System Report:
Grazed Oak Woodlands in Sardinia, Italy

Project name	AGFORWARD (613520)
Work-package	2: High Natural and Cultural Value Agroforestry
Specific group	Grazed oak woodland in Sardinia, Italy
Deliverable	Contribution to Deliverable 2.4: Detailed system description of a case study system
Date of report	30 December 2015
Authors	Federico Sanna, Giovanni Antonio Re, Antonello Franca
Contact	federico.sanna@cnr.it; giovanniantonio.re@cnr.it; antonio.franca@cnr.it
Approved	Gerardo Moreno (3 May 2016); Paul Burgess (8 May 2016)

Contents

AGFORWARD (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to Objective 2, Deliverable 2.4: "Detailed system description of case study agroforestry systems". The detailed system description covers the agroecology of the grazed oak woodland and its components (trees, pasture/forage crops and livestock), main marketable products, key ecosystem services. This report contributes to one of the AGFORWARD objectives, to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape-scales, showing the preliminary results of a pre-existing and still in progress study carried out in Sardinia, Italy. The experimental site of Monte Pisanu is one of the few Sardinian forests managed by the Regional Forestry Office (Ente Foreste della Sardegna) where grazing is permitted inside an oak woodland of high nature value.

2 Background

The Mediterranean Basin is one of 25 global hotspots of biodiversity with over 25,000 vegetal species and 770 vertebrate species (Meyers et al. 2000). Forests of *Quercus suber* L., *Quercus ilex* L. and *Quercus pubescens* Willd. are widespread in the Mediterranean. In many of these areas, the management system comprises silvopastoralism where trees, shrubs and herbaceous species are integrated with livestock.

The agro-silvopastoral systems of the Dehesa in Spain and the Montado in Portugal occupy about 7 million hectares of the Iberian Peninsula. In Greece, the Phrygana comprises short, often spiny, shrubs managed by grazing and occasional fires. Grazed oak woodlands are also widespread in Sardinia and they have an important socio-economic role providing rural employment and a range of ecosystem services (Seddaiu et al. 2013; Rossetti et al. 2015). From an ecological point of view, the appropriate management of grazing, in line with forage availability and quality, is important for the conservation of high biodiversity.

3 Description of the system

The island of Sardinia, in the Western Mediterranean area, extends over 24,090 km^2. The climate is characterized by hot and dry summers and mild winters, with rainfall concentrated in the autumn and spring. However the rainfall distribution shows a marked intra- and inter-annual variability, and the dry season can extend for 4-5 months. The rainfall and the mean annual temperature vary from 400-500 mm and 17°C along coasts to 1000-1200 mm and 12-13°C on inland mountains.

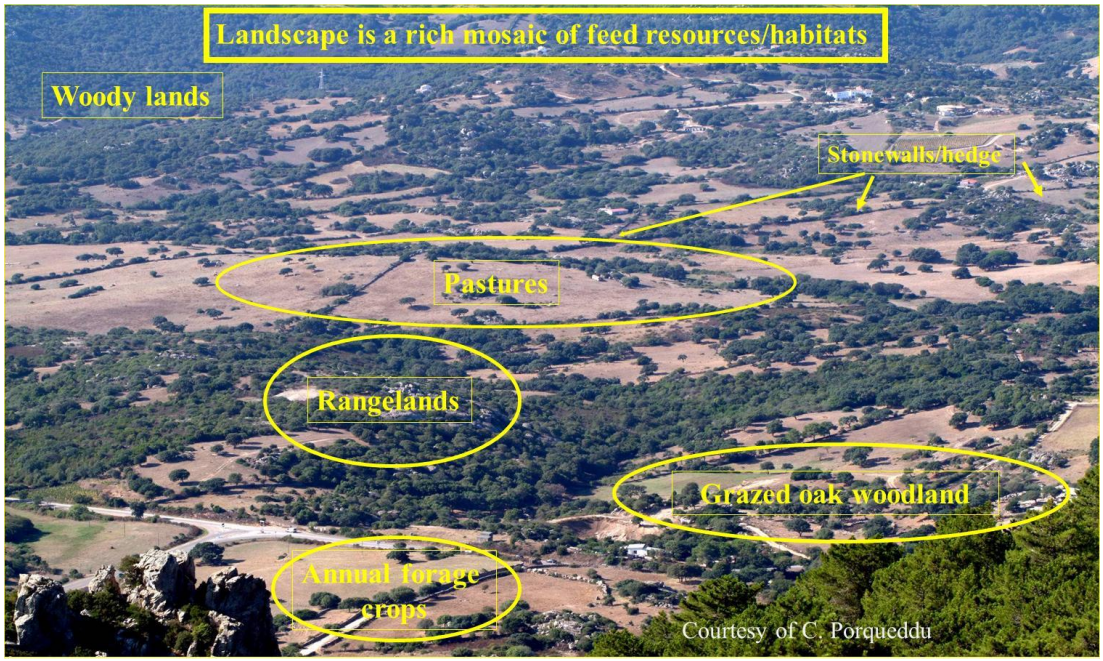


Figure 1. Sardinian typical landscape of rural areas

The island comprises mountains and hills, with the highest peak in the Gennargentu relief reaching 1834 m, although the mean altitude (380 m) is relatively low. The soils are derived from metamorphic, granite, limestone, acid and basic volcanic rocks and often are poorly structured. About 90% of the territory is considered as disadvantaged areas as designated by measure E in EU Directive 1257/99. Extensive deforestation occurred in the second half of the nineteenth century associated with the requirement of timber for railways and the start of extensive sheep breeding. Forests occupy about 5800 km^2 mainly within the hilly and mountain areas of the island. About 2000 km^2 are public and managed by the Regional Forestry Office. However if "other wooded areas" are included, Sardinia now has the largest area of tree cover of any Italian region (1,213,250 ha equivalent to 50% of the area). The Sardinian rural landscape comprises a mosaic of extensive cereal-farming systems and agro-silvopastoral systems at different level of complexity and integration. In the silvopastoral systems, livestock graze for the complete year using different feed resources (grasses, shrubs and trees) sometimes on common land and sometimes in mixed grazing (typically sheep, goats and beef cattle, and to a lesser extent pigs) (Figure 1).

Unfortunately, there is no comprehensive map of Sardinian agro-silvopastoral systems and at present there is no census of grazed forests, grazed woodlands, wooded grasslands and shrublands. However, Sedda et al. (2011) have attempted to estimate the surface covered by different oak-based formations in Sardinia, according to the most recent land use map:

1) Mixed forests composed of cork and deciduous oaks, and Mediterranean shrubs, without any cork production interest, covers 355,411 ha
2) Pure stands of cork oak forests, in which the trees are mainly cork oaks (*Quercus suber* L.), cover about 84,763 ha;
3) Low-density cork oak populations, usually associated with tilled land, are estimated to cover 53,178 ha.

Both latter systems can be considered productive in terms of cork extraction and contribute significantly to the local economy. About 80% of the Sardinian pure cork oak forests are privately

owned and characterised by high fragmentation and small average size (between 10 and 20 ha). Therefore, in Sardinia the total area of natural cork oak trees (pure and mixed) is estimated to total 493,352 ha equivalent to 20% of the surface. The productive cork oak forests and cork farms contribute 150,000,000 Euros per year through the production of cork bottle stoppers (Sedda et al. 2011; RAS 2007). Also, Rossetti et al. (2015) reported that Dehesa-like systems (wooded grasslands with cereal/fodder crops or semi-natural grass–herbs communities mixed with a tree layer mostly dominated by oak trees) cover about 113.000 ha (4.7% of the regional surface and 9.8% of the total agricultural land) (RAS 2013; ISPRA 2014). Sardinian wooded grasslands, often tilled and sown every two to eight years to grow annual mixtures for grazing and/or hay production, are mainly dominated by cork oak, with tree densities ranging from 7 to 250 ha^{-1} and are generally concentrated in the hilly northern and central areas.

Cork production is important to the Sardinian economy with an annual production of around 17,000 -20,000 tonnes. Most cork-related businesses are located inside the District of Calangianus and Tempio which handle about 70% of all cork produced in Italy. Although small compared to European production, Sardinian cork is of high quality and 60-70% is used in the wine sector. These Dehesa-like systems are principally grazed by sheep and cattle (Rossetti and Bagella 2014), but in most pure stands of cork oak, grazing is excluded and when shrubs are cleared mechanically when encroachment occurs. Beyond cork oak forests, there are Sardinian agro-silvopastoral systems (mostly under private ownership) that combine cereals, pastures and forage crops that could exceed 400,000 ha. In the public silvopastoral areas, farmers share grazing rights and agree on the partitioning of the grazing area. Subsidies (e.g. subsidies for compensation of natural handicaps) have so far kept most systems viable even if at low-income conditions.

Ecosystem services provided by Sardinian grazed oak woodlands

Re et al. (2014) reported that plant diversity of herbaceous understorey communities was higher under grazing conditions following a four-year study at Monte Pisanu (See Section **). The Shannon index in a grazed oak woodland (range: 2.49 to 4.77; mean = 3.7) was greater than that (range: 1.31 to 3.82; mean = 2.7) in the ungrazed canopy.

Regarding soil properties, under semi-arid Mediterranean conditions, Vacca (2000) compared the forest floor litter features between a dense (400 trees ha^{-1}) *Q. suber* forest mainly used for cork production and a wooded grazed grassland with about 40 *Q. suber* trees ha^{-1}. The organic C content in the floor litter ranged from 10 to 22 t ha^{-1} in the dense oak forest and from 3 to 11 t ha^{-1} in the wooded pasture. Assuming a litter C content of 490 g kg^{-1} of dry biomass from the oak trees (Vesterdal et al. 2012), results by Rossetti et al.,(2015) were comparable with those reported for the wooded pasture. Lagomarsino et al. (2011) found that total organic carbon observed in *Q. suber* forest soil was 25.1 g C kg^{-1}.

Francaviglia et al. (2014) evaluated some soil quality parameters of an agro-silvopastoral system in north-eastern Sardinia, Italy (Table 1). Good levels of soil organic matter and nitrogen were found under the cork oak forest and more conservative management systems such as the no-tilled grassed vineyard and pasture. In the surface layer, the soil organic matter and the total nitrogen in the cork oak forest was greater than in the no-tilled grazed vineyard.

Table 1. Mean (± ES) soil organic carbon (SOC) and total nitrogen (TN) expressed as concentrations and stocks and land uses (from Francaviglia et al. 2014)

Land use and depth	Soil organic matter (g kg^{-1})		Total nitrogen (g kg^{-1})	
	0-20	20-50	0-20	20-50
Tilled vineyard	14.2 ab	9.9 ab	0.99 ab	0.75 abc
No-tilled grazed vineyard	11.0 a	6.0 a	0.93 a	0.50 ab
Hay crop	24.3 c	15.5 c	1.73 c	1.01 c
Pasture	18.7 abc	10.2 ab	2.08 c	0.99 c
Cork oak forest	21.8 bc	5.0 a	1.69 bc	0.44 a
Semi-natural system	17.0 ab	14.4 bc	1.07 ab	0.75 bc

Different letters within each soil depth indicate significant differences ($p < 0.05$)

Seddaiu et al. (2013) evaluated the impact of soil management on soil organic matter quantity and quality in a semi-arid Mediterranean dehesa-like agroforestry system by analysing the humic substances (fulvic acids, humic acids and humin) of the surface soil horizons. They reported that in oak forest soils, the sharp decrease in organic carbon with depth below the high levels in the surface 4 cm might reduce the resilience of these soils to disturbance. They also identified the benefit of grazing in reducing wildfires by decreasing fuel biomass and reducing the probability of fire propagation, rate of spread and fireline intensity (Franca et al., 2012, see the following "Description of the site" paragraph for more details).

In some cases, silvopastoral areas on common land can be under pressure of overgrazing due to year-round grazing, large herd/flock sizes, the agronomic and physical marginality of the areas, and incorrect management. Moreover recurring wild fires, climate change, human settlement and abandonment of agricultural land can increase the risk of environmental degradation.

Preliminary studies indicate that High Nature Value areas in Sardinia (mostly grazed grassland and rangelands) cover roughly 50% of Utilized Agricultural Area (AAVV PSR, 2007). An EU map indicates that about 1,200,000 ha of Sardinian farmland is considered to be of high nature value, equal to the 65.4% of the agricultural land, one of the highest proportions in Italy outside of the Alps. About 30% of Sardinian forests (176,450 ha) may be considered on high nature value, on the basis of the guidelines provided by the European Evaluation Network for Rural Development, which is consistent with the National Forest Inventory data.

3.1 Regional Policy

The Rural Development Programme (RDP) 2007-2013 drawn up by Sardinian Administration allocated 37% of the budget (586 million Euros) in the first axis which aims to improve competitiveness of agricultural and forestry sector. About 45% was allocated to the second axis (about 700 million Euros) and covered topics such as safeguarding the environment, improving animal welfare, providing support for farmers in disadvantaged areas, and the protection and expansion of agroforestry systems of high natural value. However forest policy in Sardinia is very restrictive of grazing in woods. Grazing is allowed from 15 April to 15 July, in order to reduce the fuel and the fire hazard, for maximum of 3 sheep ha^{-1} and 0.5 cattle ha^{-1}. In the remaining periods, grazing is restricted to a maximum of 1 sheep ha^{-1} or 0.2 cows ha^{-1}. Grazing is prohibited in newly planted woods, or woods recently fully or partially cut or burnt by fire, until young plants and new

shoots are likely to avoid damage. Grazing can also be prohibited in old woods. In woods owned by municipalities, grazing may be exercised in compliance with the above cited rules and after the approval of the concerned municipality. Moreover, in the woods and in the lands covered by shrubs with protective function, grazing by goats is prohibited.

In 2007, Sardinia approved a Regional Forest and Environment Plan (Piano Forestale ed Ambientale della Regione, PFAR). This plan provides strategies for the promotion, protection and enhancement of forest resources and central role for sustainable forest management. The PFAR addresses challenges such as soil protection, fire prevention, sustainable agricultural practices, and protection of biodiversity. Within the PFRA, agroforestry and pastoral practices have a role in protecting biodiversity in agroforestry landscapes, such as wooded pastures with cork oaks, and cork oak forests, whilst recognising that trees need to be regenerated and maintained. However the plans within the PFAR will only be fully applied with the introduction of specific measures (in the RDP and with the support of stakeholders) to support the environmental role of pastoralism in forest areas.

3.2 Initiatives to promote High Nature and Cultural Value agroforestry

Sardinian silvopastoral systems need to be maintained and new policy strategies need to be proposed. The 2007-2013 Regional RDP did not seem to encourage and fund silvopastoral systems. Pure stands of cork oak and the other intensive cork-production systems were incentivized. Although hay and cereal production could be integrated with cork production (silvoarable systems), grazing (e.g. a silvopastoral system) was excluded. Typical silvopastoral systems, such as grazed mixed forests composed of cork and deciduous oaks, and Mediterranean shrubs do not receive specific incentives, and their ecosystem benefits (although clearly demonstrated) are not recognized by regional policy makers. Perhaps a more active policy of silvopastoral development in Sardinia could follow the rules introduced in the French Southern Alps, where agri-environmental contracts (MAE) recognize the landscape and biodiversity benefits of silvopastoralism (Legeard 2004).

3.3 Tree component

Most silvopastoral systems in Sardinia include holm oak, cork oak or deciduous oak. Holm oak woods dominate the forest landscape of Sardinia (Pignatti 1998), because *Quercus ilex* has a wide ecological range extending from sea level to above 1400 m (Camarda and Valsecchi 1983). Caballero et al. (2009) have described the main Italian Large Scale Grazing Systems (LSGS) with a specific focus on the Sardinian sector. Regarding the forest landscapes, the following associations have been recognized (Arrigoni et al. 1985, 1990; Biondi et al. 2001: Bacchetta et al. 2004a, 2009):

1) *Pyro amygdaliformis-Quercetum ilicis* which includes the edapho-mesophile holm oak and cork oak vegetation of the alluvial plains of a mixed clay-sand matrix on moderately hydromorphic soils (e.g. Nurra and Alto Campidano);
2) *Prasio majoris-Quercetum ilicis* which includes thermophile communities on different substrata under 400-500 m (e.g. Nurra, Logudoro, Montiferru, Gallura);
3) *Galio scabri-Quercetum ilicis*, which includes evergreen woods located between 600 and 1000 m on different substrata (e.g., Gallura, Montiferru, Planargia Sulcis and central-eastern Sardinia);
4) *Saniculo europaeae-Quercetum ilicis* which includes mainly the acidophilic woodlands of *Q. ilex* and *Ilex aquifolium* of the metamorphic and volcanic substrata of central-northern Sardinia between 660 and 1100 m (e.g. Goceano and Montiferru);

5) *Aceri monspessulani-Quercetum ilicis calcicole monîane* holm oak woods of the limestone substrata of central-eastern and southern Sardinia.

Serra et al. (2002) and Rivas-Martínez et al. (2003) have also recognized the presence of autonomous associations of *Q. suber* within the alliance *Quercion ilicis* (suballiance *Quercenion ilicis*) in Sardinia (Bacchetta et al. 2004a):

6) *Galio scabri-Quercetum suberis*, which includes cork-oak meso-woods on granites and metamorphic substrata between 200 and 550 m in Gallura, Sulcis, Sarrabus and Iglesiente, often subjected to intense use for the extraction of cork and/or as wooded pasture;
7) *Violo dehnhardtii-Quercetum suberis*, which includes the neutroacidophile cork-oak meso-woods on volcanic substrata of north-western Sardinia, at altitudes between 50 and 700 m and mainly subjected to an intense pastoral use, with the formation of wooded pastures (Bagella and Caria, 2010).

Deciduous oak woods have been referred to three associations (Bacchetta et al. 2004b):

1) *Lonicero implexae-Quercetum virgilianae* which includes thermophile communities on carbonated substrata mainly throughout Northern Sardinia,
2) *Ornithogalo pyrenaici-Quercetum ichnusae* more widely distributed in central-northern Sardinia on non-carbonated substrata between 200-1000 m, and
3) *Glechomo sardoae-Quercetum congestae* on basalts, metamorphites and granite between 750-1000 m.

3.4 Grass component

As in most Mediterranean semi-arid environments, most woodlands, grasslands and rangelands comprise annual self-seeding grasses. Hot, dry summers and unpredictable autumn rains favour species that spend the summer in seed form, before germinating with the autumn rains. Annual self-regenerating legumes also play a special role for their forage quality and capacity to fix atmospheric nitrogen (Crespo 1997). As explained by Porqueddu and Gonzales (2006), subterranean clovers such as *Trifolium subterraneum* L., *T. brachycalycinum* Katzn. and Morley, *T. yanninicum* Katzn. and Morley are key species in Mediterranean pastures. They are essential in any pasture improvement of semiarid zones with acid, neutral or lightly alkaline soils (Frame et al. 1997). They are important because of their good winter growth, high reseeding capacity, prostrate habit in relation to grazing, and high persistence. On alkaline or lightly acid soils in areas of low and medium rainfall (250-600 mm), annual *Medicago* species can also be important., and are better adapted than clovers to hard and clay soils. *M. polymorpha* is adapted to acid and alkaline and sandy loam and clay soils (Loi et al. 1995). Murex medic (*M. murex* Willd.) is tolerant to acid soils (from pH 4.5 up to alkali) while barrel medic (*M. truncatula* Gaertn.) and snail medic (*M. scutellata* Mill.) grow well in heavy neutral to alkaline soils. Other less common commercial species are gama medic (*M. rugosa* Desr), strand medic (*M. littoralis* Rhode) and disc medic (*M. tornata* Mill.). Yellow serradella (*Ornithopus compressus* L.) is another species widely distributed in the Mediterranean regions and recognised to be successful on acid and sandy soils, especially in granitic soils where subclovers and medics are not productive. It grows best in well drained soils but does not tolerate waterlogged conditions.

In mountain grasslands, where temperate and drought is not so limiting, the pastures are dominated by perennial grasses, prostrate chamaephytes and hemicryptophytes. They are typically associated with sheep grazing. Such pastures can be very productive, drying up in early summer, growing fast

with autumnal rainy season and remaining green during winter (Rivas-Martínez et al. 2001). They are also important for biodiversity conservation, hosting several endemic species.

A general description of the grazed the grazed oak woodlands in Sardinia is provided in Table 2.

Table 2. General description of agroforestry systems in Sardinia

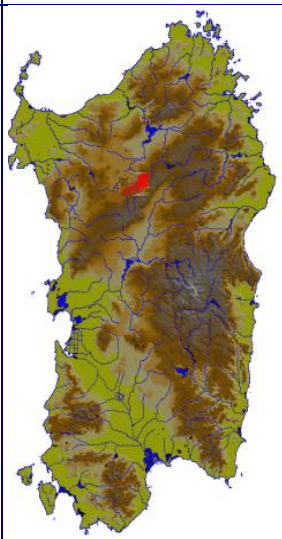
General description of system	
Geographical extent	Extensive and semi-extensive grazing systems in Sardinia encompass some 15,000 km^2 with a variety of sub-types across the island.
Typical grazing systems	Extensive cattle are dominant in the Gallura mountains and goats are dominant in the hilly and mountain areas of Sulcis-Iglesiente, Sarrabus and Ogliastra. Semi-extensive dairy sheep are present in the province of Sassari (Nurra, Logudoro) and in the south lowlands. Semi-extensive dairy sheep and cattle are dominant in the hills of Planargia, Marghine, and Goceano and mixed grazing, including pigs, is dominant in the Gennargentu mountains.
Description	The Sardinian silvopastoral systems have different and high levels of complexity. On private and public lands they are based on the use of i) trees and shrubs, ii) native and sowed pastures iii) annual forage crops (vetch + oats) and iv) cereals (barley, oats). Grazers are sheep, goats, beef cattle and pigs
Tree species	*Quercus pubescens* L, *Quercus suber* L and *Quercus ilex* L.
Grass species	Native pastures (annual and perennial species): perennial grasses (*Lolium perenne* L, *Dactylis glomerata* L.) and annual legumes (subclovers and medics)
Tree products	Cork and timber wood
Pasture utilization	Native understorey pastures are grazed directly by livestock
Animal species	Dairy sheep and extensive cattle
Animal products	Sheep milk mainly for industrial cheese production (Pecorino Romano PDO, Pecorino Sardo PDO and Fiore Sardo PDO). Lamb meat (Agnello di Sardegna PGI). Cattle meat.
Habitat services and biodiversity	Grazed oak woodlands and the associated agroforestry practices play an important socio-economic role in rural livelihoods and provide ecosystem services. From an ecological point of view, an adequate grazing management, related with the potential forage availability and quality, can encourage the conservation of high biodiversity.
Cultural services	Grazed oak woodland in public forests give social and environmental benefits such as wildfire protection, wildlife habitat, and areas of high cultural value for tourism
Key references	See end of report

4 Study site: Monte Pisanu

Monte Pisanu is a state forest, which was first protected by royal decree in 1886 (Figure 5). A description of the site at Monte Pisanu is provided in Table 3. It stretches among the mountains of the municipalities of Bono and Bottidda, in the Goceano, and has an overall surface area of 1994 hectares.

Figure 2. General view of the landscape of the Monte Pisanu site

Table 3. Description of the Monte Pisanu site

Specific description of site	
Area	2000 ha
Geographical position	  Figure 3. View of pasture within a silvopasture system
Site contact	Giovanni Piras (Ente Foreste della Sardegna, EFS - *Regional Forest Office of Sardinia*)
Site contact email	gi.piras@gmail.com

Map of system

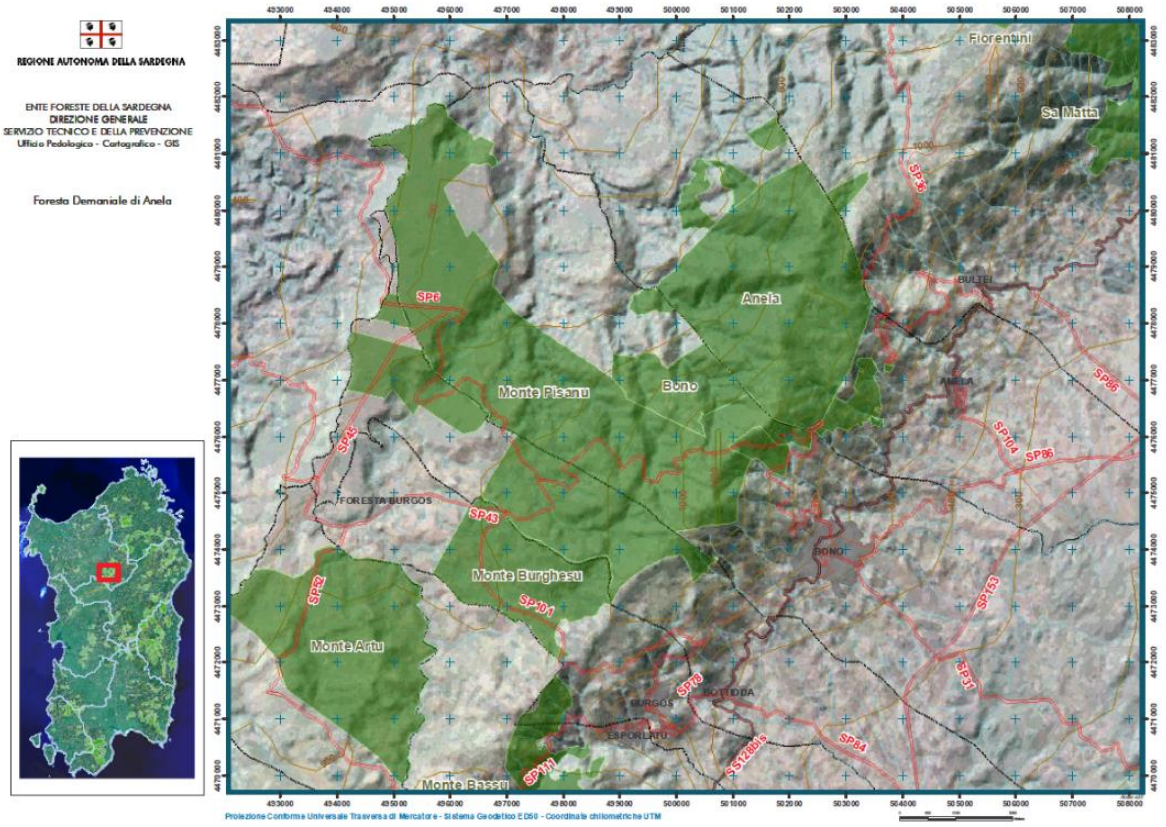


Figure 4. Map of the system

Possible modelling scenarios	
Comparison	Agro-ecological and technical analysis of grazing v not grazing
Climate characteristics	
Mean temperature	13 (± 5.8 SD) °C
Mean annual precipitation	908.5 (± 40 SD) mm
Details of weather station (and data)	Data from 1970 to 1979 from a ARPAS stations (Regional Agency of Environment Protection)
Soil	
Soil types	FAO classification: Eutric and Dystric Cambisol. Dystric and Lithic Leptosol
Soil depth	Variable: 0 – 50 cm
Soil texture	Variable: Loam to Sandy loam
Aspect	Variable: South West – North – North West
Livestock management	
Species and breed	Sarda sheep; Sarda cattle
Description of livestock system	Grazing is carried out by Sarda dairy sheep where tree canopy is less dense or open (gaps, cleared areas). Sarda cattle graze even under more dense tree canopies. Grazing is rotational heavy for dairy sheep and continuous light for cattle, with an estimated livestock of 650 L.U. per year on a total surface of 2000 ha. On more productive areas, sheep grazing pressure is heavy from September to beginning of November, before lambing.
Grazing behaviour	It is a vertical transhumance during summer and autumn for dairy sheep. During winter (from December to March), sheep graze in the plain.

	Cattle stay up on the mountain all the year and, after calving, they are free to graze everywhere
Stocking density	Grazing official authorizations for 2014 (released by EFS) for 3000 sheep and 120 cattle
Requirements	Sheep and cattle may need access to hay and water
Typical level of sheep production	Dairy sheep production may be estimated in about 0.5- 0.8 l of milk day^{-1} Daily milk production: 700-1500 l , totally sell to cheese industry

4.1 Climate

The climate of this area is bi-seasonal, with rain in the autumn-winter period and an almost completely dry spring and summer season, which can be aggravated by intense winds. The frequency of snowfall in mountainous areas of central Sardinia does not exceed 5-10 days per year. Frost can occur in the autumn, winter and spring.

4.2 Geology and soils

The geology comprises volcanic soils and clastic deposits which can permeable and fractured near the land surface, but less permeable at depth. Soils derived from crystalline schists are present across the island which have high levels of potassium, moderate contents of phosphoric anhydride, and low contents of calcium and clay.

4.3 Vegetation

The landscape vegetation at Monte Pisanu is dominated by downy oak (*Quercus pubescens* L.) that extend up to more than 1000 m above sea level. The downy oaks often have a bushy habit and are interspersed with small mountain meadows. There are no trees around the summit of Monte Rasu (1259 m), the highest peak in the area, where the vegetation is restricted to thyme, helichrysum and rockrose. However areas of oak and maple trees, with some holly, coexist on the east side of Mount Rasu (which has been less affected by fires and logging). At lower altitudes, the vegetation mainly consists of cork oaks and holm oaks; at Pedra Rujas there is an important monumental cork oak. A key feature of the forest, in the area of Sos Nibberos, is a biotope of millennial European yews (*Taxus baccata* L.) which was declared a natural monument in 1994. The trees have diameters of about 1 m and rise to over 10 m in height. In recent years, there has been some habitat restoration of some oak coppices focused on the partial or total removal of conifers. Formations of which

Figure 5. Some views of the Monte Pisanu site

4.4 Fauna

The forests of the Goceano area (that covers north-central Sardinia) are home to reptiles such as the pygmy keeled lizard (*Algyroides fitzingeri*), the European leaf-toed gecko (*Phyllodactylus europaeus*), the grass snake (*Natrix natrix*), Hermann's tortoise (*Testudo hermanni*), the European pond turtle (*Emys orbicularis*) and three-toed skink (*Chalcides chalcides*). Amphibians include the Tyrrhenian painted frog (*Discoglossus sardus*) and the Sardinian tree frog (*Hyla sarda*). Mammals are represented by wild boar (*Sus scrofa*), fox (*Vulpes vulpes*), weasel (*Mustela nivalis*), hare (*Lepus capensis*) dormouse (*Eliomys quercinus*) and hedgehog (*Erinaceus europaeus*). Birds include the goshawk (*Accipiter gentilis arrigonii*), the hawk (*Accipiter nisus*), the buzzard (*Buteo buteo*), the kestrel (*Falco tinnunculus*), the peregrine falcon (*Falco peregrinus*) and the raven (*Corvus corax*). Sardinian deer and the mouflon are no longer locally present in the wild.

4.5 Field measurements

Since 2009, 23 grazed sites were identified (Figure 6; Table 4) (Re et al. 2014). They are areas where grazing is carried out with official authorization from Ente Foreste della Sardegna (EFS). Inside each site, a representative fenced area of 4 m x 4 m was identified (Figure 7), to follow the vegetation dynamics of the herbaceous layer in ungrazed conditions. Botanical analyses were carried out both in grazed (G) and ungrazed areas (NG).

Table 4. Coordinates and altitude of grazed sites

Site	Coordinates		Altitude
	Latitude	Longitude	
MP2	40°25 463	9° 00 395	1172
MP3	40°25 738	9° 00 461	1080
MP4	40°25 192	9° 00 186	1195
MP6	40°25 477	8° 58 982	946
MP7	40°25 114	9° 00 056	972
MP10	40°25 887	8° 58 250	781
MP13	40°26 285	8° 57 875	705
MP14	40°26 287	8° 57 976	739
MP15	40°26 562	8° 57 576	683
MP17	40°26 605	8° 58 052	727
MP18	40°26 809	8° 57 614	693
MP19	40°26 936	8° 57 276	670
MP20	40°27 027	8° 57 815	601
MP21	40°27 239	8° 57 296	727
MP22	40°27 509	8° 57 511	725
MP24	40°27 153	8° 56 812	736
MP25	40°27 432	8° 56 505	736
MP26	40°27 625	8° 57 214	722
MP27	40°27 628	8° 56 613	726
MP28	40°28 069	8° 56 485	752
MP29	40°28 412	8° 56 548	697
MP30	40°28 754	8° 56 573	690
MP31	40°28 814	8° 56 435	689

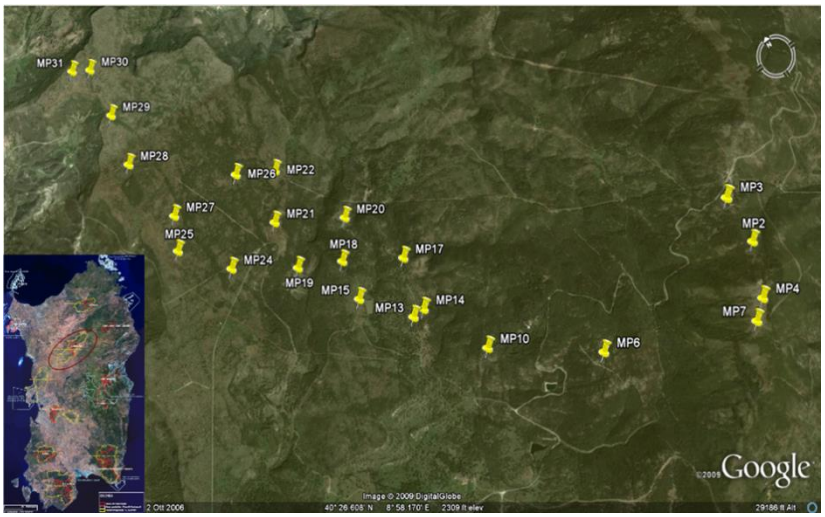


Figure 6. Location of the study sites

Vegetation data were collected by applying a point intercept method (Daget and Poissonet 1969) on 2 x 50 m line intersect transects in the grazed areas (total counts per transect = 200), and on 2 x 4 m line intersect transects in the non-grazed areas (total counts per transect = 40) (Figure 7). The surface recorded was about 2500 m^2 per site. The value of the pasture (*VP*) (Daget and Poissonet 1969; Cavallero et al., 2007)) of each site was determined using the formula:

$$VP = 0.2 \times (\Sigma SC_i \times S_i),$$

where SC_i is the specific contribution (%) of a single species and S_i is the specific index (Roggero et al. 2002).

Figure 7. Fenced area for monitoring the dynamics of pasture vegetation

Figure 8. Estimating pasture composition using transects

4.6 Response of pasture

The Forest of Monte Pisanu is identified as a Site of Community Importance (SIC ITB001102). In this area, grazing is commonly carried out where tree canopy is less dense or open. The grazing includes a heavy rotation of dairy sheep and the continuous light presence of cattle with an estimated livestock of 650 L.U. per year on a total surface of 2000 ha (Figure 9). The grazing pressure is dependent from the pasture availability:

- It is “high” on fertile and deep soils into gaps or cleared areas with low shading/tree density: on 16 out of 23 sites, cattle: 40-50 head from September to May, dairy sheep: 500-600 head from November to August, 1200-1700 head from September to November.
- It is “mid” on sites MP13, MP14 and MP17, 50 cattle all over the year, dairy sheep: 150 head all over the year plus 400 head from September up to November.
- It is “low” on sites MP10 and MP24, 20-30 head lambing at November.
- It is “rare” on sites MP6 and MP19. Low fertile soils, only cattle and sheep passing during transhumance.

Figure 9. Dairy ewes grazing

The pasture values ranged from 8.1 to 44.9 in unfenced areas and from 12.5 to 52.3 in fenced areas showing inter and intra-annual statistical significant differences among sites and between grazed and non-grazed treatments (p≤ 0.05) (Table 5).

Table 5. Estimates of the value of the pasture on 23 grazed sites

Site	2007	2008	2009		2010		2011	
	Grazed	Grazed	Grazed	Non-grazed	Grazed	Non-grazed	Grazed	Non-grazed
Mp2	34.2	33.0	24.3	21.0	30.1	n.a.	n.a.	n.a.
Mp3	26.5	32.9	18.8	32.3	28.5	n.a.	n.a.	n.a.
Mp4	17.5	20.7	9.8	18.0	22.9	19.3	15.9	41.0
Mp6	17.1	19.7	16.8	26.5	17.9	22.5	13.3	n.a.
Mp7	13.0	19.9	10.9	12.5	22.5	31.5	8.1	n.a.
Mp10	31.9	28.2	27.9	35.3	32.1	n.a.	28.5	n.a.
Mp13	28.8	30.9	26.3	37.0	35.1	40.5	29.4	36.0
Mp14	25.0	25.2	25.1	22.3	21.5	21.3	17.8	21.5
Mp15	38.4	30.6	34.3	37.8	38.1	n.a.	n.a.	n.a.
Mp17	34.9	29.6	30.9	35.0	29.7	n.a.	30.0	n.a.
Mp18	25.9	28.2	33.7	30.0	38.1	46.3	25.6	n.a.
Mp19	23.0	21.7	26.7	22.0	23.5	n.a.	26.7	n.a.
Mp20	40.2	44.9	26.8	30.0	41.4	n.a.	38.5	n.a.
Mp21	17.9	25.8	19.8	26.8	26.9	37.0	20.8	40.8
Mp22	21.5	26.2	22.1	29.8	24.2	42.0	27.9	52.3
Mp24	24.9	39.1	26.0	36.0	24.4	n.a.	23.4	n.a.
Mp25	19.1	27.1	23.4	17.5	21.6	21.3	25.4	26.5
Mp26	27.4	36.0	27.1	37.5	26.9	39.5	29.2	39.5
Mp27	17.2	26.0	19.9	25.0	22.7	22.5	24.1	36.5
Mp28	24.4	29.2	29.4	31.5	30.4	28.3	26.8	22.8
Mp29	16.6	25.5	21.2	28.8	21.9	25.3	23.8	33.8
Mp30	22.9	28.1	24.1	24.3	28.1	34.5	27.1	30.8
Mp31	23.5	25.4	28.1	30.5	31.0	25.8	24.3	24.8

The highest values of pasture value were due to the presence of perennial grasses (*Lolium perenne* L., *Dactylis glomerata* L.) and annual legumes (subclovers and medics). According to Alrababah et al. (2007), in fenced areas a high number of grazing-sensitive groups composed by high palatable species were found. Moreover a generalised linear model for the Shannon Index (SH) and Pasture value (VP) (year as random variable) showed that both were influenced significantly by site location and grazing regime, while year influenced significantly only VP. Site x grazing interactions were significantly different for both indicators, showing that the effect of grazing exclusion had a different impact depending on the variable site traits. The linear relation suggested by Daget and Poissonet (1969) and Daget and Godron (1995) where the potential carrying capacity (LU $ha^{-1}year^{-1}$) is equal to

0.02 VP, estimated in this contest a maximum level of LU value ha^{-1} = 1.05 in more fertile sites, whereas was = 0.2 in more marginal sites.

4.7 Pasture biodiversity

The ecological value was estimated by Shannon Index (SH) (Shannon, 1948). Around 200 species were identified over five years, mainly therophytes, hemicryptophytes and geophytes, referable to 34 families, mainly Graminaceae, Leguminosae and Compositae, with high presence of *Asphodelus microcarpus* Salzm. et Viv.. Some endemic species such as *Armeria sardoa* Spreng, *Bellium bellidioides*, *Oenante crocata* L., *Paeonia morisii* (Viv.) Cesca, Bernardi and N. G. Passal and *Ptilostemon casabonae* (L.) Greuter were found. The Shannon index 2.49 to 4.77 in the grazed areas (range: 2.49 to 4.77; mean = 3.7) was significantly higher than that in the ungrazed area (range: 1.31 to 3.8; mean = 2.7).

Table 6. Effect of location on biodiversity as defined by the Shannon index

Site	2007	2008	2009		2010		2011	
	Grazed	Grazed	Grazed	Non-grazed	Grazed	Non-grazed	Grazed	Non-grazed
Mp2	4.03	3.13	3.20	2.66	3.56	n.a.	n.a.	n.a.
Mp3	4.77	4.06	4.14	1.88	4.07	n.a.	n.a.	n.a.
Mp4	4.09	4.02	3.76	2.58	3.93	3.35	3.87	2.88
Mp6	4.02	4.34	4.49	3.64	4.37	3.03	4.24	n.a.
Mp7	3.68	4.04	3.48	2.57	3.44	2.63	3.33	n.a.
Mp10	4.23	3.95	4.18	3.49	4.34	n.a.	4.01	n.a.
Mp13	4.20	3.79	4.27	3.46	3.90	2.68	3.73	2.80
Mp14	3.95	3.58	3.66	1.42	3.57	2.05	3.89	1.31
Mp15	3.75	4.08	3.64	2.05	3.74	n.a.	n.a.	n.a.
Mp17	4.38	3.71	3.61	2.03	3.62	n.a.	4.00	n.a
Mp18	4.05	4.25	4.63	3.82	4.48	3.76	4.21	n.a.
Mp19	3.02	2.49	2.65	1.88	3.14	n.a.	3.57	n.a.
Mp20	4.10	3.72	3.79	2.43	3.93	n.a.	3.57	n.a.
Mp21	3.72	4.11	3.79	3.34	4.19	2.92	3.97	2.96
Mp22	3.52	3.49	3.68	3.12	3.17	2.77	3.30	2.82
Mp24	4.33	3.89	3.77	3.73	3.95	n.a.	4.24	n.a.
Mp25	3.73	3.44	3.14	2.27	3.63	2.20	3.27	1.48
Mp26	3.49	3.34	3.53	2.46	3.62	2.16	3.28	2.64
Mp27	4.07	3.83	3.44	2.68	4.00	2.83	3.56	3.44
Mp28	3.43	3.90	3.86	3.67	4.00	3.30	3.85	2.79
Mp29	3.64	4.05	4.04	3.41	4.01	3.35	4.07	3.56
Mp30	3.49	3.87	3.47	3.33	4.17	3.49	4.48	3.71
Mp31	3.90	3.63	4.11	2.64	4.37	2.60	3.95	1.99

4.8 Fire behaviour

Mediterranean rural landscapes are affected by the frequency of fires. Whatever the causes and the landscape structure, the risk of burning is related with the fuel biomass. Correct silvopastoral management can be effective in the rehabilitation of fire-prone woodlands (Franca et al. 2016). The role of grazers in reducing the fire risk within the Monte Pisanu Forest has been examined by a modelling approach based on the FARSITE simulator to estimate the probability of burning and the severity of the fires (Figure 10).

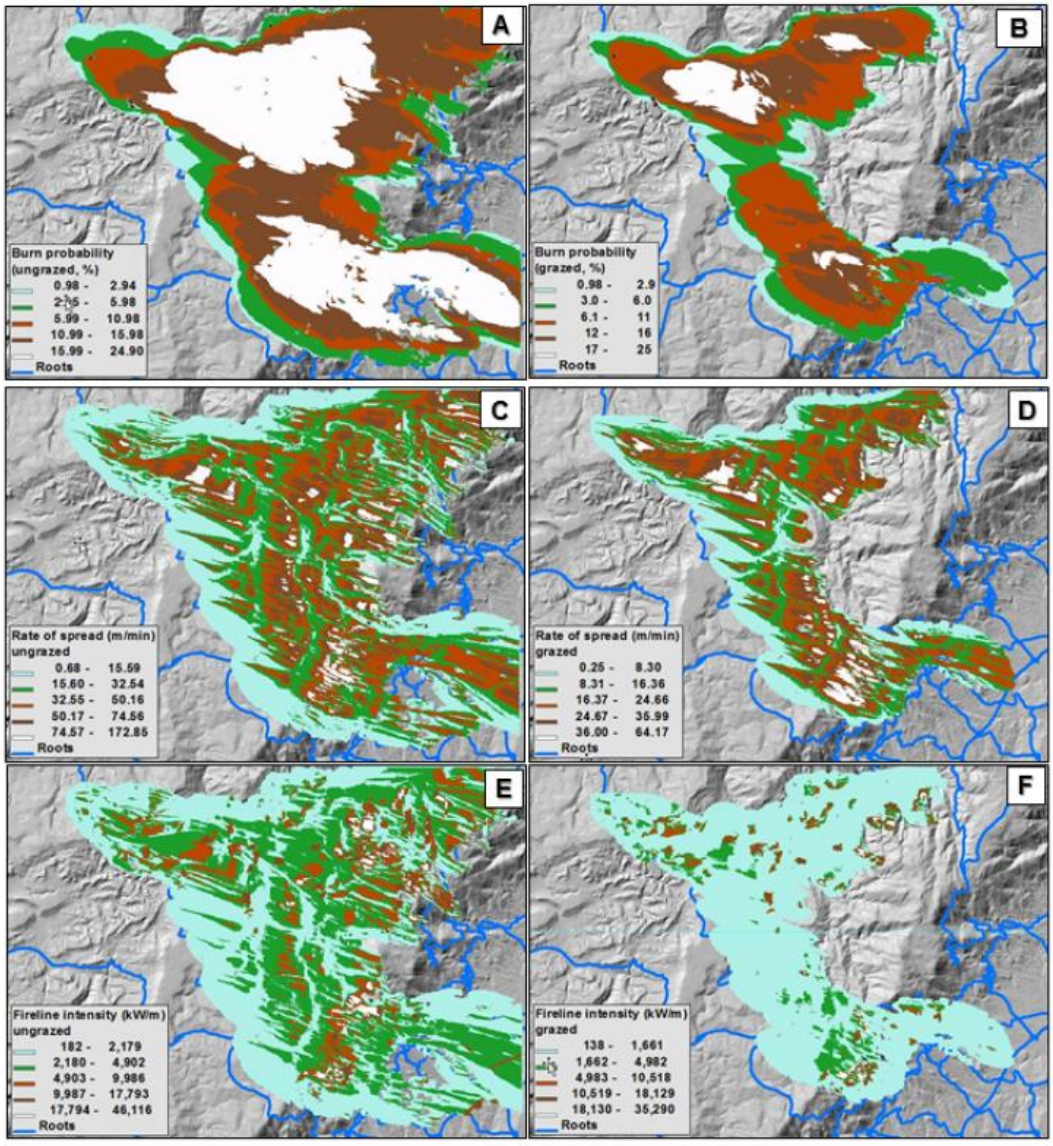


Figure 10. Values of the propagation probability, rate of spread and fireline intensity calculated for grazed (A, C, E) and ungrazed (B, D, F) conditions by FIRESITE simulator

Fuel biomass samples collected at the start and the end of the fire season in the 23 grazing sites, allowed the determination of the spatial variation of the herbaceous fuel model in grazed and non-grazed conditions and the assessment of the effect of the grazing abandonment on fire behaviour. Fuel reduction strategies tested by the simulator permitted to define the role of grazers in the fire prevention plan. FARSITE simulator were run using two custom fuel models for herbaceous

vegetation, respectively under grazed and ungrazed scenarios. The data provided by FARSITE (fire perimeter, rate of spread, fireline intensity) were used in order to describe the fire behaviour (Franca et al. 2012).

The simulated FARSITE results in the high nature value forest environment of Monte Pisanu showed that grazing affects fire behaviour. A strong reduction (-77%) of the burned area was shown in the grazed scenario. The rate of spread (ROS, m min^{-1}) was characterised by a general lower magnitude in the grazed scenario, where the highest values (>36 m min^{-1}) can be observed only in the north-west upland and in the steeper areas near the south-east flank. Regarding the fireline intensity, the grazed scenario was characterised by about the 90% of the burned area with fireline intensity values under 1700 kW m^{-1} that can be considered a critical threshold in order to establish effectiveness and feasibility of the methods of direct attack.

The Monte Pisanu silvopastoral system, based on short seasonal transhumance, is an integral part of the livestock feeding calendar, rand is an example of coexistence between livestock breeding and forestry in Sardinia. Ecological value (Shannon Index) and agronomic value (Pastoral Value) were both affected by the silvopastoral activity; opposite effects were showed on the Pastoral Value and on Shannon Index. Higher pastoral values were observed in ungrazed fenced areas, because of the selective action of livestock toward the most palatable species in grazed areas. On the other hand, lower Shannon Indexes were found inside the exclusion cages indicating a positive effect of the adopted grazing regime on that aspect of biodiversity. The high variability of pastoral types and their specific livestock carrying capacity suggests that site-specific grazing management is needed to integrate ecological and productive aspects.

4.9 Wood products

Cork production in 2015 was estimated in about 120 t, sold about 105 t (4.9 kg $plant^{-1}$). Cork was sold after public auction at 925 euros t^{-1} (in situ). Firewood is produced from coniferous (112 m^3 in 2015) and deciduous trees (30 m^3). Other deciduous (oaks) cuts are made after biotic and abiotic damages (60 m^3). They are utilized as stumps for woodworks, manufactured directly into the carpentry of EFS and destined to the woodworking of tables, windows and chairs for the recovery of old shepherd houses and the building of barbecue/picnic areas inside the forest.

4.10 Tourism and environment education

The Forest of Monte Pisanu is visited by groups of students from schools of Sardinia (in 2015 about 750 visitors), who normally carry out guided tours, accompanied by staff of the EFS. The site can be visited freely, and welcomes tourists and trekkers who can follow the trails, well identified by appropriate signage.

5 Future measurements

During the AGFORWAD project, the database we will completed and re-analyzed to answer new questions or to model system functioning:

- Measurements on light interception will be carried out, by using SunScan along the four transects utilized for the vegetation studies for each of the 23 grazed sites with the aim of studying the effect of shading on the vegetation types and the consequences on grazing behavior.

- Canonical correspondence analysis will be performed for assessing the impact of environmental variables (such as slope, aspect, elevation, soil pH, soil C content, soil OM content, and tree coverage) on the vegetation dynamics.

6 Acknowledgements

The AGFORWARD project (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD, Theme 2 - Biotechnologies, Agriculture & Food. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

7 References

AAVV (2007). PSR - Programma di Sviluppo Rurale 2007-2013: Rapporto di Valutazione Ex-ante. 174 pp.

Alrababad MA, Ahmad MA, Suwaileh A, Al-Gharaibeh M (2007). Biodiversity of semi-arid Mediterranean grasslands: Impact of grazing and afforestation. Applied Vegetation Science 10: 257-264.

Argenti A, Lombardi G (2012). The pasture-type approach for mountain pasture description and management. Italian Journal of Agronomy 7:39: 293-299.

Arrigoni PV, Di Tommaso PL, Melé A (1985). Le leccete delle montagne calcaree centro-orientali della Sardegna, Not. Fitosoc 22: 49-58.

Arrigoni PV, Di Tommaso PL, Melé A (1990). Caratteri fisionomici e fitosociologici delle leccete delle montagne calcaree della Sardegna centro-oriéntale. Boíl. Soc. Sarda Sci. Nat. 27: 205-219.

Bacchetta G, Bagella S, Biondi E, Farris E, Piligheddu R, Mossa L (2004a). A contribution to the knowledge of the order *Quercetalia ilicis* Br.-Bl. ex Molinier 1934 of Sardinia. Fitosociologia, 41(1): 29-51.

Bacchetta G, Biondi E, Filigheddu R, Farris E, Mossa L (2004b). A phytosociological study of the deciduous oak woods of Sardinia (Italy). Fitosociologia 41(1): 53-65.

Bacchetta G, Bagella S, Biondi E, Farris E, Piligheddu R, Mossa L (2009). Vegetazione foréstale e serie di vegetazione della Sardegna (con rappresentazione cartográfica alia scala 1:350.000). Fitosociologia 46(1): 3-82.

Bagella S, Caria MC (2010). Vegetation series: a tool for the assessment of grassland ecosystem services in Mediterranean large-scale grazing systems. Fitosociologia 48 (2) suppl. 1: 47-54.

Biondi E, Filigheddu R, Farris E (2001). II paesaggio vegetale della Nutra. Fitosociologia, 38(2), suppl. 2: 3-105.

Caballero R , Fernandez-Gonzalez F, Perez Badia R, Molle G, Roggero PP, Bagella S, D´Ottavio P, Papanastasis VP, Fotiadis G, Sidiropoulou A, Ispikoudis I (2009). Grazing systems and biodiversity in mediterranean áreas: Spain, Italy and Greece. Pastos 39(1): 9-154.

Camarda L, Valsecchi F (1983). Alberi e arbusti spontanei della Sardegna. Ed. Gallizzi, Sassari (Italy).

Cavallero A, Aceto P, Gorlier A, Lombardi G, Lonati M, Martinasso B, Tagliatori C (2007). I tipi pastorali delle Alpi Piemontesi. Alberto Perdisa Editore, Bologna.

Crespo D (1997). Pastagens extensivas do Sudoeste de la Península Ibérica: Producir mais conservando melhor. Actas de la XXXVII Reunión Científca de la SEEP, 163-182. Sevilla-Huelva (Spain).

Daget P, Godron M (1995). Pastoralisme: tropeaux, espaces et sociétés. Paris: Hatier. 510 pp.

Daget Ph, Poissonet T (1969). Analyse phytologique des praisies. INRA, Montpellier Document 48, 66p.

Dear BS, Roggero PP (2003). The present and potential role of perennial grass monocoltures and mixtures with annual legumes in Italian and Southern Australian farming systems. In: New perennial legumes for sustainable agriculture. Ed. Bennett. University of Western Australia Press. Crawley (Western Australia).

EFS, Ente Foreste della Sardegna, 2010, http://www.sardegnaambiente.it/documenti/3_226_20100518175225.pdf

Frame J, Charlton JFL, Laidlaw AS (1997). Temperate forage legumes. CAN International, 336 pp. Wallingford (UK).

Franca A, Sanna F, Nieddu S, Re GA, Pintus GV, Ventura A, Duce PP, Salis M, Arca B (2012). Effects of grazing on the traits of a potential fire in a Sardinian wooded pasture, Options Mediterraneennes, Series A: Mediterranean Seminars 103: 307-312.

Franca A, Caredda S, Sanna F, Fava F and Seddaiu G (2016). Early plant community dynamics following overseeding for the rehabilitation of a Mediterranean silvopastoral system. Journal of Grassland Science, doi: 10.1111/grs.12114

Francaviglia R, Benedetti A, Doro L, Madrau S, Ledda L (2014). Influence of land use on soil quality and stratification ratios under agro-silvo-pastoral Mediterranean management systems. Agriculture, Ecosystems & Environment 183: 86-92

Lagomarsino A, Benedetti A, Marinari S, Pompili L, Moscatelli MC, Roggero PP, Lai R, Ledda L, Grego S (2011). Soil organic C variability and microbial functions in a Mediterranean agro-forest ecosystem. Biology and Fertility of Soils 47(3) : 283-291.

Legeard JP (2004). Pastoralisme et contractualisation agri-environnementale. L'expérience des opérations conduites en Provence-Alpes-Côte d'Azur. Fourrages 179 : 383-392.

Loi A, Porqueddu C, Veronesi F, Cocks P (1995). Distribution, diversity and potential agronomic value of *Medicago polymorpha* in Sardinia. Journal of Agricultural Science, Cambridge 124: 419-426.

Myers N, Mittermeier R, Mittermeier CG, da Fonseca GAB, Kent J (2000). Biodiversity hotspots for conservation priorities, Nature 403: 853-858.

Moreno G, Franca A, Pinto Correia MT, Godinho S (2014). Multifunctionality and dynamics of silvopastoral systems. In: (Forage resources and ecosystem services provided by Mountain and Mediterranean grasslands and rangelands (Editors: Baumont R, Carrère P, Jouven M, Lombardi G, López-Francos A, Martin B, Peeters A, Porqueddu C), Proceedings of the joint meeting of the Mountain Pastures, Mediterranean Forage Resources (FAO-CIHEAM) and Mountain Cheese networks, Clermont-Ferrand, France, 24-26 June 2014, Options Méditerranéennes, Series A: Mediterranean Seminars 109: 421-436.

PignattI S (1998). 1 boschi d'Italia. Sinecologia e biodiversitá. Utet. Torino (Italy).

Porqueddu C, González F (2006). Role and potential of annual pasture legumes in Mediterranean farming systems. Pastos, 36(2): 125-142.

RAS-Regione Autonoma della Sardegna (2007). Progettazione integrata- Allegato 3.2 Industria Artigianato e Servizi - Comparto del Sughero. Regione Autonoma della Sardegna: Cagliari, Italy 2006.

Re GA, Franca A, Saba P, Nieddu D, Sassu M, Sanna F (2014). Impact of grazing on the agro-ecological characteristics of a Mediterranean oak woodland. Five years of observations at Monte Pisanu forest. Proceedings of the joint meeting of the "Mountain Pastures, Mediterranean Forage

Resources (FAO-CIHEAM) and Mountain Cheese" networks, Clermont-Ferrand, France, 24-26 June 2014, Options Méditerranéennes, SeriesA: Mediterranean Seminars 109: 771-776.

Rivas-Martínez S, Penas A, Díaz T (2001). Biogeographic Map of Europe (scale 1:16.000.000).University of León. León (Spain).

Rivas-Martínez S, Biondi E, Costa M, Mossa L (2003). Datos sobre la vegetación de la clase *Quercetea ilicis* en Cerdeña. Fitosociologia 40(1): 35-38.

Roggero PP, Bagella S, Farina R (2002). Un archivio dati di Indici Specifici per la valutazione integrata del valore pastorale. Rivista di Agronomia 36(2): 149-156.

Rossetti I, Bagella S, Cappai C, Caria MC, Lai R, Roggero PP, Martins da Silva P, Sousa JP, Querner P, Seddaiu G (2015). Influence of isolated cork oak trees on soil features, plant and collembolan assemblages in a Mediterranean wooded grassland. Agriculture, Ecosystems and Environment 202: 203-216.

Sedda L, Delogu G, Dettori S (2011). Forty-four years of land use changes in a Sardinian cork oak agro-silvopastoral system: a qualitative analysis. The Open Forest Science Journal 4: 57-66.

Seddaiu G, Porcu G, Ledda L, Roggero PP, Agnelli A, Corti G (2013). Soil organic matter content and composition as influenced by soil management in a semi-arid Mediterranean agro-silvo-pastoral system. Agriculture, Ecosystems & Environment 167: 1-11.

Serra G, Bacchetta G, Loddo S (2002). Relationships between soils, climate and vegetation in *Quercus súber* L. formations of the Sulcis-Iglesiente (Southern Sardinia - Italy). Options Méditerranees, Serie A 50: 127-133.

Shannon CE (1948). A mathematical theory of communication. The Bell System Technical Journal 27: 379-423.