CORK

Culture. Nature. Future.

''... When uncorking a bottle of good wine or using any of the dozens of products made from natural cork, have you ever stopped to wonder where it comes from? If not, come with us to discover the Cork Oak (Quercus suber), one of the most extraordinary trees on Earth. Whether fully clothed, in its thick, fissured, light grey cork bark, or with a brick red trunk recently stripped of its cork, this tree has great beauty, mystery, and charm.
The landscapes in which it occurs have the same charm, or even more to those who know how to read them...''

in Aronson J., Pereira J.S., Pausas J.G. (eds.)''Cork Oak Woodlands on the Edge: Conservation, Adaptive Management and Restoration''. Island Press, New York, 2009

THE CORK OAK A MILLENARY TREE

The cork oak *(Quercus suber L.)* has green leaves all year round (it is an evergreen tree) and has a very special bark – the cork.

It is included in the oak genus *(Quercus spp.)*, a group of species with common affinities and origin. The cork oak belongs to a small sub-group that embodies European and Asian species– the group Cerris. The first trees identified as cork oaks occurred millions of years ago. Since then, several episodes of climatic change have taken place affecting the vegetation.

Particularly interesting is the period that began around 1.8 million years ago – the Pleistocene Age - characterized by alternating periods of extreme cold (glacial eras) with warmer inter-glacial periods. These events decisively influenced the geographical distribution and the genetic diversity of the cork oak.

The cold forced the cork oak to take refuge in more benign climatic areas. At the end of the last glacial period, around 10,000 years ago, the cork oak colonized its present distribution area.

Currently, cork oak occurs typically in the Western Mediterranean region, i.e., in the Iberian Peninsula (Portugal and Spain), south of France and the west coast of Italy, as well as in North Africa (Morocco, Algeria and Tunisia) and the Mediterranean Islands (Sicily, Corsica and Sardinia).

The total area occupied is currently around 1.44 million hectares in Europe and 0.70 million hectares in Northern Africa. More than half of this area is located in the Iberian Peninsula (Figure 1, Chart 1 and 2).

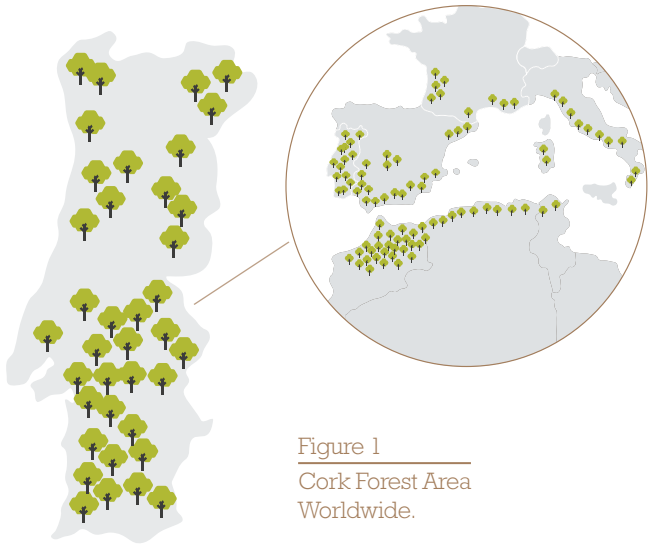


Figure 1
Cork Forest Area Worldwide.

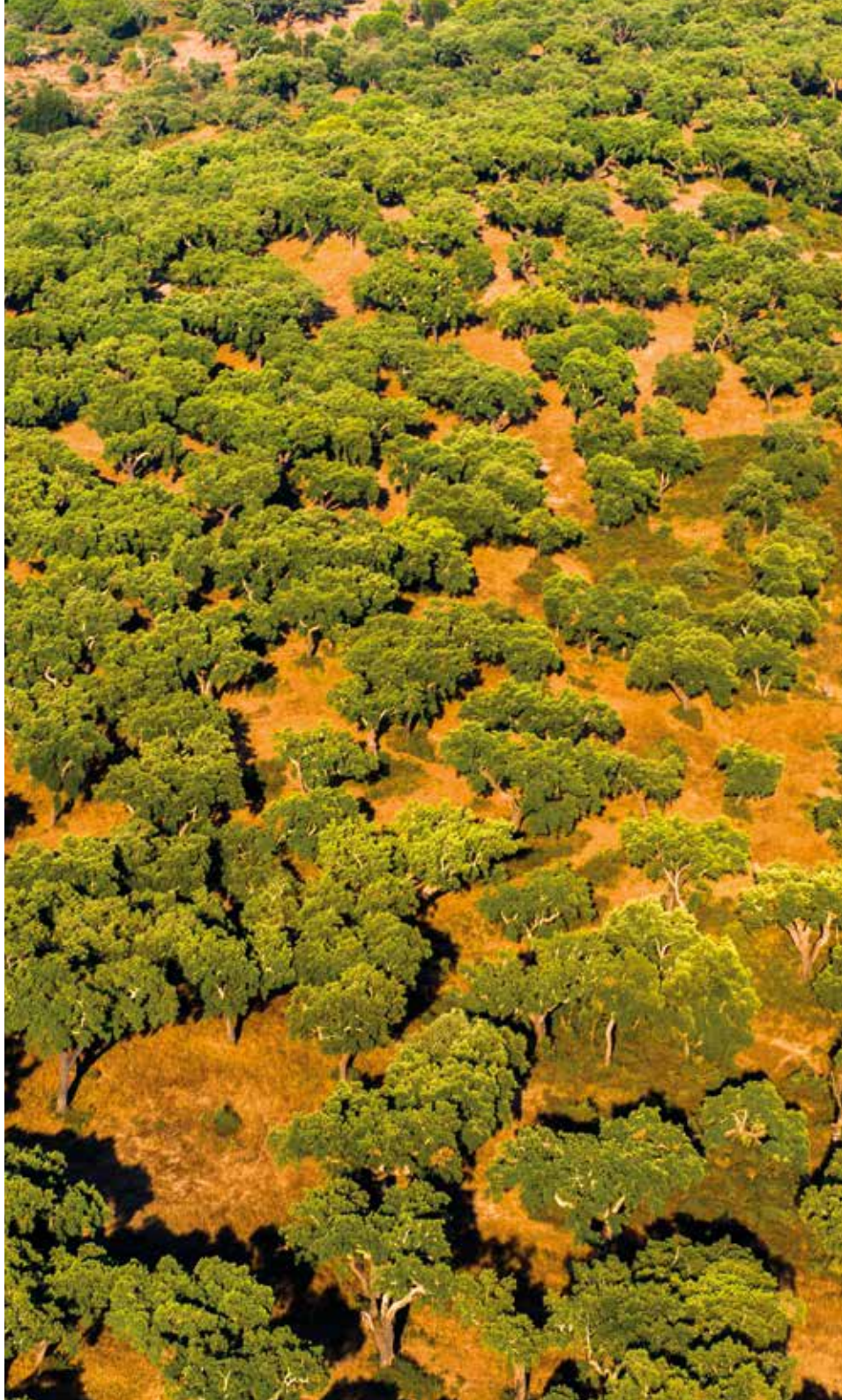


Chart 1

Cork Forest Areas

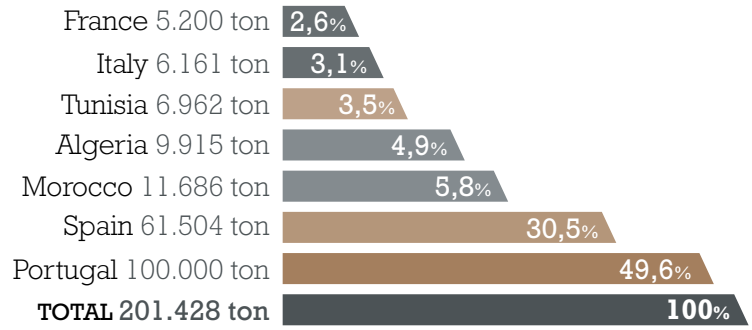
Country	Area (hectares)*	Percentage (%)
Portugal	736.775	34
Spain	574.248	27
Marocco	383.120	18
Algeria	230.000	11
Tunisia	85.771	4
France	65.228	3
Italy	64.800	3
Total	**2.139.942**	**100**

* Chart 1 - Source: Portugal: IFN, 2013; Spain: MARM, 2007; Italy: FAO, 2005; France: IM Liège, 2005; Morocco: HCEF Marroc, 2011; Algeria: EFI, 2009; Tunisia: Ben Jamaa, 2011.

Chart 2

Cork production

Anual average (ton.)*



* Source: FAO Year: 2010

MEDITERRANEAN SUMMER

A period of stress

In vast regions of Southern Europe and Northern Africa, cork oak trees do not pass unnoticed. In the summer, the dry coloured scenery is dotted with the green crowns of this tree. Sometimes the tree crown cover is shared with other species.

As an evergreen, cork oak may benefit from its ability to carry out photosynthesis for longer periods during the year compared with deciduous trees, which lose their leaves in winter. But the intake of CO_2 for photosynthesis means the outflow of water vapour by transpiration and the consequent danger of dehydration. The water loss is controlled by stomatal closure, adjustable pores located on the surface of the leaves.

In regions with a Mediterranean climate, severe summer drought is a critical period for most living beings in the cork forest. In trees, the stomatal closure has to be complemented by the absorption of water by the prolific root system, which can be several metres deep. During summer more than 70% of the water transpired by cork oaks may originate from the deepest soil and subsoil layers.

CORK OAK AND CORK

A unique relationship

The bark of trees is a protective organ containing tissues that include, cell layers made impermeable by the chemical deposition of suberin. The cork oak's most interesting particularity is that its outer layer is composed of suberized cells that form an elastic, impermeable tissue with excellent thermal properties – the cork.

The formation of cork results from the activity carried out by a layer of mother cells - the phellogen – concentric with the vascular cambium that produces wood (Figure 2). The phellogen is external to the vascular cambium, producing layers of homogeneous cork that protect the interior of the stem. In cork oak the phellogen is continuous and remains active throughout the tree's lifespan. This contrasts with the other trees where the phellogen is not continuous and only lives for a year.

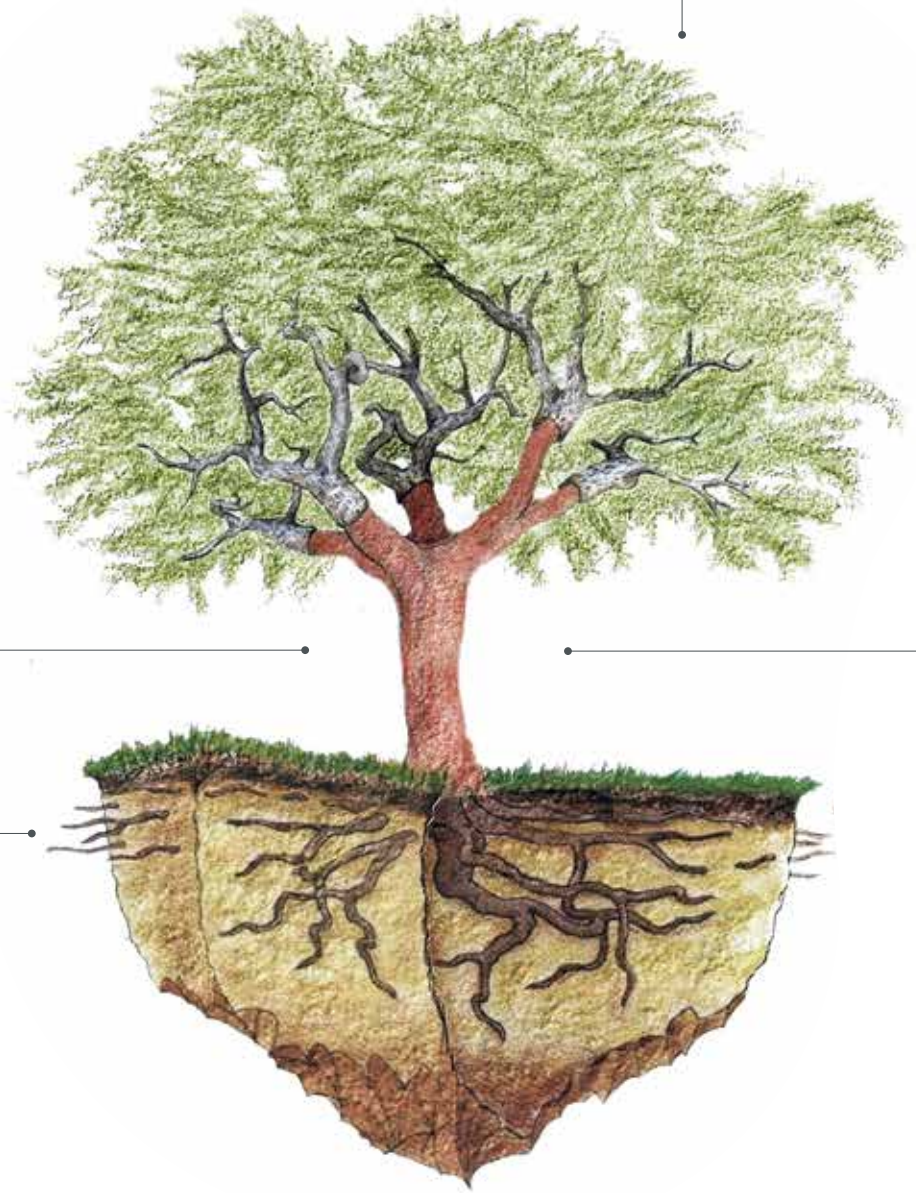
When cork is harvested, in late spring and summer, it is essential that the phellogen is active and continues dividing, and this depends on the tree being well hydrated. These are the conditions in which cork can be harvested without damaging the tree. After harvesting the bark, the phellogen cells die (dry out) but a new layer of phellogen is formed underneath.

The uniqueness of cork may have an adaptive value, that is, it has probably enhanced the cork oak's survival throughout evolution. The physical attributes of cork, namely its good insulating properties, can also protect the tree trunks and branches against fire.

If the cork is partially burnt during a fire, its insulating properties protect dormant buds ''anchored'' on the stem. Later, these buds will sprout and re-establish the tree canopy. Most other tree species die and are obligated to regenerate from seeds (like, for example, the Maritime Pine) or sprout from the base of the stem, because their aerial buds are killed by fire.

The rapid regeneration of cork oak crowns after fires allow the rapid recovery and may be advantageous during regrowth. Cork's bark may have been the cork oak's evolutionary answer in an environment where fire was an important ecological factor.

THE CORK OAK

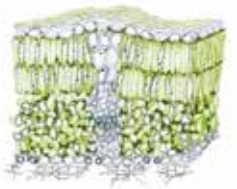


BRANCH WITH CORK

Cork is a bark that persists on the tree.

MYCORRHIZA

The cork oak has deep roots that grow downwards but most of the root structure is located in the soil's surface layer. The surface roots can, at times, be associated with fungi (mycorrhiza) in a mutually beneficial relationship for both cork and fungi (the tree feeds the fungus that facilitates access for tree roots to nutrients in the soil).



LEAVES

Leaves are thick, with palisade cells and abundant microscopic stomata under the leaf. Photosynthesis, which is the basis of all plant production occurs in the leaves.

TRUNK STRIPPED OF ITS BARK

When harvested, the cork oak's phellogen regenerates and produces new layers of cork.

Figure 2
Illustrator: Francisco Quirino.

MONTADOS AND SOBREIRAIS (CORK OAK FORESTS)

A cultural heritage

In the western Iberian Peninsula, the cork oak is found naturally in mixed plant communities called *Sobreirais* (cork oak forests).

These communities may include deciduous oaks – such as the Portuguese Oak *(Quercus faginea)*, or softwood species such as Maritime Pine *(Pinus pinaster)* or the Umbrella Pine *(Pinus pinea)*. Typically riverbank species may occur close to water courses, such as willows *(Salix spp.)* and poplars *(Populus spp.)*.

As cork oaks occur in a range of conditions, stretching from high rainfall (> 1000 mm) to semi-arid locations, the understory, namely shrubs that occur below the cork oak forest canopy, may vary. In more humid locations we find species that do not tolerate severe droughts, such as madroño *(Arbutus spp)*, whereas in drier environments we find species that are usually well adapted to drought and often to forest fire as well. The more common shrubs in dry Mediterranean sites are rockroses *(Cistus spp.)* and brooms *(Cytisus spp., Retama spp)*. There is a great diversity of herbs, including leguminous plants such as clovers *(Trifolium spp)*; and grasses such as ryegrass *(Lolium spp.)* and oats *(Avena spp.)*, as well as plants of other families, such as plantain *(Plantago lanceolata)*. Often this vegetation stratum is used as pasture for cattle.

Currently, the oaks of the Iberian Peninsula, i.e. those contributing the most to the global production and trade of cork, are in open canopy stands where cork oak is dominant, but are managed as multiple use agro-forestry stands, called montados. These are more open than the sobreirais (cork oak forests) and are reminiscent of savannas.

These stands may have occurred in prehistory, resulting from the use of fire by man, as is the case still today, in savannas. There is evidence of the continuity of these stands throughout history, making them part of the cultural heritage of the Western Mediterranean and in some regions, such as the South-western Iberian Peninsula and Sardinia, they are even part of the regional identity.

The reconstitution of many of today's cork oak stands, especially the montados, occurred from the mid-19th century due to the increased market value of cork and demand in the booming cities for livestock products such as pork, which was produced in the montados (pasture and acorns).

Although possibly more specialized in the production of cork than in the past, the montados form cultural landscapes - systems that resulted from human activity that take advantage of various resources: cork, fruits for animal feed, the pasture or agricultural crops that often coexist in the same area and that provide the montado with its agro-forestry-livestock nature.

THE ECONOMIC AND SOCIAL IMPORTANCE OF THE MONTADOS

The economic value of cork is complemented by other sources of income associated with the cork forest: hunting, honey, mushrooms and livestock farming.

Today, eighty per cent of global cork exports come from the Iberian Peninsula. More than 60% of the world's exports originate from Portugal, where the cork oak occupies approximately 736,000 hectares, (i.e. one-third of the total worldwide distribution of the species and 23% of the Portuguese forest area).

These numbers reflect the social and economic importance of the cork oak for Portuguese society: cork oak creates 9,000 direct jobs in the cork industry, 6,500 jobs in forestry and, indirectly, thousands of jobs related to other cork oak forest products (livestock farming, restaurants, tourism, etc.), contributing about 2% to total annual national exports and 30% of Portuguese forestry product exports.

The area of cork oak stands in the Iberian Peninsula saw a steady increase during the 20th century, and has since stabilized. Recently, there has been a slight increase due to reforestation and other protective measures that prevent the felling of cork oaks or the conversion of cork oak forests to other uses. In recent decades, reforestation has contributed about 1% per year to the increase of the cork forest area in Portugal.

Approximately 150,000 hectares of cork oak were planted in Portugal and Spain. In Spain, the increase in the cork forest area has been accompanied by an increase in the tree density of stands. On the other hand, a decrease in tree density has occurred in some cases because of old age and the death of adult trees. The forest fires of recent years have severely affected Portuguese forests and in less scale the montado.

However, the cork oak montado burns less than forest stands of other species such as maritime pine or eucalyptus. The area of montados affected by fires has been compensated by reforestation, and by the natural recovery of the burnt areas.

ECOLOGICAL IMPORTANCE OF THE CORK OAK FORESTS

Ecosystem services

In addition to providing goods and services that have direct market value (e.g. food, fibre), cork oak ecosystems also generate environmental services that are essential to the survival of Man. The quantification of these is difficult and often non-existent or made indirectly.

Biodiversity conservation, regulation of the hydrological cycle, soil protection and carbon sequestration, are examples of services generated by forest ecosystems.

Marbled Newt

THE HIGH BIODIVERSITY OF THE MONTADO

Mediterranean ecosystems are particularly rich in species of fauna and flora, constituting biodiversity hotspots. The Mediterranean Basin has between 15,000 and 25,000 plant species, a much higher number of species than that found in the rest of Europe. More than half of these species are endemic to the Mediterranean region.

Cork oak is one of such species. The cork oak forests are also important reservoirs of biological diversity. The Natura 2000 network, a pan-European network of classified nature conservation areas, classifies montados (habitat 6330) and sobreirais (habitat 6390) as very important for the conservation of biodiversity.

The montados form heterogeneous habitats with a ''mosaic'' of uses that vary from areas of scrub, normally with varying age and height, and pasture land or crops, with varying tree density (from 30 or 40 trees to over 100 trees per hectare). The cork oak, the keystone species of the cork oak forest, is the basis of a food chain that includes everything from insects that feed on its leaves to the birds that prey on these insects.

The heterogeneity caused by the canopies of cork oaks gives the system both vertical and horizontal diversity (the ''mosaic'' of use), which favours various species of fauna and flora by establishing niches: different characteristics of microclimate and soil fertility between areas under the influence of the canopy and open spaces.

Despite being managed as agro-forestry-livestock systems with restricted multifunctionality, montados also comprise native vegetation elements.

The longevity of the trees (which can live to 200 years on average) and their persistence contribute to the high biodiversity of the montados.

Pasture land within montado areas is also very rich in species of herbs. For instance, more than one hundred species have been recorded in plots of 0.1 hectares. The majority of these are annual species, i.e. they grow, live, produce seed and die within a period of 1 year, spending the dry summer period in the form of a seed buried in the soil: a form of adaptation to the hot and dry Mediterranean climate.

These plant communities also vary from year to year - depending on the rainfall and temperature, which means that each year certain species are favoured over others. Moreover, the canopy creates microclimate conditions that ensure that the species growing underneath are often different from those that occur beyond the influence of canopy.

This contributes to the diversity of the pasture plants of the montado. In addition to the plant diversity, the montados provide protection for animals escaping predators and for building nests, as well as foraging areas for unique species of fauna, some with protected status.

Iberian Lynx

Wild Hare

Buzzard

The preferred habitat of the Iberian lynx *(Lynx pardinus)*, one of the most threatened cats of the world, and endemic to the Iberian Peninsula, is the cork and holm oak forests.

The Imperial Eagle *(Aquila adalberti)*, a bird of prey in danger of extinction, nests in the trees and hunts in open areas of the montado. Other species such as the Wildcat (Genet) *(Felis sylvestris)* and birds of prey like the Short-toed Eagle *(Circaettus gallicus)*, the Booted Eagle *(Hierattus pennatus)* and the Bonnelli's Eagle *(Hieraaetus fasciatus)* nest in the montados. The scrub, typical of many zones of the montado (*Cistus spp.*, arbutus, myrtle, heather) are also an essential habitat for bird species of conservation interest, for example some species of warbler *(Sylvia spp)*.

Insects form the basis of a diverse feeding network in the montado (Figure 3). Young cork oak leaves are a very desirable food for some of these insects, especially species like the cork tree caterpillar *(Lymantria dispar)*, the lackey moth caterpillar *(Malacosoma neustria)* and the tortrix moth *(Tortrix viridiana)*, which can even cause severe defoliation in certain years, overcoming the chemical defences (anti-nutritive chemicals) and structural defences (leathery and spiny leaves) that the leaves have evolved during thousands of years of cohabitation.

Mushrooms are another type of organism that occurs in montados. These species play an important role in the decomposition of organic matter in the soil, although some species may be pathogenic.

Many species are mycorrhizas (Figure 3) - that is, they associate symbiotically with the cork oak roots, sharing organic food with the tree and helping it absorbing soil nutrients. Mycorrhizas are essential for the cork oak.

Without them the trees would find it difficult to absorb phosphorous and other minerals from the poor soils in which they grow.

Many mushrooms are edible, some having great gastronomic value. Mushroom picking is an important activity in many montados in the Iberian Peninsula.

Figure 3

The montado hosts a large variety of animal and plant species that form food chains centred on the cork oak.

HYDROLOGIC REGULATION AND SOIL CONSERVATION

The cork oak forests perform a fundamental role in the regulation of the water balance. Infiltration processes and surface water drainage, for example, are influenced by the presence of the trees and their root systems.

The tree crowns intercept more rain water than the lower vegetation and ''channel'' it to the soil beneath the tree as it flows down the tree trunk and drips from the foliage. The soil beneath the crowns is frequently more permeable and has a much greater capacity to retain water than the uncovered soil.

Soil conservation is a fundamental aspect of the montados' sustainability. In many cases, especially in regions with a Mediterranean climate, soil fertility is dependent on the organic matter that results from the decomposition of organic waste (for example, leaves, branches, dry grass). Soils richer in organic matter are characterized by having better water infiltration and storage capacity, nutrient retention, aeration and root growth capacities. In the case of the montado, the leaves are renewed annually (despite the fact that the canopy remains green all year round).

The old leaves (as well as other plant and animal waste) fall to the ground where they decompose and contribute to the soil's organic matter, recycling the nutrients absorbed by the plants. The main contributor of organic matter to the soil is the thin roots that proliferate close to the soil surface and have a short lifespan.

The crowns are also important for soil protection as they protect the soil from the direct impact of rain that may cause soil slippage and erosion, especially during torrential rain and on sloping surfaces. The area underneath the crowns is also rich in nutrients (for example holding about 50% more nitrogen) and has more carbon (about 60%) than bare soil. By promoting the infiltration of rain and preventing soil erosion, the montados contribute to water cycle regulation, an environmental service particularly important in Mediterranean climatic areas where water is a scarce resource (a situation that may worsen in the future).

The felling of trees has led to irreversible soil degradation processes and physical desertification. The cork oak can, in this regard, play an essential role in soil conservation and protection and thus help combat desertification. This is particularly significant in North Africa, where forest degradation due to demographic pressure and climate, accentuates the risks of desertification.

The cork forests, due to their potential economic value, may also be crucial in forming a barrier to desertification.

CORK AND CARBON SEQUESTRATION AND STORAGE

SEQUESTRATION = 14,7 t de CO_2 per ha/year

The latest (2014) IPCC document (Intergovernmental Panel on Climate Change) of the UN reiterates what is now accepted by the scientific community: the increase in concentrations of greenhouse gases such as carbon dioxide (CO_2) in the atmosphere is responsible for important changes in the climate. While humanity is responsible for the burning of fossil fuels, the assimilation and storage in the medium term of carbon in forests can contribute to the mitigation of carbon dioxide emissions of fossil origin.

Carbon sequestration in forest ecosystems is measured by the balance between photosynthetic assimilation of carbon and the carbon dioxide emitted by respiration of the ecosystem (including the decomposition of organic matter in the soil that provides the essential minerals for life). Hence the importance of measuring this balance or net productivity of the ecosystem.
The European Union created the ICOS (Integrated Carbon Observation System) to assist the worldwide effort to quantify the carbon balance. Work has been conducted in Portugal in this field which has quantified the annual carbon retention capacity of the montado.

For example, in central Portugal (Évora), a low density montado (about 30% tree coverage) retained on average 88g of carbon per m^2 per year (i.e. 3.2 tons of CO_2 per hectare per year). But the annual carbon sequestration in a montado in best soil and climate conditions, with certified forest management and with more plants (50% tree cover), quadrupled that figure to 400g of carbon per m^2 per year (i.e. 14.7 tons of CO_2 per hectare per year)*. However, the occurrence of adverse conditions such as a dry year can lead to significant decreases (about 40%) in carbon sequestration.

*Thank you to Filipe Costa e Silva (ISA) for his assistance

THE SUSTAINABLE MANAGEMENT OF THE MONTADOS

For montados to maintain their cork production capacity and provide the referred environmental services, it is necessary that they are adequately managed.

The management of scrubland, which increases the risk of fire and decreases the heterogeneity of the montado habitat if it is not done, and also the promotion of natural regeneration by regulating livestock, are examples of management measures necessary for the maintenance of this ecosystem.

Certification of forest management is a mechanism that ensures the sustainable management of forest ecosystems complying with environmental and social-economic criteria.

The two major forest certification systems are the Program for Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC), which in Portugal cover 250,000 and 340,000 hectares of forest area, respectively.

In Portugal, Spain and Italy about 150,000 hectares of cork oak forest are certified by the FSC system, with more than 100,000 hectares of this located in Portugal.

THE CORK STOPPER AND THE ENVIRONMENT

Approximately 200,000 tons of cork are harvested annually, with Portugal accounting for nearly 50% of the world's cork production.

Approximately one-third of the cork is transformed into stoppers which represents 70% of the total value.
In the past few decades, alternatives to cork stoppers have emerged which have encouraged a comparison of the environmental effects between different bottle closures. What are the advantages and disadvantages of cork compared to plastic or aluminium stoppers in terms of the environment?
As a plant product, cork retains carbon which results from the photosynthetic assimilation of carbon dioxide (CO_2) from the atmosphere. Part of this carbon is used in the metabolism (quantified by the release of CO_2 in respiration) and the rest in the growth of the plant.
In forests, growth has a component which is accumulated in the ecosystem as it integrates ''long life'' products, such as wood and cork.
Manufactured cork products will continue to retain carbon (half of their dry weight, i.e. approximately 1.7g of carbon per stopper, or the equivalent of 6.2g of CO_2), compared to alternative stoppers which do not retain any carbon. This function only ends with the return of the carbon to the atmosphere in the form of CO_2.

This capture of carbon in non-greenhouse compounds, namely CO_2, contributes to mitigation.
The manufacturing process, distribution and use of cork stoppers is able to change carbon accumulation.
According to a study carried out by PricewaterhouseCoopers (PwC)/ Ecobilan, on behalf of Corticeira Amorim on the life cycle of cork stoppers compared to aluminium capsules and plastic closures, it was determined that concerning the emission of greenhouse gases, the manufacture and use of each plastic closure emits 10 times more CO_2 than a cork stopper, while CO_2 emissions from aluminium capsules are 24 times higher than those of cork stoppers.
It is also possible to reduce the ''carbon footprint'' of cork products by increasing the recycling of the raw material (for example by recycling cork stoppers), increasing the share of renewable energy, improving the use of energy efficiency and decreasing the consumption of fossil fuels in transport, industrial processing and distribution. Cork stoppers have environmental advantages compared to alternative stoppers if we consider greenhouse gas emissions into the atmosphere.
Contrary to forests exploited for wood production, where trees are felled, the commercialization of cork leaves the trees intact. Only the cork from the trunk and thick branches is extracted every 9 years and represents a minute proportion of the total productivity of the trees (1%). The harvesting of such a small proportion of the stock of cork does not alter the forest structure or physiology of the trees.
In a forest with a good structure and productivity such as in the central region of Portugal in Coruche, for each ton of cork extracted, the carbon equivalent of 73 tons of CO_2 from the atmosphere can be captured* in the forest.
Consequently, the exploitation of cork hardly affects the role of the cork oak forest as a carbon sink.
In the study carried out by PwC, when the cork oak forest's role as a carbon sink is taken into account, it can be concluded that the cork stopper is associated with a carbon retention rate of 112 g of CO_2.
The cork oak forest's ability to retain carbon is variable, but that amount can be considered as a conservative estimate.
In the Coruche case study, in cork oak forests with higher productivity than that considered in the PwC study, carbon capture can be substantially higher and enables the retention of 250 g of CO_2 per stopper to be associated with the cork stopper.

*Thank you to Filipe Costa e Silva (ISA) for his assistance

THE CORK OAK AND THE MONTADO AT A GLANCE

The Cork Oak is an emblematic tree from the Mediterranean Basin, particularly South-western Europe and North Africa. It is an essential component of the forest ecosystems.

The montados and sobreirais, particularly the former, are multifunctional systems of land use that are found in landscapes of social, economic and cultural value. Cork oaks are reasonably tolerant to drought. They have deep root systems that capture water from the depths of the soil, far from competition from other plants, and they are able to face the stress of the hot, dry Mediterranean summers.

Their leaves are reactive to drought, with ''pores'' (stomata) that close, reducing water loss by transpiration during the dry seasons. In addition to cork and products, such as hunting or pastures, the cork oak forests perform important roles in regulating the water cycle and in soil conservation, and are important in combating desertification. Because they normally constitute heterogeneous, resilient habitats, the cork oak forests are home to high levels of biodiversity.

Just like other forests, cork oak forests function like carbon sinks, being able to contribute to mitigating the greenhouse gas effect. Preliminary estimates substantiate the idea that cork harvested every 9 years represents an insignificant quantity of the montados' carbon storage.

Cork stoppers are natural products whose extraction, besides not affecting the ecosystem processes, allows the cork oak forests to provide essential ecosystem services.

Careful management and adequate added value of the services rendered by these systems are essential for their sustainability and to maintain the benefits generated for society.

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Photography: Image Bank APCOR
Year: 2015
Legal Deposit: 383431/14
ISBN: 978-989-99232-2-5
No. of Prints: 5000

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QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
PORTUGAL 2007.2013

UNIÃO EUROPEIA
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