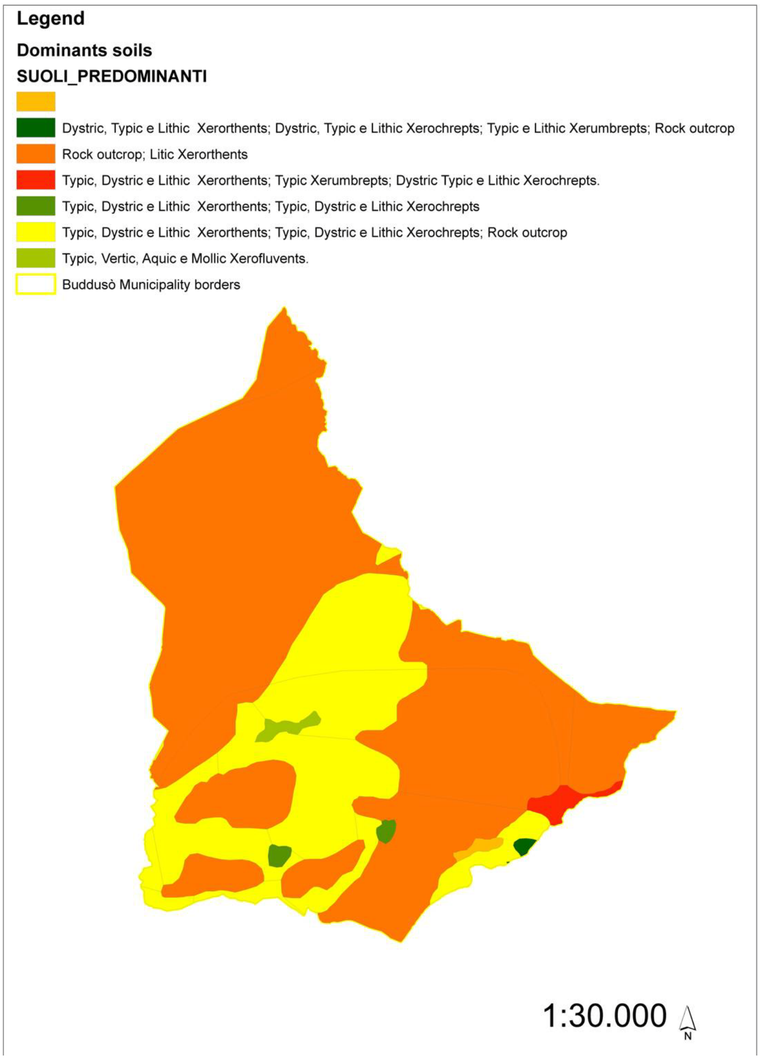

Figure 22. Pedological profil of the Municipality of Buddusò.

1) Profil A-R, AC with an average depth <30 cm. Skeleton from poor to moderate. Texture from sandy-franky to frank-sandy or frank (Lithic Xerothents, Dystric Xerothents, Rock outcrop). Landscapes attributed to this unit are inappropriate

for any agricultural use. Reforestation aimed at soil protection and grazing of native breeds with restricted loads is possible.

2) Profil A-C with an average depth of 50 cm or A-Bw-C with a depth of 40-70 cm. Scarce skeleton, which tends to increase due to the presence of coarse elements in colluvial deposits. Texture from sandy-frank to frank-sandy-clay. Acid reaction. Saturated and unsaturated flows. Drainage from normal to moderately fast depending on the texture (Lithic Xerorthents, Dystric Xerorthents, Lithic Haploxerepts, Typic Haploxerepts, Lithic Dystroxerepts and Typic Dystroxerepts). Marginal surfaces to the use of intensive agricultural activities and could be allocated to cereal crops, forage, pasture and mechanized reforestation. Irrigation is possible locally depending on the morphology and availability of adequate water supplies.
3) Profile A-Bw-C with an average depth varying between 30-40 and 60-80 cm. Skeleton scarce to common. Texture from sandy-frank to frank-sandy-clay. Acid reaction. Saturated and unsaturated flows. Drainage from normal to moderately fast depending on the texture (Lithic Haploxerepts, Typic Haploxerepts, Lithic Dystroxerepts, Typic Dystroxerepts Fluventic Haploxerepts).
4) Profile A-Bw-C with an average depth > 80-100 cm. Texture from sandy-frank to frank-sandy-clay or frank-clay (Typic Haploxerepts, Lithic Dystroxerepts, Typic Dystroxerepts, Fluventic Haploxerepts). Scheleton scarce to common. Acid reaction. Saturated and unsaturated flows. Drainage normal. Moderate risks of erosion depending on the micromorphology. Stagnant water brief and spread in the vicinity of rivers and their estuaries.

The last two soil profiles correspond to landscapes, which have moderate to severe limitations for intensive agricultural use, thus are allocated to cereal crops, forage, pasture and reforestation, and are aimed at the production of wood construction and cellulose. Irrigation is possible depending on the morphology and availability of adequate water supplies.

6.4. Biotic characteristics

6.4.1. Anthropic activities

The Mediterranean climate, with a pronounced bi-seasonality, not to mention its elevated topographical variability, has produced one of the most highly diversified anthropic natural ecosystems of the world (Scarascia-Mugnozza et al., 2000). The long history of human intervention in forests contributed to forest degradation due to several mismanagement of settlements, such as roads building, grazing and agricultural practices.

Wooded forests in Sardinia have always been areas of interest for pastoralism rather than forestry (Beccu, 2000). Various kinds of livestock, were displaced, seasonally or throughout the year, in clearly defined areas or promiscuously gathered together on the same land in which their livelihood was ensured. Not all livestock are formed equal nor they do use the pasture resource in the same way. In Sardinia, and according to the Art. 43 of the Regional Law of August 11, 1983, N. 19, one animal unit (AU)[8] is equivalent to one mature cow over the age of two years, weighing up to 500 kg, and 0.6 AU if under the age of two years.

[8] Equivalent to UBA (Unità di bestiame adulto)

Assuming a forage dry matter demand of 11.8 kg/day, 1,000 lbs (nearly 453 kg) cow issued as the base animal unit to which other livestock are compared (Redfearn & Bidwell, 1964), an average cow weighing 400 kg will consume approximately 10.67 kg of dried forage per day, that is 320 kg/month.

Other livestock equivalents are as follow:

- one goat (between 6 months and two years) corresponds to 0.15 AU, and 1 AU is equivalent to 6.7 AUE[9];
- one sheep (between 6 months and two years) corresponds to 0.15 AU, and 1 AU is equivalent to 6.7 AUE;
- one pig corresponds to 0.2 AU, and 1 AU is equivalent to 5 AUE (Regione Autonoma della Sardegna, 1983).

According to the most recent data available on the livestock in the Municipality of Buddusò (ISTAT, 2010), the total number of livestock is given in the Table 9 below.

Table 9. Livestock in the Municipality of Buddusò (*source*: ISTAT, 2010).

Livestock species	AUE	Head (no.)
Sheep	0.15	16119
Goat	0.15	7211
Cow	0.80	2730
Pig	0.20	332

[9] AUE or Animal Unit Equivalent estimated the potential forage demand for cattle that weigh more or less 500 kg

6.4.1.1. Stocking rate

Stocking rate expresses the number of livestock per unit area over a given period of time. For estimating the stocking rate of livestock using AUEs, first we estimate the total number of AUs based on AUEs then we calculate the stocking rate using the following formula:

Total land area (ha) / [(# AUs) x (grazing season)]

Stocking rate for cows for a total land area of 7,767 ha in Buddusò:

2,730 x 0.8[10]= 2,184 AUs.

7,676 / (2,184 x 6)= 0.58 ha per AUM[11] or 3.51 ha per season.

Stocking rate per season for the other livestock is given in the Table 10.

Stocking Rate per month and per hectare, in terms of weight of each livestock is as follows:

- goat: 16,119 x 75 kg= 1,208,925 kg;
- sheep: 7,211 x 75 kg= 540,825 kg;
- cow: 2,730 x 400 kg= 1,092,000 kg;
- pig: 332 x 100 kg= 33,200 kg.

Thus the total net weight is equal to 2,874,950 kg (28,749.5 quintals). The monthly net weight is around 2,395.8 quintals, in consequence on a total land area of 7,676 ha, the average net weight per month is 0.31 quintals/ha.

As an average, goat weighs 75 kg, the stocking rate in number of goat per hectare is equal to 2.08. The results of stocking rate in number of livestock/ha are given in the following table (Table 10).

[10] We considered the average AU for an average cow weighing 400 kg

[11] Animal Unit per Month

Table 10. Stocking rate in the Municipality of Buddusò.

Livestock species	Total AUs	Stocking rate per AUM (ha)	Stocking rate per season (ha)	Head * Weight (kg)	Stocking rate (heads/ha)
Cow	2417.9	0.53	3.17	1,208,925	0.39
Goat	1081.7	1.18	7.10	540,825	2.08
Sheep	2184.0	0.58	3.510	1,092,000	2.08
Pig	66.4	19.27	115.60	33,200	1.56

In the economical plan of silvo-pastural goods drafted by Beccu (1976) for the Municipality of Buddusò, the stocking rate for livestock was calculated for the period 1962-1965 in three different localities; Sos Canales, Sa Matta and Su Monte, for a total surface of nearly 7511 ha. The average stocking rate for livestock in these localities was nearly 1.3 heads per hectare. Following the same calculations [12] adopted in the economical plan, the stocking rate in 2014 is lower and is estimated at 0.62 heads/ha.

[12] 30 kg as average net weight of adult sheep

7. CORK OAK EXTRACTION IN BUDDUSÒ

7.1. Legal status

Buddusò's cork oak forests are a carefully protected resource. The importance of cork industry to the economy of Sardinia had led to strict regulation preventing harvesting beyond sustainable limits. Cork harvesting in Buddusò is performed in accordance with the Prescrizioni di Massima e di Polizia Forestale (P.M.P.F.), and in compliance with the Regional Law N. 4 which came into force on February 9, 1994. The numbering of the sites in which bark will be harvested corresponds to the former economic plan drafted by the *Ex Azienda Speciale per la Gestione dei Beni Silvopastorali* of the municipality of Buddusò in the decade 1967-1976. These sites are made up of pure stands of cork oaks with the characteristics of irregular uneven-aged forests. The processing of cork oak must be performed within the terms of the cork oak season of each year as set out in the Article 27 of the Regional Law N. 4 of 1994. The harvesting proceeding must preferably take place on the third/fourth week of June and pursue throughout July (Fig. 23).

Figure 23. Cork oak trees under cork production in Buddusò during 2015.

All cork material must be extracted simultaneously in terms of time and place under the supervision of the director of the harvesting, who will, among other tasks and in accordance with the contractor, indicate the starting date of the proceeding. Cork oak trees must be harvested at ground level without leaving behind any "stockings" in both the top and bottom. If any adverse weather conditions emerge, the harvesting will be suspended by giving notice to the CFVA of Buddusò.

The director of the extraction and other 11 people, which are appointed by the Municipality of Buddusò, are responsible for the supervision of stripping process and the extracted material. This, in addition to other 40 people, appointed by the enterprise interested, being in charge of providing various services in relation with the harvesting i.e. employees, temporary strippers.

Given the surface of the sites in which the harvesting proceeding will be carried out and the quantity of cork material to be extracted, the number of strippers interested in debarking the cork is determined by the director of the operations. During the harvesting operations of 2015 in Buddusò (Fig. 24, 25 and 26), a total of 16 extractors were necessary and each pair of strippers is in fact capable of extracting 9 to 10 quintals of cork daily (N. Solinas, 2015, personal communication).

Gentle cork or *sughero gentile* is offered for sale through an auction to the factories of the area, exclusively by the municipality of Buddusò, however, in cases in which gentle cork is extracted from lands managed by the *Ente Foreste*, the product is sold by the latter body. In 2015, the age of *sughero gentile* sold was between 10 and 13 years. It is believed that gentle cork of this range has reached the proper maturity required by the market for a better quality.

Figure 24. Cork oak extraction in Buddusò: tree is opened and separated (A), tree is stripped by chopping delicately into the bark using an axe (B), a young tree with virgin cork and first cork respectively, in the upper and lower part of the stem (C) and a newly stripped tree showing any kind of pest or fungal disease, is marked with an “x” to be monitored by CFVA at a later time.

Figure 25. Cork oak first[13] extraction: base of the stripped bark is cut and the dust produced is kept to be used in producing biomass (A) and cork extracted products are loaded onto truck and transported to a courtyard in Loelle (B).

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[13] In the above pictures, we showed the proceeding of the first harvesting of cork oak trees, which consists on separating virgin cork and first reproduction cork

Figure 26. Cork oak separation: gentle cork (*sughero gentile*) showing regular plank but still have numerous longitudinal running cracks (A) and virgin cork (*sugherone*) showing irregularity and roughness (B).

7.2. Economic analysis

In order to determinate the quality of cork material, and since a reliable data of the amount of material extracted in the previous cycle (10-13 years earlier) is lacking, applying a comparative method is not possible, hence a synthetic-descriptive methodology is used for the estimation of the harvested gentle cork. Several surveys are carried out to check whether the quality, quantity and productive density of gentle cork in the particles are appropriate. The qualitative assessment of gentle cork is subjective and is based on a qualitative evaluation performed by experienced operators. The quality classification is carried out according to certain criteria based on the workability of cork planks. These criteria are the thickness of the planks, elasticity and malleability, specific weight, presence of flaws and texture of the fabric. The final price of high quality cork is evaluated given the following estimates, the trend of the past trades, the current trends in the local market, and the cork quality in the areas interested in the upcoming proceeding operations. Other parameters may affect the estimation of the final value of cork products, in particular gentle cork, namely the itineraries driven, strippers, extraction season and good or bad management of the cork oak forest in the Municipality in question. In 2015, and for the reasons mentioned previously, the estimated value of gentle cork was around 220 Euro/quintal (N. Solinas, 2015, personal communication) (Table 11). According to the list of the Chamber of Commerce of Sassari in January 2015, the price of poor cork or *sugherone* was zero Euro/quintal.

Table 11. Number of localities, total surface harvested, quantities and prices of gentle cork (*sughero gentile)* and virgin cork (*sugherone*) in Buddusò for the years 2013, 2014 and 2015 (*source*: N. Solinas, 2015).

Year	Site (no.)	Total area (ha)	Gentle cork (q)	Virgin cork (q)	Price per quintal (Euro)	Estimated price (Euro)
2013	17	56.01	3,234	808	185	598,290
2014	9	42.850	2,683	663	180	482,940
2015	10	35.552	1,834	275	220	403,480

In the economical plan of silvo-pastoral goods drafted by Beccu (1976) for the *Ex Azienda Speciale* in the Municipality of Buddusò, the surface harvested for the period 1954-1976 was estimated at a total of 31,866.5 ha (Table 12). As for gentle cork and virgin cork, 36,643 and 5,746 quintals, respectively, were exploited. The price assigned to gentle cork in the period 1954-1965 ranged around 14,000 and 16,000 Lire. Cork oak coming from Buddusò, as well as of the entire area was and still actively sought after by traders and manufacturers for its excellent characteristics (Beccu, 1976; N. Solinas, 2015, personal communication).

Table 12. Total surface of cork oak and quantities of gentle cork and virgin cork in Buddusò for the period 1954-1976 (Beccu, 1976).

Year	Total area (ha)	Gentle cork (q)	Virgin cork (q)
1954	6.441	3,694	1,186
1956	3.461	2,270	399
1958	3.543	1,885	501
1959	9.882	5,496	430
1963	3.682	3,003	266
1965	1.983	1,333	200
1967	226.900	1,029	134
1968	384.200	1,935	559
1969	225.500	2,051	255
1970	453.600	2,181	266
1971	354.700	2,342	295
1972	125.800	2,022	246
1973	161.300	1,850	230
1974	312.600	1,898	245
1975	225.800	1,768	219
1976	404.100	1,886	315
Total	**31,866.500**	**36,634**	**5,746**

8. WILDFIRES IN BUDDUSÒ: HISTORICAL BACKGROUND

The long time series of fire data available in the CFVA of Buddusò justifies a separate analysis, as is the case for most of municipalities in Sardinia Region.

During the period 1965-2015[14], fires in this territory burned a total area of about 16,050 ha (Fig. 27), of which 4,649 ha of woodland representing almost 29% of the total area burned (Fig. 28, 29). The total number of fires reported during this period was 525 (Fig. 30). The largest fire was recorded in 1981. In this event, a total of 4,412.3 ha were burned out of which 1,641.5 are wooded.

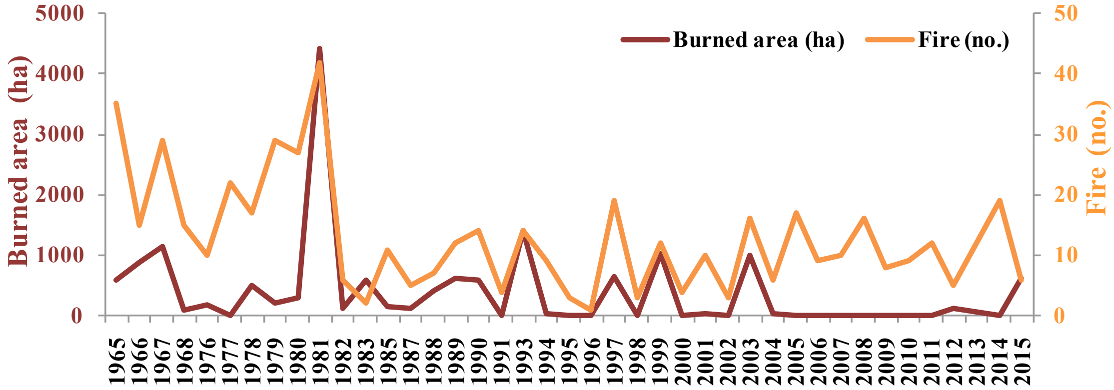

Figure 27. Number of fires and total burned area in Buddusò for the period 1965-2015.

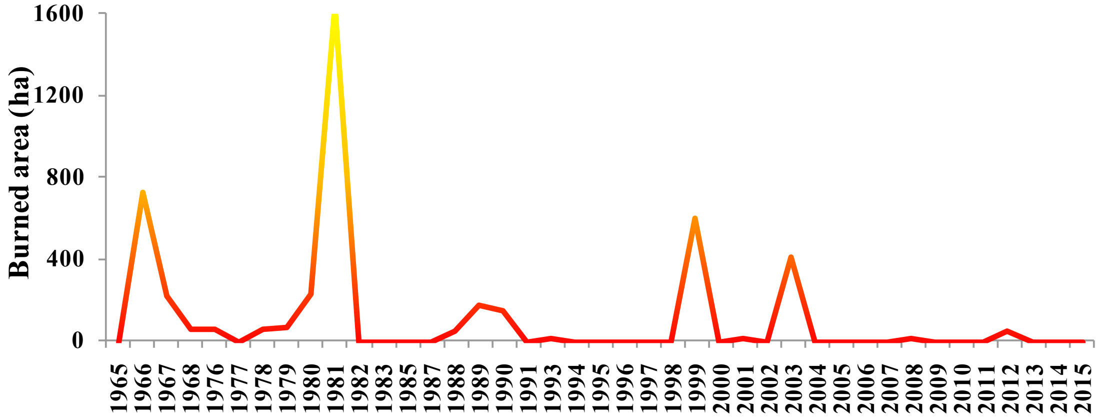

Figure 28. Wooded burned areas in Buddusò for the period 1965-2015.

[14] Fire data for the period 1969-1975 were missing

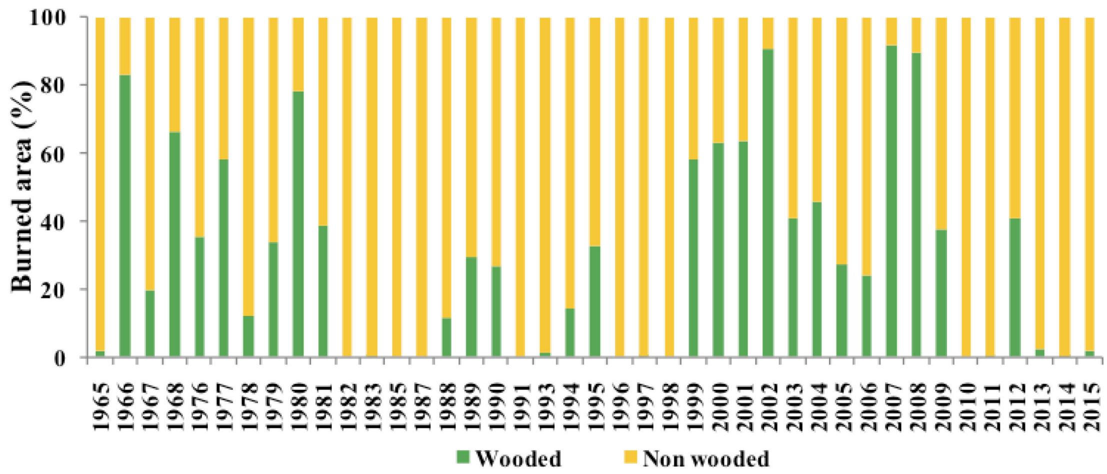

Figure 29. Proportion of wooded and non-wooded burned areas in Buddusò for the period 1965-2015.

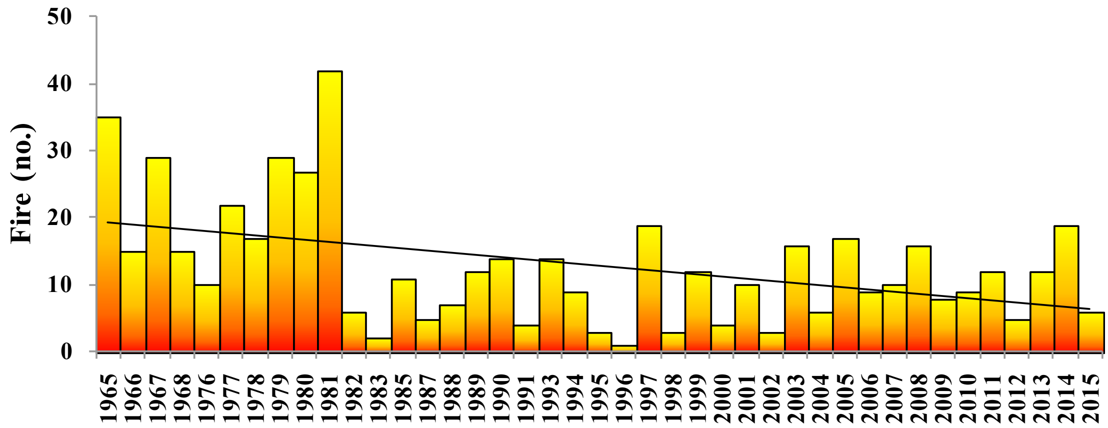

Figure 30. Number of fires in Buddusò for the period 1965-2015.

The Figure 27 shows the total burned area per year in the Municipality of Buddusò since 1965. The statistics vary considerably from one year to the next, which indicates clearly how much the burned area depends on seasonal meteorological conditions. The years 2010 and 2011 register a very low burned area (0.48 and 0.73 ha, respectively), which can be considered amongst the lowest in the last 50 years for the territory of Buddusò.

The yearly number of fires in Buddusò for the same period of time is shown in Figure 30. After the high trend during the period 1965-1981, a decrease in the occurrence of fires was observed around almost the last three decades. This trend seems to continue in the last years but with a peak in 2014 reaching 22. This result could largely be due to the improvements of the fire protection services.

The yearly trends in terms of number of fires and average of burned areas in Buddusò since 1965 are shown in Figure 31. The number of fires registered in 2015 confirms the stable trend of fire occurrence of the last years.

The subdivision of long series of registered fires in Buddusò, in three sub-categories, enables us to underline three different trends:

- the period 1965-1981 shows a high trend of number of fire events;
- in the period 1982-1996, we observe mainly a stable trend of the number of fires;
- the period 1997-2015 registers an increase in the number of fires with a peak of 22 in 2014.

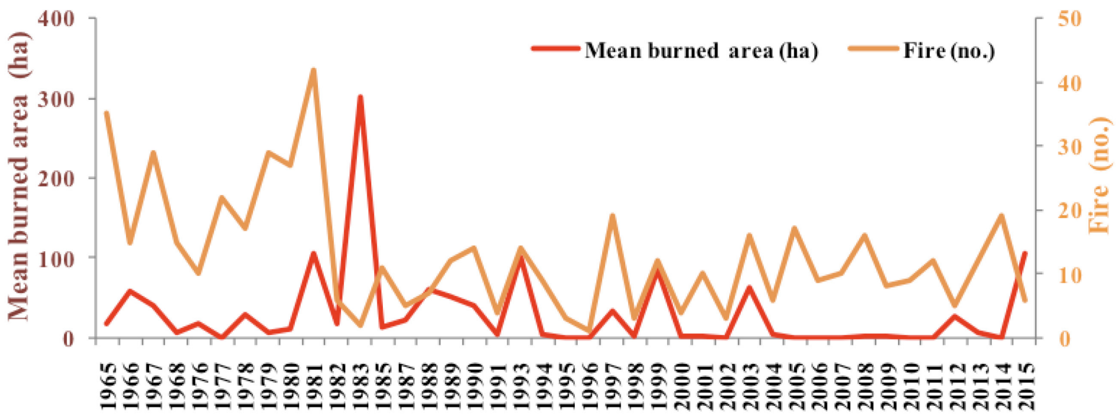

Figure 31. Average burned area and number of fires in Buddusò for the period 1965-2015.

The Table 13 shows the yearly average fire size in the Municipality of Buddusò since 1965. We can observe that the size classes of fires are more or less inversely proportional to the number of fires. However, detecting the extent of such distribution in terms of total surface is more significant. Indeed, for the period 1965-2015, 38,86% of forest fires representing a total number of 204 fires, burned an area of less than one hectare affecting a total area of 1,255 ha (0.01% of the total). 89.71% of forest fires affecting Buddusò for the period 1965-2015 remained below the threshold of 50 ha, affecting a total area of 176 ha representing only 1.1% of the total area, whereas fires larger than 500 ha registering a small percentage of 1.9 of the total number of fires, burned around 14.079 ha representing the 87.72% of the total area burned in Buddusò during the period 1965-2015.

Table 13. Fire intensity and fire occurrence in the Municipality of Buddusò for the period 1965-2015.

Fire size	Fire	Surface area affected by fire				Total
		Wooded		Non Wooded		
(ha)	(no.)	(ha)	(%)	(ha)	(%)	(ha)
< 1	204	8.0	0.2	24.2	0.2	32.2
1-5	156	72.2	1.6	243.9	2.1	316.1
5-50	111	453.8	10.3	1084.9	9.5	1538.7
50-100	17	152.0	3.4	1074.0	9.4	1226.0
100-500	27	1851.0	41.9	3281.0	28.8	5132.0
> 500	10	1875.7	42.5	5670.9	49.8	7546.6
Total	**525**	**4412.7**	**100.0**	**11379.0**	**100.0**	**15791.7**

Over the last decade, combating forest fires phenomenon in Sardinia though the territory offices of the Region Forest Service and Fire Brigades CFVA has become crucial not solely to bring arsonists to justice whether intentional of by negligence, but also to promote restoring the damages of which the community suffer and to depict the causes, which seriously affect the whole island. Such action is put in place by the operating units of the CFVA and, in particular, by the Investigative Division of the Environmental and Forest Police hinged at each territorial service of the CFVA.

Fire causes in Sardinia have been classified according to the possible origin, in accordance with the Regulation (CE) No. 804/94, in four categories; unknown, natural, voluntary or intentional and involuntary or unintentional (CFVA, 2012).

Overall, the investigations against forest fires carried out by territorial office of CFVA of Buddusò resulted in reporting a total of around 49% of voluntary fire causes in the period 1965-2015 (Fig. 32). The motivational levels are mainly at the basis of the phenomenon. According to available data, humans are the number one causative agent of forest fires (Catry et al., 2009; Conedera et al., 2011, M.P Mulas, 2015, personal communication), either intentionally or indirectly as a result of their activity such as agricultural practices.

Reasons behind forest fires initiation include mainly:

- negligence caused by inadequate agriculture practices such as the destruction of plant residue or clearing large fields during summer season;
- widespread illegality, linked to poaching wild boar, limited availability of skilled human resources able to detect early fire ignitions and intervene on time;
- rural criminality in situations where shepherds are linked to criminal contexts, intentions to depreciate lands and woodlands, interests in subsequent construction and reforestation, conflicts and revenges among farmers and shepherds and public administration.

Regarding unintentional fire causes, negligence caused by the removal of crop residues, burning of stubble, cleaning of fallow or even the negligent use of electrical or mechanical motor equipment can develop sparks causing fires. Involuntary fires correspond only to 1.7% of the total number of deliberated fires (Fig. 32).

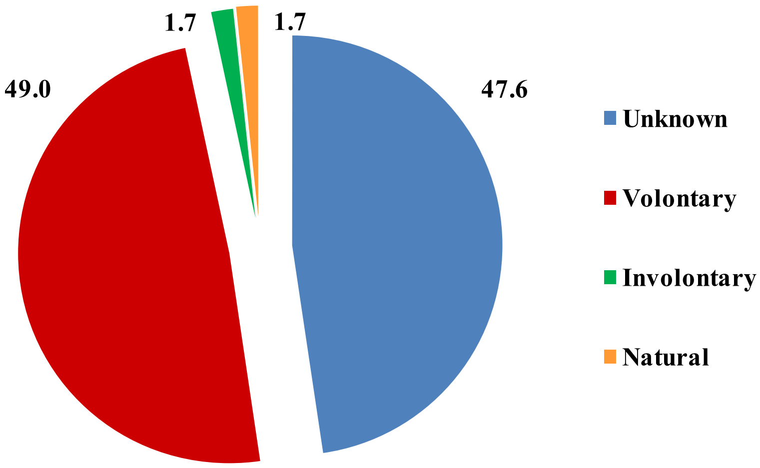

Figure 32. Fire causes distribution in the Municipality of Buddusò for the period 1965-2015.

As for fires of natural origin, in the period 1965-2015 the territory of Buddusò, reported 9 fires representing a phenomenon almost inexistent except those caused by lighting during strong summer storms. The statistical analysis of the collected data during the period 1965-2015 indicates that 47.65% of fires in Buddusò correspond to unknown motives and causes (Fig. 32).

In the first half of the nineteenth century, Stefani (1855) reported some interesting data about the territorial distribution of public and private lands in Sardinia. Indeed, 510, 898 ha were owned by the State, out of which 231,106 ha wooded-lands, and 511,770 ha by the Municipalities; as for the private lands they constituted a total area of 1,234,618 ha. A course of almost a hundred years later, forest ownership in Sardinia as reported approximately by the cadastral surveys indicate the significant presence of public lands in the island: 10,898 ha of lands owned by the State, 512,770 ha are communal lands owned by a municipality and managed by the municipal council, and 1,385,938 ha are private lands, owned by individuals (Rau, 1969). The latest data available for Sardinia Region (ISTAT, 1997) reporting the ownership of pure cork oak forests indicates that 2,177 ha are owned by the State or the Region, 1,276 ha by the municipalities, 822 ha by other organizations or *Enti*, whereas the private sector owns around 75,934 ha. However, according to (Dettori et al., 2001) 80% of the Sardinian pure cork oak forests are privately owned, in which emerge some limitations in terms of management programs, silvicultural activities and patrimony conservation (Carta, 2000). As for the latest data available for the Island reporting the ownership of wooded forests in general goes back to 2005, in which 377,297 ha are reported as private lands representing 65% of the total wooded lands in Sardinia, and 201,324 ha (35%) are owned by the Municipality (INFC, 2005). In (Fig. 33) 57% of registered fires occurred in private lands. According to M.P. Mulas and G. Ligios (2015, personal communication) 18,000 ha of lands in Buddusò are almost equally owned by the public and private sector.

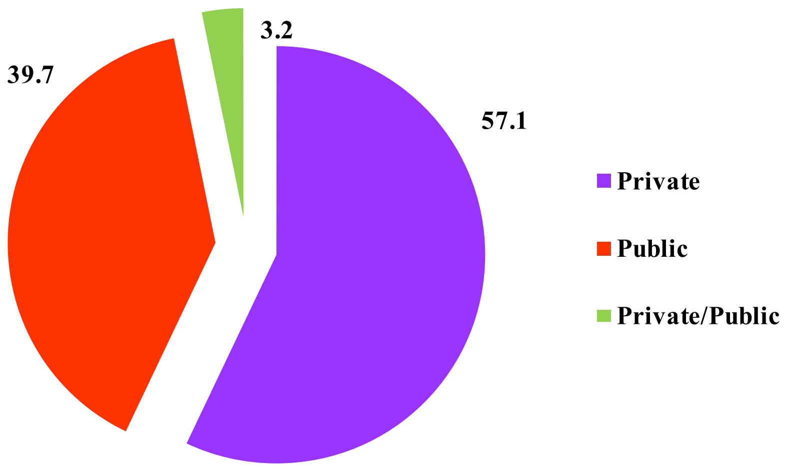

Figure 33. Fire distribution by lands ownership in the Municipality of Buddusò for the period 1965-2015.

9. PLANT DIVERSITY IN CORK OAK FOREST

The *Ex-Azienda Speciale* through its detailed economical plan of silvo-pastoral goods of the Municipality of Buddusò, developed by Beccu (1976), has carried out in spring-summer 1966 a series of floristic relevés in 25 sites in different localities following "Transect" and Raunkiaer methods, in which 136 species were identified. Chiappini and Palmas (1972b) carried out 5 floristic relevés in different sites of cork oak forest in the nearest territory of Bitti, in which two in a pure cork oak forest stands and the other three in a mixed cork oak forest with *Q. ilex* and *Q. pubescens*. In their survey, 72 species were reported. In his research, Sirigu (1994) has studied the vegetation aspects and flora of the cork oak forest of Marghine-Goceano, which is located in the Province of Sassari. The experimental part was conducted in spring-summer 1993-1994 in 18 different sites, out of which 210 species were identified. Ruiu and Pintus (1995) conducted a floristic research in the period 1994-1995 in the *Stazione Sperimentale del Sughero* in winter and spring-summer period in which 420 species were identified, out of which 137 (including medicinal plants) in the cork oak forest of Cusseddu. Finally, the species diversity of cork oak forest was studied by Camarda and Carta (2006), who carried out a survey in the territory of Sa Serra in Orani-Orune and the territory of Mandrolisai in Sorgono-Ortueri, in which 107 species were identified. Overall, following the phytosociological studies conducted as showed previously, 360 species were encountered.

9.1. Materials and methods

9.1.1. Biological spectrum

Life form refers to the vegetative form of the plant body, which is assumed by many ecologists to be a result of morphological adjustments to the environment (Cain, 1950). Those organisms are classified on the basis of adaptation of their perennial organs to tide over the less favourable conditions. Raunkiaer (1934) delimited plant life forms by the position and the degree of protection afforded the growing points of the perennial buds, which are responsible of the renewal of the plant's aerial body after an unfavourable season. Upon this system, plant species can be grounded into five main classes according to increased protection of the buds: phanerophytes, chamaephytes, hemicryptophytes, cryptophytes and therophytes. The percentage of these life form classes for any region put together is called the *biological* or *phyto-climatic spectrum*.

Class I. Phanerophytes (Ph) have their bud-bearing shoots projected freely into the air (over 50 cm high) and exposed to the atmosphere during unfavorable season, and are woody trees and shrubs.

Class II. Chamaephytes (Ch) have their renewal buds above the soil surface but lower than about 50 cm, so that in cold countries they will be protected in winter period, whereas in other countries with dry season some protection will be provided by the plant itself.

Class III. Hemicryptophytes (H) have their buds perennial at the surface of the ground. This class constitute half or more of the total species of an area, particularly in deciduous forests and grasslands.

Class IV. Cryptophytes (Cr) or the "hidden plants" include plants with their buds subterranean in the case of **geophytes (G)**, with bulbs, rhizomes, tubers on stem and root, and root-buds. Geophytes have tuberous subterranean organs filled with stored food, which enables them to make a quick vegetative development with the return of favorable conditions.

Class V. Therophytes (Th) live through the unfavorable season as seeds, hence are annual plants. Annuals are particularly characteristic of desert climates, steppes and of regions under high cultivation.

Whilst the above grouping is easily determined in most cases, there is sometimes a certain difficulty in deciding on the type, as the Danish botanist notes a species might belong to one type in one country and to another type elsewhere. That is, all the larger environmental types, the climates and the major associated soil types, have plant communities composed of several life forms (Cain, 1950).

Ruscus aculeatus, belonging to Liliaceae Family, is known as a bushy plant or chamaephyte. The growth habit has therefore also geophytic traits, as new shoots are produced yearly from underground buds, and the plant produces a dense net of rhizomes, suitable for vegetative propagation (D'Antuono & Lovato, 2003).

Smilax aspera, which belongs also to Liliaceae Family, has a phanerophytic growth habit. In addition, vigorous root suckers are produced from rhizome buds as well, so that the species may occasionally behave as a geophyte, for instance after fires or when the areal part is killed by frost.

Cistus salvaefolius, belonging to Cistaceae Family, is considered a nanophanerophyte, which reaches on average 30-80 cm in height, when in fact it must be considered a bushy plant or chamaephyte when it does not reach 50 cm in height (e.g. along windy coasts nearest to the sea).

9.1.2. Chorological spectrum

Every species occupies a determined territory, which could have a large or a reduced extension. The distribution of the species could be limited to an island or some mountains, whereas other species could be largely extended worldwide. Between these two extremes, intermediate possibilities exist. Species of the Italian Flora could be mainly sorted out in the following groups (Pignatti, 1982): a) Endemic; b) Steno-Mediterranean; c) Euri-Mediterranean; d) Mediterranean-Mountainous; e) South-European orophytes f) Euro-Asiatic; g) Atlantic; h) Northern and i) Cosmopolitan.

Each group corresponds to a chorological type of the flora and of which distribution is called geographical area. The chorological types are identified as in Flora d'ltalia (Pignatti, 1982), considered as most proper due to its specialization on the Mediterranean and South European flora.

Endemic species are those restricted to a defined geographic area.

Steno-Mediterranean species are those, which live directly on the shores of the Mediterranean and are greatly influenced by marine climate. These species are mostly evergreen and are indicators of warm weather and mild winters.

Euri-Mediterranean species correspond to those, which are largely distributed in the Mediterranean from where they spread out towards the North up to the Alps, and in some cases, these species could even overcome the Alps and reach the warmer areas of Central Europe.

Mediterranean-Mountainous species are those spread exclusively in the mountains and are often endemic.

South-European Orophytes species are those spread on the mountains of meridional Europe. The evolutionary processes, which contributed on emerging these species, are one of the most interesting ones in the Italian territory and Mediterranean islands.

Eurasiatic species, which are largely spread from and in the Asiatic continent.

Atlantic species are those, which have their optimum on the Atlantic coasts.

Northern species are those spread across the landmasses surrounding the North Pole, and in the northern hemisphere areas of Europe, Asia and America.

Cosmopolitan species are those widely distributed in all continents of the globe with different climatic conditions.

In our study, we have considered Orophyte and Mediterranean-Mountainous species together (hereafter Mediterranean-Mountainous) and split in two distinct groups European and Euro-Asiatic species. We also added **Exotic species** category to which a single species belongs in studied sites.

9.1.3. Floristic composition sampling

Regardless of the method used for field analysis, each relevé plot should fulfill the following requirements: 1) it should be large enough to contain most species regularly distributed through the sample stand; 2) the site must be uniform in vegetation composition and structure as well as in habitat type such as substrate and aspect; 3) the plant cover must be as homogeneous as possible. For instance, it should not show large openings or should not be dominated by one species in one half of the site and by a second species in the other half. This requirement of relative homogeneity throughout the sample stand area allows a better result in a meaningful average in terms of statistical records (Muller-Domois & Ellenberg, 1974). Floristic diversity study was conducted during spring-summer period of 2015. The floristic composition of trees, shrubs along with herbs was recorded.

Sites were selected between 762 and 810 m for the field study and analysis of floristic diversity. Geographical coordinates of the sites were registered with the help of Global Positioning System (GPS).

In our study, the floristic method used was the phytosociology relevé method of Braun-Blanquet (Braun-Blanquet, 1965). Relevés were carried out in a an average of 100 m radius plot devoted specially to the floristic study by registering all species that occur within this area. The species were recorded in height strata and the cover extent of each layer was estimated in percent of the plot area. The woody and semi-woody species were divided intro four groups: plants higher than 5 m, plants between 2 and5 m, plants between 0.5 and 0.8, and smaller than 0.5 m. The understory plants were listed in the herbaceous layer. In the inventory data the biological and chorological forms according to Raunkier (Raunkier, 1934) and Pignatti (Pignatti, 1982), respectively, were added to each species. Once the listing was complete, each plant was affected with a coefficient composed of one digit corresponding to the plant's abundance. A visual estimate of the extent of land cover for each layer was also recorded as percentage of the plot area. According to Pignatti (1964), each species was affected by one of the following cover indexes:

R= rare specie

+ = cover < 1%;

1 = cover 1-5%;

2 = cover 6-25%;

3 = 26-50%;

4 = 51-75%;

5 = > 75%.

An overall of 9 sites were selected to study the floristic composition of cork oak forest (Fig. 34).

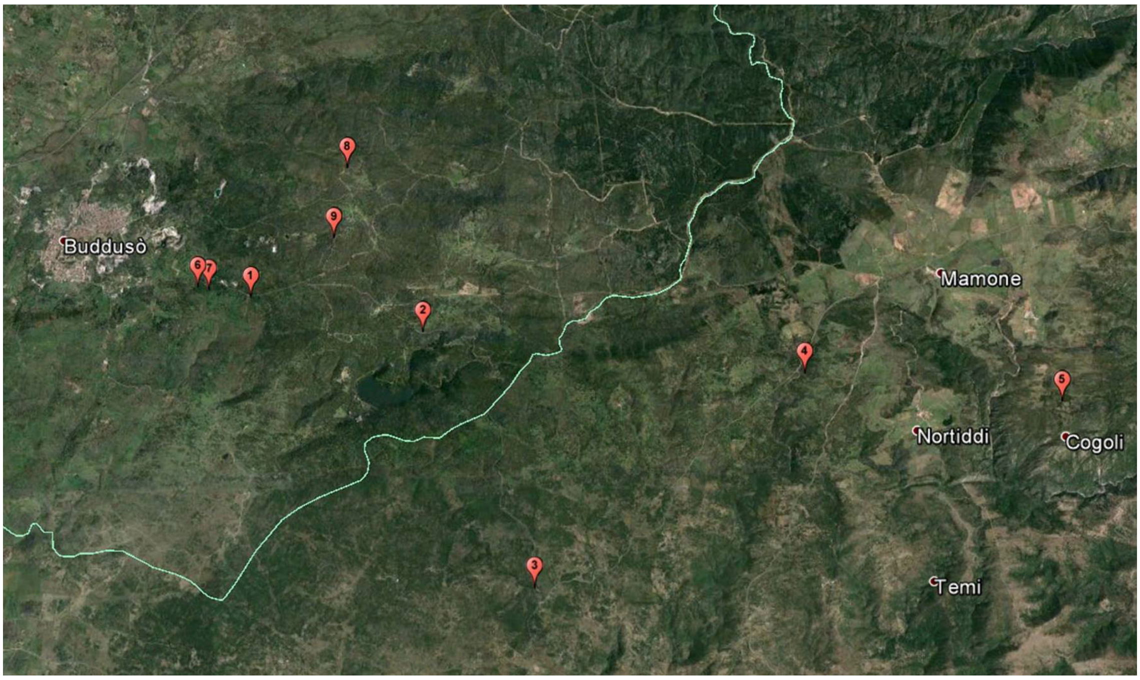

Figure 34. Location of cork oak forest stands sampled for vegetation composition.

9.2. Results and discussion

9.2.1. Species diversity

A total of 362 plant taxa were identified across the five phytosociological studies conducted in cork oak forests from 1967 to 2006 and the last floristic study conducted in our thesis in 2015. The results are shown in the Annex 1.

Out of 362 species, 62 were reported as the most frequent species observed in the overall six floristic relevés studied Annex 2. The list of correspondent authors is given in Annex 6.

Amongst the most frequent species, expect *Q. ilex* and *Q. pubescens,* which are mainly associated with *Q. suber* in mixed forests, *C. salvaefolius*, *C. mosnpeliensis* and *C. villosus* were encountered, known to germinate under light regimes enhanced by heat exposure, which creates conditions needed for the regeneration of post-fire seeders. This, in addition to their heliophilly, these species exploit, as expected, post-fire open areas, characterizing thus the physionomy of herbaceous taxa. Thermophilic evergreen species such as *A. unedo*, *D. gnidium* and *E. arborea* constitute a layer of Mediterranean bush of cork oak forest. As for herbaceous species associated to the cork oak forest, *P. odora*, *Leontodon tuberosus* are found among others. Other frequent annuals or perennials herbaceous species such as *Brachipodium distachyon*, *Briza maxima*, *C. corymbosa*, *Galactites tomentosa*, *Sherardia arvensis* and *Trifolium spp.* are important features for Mediterranean pastures. The high occurrence of species associated to pasture-based systems puts in evidence the economical interest of cork oak forest for both cork extraction and pasture-raised livestock. *Stachys glutinosa*, a bush species, was encountered in 5 out of floristic relevé and is endemic to both islands, Sardinia and Corsica.

9.2.2. Biological spectrum

In the whole study, the analysis of the biological spectrum (Fig. 35) shows the dominance of therophytes (44.5%, n = 162) followed by hemicryptophytes (32%, n = 115). Therophytes indicate a high period of summer aridity, in accordance with the main parameters of the regional climate. Indeed, they lose their importance, proceeding towards North, whilst moving away from countries bordering the Mediterranean basin. High values of therophytes are related to the inclusion of areas highly grazed, in which annual species are the most abundant. Indeed, therophytes reveals the importance of pasture systems, which could be outlined by the presence of pasture-based species in the understory vegetation such as *B. minor*, *Cerastium glomeratum*, *Medicago polymorpha, Silene gallica, Stellaria media*, *Trifolium glomeratum*, *Vicia sativa, Tuberaria guttata* and *G. tomentosa*. These last two species are linked indeed to fires.

Cork oak forests studied in our research are located in altitudinal range between 600 and 800 m, which is alleged by the high percentage of hemicryptophytes thriving in cold environments. Broadly, the codominance of therophytes and hemicryptophytes in the biological spectrum could be explained by climatic conditions as well as the importance of the anthropic activities in cork oak forest, whether as a forest for cork extraction or as a pasture for livestock breeding. Phanerophytes and geophytes occupy a percentage of 11 (n = 40) and 10.0% (n = 36) respectively. Chamephytes with only 9 species represent the biological form less frequent in the cork oak forest studied.

The biological spectrum of *Q. suber* forest species is shown in Annex 3.

Considering only the floristic relevés carried out in Bitti-Buddusò in spring-summer period of 2015 and represented by a total number of 83 species, hemicryptophytes are largely represented (34.9%, n = 29) followed by therophytes (28.9%, n = 24) and phanerophytes (22.9%, n = 19) (Fig. 36). The histogram (Fig. 37) puts in evidence the results of biological spectrum of the overall with that of the phytosociological study conducted in the 9 sites in 2015. Indeed, our relevés were conducted exclusively in cork oak sites at an altitude of 734-810 m, and the overall factors of exposure and altitude are in favor of hemicryptophytes, which are prevalent in cold and mountainous environments on the detriment of therophytes that are most frequent in Mediterranean areas characterized by a long period of arid summers.

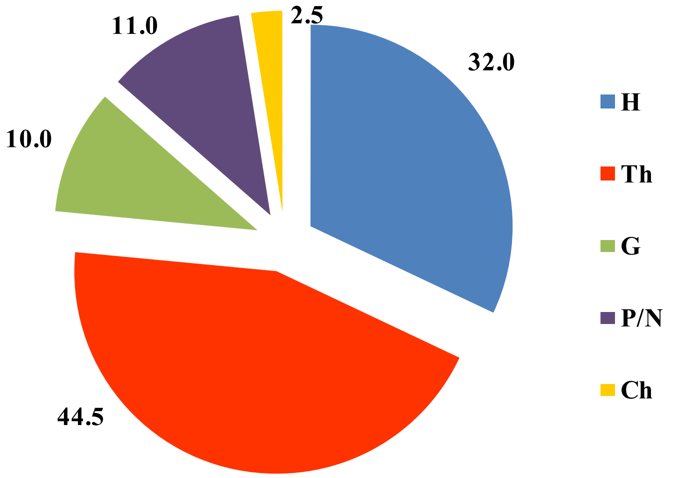

Figure 35. Biological spectrum of species encountered in *Quercus suber* forest sites.

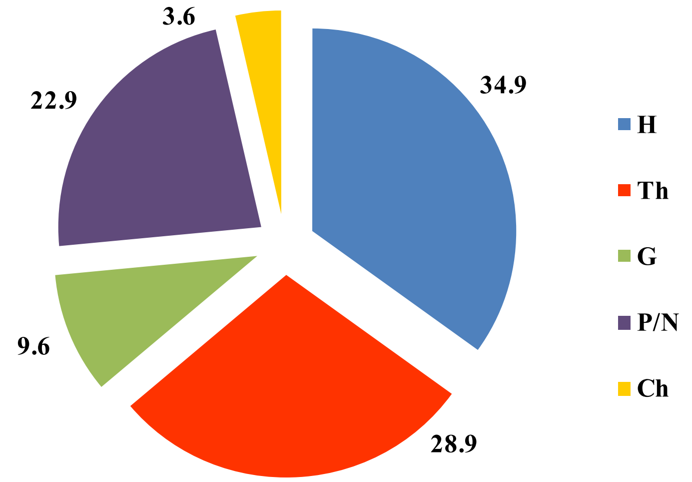

Figure 36. Biological spectrum of species encountered in *Quercus suber* forest sites of Bitti-Buddusò.

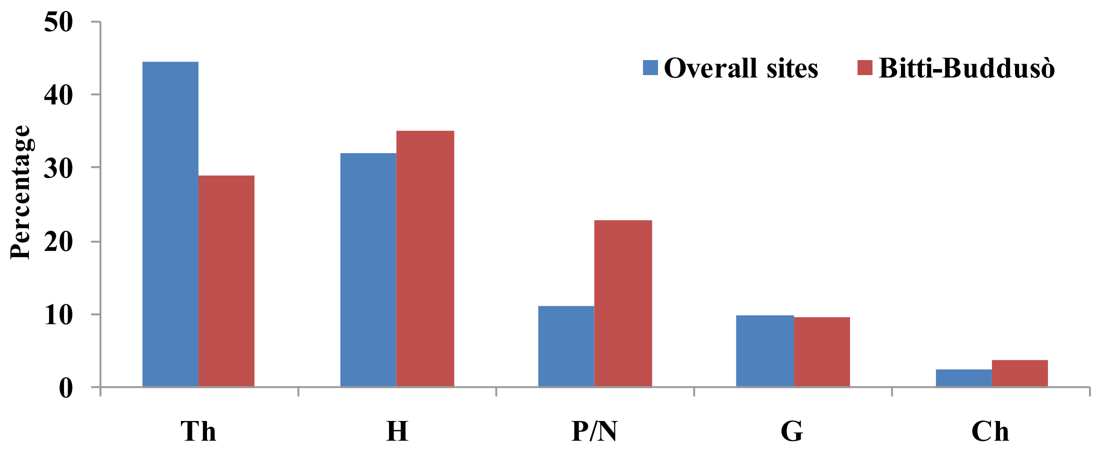

Figure 37. Biological spectrum of species encountered in *Quercus suber* forest in both overall phytosociological studies and Bitti- Buddusò.

Phanerophytes are significantly represented in our sites and correspond indeed to formations mainly evolved, characterized by an important shrub cover, which explain the considerable number of species corresponding to the phanerophytes. Geophytes are most frequent than chamephytes represented by 8 (n = 9.6%) and 3 species (n = 3.6%) respectively.

As a matter of fact, it seems reasonable to draw a basis for comparison for the biological spectrum with a larger geographic area (e.g. regional level), accordingly the study of the biological spectrum of Sardinia was conducted by Camarda (1984). Analyzing the biological spectrum of *Q. suber* species in the floristic composition studies conducted by the authors during the period 1967-2006 and those of our study carried out in 2015 with the biological spectrum of all species encountered in Sardinia (Fig. 38), we can notice that hemicryptophytes occupy the largest percentage in cork oak forest of Bitti-Buddusò (34.9%) in comparison with those in both the overall sites of *Q. suber* studied and all species of Sardinia (32 and 28.9%, respectively). This result is in fact in accordance with the fact that the floristic composition studies were conducted in the altitudinal range of 734-810 m, which is on average higher than that of Sardinia as a whole. By way of contrast, therophytes are more abundant on a regional level (38.9%) than in cork oak forest of Bitti-Buddusò (28.9%) depicting indeed the arid character of the Island. In addition, this comparison registers also the highest abundance of phanerophytes (belonging in particular to *Cistus* spp.) in *Q. suber* forest of Bitti-Buddusò (22.9%). Actually, this result could be explained by the succession of degradation observed in the sites we studied in 2015, such as cutting, grazing and fire.

9.2.3. Chorological Spectrum

Figure 39. shows a considerable prevalence of the species related mostly to the Mediterranean Basin, in particular Steno-Mediterranean (34.1%, *n* = 123), Euri-Mediterranean (26.9%, *n* = 97) and Mediterranean-Mountainous (7,8%, *n* = 28). Some Steno-Mediterranean species such as *C. villosa*, *C. salvaefolius, E. arborea and P. angustifolia* are heliophilic, favored by fires, are always present in cork oak forest. Species encountered in the pastured woodlands, such as *C. corymbosa*, *Hypochoeris achyrophorus, L. tuberosus* belong as well to the most dominant chorological group. Euri-Mediterranean species are those which constitute a floristic nucleus of rainy environments, with mainly temperatures not very high, representing thus the ideal habitat for *Q. suber* species, which is a thermo-mesophilous species, even though shows a certain resistance on the aridity and higher temperatures. Euro-Asiatic species such as *Anthoxanthum odoratum*, *Crataegus monogyna*, *Poa bulbosa*, *Ranunculus bulbosus* and *S. aspera* are well represented in cork oak forest. Euro-Asiatic species are similar to Euri-Mediterranean species in terms of ecological needs and contribute to the classification of the Mediterranean cortege but with some oceanic characteristics, that is high temperatures in summer and mild in winter, abundant rainfall and limited period of aridity. Endemic species, represented by 8 species, contribute only to 2.2% of the chorological spectrum. As previously mentioned, only one species is “Exotic” (*Xanthium spinosum*).

The chorological spectrum of *Q. suber* forest species is shown in Annex 3.

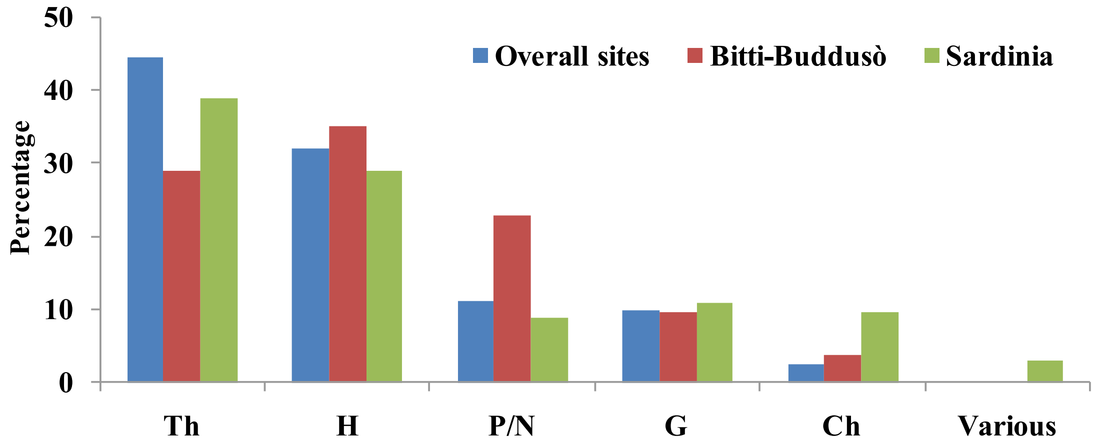

Figure 38. Biological spectrum of species encountered in *Quercus suber* forest in both overall phytosociological studies and Bitti- Buddusò, and overall species in Sardinia.

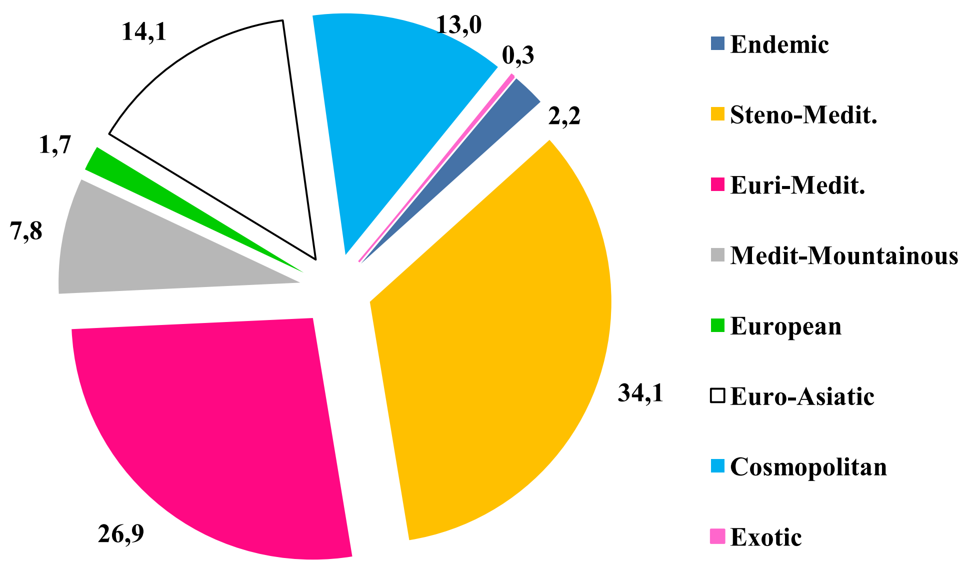

Figure 39. Chorological spectrum of encountered species in the overall *Quercus suber* forest sites.

9.2.4. Floristic composition

Within the communities so delineated, we recorded 83 species (Annex 4) of plants distributed in different life forms. Two additional species *Poa nemoralis* and *Vicia fasciculata* were added to the previous phytosociological studies. The phytosociological study conducted in 9 sites of *Q. suber* forest in Bitti- Buddusò is shown in Annex 5.

The analysis of the phytosociological study carried out in Bitti-Buddusò reveals the structure of cork oak forest. As such, tree cover is characterized by a dominance of *Q. suber* trees with a cover ranging between 40 and 80%, and the presence of *Q. pubescens* (a cover index of 2) in site n. 3. We recognize then the presence of mixed forests of cork and pubescent oak in site n. 3, in which the average height of trees reaches nearly 15 and 9 m.

Site n. 1

Altitude 780 m. Orientation W. Municipality of Buddusò.

A *Q. suber* forest, with an average height of 10 m. The understory is formed by woody shrub species of *Q. suber*, *Q. pubescens*, *Q. ilex*, *C. monogyna* and *R. ulmifolius* with an average height of 2 m. The fire may be 6 or 7 years old. Presence of livestock grazing (Fig. 40).

Site n. 2

Altitude 810 m. Orientation NW. Municipality of Bitti.

A *Q. suber* forest reaching an average height of 9 m and a cover of 70%. The understory, between 0-5 and 2 m, occupy almost 10% of the cover and is formed of, besides *Q. suber* and *Q. ilex*, a layer of *C. salvaefolius* of 25%. Herbaceous layer is rich and occupy 80% of the cover. *Q. pubescens* shows a higher regeneration than *Q. ilex*. The fire may be 20 years old. Presence of pasture (Fig. 41).

Site n. 3

Altitude 783 m. Orientation SE. Municipality of Bitti.

A mixed forest of codominance of both *Q. suber* and *Q. pubescens* with an average height of 15 m and a cover of 20%. The understory is formed of a layer of *C. salvaefolius* of 30%. Many herbs and subshrubs form the herbaceous layer, among others, *A. ramosus*, which is the most prevalent in this layer. The fire may be 15 years old. No human disturbance is noted (Fig. 42).

Figure 40. Overview of site n. 1.

Figure 41. Overview of site n. 2.

Site n. 4

Altitude 762. Orientation SW. Slope of 5 °.

A *Q. suber* forest with an average height of 5-7 m and a rich understory constituting a cork oak layer of shrub species (*A. unedo* and *E. arborea*) of around 3-5 m. The herbaceous layer is amongst the richest in the studied sites with a cover of 20% (Fig. 43). The fire seems to be the oldest and may be 20 years old.

Figure 42. Overview of site n. 3.

Figure 43. Overview of site n. 4.

Site n. 5

Altitude 762 m. Orientation SW. Municipality of Bitti.

A *Q. suber* forest occupying a cover of 40%. The shrub layer is formed of *Genista corsica*, *C. salvaefolius*, *C. monspelliensis*, *L. stoechas* and *Cistus creticus eriocephalus*. Herbs and subshrubs cover 80% of the layer and are, among others, *A. ramosus* and *Cyclamen repandum* (Fig. 44).

Site n. 6

Altitude 769 m. Orientation N and slope 5 °.

A forest of *Q. suber* trees with an average height of 8 m and a cover of 50%. The understory is formed by a dominant layer of *C. villosus* associated to *Q. pubescens*, with a height of around 0.6 m and a high cover of 60%. The herbaceous layer is rich of species with a dominance of *B. maxima*, *Bromus sterilis* and *Hedera helix* occupying a cover of 80%. Presence of grazing and interventions of tree cutting dating back to two years (Fig. 45). The fire may be 10 years old.

Site n. 7

Altitude 780 m. Orientation N Slope 5 °.

A forest of *Q. suber* with an average of 10 m and a cover of 50%. The understory is formed by a layer of *C. villosus* and *Q. pubescens* with an average height of 0.8 m and a cover of 40%. Herb species richness is abundant with a dominance of *B. sterilis*, occupying a cover of 50%. Presence of grazing is noted (Fig. 46).

Figure 44. Overview of site n. 5.

Figure 45. Overview of site n. 6.

Site n. 8

Altitude 734 m. Orientation SW. Slope 5 °.

A dense forest of *Q. suber* trees with a high cover of 80% and an average height of 12 m. An understory rich of shrub species with a dominance of *E. arborea* and a cover of 20%, which identify the affinity of this forest to *Quercetum suberis ericetosum*. The herbaceous layer occupies a cover of 40% and is formed by, among others, *C. distachya*, *B. maxima*, *Cynosorus effusus*, *C. corymbosa*, *Cynosorus echinatus* and *B. retusum*. Presence of pasture is noted (Fig. 47).

Figure 46. Overview of site n. 7.

Figure 47. Overview of site n. 8.

Site n. 9

Altitude 768 m. Orientation E. Slope 5 °.

A forest of *Q. suber* with an average of 8 m of height and a cover of 50%. Dominant species in the shrub layer are *C. monspeliensis* and *C. salvaefolius*. The herbaceous layer is formed by several species such as *A. ramosus*, *Carex distachya*, *B. maxima*, *C. effusus* and *P. odora,* outlining the presence of pasture (Fig. 48).

Figure 48. Overview of site n. 9.

10. FIRE EFFECTS ON CORK OAKS

The ecological effects of forest fires in the Mediterranean region are very diverse. This is the result not only of the complexity of plant communities, but also as a consequence of the several responses to the type, duration and intensity of fire, the season in which it occurs and its frequency (Le Houerou, 1987). Cork oak has excellent insulation properties consisting of cork bark made of continuous layers of suberized cells (Pereira, 2007), and can grow up to 30 cm thick or a little more (Natividade, 1950), which provide the species a high protection in relation to understory fires. Indeed, cork oak has been considered a highly fire-resilient species, being the only European tree with stem and crown resprouting capability following intense crown-fires (Pausas, 1997; Paula et al., 2009). *Quercus suber*, as a result of its bark thickness, is considered as the most fire-resistant forest species (Camarda & Carta, 2006; Camarda et al., 2015).

We carried out a study of post-fire cork oak survival in the Municipality of Buddusò with the particular aims of: a) evaluating *Q. suber* tree survival in this region 2 to 3 years after wildfire and b) exploring whether stripping, tree height and tree size influenced post-fire response types of cork oak trees.

10.1. Materials and methods

10.1.1. Study area and forest sites

We compiled data on post-fire *Q. suber* tree responses from 2 wildfires that occurred between 2012 and 2013 in the Municipality of Buddusò (Fig. 49).

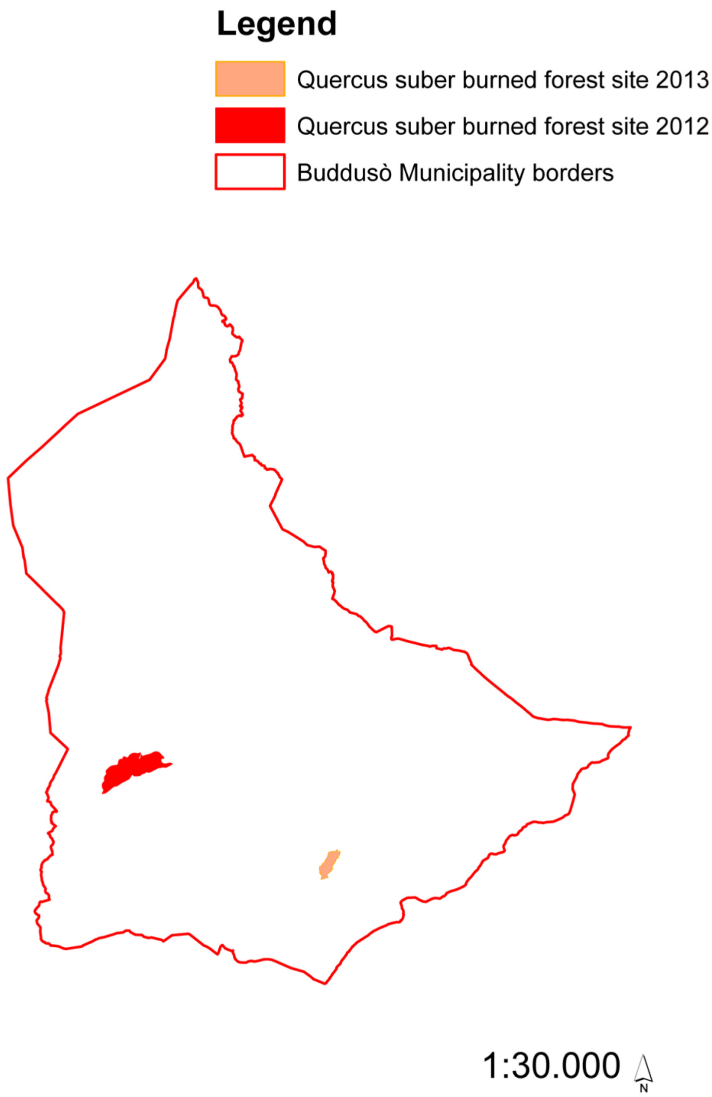

Figure 49. Location of *Quercus suber* burned sites.

Elevation of the study stands ranges from 720 to 800 m of altitude, and soils are granitic.

Quercus suber was the dominant species mixed with *Q. pubescens*. In both sites, understory vegetation was composed of a shrub-herbaceous layer that favoured fire spread. These forest sites were all selected within the Municipality of Buddusò: a forest at E 524316, N 4489483 on a SE slope; and a woodland located at E 517799, N 4492391 on E slope.

The forest exhibited the highest tree density and low light availability at ground level. The overstory consisted of a well-developed mixed *Q. suber*-*Q. pubescens* stands and the shrub layer was dominated by *P. angustifolia, C. villosus* and *C. salvaefolius*. The main forest enterprises[15] are cork extraction from *Q. suber* trees and livestock grazing. No human disturbance was observed (i.e. hunting).

The open *woodland* or Spanish *Dehesa* exhibited a lower density of trees and higher light availability in comparison with the *Forest* site. Oaks (*Q. suber* and *Q. pubescens*) shared the overstory while the shrub layer was dominated by *P. angustifolia* reaching 1.2 m of height. The understory was covered by a *C. salvaefolius* of 30 to 60 cm height. The anthropic uses of the woodland are limited to the extraction of cork oak. No pasture was observed during our surveys.

10.1.2. Data collection

In October and November of 2015, between 2 and 3 years after burning, a total number of 446 (in 2012) and 410 (in 2013) of burned trees were assessed. The overall subset included 856 individuals of *Q. suber* trees sampled.

For each tree, we observed several parameters: bark exploitation status was defined as a binary variable (exploited or non exploited) based on the presence of harvesting marks on the stem in order to distinguish unstrapped trees with virgin cork from harvested trees where cork striping had occurred at least once. We recorded the trunk diameter at 1.30 m above ground level, which is the average person's breast height (DBH) (Fig. 50A).

[15] Abandoned beehives were observed

Figure 50. Measurement of the tree diameter at breast height with a bark gauge.

We measured also the total tree height. The post-fire response type of each tree was classified in four categories: a) dead (D) (no resprouting from the base nor crown) (Fig. 51A) b) resprouting only from the base (B) (thus with a stem mortality) (Fig. 51B); c) resprouting only from the crown (C) (Fig. 51C); and d) resprouting from both the base and crown (BC). Trees were considered alive when having any green foliage remaining (independently of the proportion of crown recovered). Presence of injuries on trunk and branches was registered for each tree in a binary variable (presence or non-presence)

(Fig.52A and B). Pertinent comments such as moth infestation or presence of fungi were reported when present (Fig 53A and B).

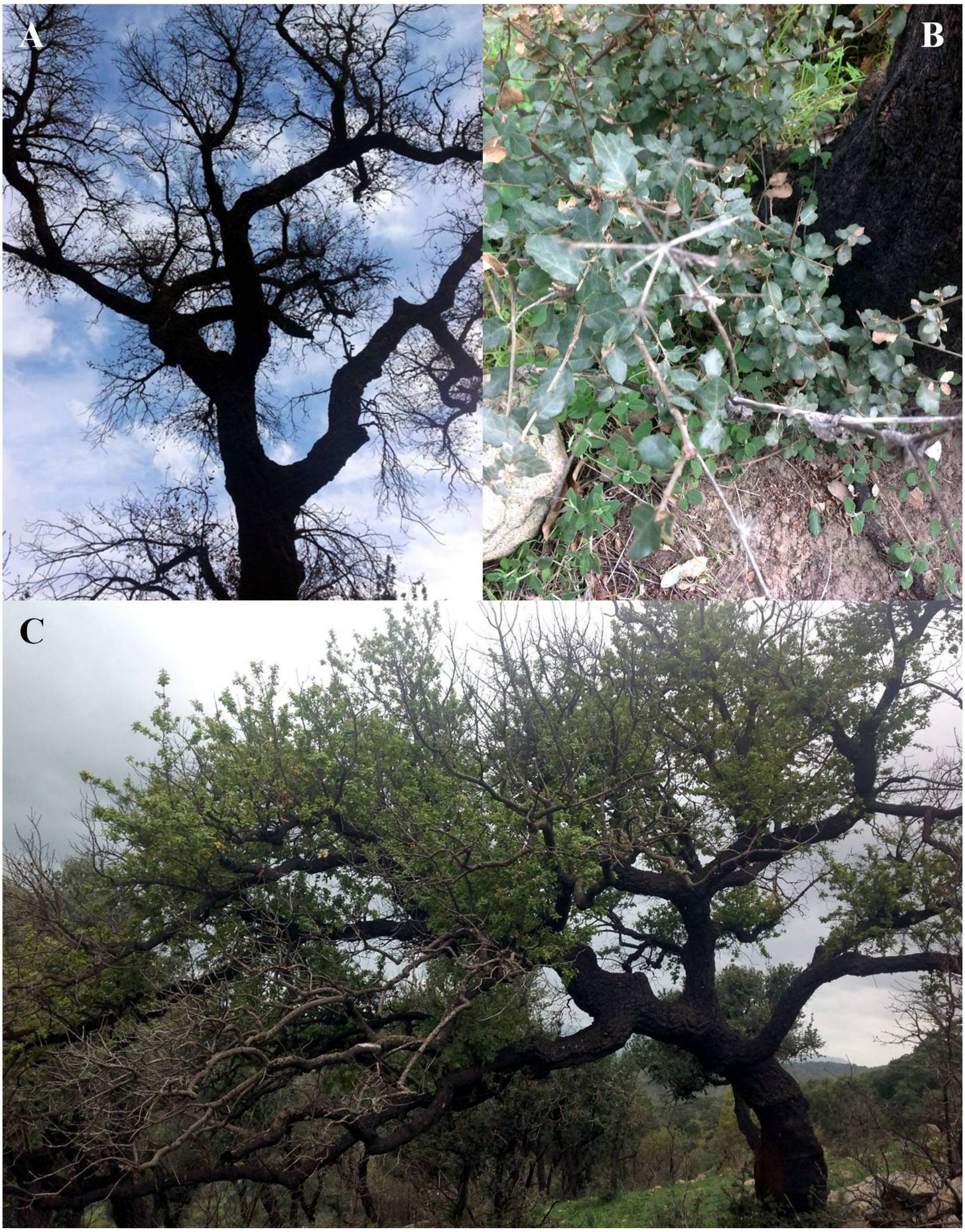

Figure 51. *Quercus suber* tree mortality (A) tree showing sprouts at base (B) tree showing crown regeneration and burned crown on upper and lower part, respectively (C).

Figure 52. Presence of wounds on a burned *Q. suber* tree: on the trunk (A) and on branches (B).

Figure 53. Phytosanitary conditions of burned *Q. suber* tree trunk: infestation by *Lymantria dispar* (A) and presence of fungi (B).

Foliage scorch defined by a change of colour as a result of the fire was not easily distinguished as between 2 and 3 years has passed after the last fire. Large variability within-plot in tree size and bark thickness was common, since cork was not exploited simultaneously in all individuals (uneven-aged cork).

For both sites, mean elevation was registered. We also used Geographic Information System (GIS) and Google Earth to locate the study sites and obtain additional data at the site-level. Accurate dates and burned areas were determined from archival reports and maps from the Regional Forest Service and Fire Brigades (CFVA, Servizio Ispettorato Ripartimentale di Sassari).

10.1.3. Data analysis

The influence of the investigated three parameters (tree size, tree height and harvesting) on the post-fire *Q. suber* tree response was investigated through an information-theoretic approach based on the Akaike Information Criterion (AIC) (Burnham & Anderson, 2002). The AIC values of all the candidate models that could explain the phenomenon were compared, and the model with lower AIC was chosen as the best fitting the data (i.e. most parsimonious). The post-fire tree responses (D, B, C, and BC) were selected as dependent variables and were modeled in a binary manner, taking "yes" for a response and "no" for all the other possible responses, using a generalized linear model with binomial distribution and a logit link function (Moreira et al., 2009). The explanatory variables were selected by backward stepwise selection, considering all the single interactions among variables, and including in the model all variables concurring to reduce the AIC value. The "glm" function of the base package of R was used to perform the analysis (R Development Core Team, 2010).

10.2. Results and discussion

10.2.1. General post-fire cork oak response patterns

Two to three years following wildfire, from all 856 *Q. suber* trees sampled, only 3.4% (n = 29) randomly distributed within the stand, showed mortality of all aboveground and belowground and 6.2% (n = 54) lost their crowns regenerating only from the base of the trunk.

The remaining trees (90.3%, n = 773) survived the fire and regenerated their crown, registering a percentage of 18.5 (n = 158) of trees resprouting from the crown only and 71.8 (n = 615) with both crown and basal resprouting. Average DBH was 22 cm.

The proportion of exploited trees in both sites was 48.9% (n = 419) and the remaining (51.1%, n = 437) was not exposed to harvesting. Twenty-five harvested trees suffered high individual tree mortality (6.0%), while stem mortality was observed in 41 trees (9.8%). In contrast, unharvested trees showed lower tree (0.9%, n = 4) and stem mortality (3.0%, n = 13). In our database, we registered the presence of stem wounds in 36.4%(n = 312) of the total trees sampled. 54.8% of damaged trees (n = 172) were harvested during their lifetime.

10.2. 2. Cork oak mortality and resprouting models

Variables significantly involved in the different post-fire tree responses (D, B, C and BC) are shown in Table 14. The model for tree death best fitting the data showed that the most significant variables involved in tree mortality were DBH, height and stripping. Indeed thicker cork oak trees correspond to older trees, which might have been exploited more often during their lifetime and were probably subjected to inappropriate or poor management practices. In fact, Barberis et al., (2003) observed that higher mortality in trees submitted to several bark exploitation (40%) than in trees debarked only once (17%). Consequently, stripped trees may be more susceptible to stress or diseases affecting tree growth and vitality (Natividade, 1950; Silva & Catry, 2006). This is confirmed by the positive correlation between tree stripping and mortality, suggesting that unexploited trees are more fire-resistant than exploited trees. In fact, harvesting is a stress factor for trees and has been associated to vigor loss (Natividade, 1950). Cork is stripped usually during the period of periderm activity when it is relatively easy to separate the cork layer at the level of phellogenic active zone without damaging the underlying phloem and vascular cambium (Natividade, 1950; Pereira, 2007).

Survival was also affected by tree height, as bigger trees were more likely to survive. Indeed, bigger trees will have their canopy further away from flames during the passing fire front, and in consequence will suffer less crown scorch from a surface fire (Miller, 2000; Rigolot, 2004) and will be less prone to crown fire (Van Wagner, 1977), which explains most likely the higher probability of post-fire survival.

The most parsimonious model for simultaneous response from the base and crown included DBH and tree height. In fact, larger trees with higher heights are supposedly older and should have larger belowground reserves (Gurvich et al., 2005) and in consequence a higher capacity to mobilize reserves in response to disturbance (e.g. fire) (Bellingham & Sparrow, 2000). Indeed, this could be expected, as sprouts of adult trees should have established root system that enables higher survival when compared to younger trees. Conversely, the interaction DBH x tree height shows a negative correlation with the ability of cork oak tree to regenerate after fire from both base and crown. As a matter of fact, a study carried out by Bond and van Wilgen (1996) outlined that resprouting ability decreases with age. Moreover, since older trees have most likely been subjected to a higher number of harvesting operations, belowground carbohydrate storage would be more compensating damages after disturbance rather than allocating them for regeneration (Bellingham & Sparrow, 2000).

Adult trees may be relevant for their resprouting failure. The lack of interactions between DBH and exploitation status, on one hand suggests that DBH exerts a similar effect on exploited and unexploited trees (Catry et al., 2012) and on the other hand could be due to the fact that initially exploitation status of trees studied was equally distributed between stripped and unstrapped (48.9 and 51.1%, respectively).

As a matter of fact, other factors should have been taken into account for better results. In fact, post-fire tree survival and regeneration capacity are influenced by factors related to fire severity (DeBano et al., 1998; McHugh & Kolb, 2003), which is function of fire intensity and duration of burn, climatic, topographic and vegetation characteristics (Schwilk et al., 2006). Not considering these factors may most likely affect the overall proportion of variability in the observed patterns.

Table 14. Generalized linear models with the lowest AIC showing correlations between post-fire tree responses (resprouting from both base and crown; resprouting exclusively from crown; resprouting exclusively from base; death) and the investigated variables.

Variables and interactions	**Post-fire tree response**			
	Resprouting from base and crown	**Resprouting from crown**	**Resprouting from base**	**Death**
Tree height	0.195 ± 0.097 *	-0.036 ± 0.104	-0.451 ± 0.172 **	-0.250 ± 0.077 **
DBH	8.072 ± 2.176 ***	-8.108 ± 1.976 ***		4.776 ± 2.309 *
Stripping				0.841 ± 0.557 *
DBH × tree height	-0.604± 0.290 *	0.479 ± 0.327	1.116 ± 0.502 *	
AIC	797.47	991.03	369.74	479.84

* = $P < 0.05$; ** = $P < 0.01$; *** $P < 0.001$

10.2.3. Post-fire management applications

Cork oak trees that died following wildfire or suffered stem mortality as a consequence, showing regeneration exclusively at the base can be coppiced. Several authors mentioned that trunk logging is a good solution when trees have serious trunk damages that compromise future cork production, and when the crown regeneration is predicted to be nil o very weak (Amo & Chacón, 2003; Barberis et al., 2003). According to Pintus (2003), sucker growth can be higher in coppiced trees than non-coppiced trees or than those coppiced later. Furthermore, the latter authors showed that there is a higher rate of recovery when trunk is logged before the next growing season following the fire. In this context, whether burned trees would show good or poor crown regeneration may help management decisions immediately after the occurrence of fire.

Additionally, trees with severe stem damages as a result of inappropriate cork harvesting or even sanitary conditions such as pest attacks and pathogen invasion, can also be removed. As a matter of fact, for our knowledge, the existing information suggesting that the weakened status of burned *Q. suber* trees predisposing them to suffer more severe insect attacks is relatively poor. Accordingly, pests and fungi pathogens may take advantage of cork weakness and open wounds to attack burned trees causing more damages. In fact, bark injuries, which are often inflicted to trees during bark exploitation processing, could be avoided by appointing skilled strippers or using automatic equipment for cork extraction (Cardillo et al., 2007). Nevertheless, managers find more interest in stripping cork at the nearest, a premature cork removal after fire is not a good strategy since exploiting charred bark would inhibit the healing process. Furthermore, a higher number of experienced strippers thus more expenses will have to progress slowly as burned trunk shows less resistance and more penetration of the axe. In fact, there is no legislation defining clearly the time to start harvesting again after fire. For instance, in Portugal, cork harvesting is allowed until crown covered with green foliage has reached at least 75% of its regeneration even though no tree recovery is guaranteed (DGRF, 2006), as for Spain managers recommend a minimum of 2-3 years and the cork has reached at least 2 cm thickness (Amo & Chacón, 2003). Oliviera and Costa (2012) pointed out that severe drought events such as fires lengthen the production cycle of cork as harvesting may be cancelled and consequently this procedure may prevent further stress on the already suffering trees. Such extension of the cork production cycle would not necessarily imply lower economic income (Natividade, 1950).

When crown regeneration is nil or very poor, sprouts located at the base of severely damaged trees or under the soil surface can be used to naturally regenerate forest stands as having good chances to survive after a fire than attached to higher parts of the trunk. In case of good crown regeneration, no interventions are usually needed, as burned tree will show a regular homogeneous regeneration.

In the second site studied in our research, no livestock grazing was observed. However the first one showed the presence of large domestic herbivores such as goat and sheep, hence considering some protective measures is highly recommended. Indeed, with the presence of burned trees regenerating exclusively from basal sprouts (stem death), those herbivores, not being able to reach the crown, will be most likely feeding on new tender shoots, endangering thus dormant buds and influencing negatively the regeneration capacity of trees. Consequently, reducing animal densities following the first years of fire is a good option for a better plant regeneration. Catry et al. (2007) described an approach in which each tree is protected with a cylindrical-shaped wire mesh shelter at a height of at least 2 m preferably 2.5 m to prevent red deer to have access to regeneration plantations.

In fire-prone areas like the Mediterranean, as conserving the ecosystem should be given priority in terms of fire prevention, not only the exclusive economic cork value should be considered when defining post-fire management implications and objectives, but also and in particular safeguarding the ecological and environmental value through promoting responsible management making profit of all goods and services provided by these resources.

11. CONCLUSIONS

In cork oak forests, human-dominated ecosystems, one of the fundamental problems faced by species and communities is the ability to adapt and survive in case of any disturbance induced and enhanced by modern anthropic activities. Indeed, species have co-evolved with both natural and human disturbance (Lavorel, 1999). Consequently, they have acquired traits that confer them resistance and resilience to those disturbances (White & Jentsch, 2001). Nevertheless, anthropic activities have strongly affected these landscapes in various magnitudes of intensity, periodicity and extent owing to, for instance, irrelevant agro-silviculture practices, rearing of livestock breeds at high stocking densities, inappropriate exploitation of cork and man-induced fire events.

Forest sites with long-term grazing livestock impact are often characterized by floristic features of high conservation interest, which produce sprouts and leaves of good forage value making of these stands open spaces for livestock browsing. Cork oak forests are indeed a good example of such habitats, having grown into large solitary individuals over time due to the impact of grazing. In fact, the cork oak forest in Buddusò is highly diversified in terms of livestock components (i.e. sheep, goats, cattle and pigs) with a prevalence of sheep presence. As expected, a higher stocking rate characterized the sheep than cattle livestock system (2.08 and 0.39 heads/ha respectively). The same result was already observed by Moreno and Pulido (2009) in the *Dehesa.*

As a matter of fact, *Dehesa* has a double meaning, the first as a vegetation type and the second as private grazing land (Righeiro-Rodríguez et al., 2009). Indeed, cork oak lands serve often as a multi-purpose agroforestry and agro-pastoral system with an open tree layer above a grass layer, which depends on anthropic activities such as grazing.

Forest grazing takes place in summer when animals seek shadow and green leaves, and in winter when trees provide shelter from cold winds (Talamucci et al., 1995). In fact, as unstable vegetation type, cork oak forests require continuous anthropic interventions to prevent shrub encroachment (Montero et al., 1998). The poor presence of herbivores, namely undergrazing, encourages the invasion of various shrub species such as *C. salvaefolius*, *C. monspeliensis* and *C. villosus*. Additionally, grazing by livestock improve conditions for tree regeneration by reducing accumulated liter creating hence better conditions for germination.

As a matter of fact, Beccu (1976) revealed in his economical study in Buddusò, average stocking rate for livestock of around 1.3 animals/ha for the period 1962-1965 while in 2014 this number has decreased to 0.62 heads/ha for almost the same total surface (7511 and 7676 ha, respectively). Even though there is a lack of information of the total area grazed in Buddusò at present (G. Ligios, 2015, personal communication), this finding outlines indeed a lower stocking density rate than in the past depicting the importance of suggestions proposed in the economical plan to local shepherds in terms of managing seasonal grazing and lack of shepherding, replacing large-scale free-range grazing, which indeed appears to favor the colonization of trees and shrubs. However, even if it seems that in Buddusò there is no current widespread of overgrazing owing to a lower stocking rate than 50 years ago, there might be localized overgrazing of seedlings and regeneration trees due to their higher palatability (i.e. *Q. suber* forest).

Similarly, damage to the forest vegetation can happen in case of continuous grazing strategies when animals can freely graze abandoned lands. Herbivores used in extensive grazing regimes are often adapted to mountainous topography (i.e. *Q. suber* stands) being meat-producing livestock. As such, livestock could restrain natural regeneration of cork oak as occurred in Iteimia (Tunisia) where there are no restrictions on livestock grazing (Ben-Mansoura et a., 2001).

Combining action of grazing and cork oak forest pastures represent a valuable tool of multiple use of natural resources. Since half of lands (9,000 ha) in Buddusò are owned and managed by private landowners (M.P. Mulas, 2015, personal communication), those have the responsibility to shepherd livestock and manage seasonal grazing by rearing traditional livestock breeds at adequate stocking densities and careful cork oak exploitation.

The analysis of both biological and chorological spectrum based on the floristic and phytosociologic tables highlights the Mediterranean character of the region in which relevés have been conducted, reporting a high number of therophytes and hemicryptophytes as well as the dominance of Steno and Euri-Mediterranean species. Additionally, the climatic data collected at the nearest meteorological stations to the study areas, which was identified by a high annual average of precipitations and a dry period during summer revealed more the Mediterranean identity of the region in which cork oak forests insure an optimum vegetative growth. As a matter of fact, the differences observed in the surveys conducted in limited areas (i.e. cork oak forest in Bitti-Buddusò) are most likely related to variations owed to anthropic activities and management practices when confronted to areas of larger extension (i.e. Sardinia Region). In consequence, this allows a better interpretation of vegetation complexes and suggests, when possible, appropriate and corrective management interventions strongly required for restoring the integrity and preservation of the ecosystem.

The fact of dividing cork oak populations in various areas for cork exploitation have let to cork harvesting at lower costs, a yearly cork product on more or less regular basis and also to a better quality (between 14,000 and 16,000 Lire in the period 1954-1965 and between 180 and 220 Euro in the last three years), and larger quantities of gentle cork and virgin cork (an average of 2,290 and 359, respectively in the period 1954-1976 and 2,584 and 582 quintals for the period 2013-2015) since the minimum rotation period of cork harvesting between successive extractions was set to 10 years.

Cork oak forests are of an unparalleled biological richness. Preserving these landscapes means not only perpetuating a profitable exploitation resource but also protecting a unique habitat with an extraordinary ecological value. It is no wonder that cork oak woodlands are a remarkable component of the Mediterranean Region. Caring for *Q. suber* trees is in part caring for an intergenerational patrimony, as such appropriate and responsible planning is strongly required for a better cork oak growth, survival and preservation.

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ANNEXES

Annex 1. Floristic composition surveys conducted in *Quercus suber* forest.

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
1	*Achillea ligustica*	.	.	1	1	1	1
2	*Agrostis pourretii*	1	.	.	.	.	.
3	*Aira caryophyllea*	1	.	1	.	.	.
4	*Aira cupaniana*	.	.	.	1	.	.
5	*Aira elegans*	.	.	1	.	.	.
6	*Allium subhirsutum*	.	1	1	.	1	.
7	*Allium triquetrum*	.	.	1	1	.	.
8	*Allium vineale*	.	.	.	.	.	1
9	*Alnus glutinosa*	.	.	.	1	.	.
10	*Ammoides pusilla*	.	.	1	.	.	.
11	*Anacamptis coriophora*	1	.	.	.	.	1
12	*Anacamptis mori* subsp. *longicornu*	.	.	1	1	.	1
13	*Anacamptis papilionacea*	.	.	1	1	.	.
14	*Anagallis arvensis*	1	.	1	1	.	.
15	*Anagallis parviflora*	.	.	1	.	.	.
16	*Andryala integrifolia*	.	.	.	.	1	.
17	*Anemone hortensis*	.	.	1	1	.	.
18	*Anthemis arvensis*	1	.	1	.	.	.
19	*Anthoxanthum gracile*	.	.	1	.	.	.
20	*Anthoxanthum odoratum*	1	.	.	1	.	1
21	*Antractylis gummifera*	.	1	.	.	.	.
22	*Arbutus unedo*	1	1	1	1	1	1
23	*Arisarum vulgare*	.	.	1	1	.	.
24	*Aristolochia rotunda* subsp. *insularis*	.	.	.	1	.	.
25	*Asparagus acutifolius*	.	1	1	.	1	1
26	*Asperula laevigata*	.	.	1	.	.	.
27	*Asphodelus ramosus*	1	1	1	1	1	1
28	*Asplenium obovatum*	.	.	.	.	1	.
29	*Asplenium onopteris*	.	.	1	1	1	.
30	*Asterolinon linum-stellatum*	1	.	.	.	.	.
31	*Atractylis gummifera*	.	.	.	1	.	.
32	*Avena barbata*	.	.	1	1	1	1
33	*Avena fatua*	.	1	.	.	.	.
34	*Avena sativa*	.	1	.	.	.	.
35	*Bellardia trixago*	1	.	.	.	.	.

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
36	*Bellis perennis*	.	.	1	1	.	1
37	*Bellium bellidioides*	1	.	.	.	.	.
38	*Brachypodium distachyon*	1	1	1	.	.	1
39	*Brachypodium retusum*	.	.	1	1	1	1
40	*Brachypodium sylvaticum*	.	.	1	.	1	.
41	*Brassica oleifera*	.	.	1	.	.	.
42	*Briza maxima*	1	1	1	1	1	1
43	*Briza minor*	1	1	.	.	.	.
44	*Bromus hordaceus*	1	.	1	1	.	.
45	*Bromus madritensis*	.	.	1	1	1	.
46	*Bromus rubens*	1	.	.	.	.	.
47	*Bromus scoparius*	.	.	1	.	.	.
48	*Bromus sterilis*	1	1	1	.	1	1
49	*Calamintha nepeta* subsp. *glandulosa*	.	.	.	1	.	.
50	*Calicotome villosa*	.	1	.	.	1	.
51	*Capsella bursa-pastoris*	.	.	1	1	.	.
52	*Cardamine hirsuta*	1	.	1	.	.	.
53	*Carduus pycnocephalus*	1	.	1	.	1	.
54	*Carex distachya*	.	1	1	.	1	1
55	*Carex divisa*	1	.	.	.	.	.
56	*Carex divulsa*	.	.	1	.	.	.
57	*Carex flacca*	1	1	.	.	.	.
58	*Carlina corymbosa*	1	.	1	1	1	1
59	*Carthamus lanatus*	.	1	.	.	.	.
60	*Castanea sativa*	.	.	.	1	.	.
61	*Catapodium rigidum*	.	.	1	.	1	.
62	*Centaurium erythraea*	.	.	.	1	.	.
63	*Centaurium maritimum*	.	.	1	.	.	.
64	*Centaurium pulchellum*	.	1	.	.	.	.
65	*Cerastium glomeratum*	1	.	1	.	1	.
66	*Chamaemelum fuscatum*	.	.	.	.	1	.
67	*Chamaemelum mixtum*	1	.	.	.	.	.
68	*Chenopodium album*	.	.	.	.	1	.
69	*Chrysanthemum segetum*	1	.	.	.	.	.
70	*Cistus creticus* var. *eriocephalus*	.	1	.	1	1	1
71	*Cistus monspeliensis*	1	1	1	1	.	1
72	*Cistus salvaefolius*	1	1	1	1	1	1
73	*Clematis cirrhosa*	.	1	.	.	.	.
74	*Clinopodium vulgare* subsp. *arundanum*	.	.	1	.	1	1

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
75	*Convolvulus arvensis*	1	.	.	.	.	.
76	*Coronilla scorpioides*	.	1	.	.	.	.
77	*Crataegus monogyna*	.	.	1	1	1	1
78	*Crepis leontodontoides*	.	.	1	.	.	1
79	*Crepis vesicaria*	.	.	1	.	.	.
80	*Crocus minimus*	.	.	1	.	.	.
81	*Cruciata glabra*	.	.	1	.	.	.
82	*Cruciata laevipes*	.	.	.	.	1	.
83	*Crupina crupinastrum*	.	.	1	.	.	.
84	*Cyclamen repandum*	.	1	1	1	.	1
85	*Cynara cardunculus*	1	.	.	.	.	.
86	*Cynoglossum creticum*	.	.	.	.	1	.
87	*Cynosorus effusus*	.	.	.	.	1	1
88	*Cynosorus elegans*	.	.	1	.	.	.
89	*Cynosurus cristatus*	1	.	1	1	.	.
90	*Cynosurus echinatus*	1	1	1	1	1	1
91	*Cynosurus polybracteatus*	.	.	1	1	1	1
92	*Cyperus badius*	1	.	.	.	.	.
93	*Cytinus hypocistis*	.	.	.	1	.	.
94	*Cytisus villosus*	1	1	1	1	1	1
95	*Dactylis glomerata*	1	1	1	.	.	1
96	*Dactylorhiza insularis*	.	.	.	1	.	.
97	*Daphne gnidium*	1	1	1	1	1	1
98	*Dasypyrum villosum*	1	1	.	.	.	.
99	*Daucus carota*	.	1	1	1	.	1
100	*Digitalis purpurea*	.	.	1	.	.	.
101	*Dipsacus fullonum*	1	.	.	.	.	.
102	*Drimia pancration*	.	.	.	.	1	.
103	*Echium creticum*	1	.	.	.	.	.
104	*Echium plantagineum*	.	.	1	.	.	.
105	*Erica arborea*	1	1	1	1	1	1
106	*Erica scoparia*	1	.	.	1	.	.
107	*Erodium ciconium*	1	.	.	.	.	.
108	*Eryngium campestre*	.	.	1	1	1	1
109	*Eryngium tricuspidatum*	.	.	1	.	.	.
110	*Erythraea maritima*	1	.	.	.	.	.
111	*Euonymus europaeus*	.	.	.	1	.	.
112	*Euphorbia characias*	.	1	.	.	1	.
113	*Euphorbia exigua*	1	.	.	.	.	.
114	*Euphorbia helioscopia*	.	.	1	.	.	.

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
115	*Euphorbia peplis*	.	.	1	.	.	.
116	*Ferula communis*	1	.	1	.	.	1
117	*Filago gallica*	1	1	1	.	.	.
118	*Filago germanica*	1	1	1	.	.	.
119	*Foeniculum vulgare*	1	.	.	.	.	.
120	*Fraxinus ornus*	.	.	.	1	.	.
121	*Fumana thymifolia*	1	.	.	.	.	.
122	*Fumaria officinalis*	.	.	.	1	.	.
123	*Galactites tomentosa*	1	1	1	.	1	1
124	*Galium aparine*	.	.	1	.	.	.
125	*Galium divaricatum*	.	.	1	.	.	.
126	*Galium parisiense*	1	.	.	.	.	.
127	*Galium rotundifolium*	.	.	1	.	.	.
128	*Galium scabrum*	.	.	1	.	1	.
129	*Gastridium ventricosum*	.	1	.	.	.	.
130	*Gaudinia fragilis*	1	.	.	.	.	.
131	*Genista corsica*	.	.	.	.	.	1
132	*Geranium dissectum*	.	.	.	.	1	.
133	*Geranium lucidum*	.	.	1	1	.	1
134	*Geranium molle*	1	.	1	.	1	.
135	*Geranium purpureum*	.	.	1	.	1	1
136	*Geranium robertianum*	.	.	.	1	.	.
137	*Gladiolus italicus*	.	1	1	.	.	.
138	*Glechoma sardoa*	.	.	.	.	1	.
139	*Halimium halimifolium*	1	.	.	.	.	.
140	*Hedera helix*	.	.	1	1	.	1
141	*Hedypnois cretica*	1	.	.	.	1	.
142	*Helianthemum salicifolium*	.	.	.	.	.	1
143	*Helichrysum italicum*	1	1	1	.	.	.
144	*Helichrysum italicum* subsp. *microphyllum*	.	.	.	1	.	.
145	*Hieracium zizianum* subsp. *sardonium*	.	.	.	1	.	1
146	*Holcus lanatus*	1	.	1	.	1	1
147	*Holcus mollis*	.	.	.	1	.	.
148	*Hordeum bulbosum*	1	.	.	.	.	.
149	*Hordeum leporinum*	.	.	1	.	.	.
150	*Hyoseris radiata*	.	1	1	1	.	.
151	*Hypericum perfoliatum*	.	.	.	1	.	1
152	*Hypericum veronense*	.	1	1	1	1	1
153	*Hypochaeris achyrophorus*	1	.	1	.	1	.
154	*Hypochaeris glabra*	1	.	1	.	.	.

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
155	*Hypochaeris pinnatifida*	1	.	1	.	.	.
156	*Hypochaeris radicata*	1	.	1	.	.	.
157	*Ilex aquifolium*	.	.	.	1	.	.
158	*Jasione montana*	1	.	1	.	.	1
159	*Juncus conglomeratus*	1	.	.	.	.	.
160	*Juncus pygmaeus*	1	.	.	.	.	.
161	*Lactuca muralis*	.	.	.	.	1	.
162	*Lagurus ovatus*	.	.	1	1	1	.
163	*Lamium maculatum*	.	1	.	.	.	.
164	*Lathyrus angulatus*	.	.	.	1	.	.
165	*Lathyrus aphaca*	.	.	.	1	1	1
166	*Lathyrus cicera*	.	.	1	.	.	.
167	*Lathyrus hirsutus*	.	.	1	.	.	.
168	*Lathyrus latifolius*	.	.	.	1	.	.
169	*Lathyrus sphaericous*	1	.	.	.	.	.
170	*Lavandula stoechas*	1	1	.	1	1	1
171	*Legousia hybrida*	.	.	.	.	1	.
172	*Leontodon tuberosus*	1	.	1	1	1	1
173	*Leopoldia comosa*	.	1	1	1	.	.
174	*Limodorum abortivum*	.	1	.	1	.	.
175	*Linaria arvensis*	.	.	1	.	.	.
176	*Linaria pelisseriana*	1	.	1	.	.	.
177	*Linum bienne*	.	.	1	1	.	.
178	*Linum strictum*	1	1	1	.	.	.
179	*Linum trigynum*	.	.	1	.	.	1
180	*Linum usitatissimum*	1	.	.	.	.	.
181	*Lolium multiflorum*	.	.	1	.	.	.
182	*Lolium perenne*	.	1	1	.	.	.
183	*Lolium rigidum*	1	.	1	.	.	1
184	*Lonicera implexa*	.	1	1	1	1	.
185	*Lotus angustissimus*	1	.	.	1	.	.
186	*Lotus conimbricensis*	1	.	.	1	.	.
187	*Lotus ornithopodioides*	1	.	.	.	.	.
188	*Lupinus angustifolius*	.	.	1	.	.	.
189	*Lupinus micranthus*	1	.	1	1	.	1
190	*Luzula forsteri*	.	.	1	1	1	1
191	*Malva sylvestris*	.	.	.	1	.	.
192	*Marrubium vulgare*	.	.	.	.	1	.
193	*Matricaria chamomilla*	.	.	.	1	.	.
194	*Medicago arabica*	.	.	1	1	.	.

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
195	*Medicago murex*	1	.	.	.	.	.
196	*Medicago polymorpha*	1	.	.	.	1	.
197	*Medicago truncatula*	.	.	1	.	.	.
198	*Melica ciliata*	.	.	.	1	.	.
199	*Melica minuta* var. *arrecta*	.	.	1	1	1	.
200	*Mentha aquatica*	.	.	.	1	.	.
201	*Mentha pulegium*	.	.	.	1	.	.
202	*Micromeria graeca*	.	1	.	.	.	.
203	*Micropyrum tenellum*	.	.	1	.	.	.
204	*Milium scabrum*	1	.	.	.	.	.
205	*Moenchia erecta*	.	.	.	1	.	.
206	*Molineriella minuta*	.	.	.	1	.	.
207	*Myosotis arvensis*	.	.	1	.	1	.
208	*Myosotis ramosissima*	.	.	1	.	.	.
209	*Narcissus tazetta*	.	.	1	1	.	1
210	*Odontites luteus*	.	.	1	.	.	.
211	*Oenanthe fistulosa*	.	.	.	.	1	.
212	*Oenanthe pimpinelloides*	.	.	1	1	1	1
213	*Olea europea*	.	.	1	1	.	.
214	*Ophrys tenthredinifera*	.	.	1	.	.	.
215	*Orchis provincialis*	.	.	.	1	.	.
216	*Ornithogalum corsicum*	.	.	1	1	.	1
217	*Ornithopus compressus*	1	.	1	1	1	.
218	*Ornithopus pinnatus*	1	.	.	.	.	.
219	*Orobanche minor*	.	.	1	.	.	.
220	*Osyris alba*	.	1	.	.	1	.
221	*Paeonia morisii*	.	.	1	.	.	.
222	*Pancratium illyricum*	.	.	1	.	.	.
223	*Parentucellia latifolia*	.	.	1	.	.	.
224	*Parentucellia viscosa*	1	.	1	.	.	.
225	*Petrorhagia dubia*	.	.	1	1	1	.
226	*Petrorhagia prolifera*	1	.	.	.	.	.
227	*Phagnalon rupestre*	1	.	.	.	.	.
228	*Phalaris aquatica*	.	1	.	.	.	.
229	*Phillyrea angustifolia*	1	1	1	1	1	1
230	*Phillyrea latifolia*	.	1	1	1	1	.
231	*Picris echioides*	1	.	.	.	.	.
232	*Piptatherum miliaceum*	1	1	.	.	1	.
233	*Pistacia lentiscus*	.	1	.	.	.	.
234	*Plantago bellardii*	1	.	1	.	.	.

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
235	*Plantago coronopus*	1	.	.	.	.	.
236	*Plantago lagopus*	.	1	.	.	.	.
237	*Plantago lanceolata*	1	.	1	1	.	1
238	*Poa bulbosa*	.	.	1	.	.	1
239	*Poa nemoralis*	.	.	.	.	.	1
240	*Poa trivialis*	.	.	1	.	.	.
241	*Polycarpon diphyllum*	.	.	1	.	.	.
242	*Polygala vulgaris*	.	.	.	1	.	.
243	*Polypodium australe*	.	.	.	.	1	.
244	*Potentilla micrantha*	.	.	1	.	.	.
245	*Potentilla recta*	.	.	.	1	.	.
246	*Potentilla reptans*	.	.	.	1	.	.
247	*Prasium majus*	.	1	.	.	.	.
248	*Prunella laciniata*	.	.	1	.	.	.
249	*Prunella vulgaris*	.	.	.	1	.	.
250	*Prunus spinosa*	.	1	1	1	1	.
251	*Pteridium aquilinum*	.	.	1	1	1	.
252	*Pulicaria odora*	1	1	1	1	1	1
253	*Pyrus spinosa*	1	.	1	1	.	1
254	*Quercus ilex*	1	1	1	1	1	1
255	*Quercus pubescens*	1	1	1	1	1	1
256	*Quercus suber*	1	1	1	1	1	1
257	*Ranunculus bulbosus*	.	.	1	.	.	1
258	*Ranunculus ficaria*	.	.	1	1	.	.
259	*Ranunculus macrophyllus*	.	.	.	1	.	.
260	*Ranunculus monspeliacus*	1	.	.	.	.	.
261	*Ranunculus ophioglossifolius*	1	.	.	.	.	.
262	*Ranunculus paludosus*	1	.	1	.	.	.
263	*Ranunculus parviflorus*	.	.	1	.	.	.
264	*Ranunculus velutinus*	.	.	.	.	1	.
265	*Raphanus raphanistrum*	.	.	1	1	.	.
266	*Reichardia picroides*	.	1	1	1	1	1
267	*Rhagadiolus stellatus*	.	.	1	.	.	.
268	*Rhamnus alaternus*	.	.	.	1	.	.
269	*Romulea bulbocodium*	1	.	.	.	.	.
270	*Rosa canina*	.	.	1	1	1	.
271	*Rosa sempervirens*	.	.	1	.	1	1
272	*Rubia peregrina*	.	1	1	1	1	1
273	*Rubus ulmifolius*	1	.	1	1	1	1
274	*Rumex acetosa*	1	.	.	1	.	1

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
275	*Rumex acetosella*	1	.	.	.	.	.
276	*Rumex bucephalophorus*	1	1	1	.	.	.
277	*Rumex sanguineus*	1	.	.	.	.	.
278	*Rumex thyrsoides*	1	.	1	.	.	.
279	*Ruscus aculeatus*	.	.	1	1	1	1
280	*Sanguisorba minor*	1	.	1	1	1	1
281	*Sanicula europaea*	.	.	.	.	1	.
282	*Scolymus hispanicus*	.	.	1	.	.	.
283	*Scorzonera callosa*	1	.	.	.	.	.
284	*Sedum caeruleum*	.	.	1	.	.	.
285	*Sedum stellatum*	.	.	1	.	.	.
286	*Senecio lividus*	.	.	1	.	.	.
287	*Senecio vulgaris*	.	.	1	1	.	.
288	*Serapias lingua*	.	.	1	1	.	.
289	*Serapias parviflora*	.	.	.	1	.	.
290	*Sherardia arvensis*	1	.	1	1	1	1
291	*Sideritis romana*	.	.	1	.	.	.
292	*Silene gallica*	1	.	1	.	.	.
293	*Silene laeta*	1	.	.	.	.	.
294	*Silene latifolia*	.	.	1	1	1	.
295	*Silene vulgaris*	.	.	1	1	1	1
296	*Sinapis pubescens*	.	.	1	.	.	.
297	*Sisymbrium officinale*	.	.	1	.	.	.
298	*Sisymbrium orientale*	1	.	.	.	.	.
299	*Smilax aspera*	.	1	1	1	1	.
300	*Smyrmium olusatrum*	1	.	1	.	1	1
301	*Smyrnium rotundifolium*	.	.	1	1	.	.
302	*Sonchus tenerrimus*	.	.	1	.	.	.
303	*Spergula arvensis*	1	.	.	.	.	.
304	*Spergularia rubra*	1	.	.	.	.	.
305	*Spiranthes spiralis*	.	.	.	1	.	.
306	*Stachys glutinosa*	1	1	1	1	.	1
307	*Stellaria media*	.	.	1	1	1	1
308	*Tamus communis*	1	1	1	1	1	1
309	*Teesdalia coronopifolia*	.	.	1	.	.	.
310	*Teline monspessulana*	.	.	1	1	1	.
311	*Teucrium camaedrys*	1	.	.	.	.	.
312	*Teucrium massiliense*	.	.	.	.	1	.
313	*Thapsia garganica*	.	1	1	1	.	1
314	*Tolpis umbellata*	1	.	1	.	.	.

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
315	*Tolpis virgata*	1	.	.	.	.	.
316	*Torilis africana*	.	.	1	.	.	.
317	*Torilis nodosa*	.	.	1	.	.	.
318	*Trifolium angustifolium*	.	1	1	.	1	.
319	*Trifolium arvense*	.	1	1	.	.	.
320	*Trifolium bocconei*	1	.	.	.	.	.
321	*Trifolium campestre*	1	1	1	.	1	.
322	*Trifolium cherleri*	1	1	1	.	.	.
323	*Trifolium diffusum*	.	.	1	.	.	.
324	*Trifolium glomeratum*	1	.	1	.	1	.
325	*Trifolium incarnatum*	.	.	1	.	.	.
326	*Trifolium lappaceum*	1	.	.	.	.	.
327	*Trifolium ligusticum*	.	.	1	.	.	.
328	*Trifolium nigrescens*	1	.	1	1	.	.
329	*Trifolium ochroleucon*	.	.	.	.	1	.
330	*Trifolium pratense*	.	.	.	1	1	.
331	*Trifolium scabrum*	.	.	1	.	.	.
332	*Trifolium stellatum*	1	1	1	1	1	1
333	*Trifolium strictum*	1	.	.	.	.	.
334	*Trifolium subterraneum*	1	.	1	1	1	.
335	*Trifolium tomentosum*	.	.	1	.	.	.
336	*Tuberaria guttata*	1	.	1	1	.	.
337	*Umbilicus rupestris*	.	.	1	.	1	.
338	*Urospermum dalechampii*	1	1	1	1	.	1
339	*Urtica atrovirens*	.	.	1	.	.	.
340	*Verbascum pulverulentum*	.	.	.	.	1	.
341	*Verbena officinalis*	.	.	.	1	.	.
342	*Veronica arvensis*	.	.	1	.	.	.
343	*Veronica brevistyla*	1	.	.	.	.	.
344	*Vicia angustifolia*	.	.	1	.	.	.
345	*Vicia benghalensis*	1	.	.	.	.	.
346	*Vicia cracca*	.	.	1	.	1	.
347	*Vicia disperma*	.	.	1	1	.	.
348	*Vicia hybrida*	.	.	1	.	.	.
349	*Vicia lathyroides*	.	.	1	.	1	.
350	*Vicia lutea*	.	.	.	1	.	.
351	*Vicia sativa*	1	.	1	1	1	.
352	*Vicia villosa*	1	.	.	1	.	1
353	*Viola dehnhardtii*	.	.	1	1	1	1
354	*Viola riviniana*	.	.	.	1	.	.

	Species	Economical plan Buddusò (1967)	Chiappini & Palmas (1972)	Sirigu (1994)	Pintus & Ruiu (1995)	Camarda & Carta (2006)	Makdissi (2015)
355	*Vulpia ciliata*	1	.	1	.	.	.
356	*Vulpia fasciculata*	.	.	.	.	.	1
357	*Vulpia geniculata*	1	.	.	.	.	.
358	*Vulpia hybrida*	.	.	1	.	.	.
359	*Vulpia ligustica*	.	.	1	.	.	.
360	*Vulpia myuros*	1	.	1	.	.	.
361	*Vulpia sicula*	.	.	1	.	1	.
362	*Xanthium spinosum*	.	.	.	.	1	.

Annex 2. List of the most frequent species in *Quercus suber* forest.

	Species	Presence		Species	Presence
1	*Arbutus unedo*	6	**32**	*Avena barbata*	4
2	*Asphodelus ramosus*	6	**33**	*Brachypodium distachyon*	4
3	*Briza maxima*	6	**34**	*Brachypodium retusum*	4
4	*Cistus salvaefolius*	6	**35**	*Carex distachya*	4
5	*Cynosurus echinatus*	6	**36**	*Cistus creticus* var. *eriocephalus*	4
6	*Cytisus villosus*	6	**37**	*Crataegus monogyna*	4
7	*Daphne gnidium*	6	**38**	*Cyclamen repandum*	4
8	*Erica arborea*	6	**39**	*Cynosurus polybracteatus*	4
9	*Phillyrea angustifolia*	6	**40**	*Dactylis glomerata*	4
10	*Pulicaria odora*	6	**41**	*Daucus carota*	4
11	*Quercus ilex*	6	**42**	*Eryngium campestre*	4
12	*Quercus pubescens*	6	**43**	*Holcus lanatus*	4
13	*Quercus suber*	6	**44**	*Lonicera implexa*	4
14	*Tamus communis*	6	**45**	*Lupinus micranthus*	4
15	*Trifolium stellatum*	6	**46**	*Luzula forsteri*	4
16	*Bromus sterilis*	5	**47**	*Oenanthe pimpinelloides*	4
17	*Carlina corymbosa*	5	**48**	*Ornithopus compressus*	4
18	*Cistus monspeliensis*	5	**49**	*Phillyrea latifolia*	4
19	*Galactites tomentosa*	5	**50**	*Plantago lanceolata*	4
20	*Hypericum veronense*	5	**51**	*Prunus spinosa*	4
21	*Lavandula stoechas*	5	**52**	*Pyrus spinosa*	4
22	*Leontodon tuberosus*	5	**53**	*Ruscus aculeatus*	4
23	*Reichardia picroides*	5	**54**	*Silene vulgaris*	4
24	*Rubia peregrina*	5	**55**	*Smilax aspera*	4
25	*Rubus ulmifolius*	5	**56**	*Smyrmium olusatrum*	4
26	*Sanguisorba minor*	5	**57**	*Stellaria media*	4
27	*Sherardia arvensis*	5	**58**	*Thapsia garganica*	4
28	*Stachys glutinosa*	5	**59**	*Trifolium campestre*	4
29	*Urospermum dalechampii*	5	**60**	*Trifolium subterraneum*	4
30	*Achillea ligustica*	4	**61**	*Vicia sativa*	4
31	*Asparagus acutifolius*	4	**62**	*Viola dehnhardtii*	4

Annex 3. The biological and chorological spectrum of *Quercus suber* forest species.

	Species	Biological Spectrum	Chorological Spectrum
1	*Achillea ligustica*	H	Steno-Medit.- Occid.
2	*Agrostis pourretii*	H	_
3	*Aira caryophyllea*	Th	Paleo-Subtrop.
4	*Aira cupaniana*	Th	Steno-Medit.
5	*Aira elegans*	Th	Euri-Medit.
6	*Allium subhirsutum*	G	Steno-Medit.
7	*Allium triquetrum*	G	Steno-Medit.-Occid.
8	*Allium vineale*	P	Euri-Medit.
9	*Alnus glutinosa*	P	Paleotemp.
10	*Ammoides pusilla*	Th	Steno-Medit.
11	*Anacamptis coriophora*	G	Euri-Medit.
12	*Anacamptis mori* subsp. *longicornu*	G	Steno-Medit.-Occid.
13	*Anacamptis papilionacea*	G	Euri-Medit.
14	*Anagallis arvensis*	Th	Euri-Medit.
15	*Anagallis parviflora*	Th	Steno-Medit.- Occid.
16	*Andryala integrifolia*	Th	Medit.-Occid.(Euri-)
17	*Anemone hortensis*	G	N-Medit.
18	*Anthemis arvensis*	Th	Steno-Medit.
19	*Anthoxanthum gracile*	Th	Steno-Medit. Centro-orient.
20	*Anthoxanthum odoratum*	H	Eurasiat.
21	*Antractylis gummifera*	H	S-Medit.
22	*Arbutus unedo*	Th	Steno-Medit.
23	*Arisarum vulgare*	G	Steno-Medit.
24	*Aristolochia rotunda* subsp. *insularis*	G	Euri-Medit.
25	*Asparagus acutifolius*	G	Steno-Medit.
26	*Asperula laevigata*	H	C-Medit.
27	*Asphodelus ramosus*	G	Steno-Medit.
28	*Asplenium obovatum*	H	Steno-Medit.
29	*Asplenium onopteris*	H	Subtrop.-nesicola.
30	*Asterolinon linum-stellatum*	Th	Steno-Medit.
31	*Atractylis gummifera*	H	S-Medit.
32	*Avena barbata*	Th	Euri-Medit.-Turan.
33	*Avena fatua*	Th	Eurasiat.
34	*Avena sativa*	Th	Settentrionale
35	*Bellardia trixago*	Th	Euri-Medit.
36	*Bellis perennis*	H	Europeo-Caucas.
37	*Bellium bellidioides*	H	Steno-Medit.-Occid.
38	*Brachypodium distachyon*	Th	Steno-Medit.-Turan
39	*Brachypodium retusum*	H	Steno-Medit.-Occid.

	Species	Biological Spectrum	Chorological Spectrum
40	*Brachypodium sylvaticum*	H	Paleotemp.
41	*Brassica oleifera*	H	It. Centr.
42	*Briza maxima*	Th	Paleo-Subtrop.
43	*Briza minor*	Th	Subcosmop.
44	*Bromus hordaceus*	Th	Subcosmop.
45	*Bromus madritensis*	Th	Euri-Medit.
46	*Bromus rubens*	Th	S.Medit.-Turan
47	*Bromus scoparius*	Th	Steno-Medit.
48	*Bromus sterilis*	Th	Euri-Medit.-Turan.
49	*Calamintha nepeta* subsp. *glandulosa*	H	Endem.
50	*Calicotome villosa*	P	Steno-Medit.
51	*Capsella bursa-pastoris*	Th	Cosmopol.
52	*Cardamine hirsuta*	Th	Cosmopol.
53	*Carduus pycnocephalus*	H	(Euri-)Medit.-Turan
54	*Carex distachya*	H	Steno-Medit.
55	*Carex divisa*	G	Euri-Medit.-Atlant.
56	*Carex divulsa*	H	Euri-Medit.
57	*Carex flacca*	G	Eurasiat.
58	*Carlina corymbosa*	H	Steno-Medit.
59	*Carthamus lanatus*	Th	Euri-Medit.
60	*Castanea sativa*	P	SE-Europ.
61	*Catapodium rigidum*	Th	Euri-Medit.
62	*Centaurium erythraea*	H	Paleotemp.-Euasiat.
63	*Centaurium maritimum*	Th	Steno-Medit.
64	*Centaurium pulchellum*	Th	Paleotemp.
65	*Cerastium glomeratum*	Th	Subcosmop.
66	*Chamaemelum fuscatum*	Th	W-Medit.(Steno-).
67	*Chamaemelum mixtum*	Th	Steno-Medit.
68	*Chenopodium album*	Th	Subcosmop.
69	*Chrysanthemum segetum*	Th	Steno-Medit.-Turan
70	*Cistus creticus* var. *eriocephalus*	NP	Steno-Medit.
71	*Cistus monspeliensis*	NP	Stenomedit.Macaronesiano
72	*Cistus salvaefolius*	NP	Steno-Medit.
73	*Clematis cirrhosa*	P	Steno-Medit.-Turan
74	*Clinopodium vulgare* subsp. *arundanum*	H	Circumbor.
75	*Convolvulus arvensis*	G	Cosmop.
76	*Coronilla scorpioides*	Th	Euri-Medit.
77	*Crataegus monogyna*	P	Paleotemp.
78	*Crepis leontodontoides*	H	W-Medit.-mont.
79	*Crepis vesicaria*	H	Sub-Medit.-Subalt.

	Species	Biological Spectrum	Chorological Spectrum
80	*Crocus minimus*	G	Endem.
81	*Cruciata glabra*	Th	Eurasiat.
82	*Cruciata laevipes*	H	Eurasiat.
83	*Crupina crupinastrum*	Th	Steno-Medit.
84	*Cyclamen repandum*	G	N-Medit.
85	*Cynara cardunculus*	H	Steno-Medit.
86	*Cynoglossum creticum*	H	Euri-Medit.
87	*Cynosorus effusus*	H	Steno-Medit.
88	*Cynosorus elegans*	Th	Steno-Medit.
89	*Cynosurus cristatus*	H	Europeo-Caucas.
90	*Cynosurus echinatus*	Th	Euri-Medit.
91	*Cynosurus polybracteatus*	Th	Steno-Medit.-Occid.
92	*Cyperus badius*	G	Paleotemp.
93	*Cytinus hypocistis*	P	Medit.-Macarones.
94	*Cytisus villosus*	P	W e Centro-Medit.
95	*Dactylis glomerata*	H	Paleotemp.
96	*Dactylorhiza insularis*	G	Steno-Medit.-Occid.
97	*Daphne gnidium*	P	Stenomedit.Macaronesiano
98	*Dasypyrum villosum*	Th	Euri-Medit.-Turan.
99	*Daucus carota*	H	Subcosmop.
100	*Digitalis purpurea*	H	W-Medit. (Euri-).
101	*Dipsacus fullonum*	H	Euri-Medit.
102	*Drimia pancration*	G	Steno-Medit.-Macatones.
103	*Echium creticum*	H	Steno-Medit.-Occid.
104	*Echium plantagineum*	Th	Euri-Medit.
105	*Erica arborea*	P	Steno-Medit.
106	*Erica scoparia*	P	W-Medit. (Steno-).
107	*Erodium ciconium*	H	Euri-Medit.-Pontico
108	*Eryngium campestre*	H	Euri-Medit.
109	*Eryngium tricuspidatum*	Th	SW-Medit.
110	*Erythraea maritima*	Th	Steno-Medit.
111	*Euonymus europaeus*	P	Eurasiat.
112	*Euphorbia characias*	Ch	Steno-Medit.
113	*Euphorbia exigua*	Th	Euri-Medit.
114	*Euphorbia helioscopia*	Th	Cosmopol.
115	*Euphorbia peplis*	Th	Euri-Medit.
116	*Ferula communis*	H	S-Medit. (Euri-).
117	*Filago gallica*	Th	Euri-Medit.
118	*Filago germanica*	Th	Paleotemp.
119	*Foeniculum vulgare*	H	S-Medit.

	Species	Biological Spectrum	Chorological Spectrum
120	*Fraxinus ornus*	P	Euri-N-Medit.-Pontico
121	*Fumana thymifolia*	Ch	Steno-Medit.
122	*Fumaria officinalis*	Th	Subcosmop.
123	*Galactites tomentosa*	H	Steno-Medit.
124	*Galium aparine*	Th	Eurasiat.
125	*Galium divaricatum*	Th	Steno-Medit.
126	*Galium parisiense*	Th	Euri-Medit.
127	*Galium rotundifolium*	H	W-Medit.-mont.
128	*Galium scabrum*	H	W-Medit.-mont.
129	*Gastridium ventricosum*	Th	Medit.-Alt.
130	*Gaudinia fragilis*	Th	Euri-Medit.
131	*Genista corsica*	NP	Endem.
132	*Geranium dissectum*	Th	Subcosmop.
133	*Geranium lucidum*	Th	Euri-Medit.
134	*Geranium molle*	H	Subcosmop.
135	*Geranium purpureum*	Th	Euri-Medit.
136	*Geranium robertianum*	H	Subcosmop.
137	*Gladiolus italicus*	G	Euri-Medit.
138	*Glechoma sardoa*	H	Endem.
139	*Halimium halimifolium*	NP	W-Medit.
140	*Hedera helix*	P	Sub-Medit.-Subalt.
141	*Hedypnois cretica*	Th	Steno-Medit.
142	*Helianthemum salicifolium*	Th	Euri-Medit.
143	*Helichrysum italicum*	Ch	S-Europ.
144	*Helichrysum italicum* subsp. *microphyllum*	Ch	S-Europ.
145	*Hieracium zizianum* subsp. *sardonium*	H	Europ.-Caucas.
146	*Holcus lanatus*	H	Circumbor.
147	*Holcus mollis*	H	Circumbor.
148	*Hordeum bulbosum*	H	Paleo-Subtrop.
149	*Hordeum leporinum*	Th	Euri-Medit.
150	*Hyoseris radiata*	H	Steno-Medit.
151	*Hypericum perfoliatum*	H	Steno-Medit.
152	*Hypericum veronense*	H	Steno-Medit.
153	*Hypochaeris achyrophorus*	Th	Steno-Medit.
154	*Hypochaeris glabra*	Th	Euri-Medit.
155	*Hypochaeris pinnatifida*	H	Orof.NE-Medit.
156	*Hypochaeris radicata*	H	Europ.-Caucas.
157	*Ilex aquifolium*	P	Sub-Medit.-Subalt.
158	*Jasione montana*	H	Europeo-Caucas.
159	*Juncus conglomeratus*	H	Eurosib.

	Species	Biological Spectrum	Chorological Spectrum
160	*Juncus pygmaeus*	Th	Medit.-Alt.
161	*Lactuca muralis*	H	Europ.-Caucas.
162	*Lagurus ovatus*	Th	Euri-Medit.
163	*Lamium maculatum*	H	Euriasiat.Temper.
164	*Lathyrus angulatus*	Th	NW-Medit.
165	*Lathyrus aphaca*	Th	Euri-Medit.
166	*Lathyrus cicera*	Th	Euri-Medit.
167	*Lathyrus hirsutus*	Th	Euri-Medit.
168	*Lathyrus latifolius*	H	S-Europ.
169	*Lathyrus sphaericous*	Th	Euri-Medit.
170	*Lavandula stoechas*	NP	Steno-Medit.
171	*Legousia hybrida*	Th	Medit.-Atlant. (Euri-).
172	*Leontodon tuberosus*	H	Steno-Medit.
173	*Leopoldia comosa*	G	Euri-Medit.
174	*Limodorum abortivum*	G	Euri-Medit.
175	*Linaria arvensis*	Th	Sub-Medit.-Subalt.
176	*Linaria pelisseriana*	Th	Medit.-Alt.
177	*Linum bienne*	H	Euri-Medit.-Subalt.
178	*Linum strictum*	Th	Steno-Medit.
179	*Linum trigynum*	Th	Euri-Medit.
180	*Linum usitatissimum*	Th	Europ.-Caucas.
181	*Lolium multiflorum*	Th	Euri-Medit.
182	*Lolium perenne*	H	Circumbor.
183	*Lolium rigidum*	Th	Paleo-Subtrop.
184	*Lonicera implexa*	P	Steno-Medit.
185	*Lotus angustissimus*	Th	Euri-Medit.
186	*Lotus conimbricensis*	Th	W-Medit. (Steno-).
187	*Lotus ornithopodioides*	Th	E-Medit. (Steno-).
188	*Lupinus angustifolius*	Th	Steno-Medit.
189	*Lupinus micranthus*	Th	Steno-Medit.
190	*Luzula forsteri*	H	Euri-Medit.
191	*Malva sylvestris*	H	Subcosmop.
192	*Marrubium vulgare*	H	Subcosmo.
193	*Matricaria chamomilla*	Th	Subcosmop.
194	*Medicago arabica*	Th	Euri-Medit.
195	*Medicago murex*	Th	Steno-Medit.
196	*Medicago polymorpha*	Th	Subcosmop.
197	*Medicago truncatula*	Th	Steno-Medit.
198	*Melica ciliata*	H	Euri-Medit.-Turan.
199	*Melica minuta* var. *arrecta*	H	Steno-Medit.
200	*Mentha aquatica*	H	Subcosmop.

	Species	Biological Spectrum	Chorological Spectrum
201	*Mentha pulegium*	H	Subcosmop.
202	*Micromeria graeca*	Ch	Steno-Medit.
203	*Micropyrum tenellum*	Th	Euri-Medit.-Occid.
204	*Milium scabrum*	Th	Medit.-Mont.
205	*Moenchia erecta*	Th	Sub-Medit.-Subalt.
206	*Molineriella minuta*	Th	Euri-Medit.
207	*Myosotis arvensis*	Th	Europeo-W-Asiat.
208	*Myosotis ramosissima*	Th	Europeo-W-Asiat.
209	*Narcissus tazetta*	G	Steno-Medit.
210	*Odontites luteus*	Th	Euri-Medit.
211	*Oenanthe fistulosa*	H	Eurasiat.
212	*Oenanthe pimpinelloides*	H	Medit.-Atl.
213	*Olea europea*	P	Steno-Medit.
214	*Ophrys tenthredinifera*	G	Steno-Medit.
215	*Orchis provincialis*	G	Steno-Medit.
216	*Ornithogalum corsicum*	G	Endem.
217	*Ornithopus compressus*	Th	Euri-Medit.
218	*Ornithopus pinnatus*	Th	Medit.-Atl.
219	*Orobanche minor*	Th	Paleotemp.
220	*Osyris alba*	NP	Euri-Medit.
221	*Paeonia morisii*	G	Europ.-Caucas.
222	*Pancratium illyricum*	G	Endem.
223	*Parentucellia latifolia*	Th	Euri-Medit.
224	*Parentucellia viscosa*	Th	Medit.-Alt.
225	*Petrorhagia dubia*	Th	S-Medit.
226	*Petrorhagia prolifera*	Th	Euri-Medit.
227	*Phagnalon rupestre*	Ch	W-S-Medit.
228	*Phalaris aquatica*	H	Steno-Medit.-Macatones.
229	*Phillyrea angustifolia*	P	Steno-W-Medit.
230	*Phillyrea latifolia*	P	Steno-Medit.
231	*Picris echioides*	H	Euri-Medit.
232	*Piptatherum miliaceum*	H	Steno-Medit.-Turan
233	*Pistacia lentiscus*	P	Steno-Medit.-Macatones.
234	*Plantago bellardii*	Th	S-Medit.
235	*Plantago coronopus*	H	Euri-Medit.
236	*Plantago lagopus*	Th	Steno-Medit.
237	*Plantago lanceolata*	H	Cosmopol.
238	*Poa bulbosa*	H	Paleotemp.
239	*Poa nemoralis*	H	Circumbor.
240	*Poa trivialis*	H	Eurasiat.

	Species	Biological Spectrum	Chorological Spectrum
241	*Polycarpon diphyllum*	Th	Steno-Medit.
242	*Polygala vulgaris*	H	Eurasiat.
243	*Polypodium australe*	H	Euri-Medit.
244	*Potentilla micrantha*	H	Euri-Medit.
245	*Potentilla recta*	H	NE.Medit.-Pontica
246	*Potentilla reptans*	H	Subcosmop.
247	*Prasium majus*	NP	Steno-Medit.
248	*Prunella laciniata*	H	Euri-Medit.
249	*Prunella vulgaris*	H	Circumbor.
250	*Prunus spinosa*	P	Europ.-Caucas.
251	*Pteridium aquilinum*	G	Cosmop.
252	*Pulicaria odora*	H	Euri-Medit.
253	*Pyrus spinosa*	P	Steno-Medit.
254	*Quercus ilex*	P	Steno-Medit.
255	*Quercus pubescens*	P	NW-Medit.
256	*Quercus suber*	P	W-Medit. (Euri-).
257	*Ranunculus bulbosus*	Th	Eurasiat.
258	*Ranunculus ficaria*	G	Eurasiat.
259	*Ranunculus macrophyllus*	H	SW-Medit.
260	*Ranunculus monspeliacus*	H	NW-Medit.
261	*Ranunculus ophioglossifolius*	Th	Euri-Medit.
262	*Ranunculus paludosus*	H	Steno-Medit.-Turan
263	*Ranunculus parviflorus*	Th	Medit.-Atl.
264	*Ranunculus velutinus*	H	N-Medit.
265	*Raphanus raphanistrum*	Th	Circumbor.
266	*Reichardia picroides*	H	Steno-Medit.
267	*Rhagadiolus stellatus*	Th	Euri-Medit.
268	*Rhamnus alaternus*	P	Steno-Medit.
269	*Romulea bulbocodium*	G	Steno-Medit.
270	*Rosa canina*	NP	Paleotemp.
271	*Rosa sempervirens*	NP	Steno-Medit.
272	*Rubia peregrina*	P	Steno-Medit.-Macatones.
273	*Rubus ulmifolius*	NP	Euri-Medit.
274	*Rumex acetosa*	H	Circumbor.
275	*Rumex acetosella*	H	Subcosmop.
276	*Rumex bucephalophorus*	Th	Medit.-Macarones.
277	*Rumex sanguineus*	H	Europ.-Caucas.
278	*Rumex thyrsoides*	H	W-Medit.
279	*Ruscus aculeatus*	H	Euri-Medit.
280	*Sanguisorba minor*	H	Subcosmop.

	Species	Biological Spectrum	Chorological Spectrum
281	*Sanicula europaea*	H	Orof. Paleotemp. -trop.
282	*Scolymus hispanicus*	H	Euri-Medit.
283	*Scorzonera callosa*	G	Illirico-Appenninica
284	*Sedum caeruleum*	Th	SW-Medit.
285	*Sedum stellatum*	Th	Steno-Medit.
286	*Senecio lividus*	Th	Steno-Medit.
287	*Senecio vulgaris*	Th	Cosmop.
288	*Serapias lingua*	G	Steno-Medit.
289	*Serapias parviflora*	G	Steno-Medit.
290	*Sherardia arvensis*	Th	Cosmop.
291	*Sideritis romana*	Th	Steno-Medit.
292	*Silene gallica*	Th	Cosmop.
293	*Silene laeta*	Th	SW-Medit.
294	*Silene latifolia*	H	Steno-Medit.
295	*Silene vulgaris*	H	Subcosmop.
296	*Sinapis pubescens*	Ch	SW-Medit.
297	*Sisymbrium officinale*	Th	Paleotemp.
298	*Sisymbrium orientale*	Th	Euri-Medit.
299	*Smilax aspera*	P	Paleotemp.
300	*Smyrmium* olusatrum	H	Euri-Medit.
301	*Smyrnium rotundifolium*	H	S-Medit.
302	*Sonchus tenerrimus*	Th	Steno-Medit.
303	*Spergula arvensis*	Th	Subcosmop.
304	*Spergularia rubra*	Th	Subcosmop.
305	*Spiranthes spiralis*	G	Europ.-Caucas.
306	*Stachys glutinosa*	Ch	Endem.
307	*Stellaria media*	Th	Cosmop.
308	*Tamus communis*	G	Euri-Medit.
309	*Teesdalia coronopifolia*	Th	Euri-Medit.
310	*Teline monspessulana*	P	Steno-Medit.-Macatones.
311	*Teucrium camaedrys*	H	Steno-Medit.-Occid.
312	*Teucrium massiliense*	Ch	Steno-Medit.-Occid.
313	*Thapsia garganica*	H	S-Medit.
314	*Tolpis umbellata*	Th	Steno-Medit.
315	*Tolpis virgata .*	H	Steno-Medit.
316	*Torilis africana*	Th	Subcosmop.
317	*Torilis nodosa*	Th	Euri-Medit.-Turan.
318	*Trifolium angustifolium*	Th	It: Medit, C; Nord:R
319	*Trifolium arvense*	Th	W-Paleotemp.
320	*Trifolium bocconei*	Th	Steno-Medit.

	Species	Biological Spectrum	Chorological Spectrum
321	*Trifolium campestre*	Th	W-Paleotemp.
322	*Trifolium cherleri*	Th	Euri-Medit.
323	*Trifolium diffusum*	Th	S-Europ.-Caucas.
324	*Trifolium glomeratum*	Th	Euri-Medit.
325	*Trifolium incarnatum*	Th	Euri-Medit.
326	*Trifolium lappaceum*	Th	Euri-Medit.
327	*Trifolium ligusticum*	Th	Steno-Medit.
328	*Trifolium nigrescens*	Th	Euri-Medit.
329	*Trifolium ochroleucon*	H	Pontico-Eurimedit.
330	*Trifolium pratense*	H	Subcosmop.
331	*Trifolium scabrum*	H	Euri-Medit.
332	*Trifolium stellatum*	Th	Euri-Medit.
333	*Trifolium strictum*	Th	Euri-Medit.
334	*Trifolium subterraneum*	Th	Euri-Medit.
335	*Trifolium tomentosum*	Th	Paleotemp.
336	*Tuberaria guttata*	Th	Euri-Medit.-Subalt.
337	*Umbilicus rupestris*	G	Medit.-Atl.
338	*Urospermum dalechampii*	H	Euri-Medit.-Centro-Occid.
339	*Urtica atrovirens*	H	Steno-Medit.
340	*Verbascum pulverulentum*	H	Centro e S-Europ.
341	*Verbena officinalis*	H	Cosmop.
342	*Veronica arvensis*	Th	Subcosmop.
343	*Veronica brevistyla*	Th	Endem.
344	*Vicia angustifolia*	Th	It: Centro
345	*Vicia benghalensis*	Th	Steno-Medit.
346	*Vicia cracca*	H	Circumbor.
347	*Vicia disperma*	Th	W-Medit.
348	*Vicia hybrida*	Th	Euri-Medit.
349	*Vicia lathyroides*	Th	Euri-Medit.
350	*Vicia lutea*	Th	Euri-Medit.
351	*Vicia sativa*	Th	Subcosmop.
352	*Vicia villosa*	Th	Euri-Medit.
353	*Viola dehnhardtii*	H	Euri-Medit.
354	*Viola riviniana*	H	Europeo.
355	*Vulpia ciliata*	Th	Euri-Medit.
356	*Vulpia fasciculata*	Th	Medit.-Atl.
357	*Vulpia geniculata*	Th	Steno-Medit.-Occid.
358	*Vulpia hybrida*	Th	Steno-Medit.-Occid.
359	*Vulpia ligustica*	Th	Steno-Medit.
360	*Vulpia myuros*	Th	Subcosmop.
361	*Vulpia sicula*	H	W-Medit. -Mont.
362	*Xanthium spinosum*	Th	Sudamer.

Vernal Makdissi
Biodiversity, grazing, wildfires and management of *Quercus suber* forest in the mountain of Bitti-Buddusò (NE – Sardinia)
Tesi di Dottorato in Monitoraggio e Controllo degli Ecosistemi Forestali in Ambiente Mediterraneo
Università degli Studi di Sassari

Annex 4. List of species present in Bitti-Buddusò.

	Species	Presence		Species	Presence
1	*Quercus suber*	10	**43**	*Linum triginum*	2
2	*Quercus ilex*	8	**44**	*Plantago lanceolata*	2
3	*Asphodelus ramosus*	7	**45**	*Poa nemoralis*	2
4	*Cistus salvaefolius*	7	**46**	*Rosa sempervirens*	2
5	*Geranium purpureum*	6	**47**	*Rumex acetosa*	2
6	*Leotodon tuberosus*	6	**48**	*Sanguisorba minor*	2
7	*Ranunculus bulbosus*	6	**49**	*Sherardia arvensis*	2
8	*Rubus ulmifolius*	6	**50**	*Stellaria media*	2
9	*Smyrmium olusatrum*	6	**51**	*Tamus communis*	2
10	*Pulicaria odora*	5	**52**	*Trifolium stellatum*	2
11	*Quercus pubescens*	5	**53**	*Allium vineale*	1
12	*Briza maxima*	4	**54**	*Anacamptis coriophora*	1
13	*Cistus monspeliensis*	4	**55**	*Antoxanthum odoratum*	1
14	*Clinopodium vulgare* subsp. *arundanum*	4	**56**	*Bellis perennis*	1
15	*Crepis leonthodontoides*	4	**57**	*Brachypodium distachyon*	1
16	*Cynosorus effisus*	4	**58**	*Cistus creticus* var. *eriocephalus*	1
17	*Holcus lanatus*	4	**59**	*Cyclamen repandum*	1
18	*Oenanthe pimpillenoides*	4	**60**	*Cynosorus polybracteatus*	1
19	*Poa bulbosa*	4	**61**	*Dactylis glomerata*	1
20	*Rubia peregrina*	4	**62**	*Daucus carota*	1
21	*Anacamptis morio* subsp. *longicornu*	3	**63**	*Eryngium campestre*	1
22	*Avena barbata*	3	**64**	*Ferula communis*	1
23	*Carex distachya*	3	**65**	*Helianthenum salicifolium*	1
24	*Crataegus monogyna*	3	**66**	*Hieracium zizianum*	1
25	*Cytisus villosus*	3	**67**	*Hyperichum perfoliatum*	1
26	*Luzula forsteri*	3	**68**	*Hypericum veronense*	1
27	*Pyrus spinosa*	3	**69**	*Jasione montana*	1
28	*Urospermum dalechampii*	3	**70**	*Lathyrus aphaca*	1
29	*Viola alba* subsp. *denhardtii*	3	**71**	*Lavandula stoechas*	1
30	*Achillea ligustica*	2	**72**	*Lolium rigidum*	1
31	*Arbutus unedo*	2	**73**	*Lupinus micranthus*	1
32	*Asparagus acutifolius*	2	**74**	*Ornithogalum corsicum*	1
33	*Brachypodium retusum*	2	**75**	*Phillyrea angustifolia*	1
34	*Bromus sterilis*	2	**76**	*Reichardia pichroides*	1
35	*Carlina corymbosa*	2	**77**	*Ruscus aculeatus*	1
36	*Cynosurus echinatus*	2	**78**	*Silene vulgare*	1
37	*Daphne gnidium*	2	**79**	*Stachys glutinosa*	1
38	*Erica arborea*	2	**80**	*Thapsia garganica*	1
39	*Galactites tomentosa*	2	**81**	*Trifolium campestre*	1
40	*Genista corsica*	2	**82**	*Vicia villosa*	1
41	*Geranium lucidum*	2	**83**	*Vulpia fasciculata*	1
42	*Hedera helix*	2			

Annex 6. List of species with correspondent authors.

Species	Species
Achillea ligustica All.	*Bellium bellidioides* L.
Agrostis pourretii Willd.	*Brachypodium distachyon* (L.) P. Beauv.
Aira caryophyllea L.	*Brachypodium retusum* (Pers.) P. Beauv.
Aira cupaniana Guss.	*Brachypodium sylvaticum* (Huds.) P. Beauv.
Aira elegans Willd.	*Brassica oleifera* Moench
Allium subhirsutum L.	*Briza maxima* L.
Allium triquetrum L.	*Briza minor* L.
Allium vineale L.	*Bromus hordaceus* L.
Alnus glutinosa (L.) Gaertn.	*Bromus madritensis* L.
Ammoides pusilla (Brot.) Breistr.	*Bromus rubens* L.
Anacamptis coriophora (L.) R.M. Bateman et al.	*Bromus scoparius* L.
Anacamptis morio (L.) R.M. Bateman et al. subsp. *longicornu* (Poir.) H. Kretzschmar et al.	*Bromus sterilis* L.
*Anacamptis papilionacea (*L.) R.M. Bateman, Pringedon et M.W. Chase	*Calamintha nepeta* (L.) Savi subsp. *glandulosa* (Req.) P.Q. Ball
Anagallis arvensis L.	*Calicotome villosa* (Por.) Link
Anagallis parviflora Hoffmanns. et Link	*Capsella bursa-pastoris* (L.) Medik.
Andryala integrifolia L.	*Cardamine hirsuta* L.
Anemone hortensis L.	*Carduus pycnocephalus* L.
Anthemis arvensis L.	*Carex distachya* Desf.
Anthoxanthum gracile Biv.	*Carex divisa* Hudson
Anthoxanthum odoratum L.	*Carex divulsa* Stokes in With.
Antractylis gummifera L.	*Carex flacca* Schreber
Arbutus unedo L.	*Carlina corymbosa* L.
Arisarum vulgare Targ. Tozz.	*Carthamus lanatus* L.
Aristolochia rotunda L. subsp. *insularis* (Nardi et Arrig.)	*Castanea sativa* Mill.
Asparagus acutifolius L.	*Catapodium rigidum* (L.) C.E. Hubb.
Asperula laevigata L.	*Centaurium erythraea* Rafn
Asphodelus ramosus L.	*Centaurium maritimum* (L.) Fritsch
Asplenium obovatum Viv.	*Centaurium pulchellum* (Swartz) Druce
Asplenium onopteris L.	*Cerastium glomeratum* Thuill.
Asterolinon linum-stellatum (L.) Duby	*Chamaemelum fuscatum* (Brot.) Vasc.
Atractylis gummifera L.	*Chamaemelum mixtum* (L.) All.
Avena barbata Pott. ex Link	*Chenopodium album* L.
Avena fatua L.	*Chrysanthemum segetum* L.
Avena sativa L.	*Cistus creticus* L. var. *eriocephalus* (Viv.) Greuter et Burdet
Bellardia trixago L.	*Cistus monspeliensis* L.
Bellis perennis L.	*Cistus salvaefolius* L.

Species	**Species**
Clematis cirrhosa L.	*Euonymus europaeus* L.
Clinopodium vulgare L. subsp. *arundanum* (Boiss.) Nyman	*Euphorbia characias* L.
Convolvulus arvensis L.	*Euphorbia exigua* L.
Coronilla scorpioides (L.) W.D.J. Koch	*Euphorbia helioscopia* L.
Crataegus monogyna Jacq.	*Euphorbia peplis* L.
Crepis leontodontoides All.	*Ferula communis* L.
Crepis vesicaria L.	*Filago gallica* L.
Crocus minimus DC.	*Filago germanica* (L.) Huds
Cruciata glabra (L.) Ehrend.	*Foeniculum vulgare* Mill.
Cruciata laevipes Opiz	*Fraxinus ornus* L.
Crupina crupinastrum (Moris) Vis.	*Fumana thymifolia* (L.) Spach ex Webb.
Cyclamen repandum Sm.	*Fumaria officinalis* L.
Cynara cardunculus L.	*Galactites tomentosa* Moench
Cynoglossum creticum Mill.	*Galium aparine* L.
Cynosorus effusus Link	*Galium divaricatum* Pourr. Ex Lam.
Cynosorus elegans Desf.	*Galium parisiense* L.
Cynosurus cristatus L.	*Galium rotundifolium* L.
Cynosurus echinatus L.	*Galium scabrum* L.
Cynosurus polybracteatus Poir.	*Gastridium ventricosum (*Gouan) Schinz et Thell.
Cyperus badius Desf.	*Gaudinia fragilis* (L.) Beauv.
Cytinus hypocistis (L.) L.	*Genista corsica* (Loisel.) DC. in Lam. et DC.
Cytisus villosus Pourret	*Geranium dissectum* L.
Dactylis glomerata L.	*Geranium lucidum* L.
Dactylorhiza insularis Ó. Sànchez et Herrero	*Geranium molle* L.
Daphne gnidium L.	*Geranium purpureum* Vill.
Dasypyrum villosum (L.) P. Candargy, non Borbás	*Geranium robertianum* L.
Daucus carota L.	*Gladiolus italicus* Mill.
Digitalis purpurea L.	*Glechoma sardoa* (Bég.) Bég.
Dipsacus fullonum L.	*Halimium halimifolium* (L.) Willk.
Drimia pancration (Steinh.) J.C. Manning et Goldblatt	*Hedera helix* L.
Echium creticum L.	*Hedypnois cretica* (L.) Dum. - Courset
Echium plantagineum L.	*Helianthemum salicifolium* (L.) Mill.
Erica arborea L.	*Helichrysum italicum* (Roth) G. Don
Erica scoparia L.	*Helichrysum italicum* (Roth) G. Don fil. in Loudon subsp. *microphyllum* (Willd.) Nyman
Erodium ciconium (L.) L'Hér.	*Hieracium zizianum* Tausch subsp. *sardonium* Zahn
Eryngium campestre L.	*Holcus lanatus* L.
Eryngium tricuspidatum L.	*Holcus mollis* L.
Erythraea maritima (L.) Pers.	*Hordeum bulbosum* L.

Species	**Species**
Hordeum leporinum Link	*Lotus ornithopodioides* L.
Hyoseris radiata L.	*Lupinus angustifolius* L.
Hypericum perfoliatum L.	*Lupinus micranthus* Guss.
Hypericum veronense Schrank	*Luzula forsteri* (Sm.) DC.
Hypochaeris achyrophorus L.	*Malva sylvestris* L.
Hypochaeris glabra L.	*Marrubium vulgare* L.
Hypochaeris pinnatifida Cyr. ex Ten.	*Matricaria chamomilla* L.
Hypochaeris radicata L.	*Medicago arabica* (L.) Huds.
Ilex aquifolium L.	*Medicago murex* Willd.
Jasione montana L.	*Medicago polymorpha* L.
Juncus conglomeratus L.	*Medicago truncatula* Gaertn.
Juncus pygmaeus L.M.C. Rich.	*Melica ciliata* L.
Lactuca muralis (L.) Gaertn.	*Melica minuta* L. var. *arrecta* (G. Kuntze) Fiori
Lagurus ovatus L.	*Mentha aquatica* L.
Lamium maculatum (L.) L.	*Mentha pulegium* L.
Lathyrus angulatus L.	*Micromeria graeca* (L.) Benth. ex Rchb.
Lathyrus aphaca L.	*Micropyrum tenellum* (L.) Link
Lathyrus cicera L.	*Milium scabrum* L.C.M. Rich.
Lathyrus hirsutus L.	*Moenchia erecta* (L.) P. Gaertner, Meyer et Scherb.
Lathyrus latifolius L.	*Molineriella minuta* (L.) Rouy
Lathyrus sphaericous Retz.	*Myosotis arvensis* (L.) Hill.
Lavandula stoechas L.	*Myosotis ramosissima* Rochel
Legousia hybrida (L.) Delarbre	*Narcissus tazetta* L.
Leontodon tuberosus L.	*Odontites luteus* (L.) Clairv.
Leopoldia comosa (L.) Parl.	*Oenanthe fistulosa* L.
Limodorum abortivum (L.) Swartz	*Oenanthe pimpinelloides* L.
Linaria arvensis (L.) Desf.	*Olea europea* L.
Linaria pelisseriana (L.) Mill.	*Ophrys tenthredinifera* Willd.
Linum bienne Mill.	*Orchis provincialis* Balb. ex Lam. et DC.
Linum strictum L.	*Ornithogalum corsicum* Jord. et Fourr.
Linum trigynum L.	*Ornithopus compressus* L.
Linum usitatissimum L.	*Ornithopus pinnatus* (Miller) Druce
Lolium multiflorum Lam.	*Orobanche minor* Sm.
Lolium perenne L.	*Osyris alba* L.
Lolium rigidum Gaudin	*Paeonia morisii* Cesca, Bernardo et Passal.
Lonicera implexa Aiton	*Pancratium illyricum* L.
Lotus angustissimus L.	*Parentucellia latifolia* L.
Lotus conimbricensis Brot.	*Parentucellia viscosa* (L.) Caruel

Species	**Species**
Petrorhagia dubia (Raf.) G. López et Romo	*Ranunculus parviflorus* L.
Petrorhagia prolifera (L.) P.W. Ball et Heywood	*Ranunculus velutinus* Ten.
Phagnalon rupestre (L.) DC.	*Raphanus raphanistrum* L.
Phalaris aquatica L.	*Reichardia picroides* (L.) Roth
Phillyrea angustifolia L.	*Rhagadiolus stellatus* (L.) Gaertn.
Phillyrea latifolia L.	*Rhamnus alaternus* L.
Picris echioides L.	*Romulea bulbocodium* (L.) Sebast. et Mauri
Piptatherum miliaceum (L.) Cosson	*Rosa canina* L.
Pistacia lentiscus L.	*Rosa sempervirens* L.
Plantago bellardii All.	*Rubia peregrina* L.
Plantago coronopus L.	*Rubus ulmifolius* Schott
Plantago lagopus L.	*Rumex acetosa* L.
Plantago lanceolata L.	*Rumex acetosella* L.
Poa bulbosa L.	*Rumex bucephalophorus* L.
Poa nemoralis L.	*Rumex sanguineus* L.
Poa trivialis L.	*Rumex thyrsoides* Desf.
Polycarpon diphyllum Cav.	*Ruscus aculeatus* L.
Polygala vulgaris L.	*Sanguisorba minor* Scop.
Polypodium australe Fée	*Sanicula europaea* L.
Potentilla micrantha Ramond ex DC.	*Scolymus hispanicus* L.
Potentilla recta L.	*Scorzonera callosa* Moris
Potentilla reptans L.	*Sedum caeruleum* L.
Prasium majus L.	*Sedum stellatum* L.
Prunella laciniata (L.) L.	*Senecio lividus* L.
Prunella vulgaris L.	*Senecio vulgaris* L.
Prunus spinosa L.	*Serapias lingua* L.
Pteridium aquilinum (L.) Kuhn	*Serapias parviflora* Parl.
Pulicaria odora (L.) Rchb.	*Sherardia arvensis* L.
Pyrus spinosa Forssk.	*Sideritis romana* L.
Quercus ilex L.	*Silene gallica* L.
Quercus pubescens Willd.	*Silene laeta* (Ait.) Godron
Quercus suber L.	*Silene latifolia* Poir.
Ranunculus bulbosus L.	*Silene vulgaris* (Moench) Garke
Ranunculus ficaria L.	*Sinapis pubescens* L.
Ranunculus macrophyllus Desf.	*Sisymbrium officinale* (L.) Scop.
Ranunculus monspeliacus L.	*Sisymbrium orientale* L.
Ranunculus ophioglossifolius Vill.	*Smilax aspera* L.
Ranunculus paludosus Poiret	*Smyrmium olusatrum* L.

Species	Species
Smyrnium rotundifolium Miller	*Trifolium stellatum* L.
Sonchus tenerrimus L.	*Trifolium strictum* L.
Spergula arvensis L.	*Trifolium subterraneum* L.
Spergularia rubra (L.) J. et C. Presl.	*Trifolium tomentosum* L.
Spiranthes spiralis (L.) Chevall.	*Tuberaria guttata* (L.) Fourr.
Stachys glutinosa L.	*Umbilicus rupestris* (Salisb.) Dandy
Stellaria media (L.) Vill.	*Urospermum dalechampii* (L.) F.W. Schmidt
Tamus communis L.	*Urtica atrovirens* Req. ex Loisel.
Teesdalia coronopifolia (J.P. Bergeret) Thell.	*Verbascum pulverulentum* Vill.
Teline monspessulana (L.) C. Koch	*Verbena officinalis* L.
Teucrium camaedrys L.	*Veronica arvensis* L.
Teucrium massiliense L.	*Veronica brevistyla* Moris
Thapsia garganica L.	*Vicia angustifolia* L.
Tolpis umbellata Bertol.	*Vicia benghalensis* L.
Tolpis virgata (Desf.) Bertol.	*Vicia cracca* L.
Torilis africana Spreng.	*Vicia disperma* DC.
Torilis nodosa (L.) Gaertn.	*Vicia hybrida* L.
Trifolium angustifolium L.	*Vicia lathyroides* L.
Trifolium arvense L.	*Vicia lutea* L.
Trifolium bocconei Savi	*Vicia sativa* L.
Trifolium campestre Schreb.	*Vicia villosa* L.
Trifolium cherleri L.	*Viola dehnhardtii* Ten.
Trifolium diffusum Ehrh.	*Viola riviniana* Rchb.
Trifolium glomeratum L.	*Vulpia ciliata* Dumort
Trifolium incarnatum L.	*Vulpia fasciculata* (Forssk.) Samp.
Trifolium lappaceum L.	*Vulpia geniculata* (L.) Link
Trifolium ligusticum Balbis ex Loisel.	*Vulpia hybrida* (Brot.) Pau
Trifolium nigrescens Viv.	*Vulpia ligustica* (All.) Link
Trifolium ochroleucon Huds.	*Vulpia myuros* (L.) C.C. Gmel.
Trifolium pratense L.	*Vulpia sicula* (C. Presl.) Link
Trifolium scabrum L.	*Xanthium spinosum* L.