Cork Oak Vegetation Series of Southwestern Iberian Peninsula: Diversity and Ecosystem Services

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Abstract. Currently, the occurrence of thermophile cork oak communities is becoming exceptionally rare, which can be attributed to the long-lasting impact of human agroforestry and grazing land-use practices. In this work we identified the thermophilous cork oak vegetation series of southwestern of the Iberian Peninsula and present an overview of ecologic factors and processes controlling the diversity of plant communities observed in their dynamic, as well as, the characteristic vascular flora, including species with special conservation interest, is here presented. This information allows the development of sustainable management, which may enhance both biodiversity and conservation. Moreover, the sustainable economic activities of the cork oak forests, regarding to enhance their capacity to provide benefits that are essential for ecosystem services is developed and presented.

Keywords: *Quercus suber* · Thermophilous cork oak vegetation series · Phytosociology · Sustainable management of cork oak forests

1 Introduction

Cork oak (*Quercus suber* L.) woodlands are distributed widely across the western and central parts of the Mediterranean basin, mostly on silicate substrates. In southwest of the Iberian Peninsula, cork oak woodlands have high biodiversity and support a wide range of plant communities and endangered species. Moreover, cork oak forests generate substantial economic benefits: from cork and firewood, to a framework tree for agroforestry and silvopastoral systems [1]. Nevertheless, large areas of cork oak forest

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landscape, open farmland and shrubland turned into new forest plantations (mainly, *Eucalyptus sp*. and *Pinus sp.pl.*) modern permanent-crop farming systems [2], fires, pathogens, overgrazing and, therefore, have drastically affected the sustainability of Mediterranean woodland ecosystems, leading to their classification as at-risk native biodiversity hotspots [3]. For the correct management and conservation of biodiversity it is important to diagnose the cork oak vegetation series, as well as their dynamics and successional stages, which includes important habitats for many plant species of conservation importance. Hence, we provide a condensed description of the cork oak climatophilous series associated with the thermophilous areas of the southwestern Iberian Peninsula, already described within the *Querco rotundifoliae-Oleion sylvestris* alliance. In addition to supporting biodiversity, cork oak woodlands provide important ecosystem services and sustainable economic activities based on renewable flow management, since this system can regenerate cork and other useful products with economic value. Therefore, we also present the importance to promote sustainable management of cork oak forests, and halt and reverse land degradation and halt biodiversity loss, and protect the extinction of threatened species. The particular objectives were: 1) to present the cork oak vegetation series, from an ecological and dynamic point of view; 2) to identify the habitats of community interest through the correspondence between plant communities and Directive Habitats types; 3) to indicate species with special conservation interest; 4) to present the sustainable economic activities of the cork oak forests, in order to enhance their capacity to provide benefits that are essential for both, sustainable development and ecosystems, and their services.

Study Area

The research area covers the thermophilous territories with acidic soils of the southwestern Iberian Peninsula, linked to the sublittoral areas and the valley of the rivers Tagus and Sado. According to the most recent study on Iberian Peninsula bioclimatic classification by [4], these territories are classified as Mediterranean pluviseasonal oceanic, mostly thermomediterranean hyperoceanic to euoceanic. In a biogeographical context and following [5], the study area is included in the Coastal Lusitania and West Andalusian Province and westernmost part of the Lusitania and Extremadura Subprovince (West Iberian Mediterranean Province).

Materials and Methods

The climatophilous series of *Q. suber* diagnosis followed past works from [6–26]. Sintaxonomical nomenclature followed [27–29]. Taxonomic nomenclature follows [29, 30]. The classification of habitats, through the evaluation of the dominant vegetation types and their diagnostic species, follows [31]. The biogeographical and bioclimatological analysis was carried out according to [4, 5]. Generally, the information of ecosystem services and sustainable based on the available published works, such as [1, 45, 47–49].

Discussion and Results

The set of vegetation types which, by virtue of succession replace each other at a particular site has been called a series [42]. We can summarize the typical sequence of stages occurring in the cork oak vegetation series from southwestern Iberian Peninsula (See Fig. 1), within the limits of a tessela, which includes the whole forest successional sequence, depending on its degree of degradation [26, 50–55].

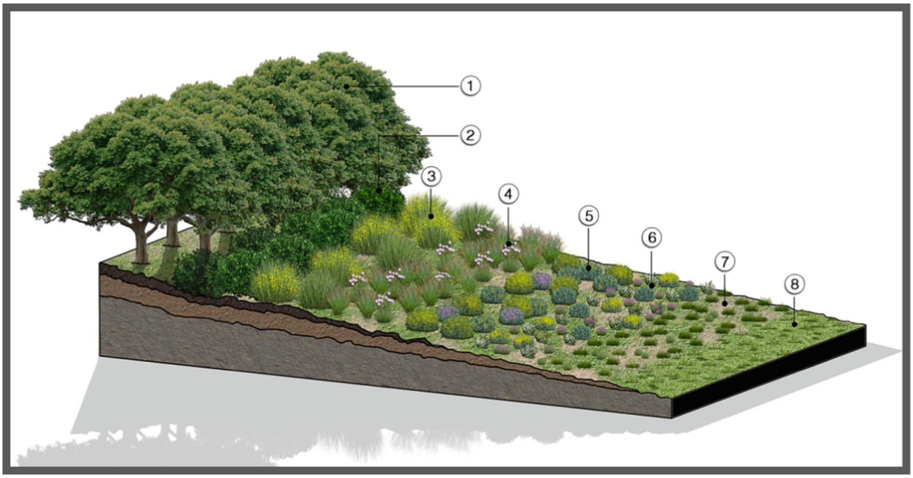

Fig. 1. Typical sequence of stages occurring in the cork oak vegetation series from southwest of Iberian Peninsula: 1 - Cork oak woodland; 2 - Maquis scrubland; 3 - Broomland; 4 - Perennial grassland; 5 - Gorse scrubland; 6 - Cistaceous scrubland; 7 - Perennial grassland; 8 - Annual grasslands (adapted from [56]).

Therefore, the four *Q. suber* woodland series identified in the study area is presented briefly, highlighting the successional stages, as well as the natural or semi-natural habitats that it may incorporate and its asset value (Table 1).

A. *Lavandulo viridis–Querco suberis* sigmetum
Vegetation series occurring along the mountainous areas of the southwest of Portugal mainland (Caldeirão, Monchique, Cercal, Grândola) (Monchique Sierran District), reaching the Aracena mountain (Aracena Sierran District), typical from silicates substrates, derived from schists and greywackes, in the thermomediterranean, hyperoceanic, lower sub-humid bioclimate areas. The mature stage *Lavandulo viridis-Quercetum suberis*, is characterized by the dominance of *Quercus suber* and the constant presence of *Lavandula viridis*, a southwestern Iberian endemic, considered a characteristic species of this association. Its fringe belongs to the *Arbutus unedo* maquis from *Cisto populifolii–Arbutetum unedonis*. Nevertheless, the removal of tree and shrub cover, leds to the *Cytisus striatus* broomlands (*Lavandulo viridis-Cytisetum striati*). In contrast, with the soil degradation and following the regressive dynamic, occurs the heathland from *Ulici argentei-Ericetum australis* and a gorse scrubland of *Cisto ladaniferi-Ulicetum argentei*, both exclusive to the Monchique Sierran District and well characterized by the endemic *Ulex argenteus*. In woodland clearings, the perennial grasslands

Table 1. Biogeographical, substratum, Habitats Directive, plant communities and species with conservation interest of the thermophilous cork oak vegetation series of southwestern the Iberian Peninsula (within the *Querco rotundifoliae-Oleion sylvestris* alliance).

Climatophilous series	Woodland and successional stages	Biogeography	Habitats Directive	Substratum affinity	Main species with conservation interest
Lavandulo viridis–Querco suberis sigmetum	*Lavandulo viridis-Quercetum suberis*; *Cisto popullifolii–Arbutetum unedonis*; *Lavandulo viridis-Cytisetum striati*; *Ulici argentei-Ericetum australis*; *Cisto ladaniferi-Ulicetum argentei*; community of *Dactylis hispanica* subsp. *lusitanica*; *Trifolio cherleri-Plantaginetum bellardii*; *Holco annui-Brachypodietum distachyi*	Monchique Sierran and Aracena Sierran Districts	9330, 5330, *6220, 4030	Schists and greywackes	*Doronicum plantagineum* subsp. *tournefortii* (Annex V Habitats Directive), *Narcissus bulbocodium* (Annex V Habitats Directive), *Drosophyllum lusitanicum*, *Gagea lusitanica*, *Senecio minutus, Centaurea crocata*
Aro neglecti–Querco suberis sigmetum	*Aro neglecti-Quercetum suberis*; *Phillyreo angustifoliae–Arbutetum unedonis*; *Cytisetum cabezudoi*; *Avenulo hackelii–Celticetum sterilis*; *Armerio macrophyllae–Celticetum giganteae*; *Euphorbio transtaganae-Celticetum gigantae*; *Hyacinthoides transtaganae-Brachypodietum phoenicoidis*; *Erico umbellatae–Ulicetum welwitschiani*; *Halimio halimifolii–Stauracanthetum genistoidis*; *Genisto triacanthi–Stauracanthetum vicentini*; *Tuberario majoris–Stauracanthetum boivinii; Thymo camphorati-Stauracanthetum spectabilis; Cistetum libanotidis*; Communities of *Corynephorus canescens* var. *maritimus*; *Tolpido barbatae–Tuberarietum bupleurifoliae*	Coastal Lusitania and West Andalusian Province	*2150, 2230, 2260, 2330, 4030, 5330, *6220, 9330	Sandy soils (paleodunes)	i)*priority species from Annex II Directive Habitats: *Thymus camphoratus*, *Thymus lotocephalus*, *Tuberaria major*; ii) Annex II Habitats Directive: *Armeria rouyana*, *Armeria velutina*, *Euphorbia transtagana*, *Halimium verticillatum*, *Hyacinthoides vicentinas* subsp. *transtagana*, *Thymus camphoratus*, *Santolina impressa*; iii) Annex IV Habitats Directive: *Thymus capitellatus*, *Thymus villosus*; iv) Annex V Habitats Directive: *Malcolmia lacera* subsp. *gracillima*, *Narcissus bulbocodium*; v) other species: *Arenaria algarbiensis*, *Armeria macrophylla*, *Armeri apinifolia*, *Centaurea exarata*, *Dianthus broteri* subsp. *hinoxianus*, *Klasea algarbiensis*, *Lupinus cosentinii*, *Ononis cossoniana*, *Scilla odorata*, *Thesium humile*, *Thymus albicans* subsp. *albicans*, *Thymus albicans* subsp. *donyanae*, *Trisetaria duforei*, *Ulex argenteus* subsp. *subsericeus*

(*continued*)

Table 1. (*continued*)

Climatophilous series	Woodland and successional stages	Biogeography	Habitats Directive	Substratum affinity	Main species with conservation interest
Asparago aphylli-Querco suberis sigmetum	*Asparago aphylli-Quercetum suberis*, *Phillyreo angustifoliae–Arbutetum unedonis*, *Erico scopariae-Quercetum lusitanicae*, *Erico umbellatae-Ulicetum welwitschianii*, *Lavandulo luisieri-Ulicetum jussiaei*, *Thymo villosae-Ulicetum airensis*, *Avenulo sulcatae-Celticetum giganteae*	Iberian Atlantic Mediter-ranean biogeographic territory	9330, 5330, *6220, 4030	Schist and sandstone	*Halimium verticillatum* (Annex II Habitats Directive), *Thymus villosus* (Annex IV Habitats Directive), *Drosophyllum lusitanicum*
Smilaco asperae-Querco suberis sigmetum	*Smilaco asperae-Quercetum suberis*, *Phillyreo angustifoliae–Arbutetum unedonis*, *Cytisetum multifloro-eriocarpi*, *Erico australis-Cistetum populifolii*, *Halimio ocymoidis-Ericetum umbellatae*, *Avenulo sulcatae-Celticetum giganteae*	Oretana Range and Tajo Sector	9330, 5330, *6220, 4030	Schists and quartzites	*Ruscus aculeatus* (Annex V Habitats Directive), *Juniperus oxycedrus* subsp. *lagunae, Centaurea coutinhoi, Iris lusitanica*

dominated by *Dactylis hispanica* subsp. *lusitanica* frequently occur where as ground clearance leads to the successive appearance of therophytic grasslands from *Tuberarion guttatae*. The *Picrido spiniferae-Cynarietum algarbiensis*, dominated by *Cynara algarbiensis*, represents the forest fringe of *Lavandulo viridis-Quercetum suberis*.

B. *Aro neglecti–Querco suberis* sigmetum
According to [23], along the thermomediterranean, dry to subhumid bioclimatic belts of the Coastal Lusitania and West Andalusian Province, occurs the *Aro neglecti-Quercetum suberis*. This psammophilous cork oak forests develops on podzol sandy soils derived from Pleistocene paleodunes [26], and is dominated by *Quercus suber* and normally accompanied by *Arum italicum* subsp. *neglectum*, *Pistacia lentiscus* and *Stauracanthus genistoides* [9]. The fringe which occurs above sandy soils belongs to the strawberry tree from *Phillyreo angustifoliae–Arbutetum unedonis*. The elimination of woody and shrubby strata leads to the broomland from *Cytisetum cabezudoi*, dominated by *Cytisus grandiflorus* subsp. *cabezudoi*. Shifting to deeper soils, in forests and shrub clearings, occurs the perennial grasslands from *Agrostio castellanae-Celticion giganteae* alliance (*Avenulo hackelii–Celticetum sterilis*, *Armerio macrophyllae–Celticetum giganteae*, *Euphorbio transtaganae-Celticetum gigantae*) [13, 16] and the orchid-rich grasslands of *Brachypodium phoenicoides* (*Hyacinthoides transtaganae-Brachypodietum phoenicoidis*) [25]. In the regressive dynamic, the domain is separate from *Erico umbellatae–Ulicetum welwitschiani* heathlands, and a psammophilous community of *Halimio halimifolii–Stauracanthetum genistoidis*. For the San Vicente Coastal District, occurs the gorse scrubland of *Genisto triacanthi–Stauracanthetum vicentini*, with *Stauracanthus spectabilis* subsp. *vicentinus* as an important endemic element. In sandy soils with clay we observe the gorse scrubland from *Tuberario majoris–Stauracanthetum boivinii*, mainly in palaeopodzolic ferruginous lithosols, subject to water logging. Through its shift, in the San Vicente Coastal and San Vicente Cape Districts, in sandy soils without the ferruginous horizon, coastal gorse scrublands of *Thymo camphorate-Stauracanthetum spectabilis* emerge and also the psammophilous community of *Cistetum bourgaeani (libanotidis)*. With more degradation, occurs the perennial grasslands dominated by *Corynephorus canescens* var. *maritimus* from *Corynephorion maritime* alliance, and the therophytic communities of *Tolpido barbatae–Tuberarietum bupleurifoliae* occur.

C. *Asparago aphylli-Querco suberis* sigmetum
This climatophilous series occurs in the Iberian Atlantic Mediterranean biogeographic territory, on siliceous substrata (schist and sandstone). The climatic domain corresponds to a cork oak forest from *Asparago aphylli-Quercetum suberis*. The pre-forestall stage is dominated by *Arbutus unedo* and *Phillyrea angustifolia* (*Phillyreo angustifoliae–Arbutetum unedonis*). As this scrubland regresses, occurs the *Erico scopariae-Quercetum lusitanicae*. According to [26] the seral stage also includes gorse/heathland dominated by *Ulex australi*s subsp. *welwitschianus* (*Erico umbellatae-Ulicetum welwitschianii*; low Tagus and Sado), *Ulex jussiaei* (*Lavandulo luisieri-Ulicetum jussiaei*; north of the Tagus) and *Ulex airensis*

(*Thymo villosae-Ulicetum airensis*). In woodland clearings, occurs the perennial grasslands dominated by *Celtica gigantea* (*Avenulo sulcatae-Celticetum gigantae*). The *Stachydo lusitanicae-Origanetum virentis* association represents the forest fringe community of *Asparago aphylly-Quercetum suberis*.

D. *Smilaco asperae-Querco suberis* sigmetum
This climatophilous series develops on siliceous substrata (schists and quartzites) of the lower subhumid areas of the central Tagus valley (Oretana Range and Tajo Sector). The climatic stage belongs to the *Smilaco asperae-Quercetum suberis*, characterized by the presence of *Juniperus oxycedrus* subsp. *lagunae*. The *Phillyreo angustifoliae–Arbutetum unedonis* represents the first substitution layer. The elimination of this shrubby strata leads to the *Cytisetum multifloro-eriocarpi*. Soil degradation promotes the development of the heathlands: *Erico australis-Cistetum populifolii* and *Halimio ocymoidis-Ericetum umbellatae*. In the woodland clearings, occurs the perennial grasslands from *Avenulo sulcatae-Celticetum giganteae*.

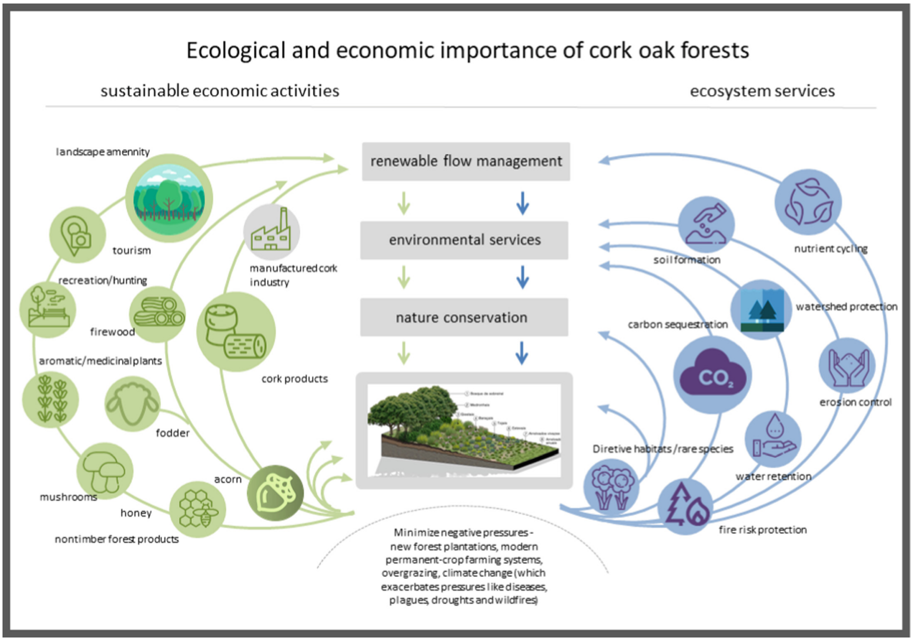

Fig. 2. Ecosystem services of cork oak forests and ecological economics tools diagram. (adapted from Ellen MacArthur Foundation [57]).

According to [32], as a direct result of human management, functional cork oak landscapes present a wide array of forest or woodland, shrubland, and open habitat components. As shown in the Table 1, a total of 8 habitats associated to European Habitats Directive (Directive 92/43/EEC), are recognized and, therefore, have a large set of rare, endemic, endangered and protected species under the Directive 92/43/EEC (about 41 species with conservation interest). Besides the high biodiversity value, the cork oak vegetation series provide, from an ecological perspective, important ecosystem services, mainly associated to soil fertility, water retention, watershed protection, erosion control, fire risk prevention and carbon sequestration [32] (See Fig. 2). Among these factors, the capacity of cork oak woodland to contribute to carbon mitigation targets must be highlighted. In fact, several studies in Portugal reveal that they store a significant amount of carbon (reaching 14.7 tons of CO_2 per year per hectare) [36] in standing biomass (cork oaks) and soil. Despite the ecological importance, the cork oak forests are one of the few examples of fully sustainable forestry exploitations, comprising multiple land uses, including cork, acorn, firewood, fruits, oils, mushrooms, recreation and tourism activities [1]. Nevertheless, they are economically sustainable mostly to the high market value of cork, where bottle stoppers that drive the cork industry, represent almost 70% of cork's market value [35]. Therefore, several authors evidence that cork, being a natural and renewable material, which in itself is the result of a CO_2 absorption and sequestration, and also a storage of C, can also contribute to the design of the post-carbon city by reducing energy waste, improving the quality and the insulation of buildings [37–49]. Moreover, the amount of carbon sequestered in cork oaks according to [34] is 0.95–1.25 tonne C/tonne cork. Hence, if the cork oak was registered in the "National Register of Agro-Forestry Carbon Tanks", then it would receive an allowance of 20 €/tonne/year [in 2005 the cost of a tonne of CO_2 fluctuated between 8 and 32 €/tonne/year] (Spampinato et al. 2019) [43].

Currently, cork oak forests are facing complex problems and are under increasing pressure, due to soil mobilization, intensification of agricultural activities, particularly overgrazing (mainly cattle grazing), climate change, which promote diseases, drought and water stress (further endangering viable cork production), forest fires, and inappropriate silvicultural management, that could seriously threatened the long-term of trees [33].

According to [32], to address the problems driving the degradation and loss of cork oak woodlands, there is a clear need to review national forestry education schemes and introduce innovative concepts for sustainable management and biodiversity conservation of cork oak woodlands and the development of sustainable markets, based on responsible management of natural resources.

2 Conclusions

We present the first approach to the cork oak vegetation series of southwestern Iberian Peninsula, through which it was possible to perceive the existence of a large diversity of plant communities and habitat type, displaying great value, with several rare endemic plants. Understanding vegetation series is of utmost importance for the diagnosis and determination of the vegetation's current conservation status. This information allows the landscape managers to present some priority measures that must be addressed strategically, to help biodiversity adapt to recent drivers of transformation and degradation, at the same time, accounting for the socio-economic activities that support the sustainable use of the existing natural resources. According to [1], a research goal for the future must be to apply environmental and ecological economics tools to the valuation of biodiversity conservation and ecosystem services of cork oak woodlands and derived cultural systems. We also recognize that promote the implementation of this valuation in management and planning, is the greatest challenge and an indispensable requirement for sustainable development in its three dimensions – economic, social and environmental.

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