MANAGEMENT OF AGROFORESTRY SYSTEMS

Ecological, social and economic approaches

Esther Fernández-Núñez

Marina Castro

Editors

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Preface

The Intensive Programme of study on "Management of agroforestry systems: ecological, social and economic approaches" resulted from the recognition of the growing importance of agroforestry systems in the European context, in particular, silvopastoral systems in the south of Europe. The European roadmap towards low carbon economy within the 2050 horizon creates enormous challenges for the agriculture sector in terms of its modernization and reconversion for which agroforestry systems are essential technological and sustainable production solutions.

At the global scale, challenges resulting from escalating demand for animal and forest products, effects of climate change, loss of natural capital and the search for sustainable development solutions strengthen the importance of agroforestry systems. Several international organizations, among which the United Nations Food and Agriculture Organization (FAO), the World Agroforestry Centre (ICRAF) and the European Union (EU), have been promoting the development and implementation of these systems. Also, within the context of the United Nations, several conventions – biological diversity, climate change, soil conservation – force deep changes to be made in production systems, to which agroforestry systems are indispensable references.

The intensive learning programme on "Management of agroforestry systems: ecological, social and economic approaches" was funded by the European Comission through the ERASMUS program (2013-1-PT1-ERA10-16673-PBRAGANC01). The Intensive Programme took place in Bragança, Portugal, from March 30 to April 12, 2014, and was organized by the Instituto Politécnico de Bragança in collaboration with the Universidad de Santiago de Compostela, Universidad da Extremadura, and Universidad de Oviedo, in Spain, and the Università degli studi di Bari Aldo Moro, in Italy.

The objective of the programme was to share with first and second cycle students from Portugal, Spain and Italy knowledge about implementation and management of agroforestry systems, in particular silvopastoral systems, considering production, economic, environmental and socio-cultural aspects. The programme was an opportunity to discuss practical and theoretical issues *related to agroforestry systems in different environmental backgrounds, particularly in Atlantic and Mediterrenean regions of the Iberian Peninsula. The programme made it also possible to the intervening institutions to establish cooperation partnerships within the scope of scientific research and knowledge transfer, with emphasis on the production of knowledge on silvopastoral systems materialized in this book.*

The content of this book corresponds to lectures taught in the programme by the researchers and professors subjected to a peer reviewing process; we would like therefore to acknowledge all authors, reviewers and institutions involved in the Intensive Programme and in this book by their collaboration and the ERASMUS Programme by the financial support provided that made it possible to organize this course on "Management of agroforestry systems: ecological, social and economic approaches".

The Editors

Prefácio

A realização do curso intitulado Management of agroforestry systems: ecological, social and economic approaches resultou do reconhecimento da importância crescente dos sistemas agroflorestais no contexto europeu e, particularmente, dos sistemas silvopastoris no do sul da Europa. O roteiro europeu para uma economia de baixo carbono no horizonte 2050 coloca ao sector agrícola enormes desafios de modernização e reconversão no qual os sistemas agroflorestais são incontornáveis enquanto soluções tecnológicas de produção sustentável.

À escala global, os desafios resultantes das necessidades crescentes de alimentos de origem animal e de produtos florestais, os efeitos das alterações climáticas, a perda de capital natural e a procura de soluções de desenvolvimento sustentável reforçam a importância dos sistemas agroflorestais. Diversas organizações internacionais, entre as quais a Organização das Nações Unidas para a Alimentação e Agricultura (FAO), o World Agroforestry Centre (ICRAF) e a União Europeia (EU), têm promovido o desenvolvimento e implementação destes sistemas. Também no âmbito das Nações Unidas, diversas convenções - diversidade biológica, alterações climáticas e conservação do solo - obrigam a alterações profundas nos sistemas produtivos para as quais os sistemas agro-florestais serão uma referência obrigatória.

O programa de aprendizagem intensivo sobre Management of agroforestry systems: ecological, social and economic approaches, foi financiado pela Comissão Europeia através do programa ERASMUS (2013-1-PT1-ERA10-16673-PBRAGANC01). O curso decorreu entre 30 de março e 12 de abril de 2014 e foi organizado pelo Instituto Politécnico de Bragança, em colaboração com a Universidad de Santiago de Compostela, Universidad da Extremadura, e Universidad de Oviedo, em Espanha, e a Università degli studi di Bari Aldo Moro, em Itália.

O objectivo do curso foi partilhar com alunos de 1º e 2º ciclo de Portugal, Espanha e Itália, conhecimento sobre implementação e gestão de sistemas agroflorestais, particularmente silvopastoris, considerando os aspectos *produtivos, económicos, ambientais e socioculturais. O curso constituiu uma oportunidade de discussão de aspectos práticos e teóricos relativos aos sistemas silvopastoris em diferentes contextos ambientais, particularmente nas zonas Atlânticas e Mediterrânicas da Península Ibérica. Permitiu ainda às instituições envolvidas estabelecerem parcerias de cooperação no âmbito da investigação científica e transferência de conhecimento, destacando-se a produção de saber no âmbito dos sistemas silvopastoris consubstanciada neste livro.*

O conteúdo do livro corresponde às lições apresentadas no curso pelos investigadores e professores das instituições responsáveis pelas sessões teóricas; assim, gostaríamos de agradecer aos autores e instituições envolvidas pela sua colaboração e ao programa ERASMUS pelo suporte financeiro que possibilitou a realizou do curso sobre Management of agroforestry systems: ecological, social and economic approaches.

Os Editores

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Chapter I

General aspects of silvopastoral systems

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Intensive program Management of agroforestry systems: ecological, social and economic approaches

ABSTRACT

The scientific history of agroforestry (AF) is brief; it wasn't until the 1990s that a collection of largely descriptive and empirical research studies was gradually transformed into a process-orientated and more robust scientific approach. AF is essentially a new term for age-old practices of integrated land-use that occurs in most parts of the world.

Silvopastoral systems (SPS) can be defined as complex management systems that integrate trees, pasture and animals in an edapho-climatic context. This introduction to SPS provides a historical perspective to highlight the sustainability of AF. It analyses the three main components of SPS, trees, pasture and animals, and their interactions as well as examines its economic and environmental benefits.

Keywords: agroforestry, benefits, components, interactions, practices.

INTRODUCTION

Agroforestry (AF) was termed in the 1970s to describe ancient and common agricultural practices used across several regions of the world, particularly tropical and Mediterranean regions. During the 1980s, AF was widely promoted as a sustainability-enhancing practice with great potential to increase crop yields, conserve soil and recycle nutrients whilst producing fuelwood, fodder, fruit and timber (Nair, 1989). In the subsequent decade, it was recognised as an applied science based on principles of natural resource management (TAC, 1999; Izac et al., 2000).

Retrospectively, first descriptions about multipurpose tree use as an AF system are found in an account of the origins of life. The ancient Indian scriptures mention the multipurpose tree species, Prosopis cineraria, as a fodder source (Flores-Delgadillo et al., 2011) and the Bible (Gen. 2:8-9) describes gardens with an assortment of trees that provide beauty and food. Home gardens were described in the Near East as early as 7000 B.C. and agricultural writers of the Roman era described a wide variety of AF systems that included livestock and the use of tree crops for food and fodder (MacDicken and Vergara, 1990).

Currently, AF is one of the most promising agricultural systems due to several reasons: i) combines productivity, sustainability and adaptability to climate change (Shibu, 2009) ii) is recognised as instrumental in assuring food security, decreasing poverty and enhancing ecosystem resilience for thousands of smallholder farmers in tropical regions (Sanchez, 1995) and iii) is an alternative approach to land use that provides ecosystem services, environmental benefits, and economic commodities as part of a multifunctional working landscape (Shibu, 2009).

AGROFORESTRY SYSTEMS AND PRACTICES

AF systems are highly diverse and complex in character and function. Hence, to understand, evaluate, and endeavour to improve them, AF systems can be classified into several categories. The most common criteria used for this classification are (Nair, 1993):

a) Structure: composition and arrangement of components (spatial, temporal).

b) Function: productive [food, fodder, fuelwood, cloth, shelter, non-timber forest products (NTFPs)] and protective [windbreaks, shelterbelts, moisture conservation, soil improvement, shade (for crop, animal and man)].

c) Socioeconomic scale: level of management (low-medium-high input) and cost/benefit associations (commercial, intermediate, subsistence).

d) Ecological areas: humid/subhumid, arid/semi-arid, highlands.

The types of AF practices found throughout Europe are categorised as (AFTA, 1997; Alavalapati et al., 2004; Mosquera-Losada et al., 2009): *i) Silvoarable AF* (comprises widely-spaced trees intercropped with annual/perennial arable crops); *ii) Forest farming* (cultivation of high-value specialty crops under the protection of a forest canopy that has been modified to provide the correct shade level); *iii) Riparian buffer strips*: strips of perennial vegetation (tree/shrub/grass), natural or planted, between croplands/pastures, water sources (streams, lakes, wetlands) and ponds to protect water quality. European forestry management has used forested buffer strips since the 1700s (Lee et al., 2004); *iv) Improved fallow*: fast growing, preferably leguminous woody species planted during the fallow phase of shifting cultivation; the woody species improve soil fertility and may yield economic products); *v) Multipurpose trees*: fruit and other trees, randomly or systematically, planted in cropland or pasture to provide fruit, fuelwood, fodder and timber, among other services, on farms and rangelands; and *vi) Silvopasture*: combines trees with forage and/or livestock production. It comprises forest or woodland grazing and open forest trees.

SILVOPASTORAL SYSTEMS

Silvopastoralism focuses on the production of livestock and tree products in one integrated pasture system. Several types of silvopastoral systems (SPS) can be identified, according to their components and the interactions between them. Examples include:

- The Iberian *dehesa* or the Portuguese *montado*, the Nordic reindeer husbandry, and multiple sets of systems based on coniferous or hardwoods in temperate regions without specific names (e.g. Northwest Spain (Galicia), New Zealand, Northwest and Southwest USA). These types of SPS (*grazing in the forest or wood pastures*) are characterised by the deliberate integration of trees and grazing livestock operations on the same land and they are managed for both forest products and forage. The Portuguese *montado* or Spanish *dehesa* (*wood pastures*) are the same system, characterised by the presence of an open tree layer, mainly dominated by Mediterranean evergreen oaks – holm oak (*Quercus ilex* L.) or cork oak (*Quercus suber* L.) – grazed by pigs, sheep, goats, cows or bulls. In the traditional *montado*, the herbaceous layer has been maintained by cereal cultivation over long rotations. Tree cover does not follow a regular pattern, and densities vary from 20 to 80 trees per hectare (Pinto-Correia and Mascarenhas, 1999).

- In other systems, trees are planted at a very low density on pastures (*ligniculture on sward)* or they are established as linear formations (*SPS in lines*). In the first instance, the low densities allow pasture maintenance as the main process but generate further income with forest products (Rois-Díaz et al., 2006); for example, in Northeast Portugal ash is grazed by cattle. In the second instance, trees act as living fences/windbreaks to prevent erosion and offer shelter for livestock. These types of SPS are widely used in Denmark (Castro, 1998) and France (Gil-Tena et al., 2015; Zimmermann, 2006), where it is called bocage or Russian steppe.

Finally, in the Mediterranean mountain areas, the agricultural mosaic landscape has an important role in a most unusual grazing system, named by San Miguel-Ayanz (2006), a *mosaic of different land uses within one management unit*. It forms a mosaic of swards, crops and forest trees not within at the stand but at landscape level (Rois-Díaz et al., 2006).

The various patches form a discontinuity that offers greater resistance to the spread of forest fires compared to large-scale continuous forest areas (Loehle, 2004). This system has a high landscape and ecological value; hence, it is seen as strategic for biodiversity conservation (Castro and Gómez-Sal, 2016).

THE COMPONENTS OF THE SILVOPASTORAL SYSTEM

SPS are an important source of income in rural areas. They produce a wide variety of NTFPs, such as cork, honey, nuts, barks, resins, medicinal plants, mushrooms, truffles, meat, milk, or hunting and tourism. They combine long-term production (timber and fuelwood) with annual production (hay, meat, milk, eggs, etc.). The management of these systems requires a balance of resource use between trees and pasture with the added grazing animal element, to produce several products in a sustainable manner. Hence, the initial choice of SPS components, *tree-pasture-livestock*, is crucial when it is established.

Tree

In an SPS, tree functions are associated with an increase in productivity and stability of the global system compared to exclusive agronomic systems. They also have an important role in preventing or decreasing ecosystem degradation, which can be caused by some agricultural practices (Gómez-Sal, 1997). Trees can be from natural vegetation or afforestation/reforestation and are used for timber, industrial products, fodder and fruit or specifically for animal production (shadow, fodder, seeds, wood) (Rois-Díaz et al., 2006). Several types of tree species can be used in SPS, however, the choice is vital because it can have decisive impacts on pasture production and therefore livestock production and its welfare. Some morphologic characteristics, such as rooting habit, litter quality, canopy architecture, allelopathy, radiation interception, phenology, growth rate, apical dominance, good self-pruning (Rigueíro-Rodríguez et al., 2009) as well as the products they offer (leaf forage, fruits, etc.) are key determinants for the choice of tree species.

Canopy cover can increase pasture biomass (Souza et al., 2010) or decrease it if shading is too high (Rigueiro-Rodríguez et al., 2011). The spacing is related to the diameter of the trees and influences the rate of tree growth and forage production. Tree-to-tree and row-to-row spacings should be evaluated to optimise returns per hectare of both forage and marketable timber.

I. Coniferous species

Coniferous species, such as *Pinus* sp., *Juniperus* sp., *Larix* sp., *Pseudotsuga* sp., *Picea* sp., *Abies* sp., *Tsuga* sp. and *Taxus* sp., are commonly used in SPS. Although most of these species are not suitable as livestock feed, forest grazing can have an important role in decreasing fuelwood and fire risk (Rigueiro-Rodríguez et al., 2009; Etienne, 2002).

Tree canopy density is a crucial consideration when establishing an SPS with a coniferous species, particularly *Pinus* sp. This genus produces abundant quantities of pine needles year round, a potentially important decrease in forage production over time (Rigueiro-Rodríguez et al., 2012; Rozados-Lorenzo et al., 2007) and due to its contribution to total tree litter, potentially decreases the amount of litter used for livestock feeding. This decreases the short- and medium-term revenues that can be obtained from *Pinus* sp. compared with other species, such as broadleaves (Pasalodos-Tato et al., 2009; Fernández-Núñez et al., 2007). However, it simplifies understorey flora and, therefore, decreases species richness (Fernández-Núñez et al., 2014).

Other species, such as *Larix* sp., have a highly valuable forage production in the sub-alpine regions of Germany; also *Juniperus sp. (J. thurifera*, *J. oxycedrus*) show an acceptable browsing value in the Mediterranean climate (San Miguel-Ayanz, 2006).

II. Deciduous species

Quercus suber L. or *Quercus ilex* L. are typical in the Spanish *dehesa* and Portuguese *montado*. Oaks produce firewood, fodder and welfare for traditionally managed flocks of small ruminants (Castro, 2009). Mediterranean SPS species, such as *Castanea sativa* Mill (Martins et al., 2011) or *Fraxinus angustifolia* Vahl (Pereira et al., 2002), show higher forage production, associated with higher soil fertility, under tree crowns rather than in open areas. Conversely, it is known that oak acorns have potential nutritive values for ruminants due to their high starch and energy contents, and low levels of condensed tannins (Rodríguez-Estévez et al., 2008; Kaya and Kamalak, 2012). In *dehesas* and Mediterranean mountains, acorns are valuable resources in scarcity periods (Rodríguez-Estévez et al., 2009, 2011).

In New Zealand, *Populus* spp. and *Salix* spp. have been planted to provide green fodder during summer and autumn droughts (Hussain et al., 2009), and for soil conservation and shelterbelts or windbreaks (Wilkinson, 1999).

Pasture

The influence of the tree canopy on light penetration, water use, and temperature are key factors affecting forage production and quality, as well as the ability to support grazing animals in an SPS (Silva-Pando et al., 2002; Fernández-Núñez et al., 2014). For these reasons, it is important to understand and predict the effects of trees on understorey forage production (Percival and Knowles, 1988; Rigueiro-Rodríguez et al., 2011). Forage suitability for SPS should be assessed from the perspective of total plant and animal production, as well as species persistence, rather than shade tolerance alone. Various plant types can be used in SPS, including grasses, legumes, shrubs and forbs. The choice should be based on site adaptability, livestock needs, compatibility with overstorey tree species and landowner objectives. In Mediterranean areas, for example, pastures are usually comprised of therophytes and perennial, summer senescing herbs, which usually decrease or cease growth in winter due to the cold (Rivest et al., 2011). Legumes are the most important component of Mediterranean SPS pasture due to the low nutritional quality of senescent grass and typically low soil fertility (San Miguel-Ayanz, 2006; Porqueddu and González, 2006). Senescent legumes usually show acceptable energy and protein contents and provide protein-rich fruits and seeds in late spring and summer (Castro and Fernández-Núñez, 2014). Herbaceous, annual plants with natural reseeding, such as *Trifolium* spp. *Medicago* spp., *Ornithopus* spp., *Lupinus* spp. and *Biserrula pelecinus*, are well adapted to Mediterranean terrains (Potes and Babo, 2003).

Conversely, species such as *Dactylis glomerata* L., is well known for its shade tolerance and has been successfully used in SPS in north-western Spain (Mosquera-Losada et al., 2006) and New Zealand (Peri et al., 2007). Furthermore, it has high productivity and nutritional quality (Mosquera-Losada et al., 2006). However, species with only a slight shade tolerance, such as *Lolium perenne* L., are recommended during tree establishment in low-density tree plantations, or to accompany tree species with open canopy structures (Lin et al., 1999; Fernández-Núñez et al., 2014).

Livestock

The selection of animals for a particular SPS will depend on landowner objectives and markets, as well as the established tree and forage species. Many landowners prefer beef cattle and sheep, although other livestock possibilities include goats, horses, pigs, and chickens, for example.

Tree/animal interactions influence many SPS processes. For example, in *dehesa* systems, animal activity accelerates the turnover of organic carbon in the soil (Simón et al., 2013) and promotes more productive grass communities (San Miguel, 2001). Also, most of the nutrients ingested by grazing animals are eventually returned to the soil as faeces and urine (Barrow, 1987; Vendramini et al., 2007), which are important sources of nitrogen, phosphorous, potassium, sulphur, magnesium and calcium (Oyanarte et al., 1997). The distribution pattern of these nutrients may be influenced by the presence of trees because animals are attracted to trees for shelter (Sibbald et al., 1995) from heat, cold and inclement weather. It is known that heat stress and cold affect livestock performance, decreasing average daily weight gain (Fraser, 2004). In an SPS, tree shade is distributed throughout the pasture and greatly decreases high-temperature stress, improving animal welfare and increasing grazing time (Garrett et al., 2004; Panadero, 2010; Betteridge et al., 2012). Conversely, in a pine SPS, Mancilla-Leytón et al. (2013) reported that trampling and fertilisation during goat grazing accelerated litter decomposition, promoted nitrogen incorporation and decreased pine needle accumulation on the soil surface, consequently decreasing fire risk.

However, thorough management is required to ensure the livestock do not damage young trees, particularly trees introduced to established pastures (Lehmkuhler et al., 2003; Rigueiro-Rodríguez et al., 2009). It is important that the tree develops rapidly because, in the early phase of the SPS system, one of the most limiting factors to the animal introduction is the low height and diameter of trees, which may confer less resistance to damage caused by animals. Individual tree protectors may be necessary to protect trees, increasing the initial cost to the farmer (Eason et al., 1996).

INTERACTIONS BETWEEN SILVOPASTORAL SYSTEM COMPONENTS

The interaction of components can be defined as the influence of one component within the system on the performance of both the other components and the whole system (Atangana et al., 2014). In SPS, complex interactions occur among trees, pasture and animals. These interactions can be positive or negative (Smith, 2010); and occur among the various components in terms of space occupation (both vertical and horizontal stratification); above- and below-ground (Anderson and Sinclair, 1993). Describing the interactions between SPS components over time is crucial to understand the evolutionary production of the system (Bergez et al., 1999). Trees and pasture compete for water, nutrients and light resources; young tree roots share approximately the same soil volume as the pasture but the intense competitiveness of pasture provides it with an advantage (Mauer and Palátová, 2003). As the tree grows, roots deep in the soil can absorb water in particular layers inaccessible to the pasture, which shelters it from competition. Conversely, the tree crown limits the radiations available for pasture, particularly at the adult stage, sometimes leading to the death or a rarefaction of the pasture under the tree. Alternatively, it can protect the pasture from radiation and wind, consequently, pasture transpiration decreases and its growth improves when drought appears. The animal can modify tree growth by branch browsing and soil compaction at the young tree stage. It also modifies the distribution of mineral nutrients by faeces and urine; these mineral nutrients can be absorbed by pasture roots in the soil surface and by tree roots deep in the soil. Trees create shelter and forage for animals; and animals may modify tree growth by browsing, rubbing, and soil compaction or by dung and urine (Bergez et al., 1999).

The interactions depend on the animal and tree types, the age of the trees and management systems. Among ruminants, cattle and sheep are well suited to integration with trees. Goats are more selective in their feeding habits because they are browsers and, therefore, more suited to SPS when both browse and forages are available (Castro and Fernández-Núñez, 2016). To ensure compatibility between livestock and trees, the correct choice of species, grazing control, and the optimum tree age when the leaf canopy is out of reach of the animal, are important considerations.

BENEFITS OF SILVOPASTORAL SYSTEMS

SPS can provide many social, economic and environmental benefits. In SPS, the production of trees, forage and livestock inhabit the same area and often at the same time, which could be the most efficient use of the resources. Such a system also decreases economic risk because it produces multiple products, most of which have an established market (Devendra and Ibrahim, 2004). SPS can produce wood, forage, meat, milk and fruit, for example. This increases the economic benefits of landowners over time because trees provide long-term returns, while forage and livestock generate an annual income (Fernández-Núñez et al., 2009; Pasalodos-Tato et al., 2009).

In an SPS, tree canopy decreases the effects of meteorological factors (wind, intense rain, temperature changes) and provides livestock and wildlife (birds, mammals, invertebrates) with shade and shelter (Bergez et al., 1997; Souza et al., 2010). Tree canopy provides protection from summer heat and winter cold, and can also contribute to the feeding (leaves, fruits) of livestock during shortage periods (Sotomayor et al., 2016).

SPS favour biodiversity by creating complex habitats that support diverse plants and animals (McDermott et al., 2015), possess a rich soil biota and increase connectivity between forest fragments.

Compared with agricultural areas, SPS can contribute to a decreased risk of soil erosion because tree roots can enhance water infiltration and improve water storage by increasing the number of soil pores. Tree roots and trunks also act as physical barriers to decrease the surface flow of water and sediment. Depending on the tree species and the climate characteristics, tree roots explore deep soil horizons and extract nutrients from soil inaccessible to grasses (Moreno and Pulido, 2009). Therefore, SPS tend to increase nutrient recycling. Trees also deposit the nutrients on the ground with the natural fall of foliage, twigs, and fruits.

In an SPS, livestock grazing can be used as a tool to lower fire risk by decreasing the amount, height and distribution of fuel (Mancilla-Leytón et al., 2013; Castro and Fernández-Núñez, 2014). Alternatively, decreasing the stand density to promote forage production (Casals et al., 2009) will lessen the likelihood of wildfire and can result in a high-value of timber (Montagnini et al., 2003).

SPS can be used to recycle urban and agricultural organic waste with the added benefit of increased forage production from the additional nutrients (López-Díaz et al., 2007; Ferreiro-Domínguez et al., 2016). Other demonstrated environmental benefits of SPS include the improvement of water infiltration, soil retention, soil productivity, land rehabilitation (Martínez et al., 2014) and the decreased need for external inputs, such as fertilisers, because manure from the pasture livestock contributes to nutrient recycling in the system (Vendramini et al., 2007).

Climate benefits of SPS are substantial due to the increased carbon content stored in the soil and vegetation and avoidance of deforestation (Ibrahim et al., 2010). SPS also decrease emissions associated with manufacturing and fertilisers use. Fertilisers are energy-intensive to produce, and once applied to the land they emit nitrous oxide, a greenhouse gas with a warming effect more than 300 times that of carbon dioxide (Cambria and Pierangeli, 2012; Somarriba et al., 2013).

Finally, from an aesthetic and recreational perspective, SPS are more attractive compared with forest plantations or open pastures. They can increase wildlife diversity and, therefore, increase opportunities for hunting and wildlife watching, for example (Bugalho et al., 2011).

However, not all benefits will be possible in every SPS, depending on the SPS design, level of management, external circumstances, and management objectives.

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Chapter II

Sistemas silvopastoris em Portugal: componentes, funções e funcionamento

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Intensive program Management of agroforestry systems: ecological, social and economic approaches

RESUMO

Nesta apresentação discute-se o conceito de agroflorestal, bem como o de sistemas e práticas agroflorestais. Identificam-se os elementos chave que estão na génese dos sistemas e faz-se uma interpretação da sua relevância em condições ecológicas limitantes. Descrevem-se os sistemas silvopastoris e as práticas agroflorestais mais relevantes, com particular interesse os do norte de Portugal.

Palabras chave: sistemas agroflorestais, práticas agroflorestais, Portugal.

INTRODUÇÃO: SISTEMAS E PRÁTICAS AGROFLORESTAIS

O termo agroflorestal de origem anglo-saxónica – Agroforestry, é usado em português como adjectivo e não nome, ocasionando por vezes traduções pouco corretas e dificuldade no uso da terminologia. Em Portugês Europeu, para nos referirmos ao conceito de "agroforestry" geralmente falamos em ciência ou uso agroflorestal. Silva-Pando e Rozados Lorenzo (2002), referem a mesma dificuldade na língua castelhana e sugerem o uso do termo Agroselvicultura de origem latino-americana, como o mais apropriado para designar a Ciência que engloba os sistemas agroflorestais. Em Português do Brasil também se usa o termo Agrosilvicultura.

Os sistemas agroflorestais correspondem a sistemas de utilização do território que associam árvores ou outros vegetais lenhosos perenes com produções animais e / ou vegetais na mesma unidade de superfície (Nair, 1991). Os três componentes presentes em diversos arranjos espaciais e / ou temporais, são as árvores e outras plantas lenhosas perenes (trees and other woody vegetation, woody perennials), plantas herbáceas (swards, herbaceous plants, crop plants) e animais (animals). De acordo com a sua composição, os sistemas classificam-se em:

- *agrosilvopastoril*, combinando árvores ou outras lenhosas, culturas agrícolas e animais e/ou pasto;

- *agrisilvicola* combinando árvores ou outras lenhosas com culturas agrícolas;

- *silvopastoril* combinando árvores ou outras lenhosas e animais e/ou pasto;

Do ponto de vista funcional podem ter uma vocação de produção ou de proteção (conservação do solo, na redução do risco de incêndios, etc.).

Nair (1985) distingue sistema de prática agroflorestal referindo-se a sistema como um grupo de componentes físicos, isto é um conjunto de objectos conectados ou relacionados de forma a funcionar como um todo (ex. Ecossistema), e prática agroflorestal como uma forma de uso do solo específico de natureza agroflorestal numa exploração agrícola ou outro tipo de exploração. De acordo com o mesmo autor, geralmente as práticas incluem a organização espacial e temporal considerando a função principal do componente arbóreo. Assim poderíamos falar de alley cropping – culturas intercaladas, forest grazing – pastoreio da floresta, scattered trees – árvores dispersas como acontece nos montados ou nos lameiros cruzados por ripicolas. De acordo com Mosquera-Losada et al. (2009), as práticas agroflorestais ou agrosilvicolas mais comuns na Europa são: Silvoarable agroforestry, Forest farming, Riparian buffers strips, Silvopasture, Multiprurpose trees, Improved fallow.

Forest farming- cultura em bosque: corresponde a um sistema de culturas especiais de alto valor sob a proteção de um dossel florestal alterado para fornecer o nível de ensombramento adequado. Culturas como a planta *ginseng* (*Panax ginseng* C.A. Mayer) usada na medicina tradicional chinesa, fetos decorativos, alguns tipos de cogumelos, são exemplos deste sistema em que os produtos geralmente são vendidos para usos medicinais, culinárias e ornamentais (http://nac.unl.edu/forestfarming.htm).

Riparian buffers- sebes amortecedoras (linhas de vegetação com função de isolamento): corresponde a formações lineares ribeirinhas naturais ou plantadas compostas por árvores, arbustos, e /ou herbáceas, com o objetivo de servirem como zona tampão de poluição adjacente aos cursos de água, reduzir a erosão das margens, proteger ambientes aquáticos, melhorar a vida selvagem, e aumentar a biodiversidade.

***Silvoarable agroforestry* –** cultura em corredor: árvores espaçadas ou dispersas com culturas intercaladas.

Silvopasture – silvopastorícia: combina árvores com produção forrageira e /ou animal. As árvores são geridas para produção de madeira de qualidade, fornecendo em simultâneo sombra e forragem para os animais (http://nac.unl.edu/silvopasture.htm).

Multiprurpose trees- árvores multifuncionais*:* corresponde a uma prática em que as árvores de fruto e /ou de outro tipo, implantadas em zonas de pastagem ou de produção agrícola podem estar dispostas casualmente ou com regularidade e tem como objetivo a produção de fruto (consumo humano ou animal), combustível, forragem e madeira, entre outros; encontram-se tanto em quintas (*farms*) como áreas de mato (*rangelands*) (Mosquera-Losada et al., 2009). Como exemplo deste tipo de uso em Portugal, citaríamos os lameiros com freixos dispersos casualmente ou dispostos em alinhamentos rectilineos da zona do planalto Mirandês.

Improved fallows- pousios de melhoramento, culturas preparatórias: prática baseada na plantação de lenhosas de crescimento rápido, geralmente leguminosas, na fase de pousio ou deslocação de culturas/ abandono / (*shifting cultivation*); a espécie lenhosa melhora a fertilidade do solo e pode produzir produtos economicamente transacionáveis (Mosquera-Losada et al., 2009). Na Peninsula Ibérica, a cultura de arbustivas leguminosas foi muito comum até aos anos 60, estas plantas eram cortadas e usadas para camas dos animais que serviam posteriormente para fertilizar os campos, as espécies mais comuns eram *Ulex europaeus* L., *Cytisus* sp. e *Genista florida* L.

Os sistemas agroflorestais correspondem geralmente a formas muito eficientes do uso dos recursos (luz, água, nutrientes), o que os torna atrativos do ponto de vista económico, ambiental e social. A eficiência, associada à diversificação de produtos levou a que estes sistemas fossem ao longo dos séculos implementados em condições ecológicas limitantes tais como as mediterrânicas e de montanha. Modernamente, também estão a ser implementados noutras regiões por razões de estabilidade ambiental e económica (Rigueiro-Rodriguez et al., 2009).

A IMPORTÂNCIA DAS CONDIÇÕES BIOFÍSICAS E DE USOS TRADICIONAIS NA GÉNESE DOS SISTEMAS SILVOPASTORIS EM PORTUGAL

Portugal continental com uma área de 90.000 Km^2 apresenta uma elevada variabilidade bioclimática, a precipitação varia entre mais de 3.000 mm na Serra do Gerês, no norte de Portugal, e 400 mm na Zona do Douro Internacional. A diversidade de sistemas silvopastoris no nosso território explica-se por essa variabilidade, e pode ser descrita através de um sistema de eixos cartesianos, diferenciando-se no primeiro as condições climatéricas (do Atlântico ao Mediterrânico) e no segundo a dimensão da propriedade (de pequena no Norte a grande no Sul do país). Considerando um terceiro eixo relativo à altitude, as condições climáticas são matizadas, surgindo as espécies próprias dos ambientes de transição (Figura 1).

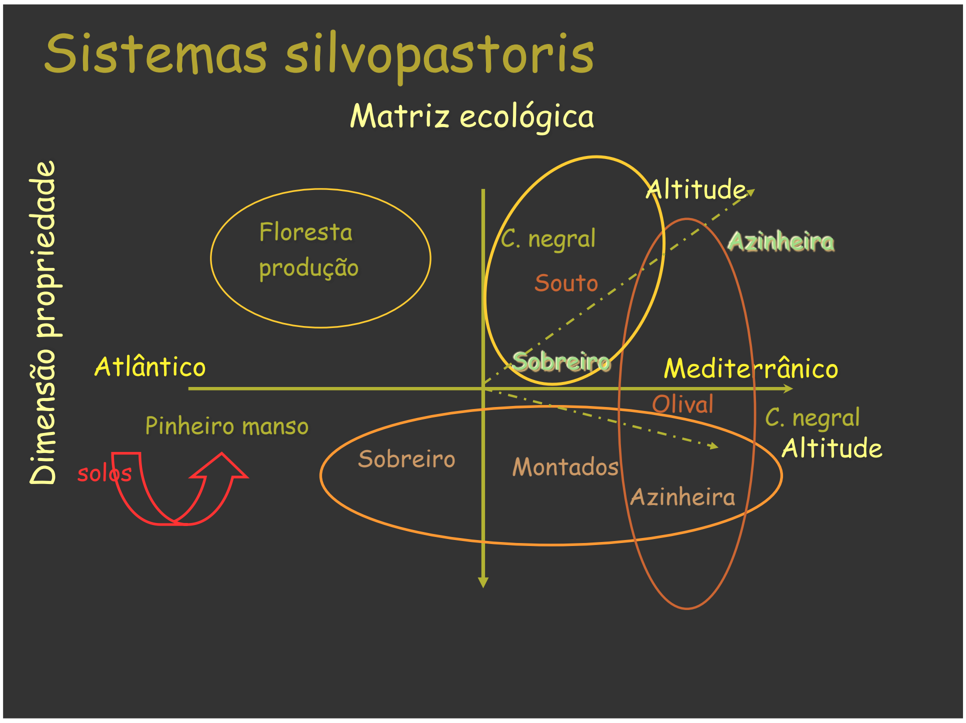

Figura 1. Distribuição dos sistemas e / ou espécies arbóreas em função das condições ecológicas e dimensão da propriedade.

Na região norte sob influência marcadamente atlântica (1º eixo), dominam as florestas de resinosas para produção de madeira. Ainda que tradicionalmente não sejam pastoreadas, é expectável um aumento do pastoreio no futuro, à semelhança do que é preconizado na Galiza (Espanha). No Sul, sob influência atlântica e em substratos arenosos (2º quadrante) desenvolvem-se os sistemas baseados em *Pinus pinea* L. para produção de pinhão associado à produção animal.

Nas situações mediterrâneas, tanto a Norte como a Sul, domina o olival (*Olea europaea* L.) como sistema agroflorestal cultivado. Nas mesmas condições, como sistema construído, surgem no Sul os *montados*, nas situações de maior humidade de sobreiro (*Quercus suber* L.) e nas situações mais interiores de azinheira (*Quercus rotundifolia* Lam.). No norte do país, os montados dão lugar a bosques em consequência, da dimensão e titularidade da propriedade.

Nas situações de transição, em condições de altitude, caracterizadas por maior humidade e rigor invernal, surge o castanheiro (*Castanea sativa* Mill.) e o carvalho negral (*Quercus pyrenaica* Willd.).

OS SISTEMAS SILVOPASTORIS TRADICIONAIS

Entre os sistemas silvopastoris tradicionais portugueses, os montados (Q*uercus suber*, *Quercus rotundifolia*) do sul do país são claramente os mais emblemáticos e de maior relevância económica, trata-se de sistemas fechados em que as diversas produções estão integradas e valoradas economicamente. Os olivais (*Olea europaea*) cultivados no Sul e Norte para produção de azeite ou azeitona de mesa são sistemas em que o valor do pasto, potencialmente utilizável para alimentação do gado, não é integrado na contabilidade da exploração. O mesmo se passa para a generalidade dos sistemas do Norte, nomeadamente os Bosques de carvalho negral – *touças*-, os pomares de castanheiro – *soutos*-, e as Árvores multifuncionais dispersas ou em alinhamentos nos lameiros, características do planalto Mirandês.

O sistema tradicional de pastoreio (pastoreio de percurso) que usa uma rede de distintos usos interligados funcionando como uma extensa área forrageira, extensamente representado nas zonas de montanha do norte de Portugal é também exemplo de uma prática agroflorestal. Em seguida serão descritos alguns destes sistemas ou práticas agrofloresatis, dando-se maior relevância aos característicos do norte de Portugal.

Bosques de *Quercus pyrenaica* pastoreados

Este sistema classifica-se como **silvopastoril** se atendermos aos seus componentes biofisicos, ou **pastoreio da floresta** (enquanto prática), se nos centrarmos na função principal do componente arbóreo (de acordo com a classificação de Nair, 1985 e Mosquera-Losada et al., 2009).

Os bosques de carvalho negral (*Quercus pyrenaica* Willd.) constituem as formações florestais autoctones características da Terra Fria Transmontana. O carvalho negral é uma espécie própria dos ambientes de transição entre a zona temperada (caducifolias) e mediterranica (esclerófitas), ocorrendo no sudoeste da Peninsula Ibérica e isoladamente no norte de Africa – Marrocos. Ocupa una área de 600.000 ha em Espanha e 62.000 ha em Portugal, distribuindo-se nas zonas bioclimáticas supramediterranicas, nos ombroclimas sub-húmido (600-1000 mm) a húmido (1001-1600 mm). Em Portugal, é muito abundante no nordeste Transmontano, constituindo cerca de 40% da cobertura arbórea dos concelhos de Bragança e Vinhais. Aparece também na Beira Interior e na Serra de São Mamede no Alentejo.

Este sistema silvopastoril apresenta um estrato arbóreo cerrado, variando a densidade entre 400 e 1100 árvores/ha. O sub-bosque está dominado pela propia regeneração em associação com arbustos do genero *Cytisus* sp., *Erica* sp. e *Genista falcata*. A produtividade do estrato herbáceo é limitada pela escassez luminosa, variando a produção anual entre 570-2500 kg MS / ha (Castro, 2004) em função das características do arvoredo. Estes bosques são explorados para produção de lenha e usados pelo gado como locais de sesteio ou fonte de recursos alimentares (Figuras 2, 3). Entre os pequenos ruminantes, os caprinos fazem uma utilização mais intensiva deste tipo de bosque (31,51% no verão e 9,57% no inverno de tempo de percurso), no inverno a passagem dos ovinos pelos carvalhais é praticamente nula (0.83% tempo percurso) enquanto no verão sobe aos 20%.

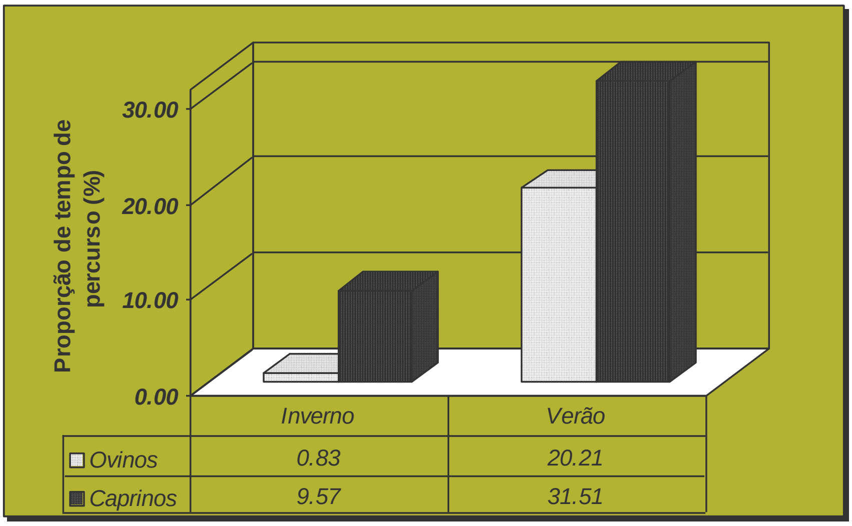

Figura 2. Percentagem de tempo passado em bosques de carvo negral por ovinos e caprinos no verão e inverno.

Por outro lado, o consumo dos recursos vegetais do carvalhal é mais intenso por parte dos caprinos.

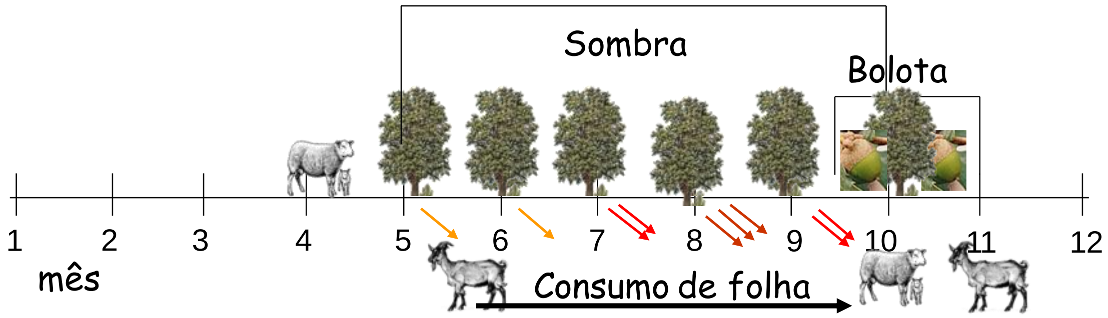

Figura 3. Recursos usados pelos animais ao longo do ano.

Os bosques de carvalho negral (*Q. pyrenaica*), à parte dos produtos de natureza comercial que produzem, são importantes do ponto de vista ambiental: sequestram carbono, favorecem a conservação das raças autóctones, conservam a biodiversidade e preservam a paisagem de elevado valor natural, entre outras (Figura 4).

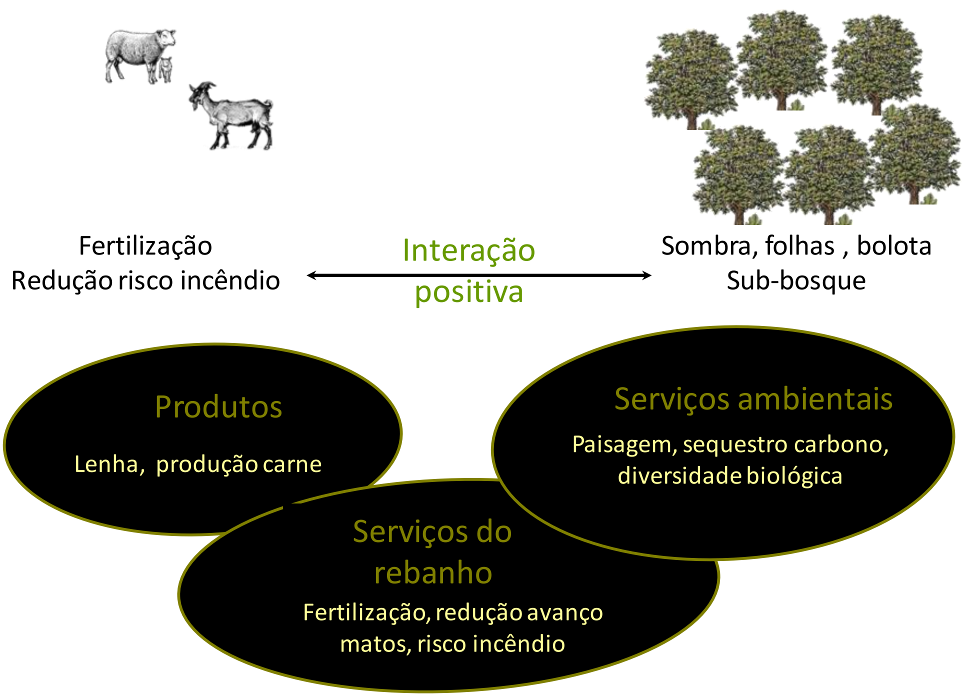

Figura 4. Produtos, serviços e componentes dos bosques de carvalho negral pasatoreados.

Castanheiro: múltiplos sistemas

O castanheiro (*Castanea sativa*) tem sido cultivado ao longo dos tempos com diferentes objetivos produtivos: madeira e /ou fruto, taninos para a industria vinícola, cogumelos entre outros. Assim, em função dos componentes e do seu uso poderemos ter diferentes tipologias ou práticas agroflorestais, por ex. *forest farming* (cogumelos, taninos), *silvopasture* / silvopastorícia (pastoreio) ou *sivoarable agroforestry* / culturas intercaladas (cultura de cereal).

O castanheiro é uma espécie amplamente difundida na Europa Mediterrânica que tal como o carvalho negral, surge em condições de humidade (acima dos 800 mm) e de clima mais temperado, propiciadas pela altitude; geralmente vegeta melhor nas encostas norte e este, devido à sensibilidade à radiação directa. Em Portugal, ocupa cerca de 35.000ha, correspondendo 90% desta área à produção de fruto – Soutos.

Os Soutos correspondem a pomares com baixa densidade de árvores (70–100 árvores/ha, compasso 12x12 ou 10x10 m) e uma cultura associada ou uma cobertura herbácea pouco densa.

Após a colheita comercial da castanha, os rebanhos entram nos soutos para fazer o "robusco" - aproveitamento da castanha que fica no solo. Neste período do ano, os animais passam cerca de 15% do tempo dos seus percursos nestas áreas (Castro, 2004). O aproveitamento dos recursos herbáceos e lenhosos do sub-bosque, podem ser feitos até ao fecho dos soutos em meados de outubro (Figuras 5, 6).

Figura 5. Souto - uso do castanheiro para produção de fruto associado a pastoreio**.**

As operações culturais no souto são tradicionalmente muito intensivas e frequentes. As lavouras ocorrem 3 a 5 vezes por ano (incorporação de manta morta-folhas e residuos da colheita, fertilização do solo na primavera, limpeza previa ao período de colheita, e por vezes, outras para limitar o crescimento arbustivo e herbáceo); a poda ocorre cada 3 anos, para melhorar a frutificação entre fevereiro e março, e a colheita ocorre entre meados de outubro e finais de novembro. Com a implementação de sistemas agroflorestais, as operações culturais relativas às mobilizações do solo podem ser reduzidas e a colheita do fruto pode ser mecanizada, sendo este um dos principais estímulos à sua implementação.

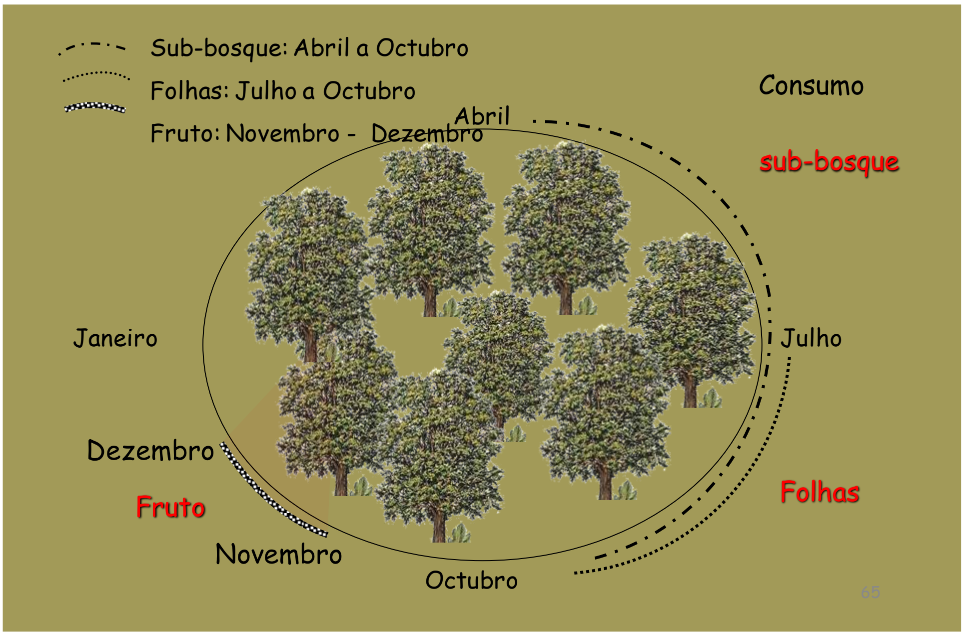

Figura 6. Recursos disponiveis ao longo do ano num castinçal**.**

Os bosques destinados à produção de madeira – castinçais –, representam apenas 10% da área do castanheiro (Monteiro, 2000), são também frequentemente pastoreados, uma vez que a castanha não tem valor comercial e é um recurso de elevado valor energético, dada a sua elevada concentração em amido e baixa em fibra. As folhas originárias das podas servem também de alimento para os rebanhos em final de inverno, princípio de primavera. No que respeita à sua composição, o conteúdo em PB varia entre 12,4 e 14,5%, o conteúdo em fibra é relativamente baixo, variando o NDF entre 33,3 – 37,5% e o ADF entre 24.3% e 26.3%.

Olival

Os pomares de oliveira (*Olea europaea* L.), por vezes cultivados em associação com culturas anuais, constituem uma paisagem muito característica e extensa das zonas do sul da Europa (Eichhorn et al., 2006). É uma cultura com extrema relevância social e económica na zona mediterrânica, em Portugal, ocupa cerca de 340.000 ha, sendo que 62.000 ha se encontram no nordeste do país (Monteiro, 1999).

A oliveira é uma espécie muito plástica, vegetando bem em condições de temperatura amena e intervalos de precipitação de 450 a 800 mm, sendo sensível ao excesso de humidade (Monteiro, 1999). Nos sistemas tradicionais, a densidade de árvores é de 100 a 125 pés/ha, no entanto, nos últimos anos, a cultura do olival intensificou-se, usando-se actualmente compassos mais apertados. Nos sistemas tradicionais a utilização pastoril do olival é feita sobretudo por ovinos.

O fruto (azeitona), amadurece em novembro – dezembro (no caso das novas variedades, o fruto tende amadurecer mais cedo). Cada 2-3 anos, fazem-se podas de frutificação para estimular a produção de fruto. Esta operação ocorre após a colheita, em fevereiro-março, e representa o maior investimento em trabalho especializado (Castro, 2009). O uso dos sub-produtos (principalmente a folha) faz parte do sistema de exploração nas zonas mediterrânicas (Sansoucy, 1985). Nas zonas onde os rebanhos coabitam com os olivais, os recursos provenientes da poda são usados como recursos alimentares para os animais. Neste período, as folhas de oliveira tem um valor nutritivo interessante, cerca de 12% de PB e 43% de digestibiliadde da matéria orgânica (Delgado-Pertíñez et al., 2000).

Montados

O *montado* é o sistema agroflorestal mais relevante da Peninsula Ibérica, ocupando uma área de cerca de 3 milhões de ha, 2 248.000 ha no sudoeste de Espanha e 869.000 ha no sul de Portugal (Eichhorn et al., 2006). Trata-se de um sistema construído pelo Homem, a partir da transformação do bosque mediterrânico, apresentando uma estrutura do tipo savanoide e a sua conservação depende da intervenção humana (Joffre et al., 1999).

O montado caracteriza-se pela presença de um estrato arbóreo muito aberto ou pouco denso, principalmente dominado por perenifólias mediterrânicas - azinheira (*Quercus ilex* L.) ou sobreiro (*Quercus suber*) – e em menor extensão, por espécies caducifólias (*Quercus pyrenaica* e *Quercus faginea* Lam.). O estrato herbáceo é dominado por terófitos e em menor grau por pequenos arbustos (Vicente e Alés 2006).

O aproveitamento da bolota – *montanheira*, por parte do porco, decorre no período compreendido entre outubro e fevereiro, obtendo-se cerca de 60 kg (peso vivo) em 75 dias. Para a aquisição de 1 kg de peso vivo de porco são necessários 9 kg de bolota de azinheira (Rupérez, 1957).

No que respeita à valorização dos produtos, a cortiça é o mais valorizado em Portugal. O país detem mais de 50% da produção mundial de cortiça, representando 1/3 das exportações florestais e 3% do total nacional (Castro, 2009). Em Espanha, os produtos de origem animal estão muito valorizados, nomeadamente os derivados do porco ibérico e os touros bravos ou de lide, utilizados nos espectáculos tauromáticos.

Outros sistemas

Entre outros sistemas que não serão descritos mas que merecem ser mencionados, encontra-se o Mosaico de distintos usos interligados funcionando como um conjunto (descrito em Castro e Gomez Sal, 2016) e o sistema Lameiro * freixo (*Fraxinus angustifolia*) - árvores multifuncionais localizados na região nordeste de Portugal. Este sistema constituído por freixos dispersos de forma linear ou irregular nos prados é muito característico do planalto Mirandês (nordeste de Portugal). As árvores são usadas para alimentar o gado (vacas) e fornecer sombra no verão e a sua exploração lenhosa geralmente está associada a necessidades monetárias especiais da família, como seja um casamento, uma doença, etc. (Castro, 1998).

CONSIDERAÇÕES FINAIS

Nesta apresentação foram descritos os sistemas silvopastoris ou agrosilvopastoris tradicionais Portugueses, com especial ênfase nos do norte de Portugal. Todos estes sistemas são passiveis de ser melhorados em termos produtivos, provavelmente não na globalidade das suas produções mas de certos componentes do sistema. O aumento da produção de carne pode ser atingido através de uma maior produção de erva e/ou bolota, mas comprometendo a produção de madeira. Contrariamente, o aumento da produção de madeira ou da sua rentabilidade económica, condicionará o aumento da produção herbácea. Em sistemas multi-complexos, como os agroflorestais, a gestão e definição de objetivos produtivos, económicos, entre outros, é fundamental, porque, geralmente, eles são mais produtivos considerando a globalidade das produções; sendo mais rentáveis quando consideradas as multi-valorizações do sistema que não apenas os produtivos. Os serviços ecossistémicos associados a estes sistemas, reconhecidos e solicitados pela sociedade, constituem também uma oportunidade para aumentar a sua rentabilidade económica.

Como considerações finais, gostariamos de salientar que a elevada diversidade de sistemas silvopastoris presentes na Peninsula Ibérica constitui um acervo de grande relevância ecológica e cultural que merece ser conservado. Esta diversidade resulta tanto da variedade de condições naturais como da história de ocupação do nosso territorio.

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Chapter III

Pasture production and tree growth in silvopastoral systems established with different tree species

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Intensive program Management of agroforestry systems: ecological, social and economic approaches

ABSTRACT

In Galicia (NW Spain), in the early stages of the development of silvopastoral systems, the productivity of both the understorey and trees could be limited by the soil's fertility. However, in the years following the establishment of silvopastoral systems, productivity depends on the effect of the trees on understorey production. Therefore, in silvopastoral systems established through afforestation an adequate selection of tree and pasture species is important. The aim of this study was to compare pasture production and tree growth in silvopastoral systems established with different tree species (*Quercus rubra* L. and *Pinus radiata* D. Don) in Galicia in which the soil was limed and fertilised with different doses of sewage sludge. The results obtained showed that in both studies the improvement in the soil's fertility associated with liming and the fertilisation with high doses of sewage sludge implied an increase in tree growth and in understorey production. Tree growth decreased when some herbaceous species such as *Holcus lanatus* L. and shrubs were established in the understorey. The dense canopy of *Pinus radiata* D. Don reduced the production in the understorey compared with *Quercus rubra* L.

Keywords: *Pinus radiata, Quercus robur,* Galicia, fertilization.

INTRODUCTION

Agroforestry systems are a sustainable land management strategy, which integrate at least two components, one woody (tree or shrub) and the other herbaceous (pasture or crop) (SEEP, 2014), but may also involve livestock as a third component in the case of silvopastoral practices. Silvopastoral systems are the most used type of agroforestry systems in Europe (Rigueiro-Rodríguez et al., 2009). During the last decade, the establishment of silvopastoral systems has been actively promoted in the EU (Council Regulation 1305/2013 (EU, 2013)) as a means of enhancing environmental services and increasing productivity and financial returns to farmers. Moreover, the reform of the EU's Common Agricultural Policy (CAP) has also created renewed interest in agroforestry and silvopastoral systems.

On the other hand, in silvopastoral systems established through afforestation an adequate selection of tree and pasture species is important. In the early stages of the development of silvopastoral systems, the competition between trees and pasture for water and nutrients is high (Nair and Graetz, 2004) and in later years the trees could have a negative impact on pasture production due to the conditions (shading) being less suitable for the development of understorey vegetation (Mosquera-Losada et al., 2006). In general, over time exotic conifers cause an important reduction in pasture production in the understorey compared with autochthonous broadleaf species due to their different canopy type, light interception and structure (Brockerhoff et al., 2001). Moreover, in silvopastoral systems established in Galicia (NW Spain), soil acidity limits pasture production and causes uneven tree growth (Mosquera-Losada et al., 2012). Therefore, it is advisable to perform management activities such as liming and fertilisation to neutralise acidity and to increase pasture and tree productivity. Liming is a common practice in Galician soils devoted to pasture production, and sewage sludge can be used as an organic fertiliser due to its beneficial effects on the soil and the recent increases in inorganic fertiliser prices (Mosquera-Losada et al., 2010). However, as the application of sewage sludge to the soil might result in an increase in heavy metal concentration and in organic soil pollutants, optimisation of the dose of this residue is clearly desirable (Passuello et al., 2012). In Europe (European Directive 86/278 (EU, 1986)) and Spain (R.D.1310/1990 (BOE, 1990)), regulations exist that limit the total heavy metal concentration in soil and sewage sludge to minimise the harmful effects of sewage sludge fertilisation on soil, vegetation, animals and human health.

The aim of this study was to compare the pasture production and tree growth in silvopastoral systems established with different tree species (*Quercus rubra* L. and *Pinus radiata* D. Don) in Galicia in which the soil was limed and fertilised with different doses of sewage sludge.

MATERIALS AND METHODS

Silvopastoral system under *Quercus rubra* L.

The experiment was conducted in abandoned agricultural land in A Pastoriza (Lugo, Galicia, NW Spain) at an altitude of 550 m above sea level. The pasture was sown with a mixture of *Dactylis glomerata* L. var. Artabro (12.5 kg ha^{-1}), *Lolium* *perenne* L. var. Brigantia (12.5 kg ha^{-1}) and *Trifolium repens* L. var. Huia (4 kg ha^{-1}) in autumn 2001, with bare root plants of *Quercus rubra* L. being planted at a density of 1,112 trees ha^{-1}. The experiment design was a randomised complete block with three replicates and four treatments. Each experimental unit had an area of 144 m^2 and 25 trees planted with an arrangement of 5 x 5 stems, forming a perfect square. Treatments consisted of no fertilisation (0N) and fertilisation with anaerobically digested sludge with an input of 100 kg total N ha^{-1} (100N), 200 kg total N ha^{-1} (200N) and 400 kg total N ha^{-1} (400N) in March 2002 and 2003. The calculation of the required amounts of sludge was conducted according to the percentage of total nitrogen (EPA, 1994) and taking into account the Spanish regulation (R.D.1310/1990) (BOE, 1990) regarding the heavy metal concentration for sewage sludge application.

Tree height and basal diameter were measured with a graduated ruler and a calliper, respectively, in September 2006 and pasture production was determined by taking four samples of pasture per plot at random (0.3 × 0.3 m^2) in June 2002, July and December 2003, June, July and December 2004 and May, July and December 2005. The samples were dried (72 h at 60 ºC) and weighed to estimate production. The cumulative production in the understorey was calculated by summing the consecutive harvests.

Data were analysed with repeated measures ANOVA (proc glm procedure), and Mauchly's criterion was used to test for sphericity. If the assumption of sphericity was met, then a univariate output approach was used, otherwise a multivariate approach was used (Wilks' Lambda test was taken into account). The Tukey's HSD test was used for subsequent pairwise comparisons ($p < 0.05$; $\alpha = 0.05$) if the ANOVA was significant. The statistical software package SAS (2001) was used for all analyses.

Silvopastoral system under *Pinus radiata* D. Don

The experiment was conducted in San Breixo Forest Community (Lugo, Galicia, north-western Spain; European Atlantic Biogeographical Region) at an altitude of 450 m above sea level. A plantation of *Pinus radiata* D. Don was established in 1998 at a density of 1,667 trees ha^{-1}. In October 1999, an experiment with a randomised block design was carried out in 15 experimental plots (5 treatments x 3 replicates) of 96 m^2, each consisting of 25 trees arranged in a 5 x 5 frame with a distance of 3 m between rows and 2 m between lines. Each plot was sown in the autumn of 1999 with a mixture of 25 kg $ha^{-1}$of *Lolium perenne* var. Brigantia, 10 kg $ha^{-1}$of *Dactylis glomerata* var. Artabro and 4 kg $ha^{-1}$of *Trifolium repens* cv. Huia after ploughing. The established treatments were two sewage sludge doses based on N application (T1: 50 kg total N ha^{-1} and T2: 100 kg total N ha^{-1}), with or without liming applied in 1999 before sowing (2.5 t $CaCO_3$ ha^{-1}). No fertilisation (NF) treatment was also established as a control in the unlimed plots. Sewage sludge fertilisation was superficially applied during 2000, 2001, 2002 and 2003. The calculation of the required amounts of sludge was realised as indicated in the case of the silvopastoral system established under *Quercus rubra* L.

The total tree height and diameter at 1.30 m were measured for the inner nine trees of each plot in August 2008 with a pole and calliper, respectively, to avoid border effects. The cumulative production in the understorey (herbaceous and shrubs) was determined by randomly collecting four samples in January, June and November 2003, in June, July and December 2004, in May and July 2005, in March, August and November 2006, in September 2007 and in June and November 2008. To calculate the cumulative production in the understorey, the pine needles were discarded in all samples.

The statistical analyses were realised as described in the previous section with the exception that the test of least significant difference (LSD) was used for subsequent pairwise comparisons ($p < 0.05$; $\alpha = 0.05$) if the ANOVA was significant.

RESULTS AND DISCUSSION

These studies were conducted in acid soils and with a low effective exchange capacity (EEC) (Ferreiro-Domínguez et al., 2011; Ferreiro-Domínguez et al., 2014), which could limit the productivity of the silvopastoral systems. However, a positive effect of lime and sewage sludge on soil fertility was observed (Ferreiro-Domínguez et al., 2011; Ferreiro-Domínguez et al., 2014) and therefore and as shown below, the tree growth and the pasture production were improved by these management techniques. In the silvopastoral system established with *Quercus rubra* L., the no fertilisation (0N) reduced the tree heights and the tree diameters, compared with the 200N and 400N treatments, and the 200N treatment ($p<0.001$), respectively (Figure 1). In the silvopastoral system under *Pinus radiata* D. Don, tree heights were not significantly affected by treatments (p>0.05). However, it was observed that the tree diameters were also lower in the no fertilisation treatment (NF) compared with the low dose of sewage sludge (T1) without previous lime inputs and with the high dose of sewage sludge (T2) combined with lime (p<0.001). The improvement of the tree growth associated with liming and the fertilisation with sewage sludge could be explained by the fact that, in general, the application of these treatments in acidic soils causes an increase in organic matter mineralisation and, therefore, higher nutrient availability for the plants (López-Díaz et al., 2007). The use of lime and fertilisers is not a widely used practice associated with tree management after afforestation because it is costly, however, tree growth can benefit from fertilisation, as shown in our study on *Quercus rubra* L. and *Pinus radiata* D. Don and in that of Balcar et al. (2011) on *Fagus sylvatica* L. and *Acer pseudoplatanus* L.

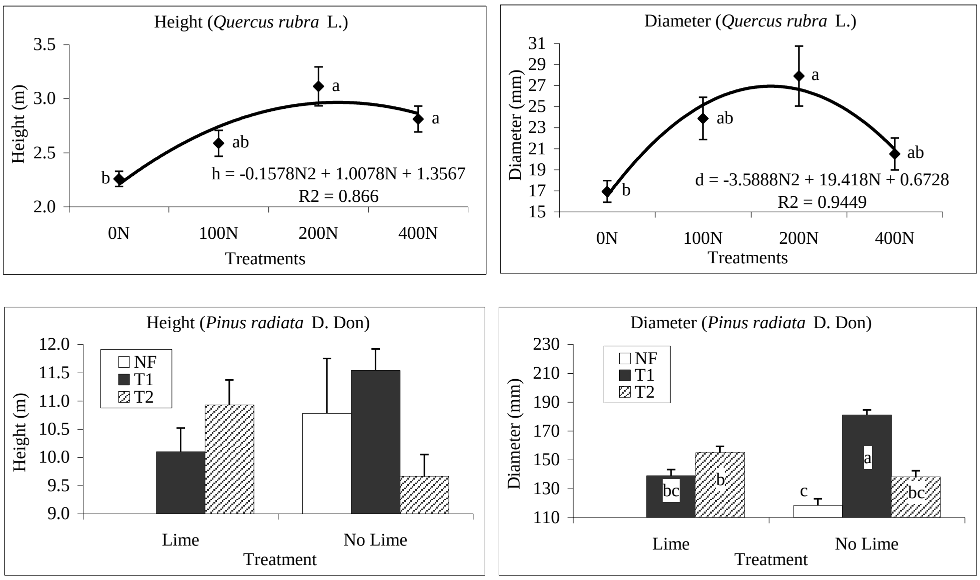

Figure 1. Tree heights and tree diameters under each treatment in silvopastoral systems established with *Quercus rubra* L. and *Pinus radiata* D. Don. 0N: 0 kg total N ha^{-1}; 100 N: 100 kg total N ha^{-1}; 200 N: 200 kg total N ha^{-1}; and 400 N: 400 kg total N ha^{-1}. NF: no fertiliser; T1: low sewage sludge doses (50 kg total N ha^{-1}); T2: high sewage sludge doses (100 kg total N ha^{-1}). Different letters indicate significant differences between treatments. Vertical lines indicate mean standard error.

In these studies, it is also important to be aware of the effect of the understorey vegetation on the tree growth. In the silvopastoral system established with *Quercus rubra* L., the higher proportion of *Holcus lanatus* L. in the 400N treatment compared with the other treatments in which *Agrostis capillaris* L. was the dominant species in the pasture (Ferreiro-Domínguez et al., 2011), implied that the 400N treatment did not significantly modify the tree diameters. *Holcus lanatus* L. is a species associated with more fertile soils than *Agrostis capillaris* L. (Grime et al., 2007) and can capture more soil N, which typically limits the diametral growth of trees as observed by Laliberté et al. (2008) in a study by directly seeding *Quercus rubra* L. on recently abandoned pastureland in Canada. The negative effect of the understorey vegetation on the tree growth was also observed in the silvopastoral system under *Pinus radiata* D. Don, in which the high production of shrubs in the NF treatment probably also explains the lower tree diameters in this treatment than in the lime treatments and fertilisation with sewage sludge. The negative effect of shrubs on tree growth might be explained by the deeper root development of shrubs than that of the herbaceous layer, so when trees age, there might be competition for nutrients at greater depths (Wagner et al., 2006).

On the other hand, in both studies the production in the understorey depended on the climatic conditions, because the lack of drought during the summer months implied an increment in the production in the understorey due to the increase in the length of the growing season. This result was also observed by Rigueiro-Rodríguez et al. (2010) and Mosquera-Losada et al. (2011) in silvopastoral systems established in the same area under *Pinus radiata* D. Don and *Populus canadensis* Moench, respectively. Moreover, the production in the understorey was higher in the silvopastoral system established with *Quercus rubra* L. (Figure 2) than in the silvopastoral system under *Pinus radiata* D. Don (Figure 3). This result could be explained by several factors. Firstly, the silvopastoral system with *Quercus rubra* L. was established in an agronomic soil with a recent history of liming and fertilisation and the study with *Pinus radiata* D. Don was carried on in forest land. Secondly, *Pinus radiata* D. Don is characterised by its very dense canopy, which can reduce pasture production because the radiation input to the understorey is limited by tree cover. Finally, the accumulation of pine needles in the understorey due the advanced state of the forest stand could also reduce the pasture production in the silvopastoral system with *Pinus radiata* D. Don.

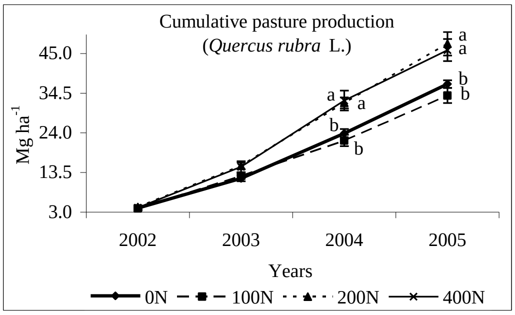

Figure 2. Cumulative pasture production under each treatment for the period 2002–2005 (Mg ha^{-1}). 0N: 0 kg total N ha^{-1}; 100 N: 100 kg total N ha ha^{-1}; 200 N: 200 kg total N ha^{-1}; and 400 N: 400 kg total N ha^{-1}. Different letters indicate significant differences between treatments in each year. Vertical lines indicate mean standard error.

With regard to the effect of the treatments on the production in the understorey, it was observed that pasture production increased in the treatments in which the soil fertility was enhanced. In the case of the silvopastoral system with *Quercus rubra* L., the cumulative pasture production was higher in the 200N and 400N treatments than in the other treatments (0N and 100N) in 2004 and 2005 ($p<0.001$). In the silvopastoral system under *Pinus radiata* D. Don the cumulative production of the herbaceous component of the understorey was significantly lower in the NF treatment than when a high dose of sewage sludge with or without lime was applied in 2004 ($p<0.01$). In 2005, the cumulative production of herbaceous vegetation in the understorey was lower in the NF treatment compared with the other treatments, with the exception of the treatment in which a low dose of sludge was combined with lime ($p<0.01$). Conversely, in all years of the study, the cumulative production of shrubs in the understorey was significantly higher in the NF treatment ($p<0.001$), in which the soil nutritive conditions remained very poor. The reduction in the proportion of shrubs in the understorey due to the improvement of soil fertility is highly relevant for management from an environmental perspective in the region in which this experiment was performed because the fire risk might be reduced, as shrubs are more inflammable than herbaceous vegetation.

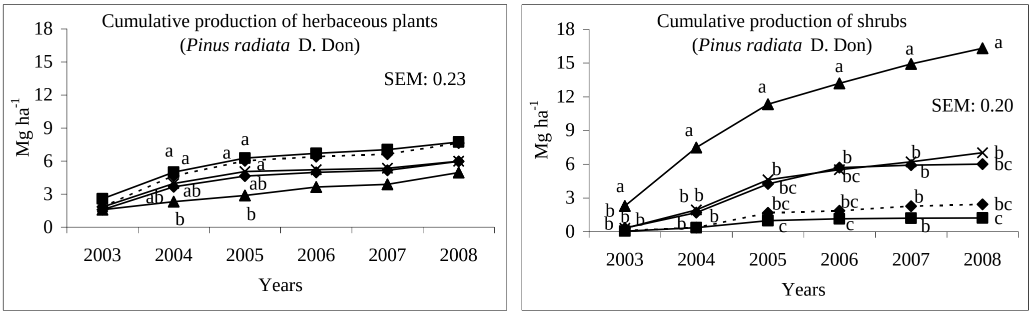

Figure 3. Cumulative production of herbaceous plants and shrubs in the understorey (Mg ha^{-1}) under each treatment for the period 2003–2008. NF: no fertiliser; T1: low sewage sludge doses (50 kg total N ha^{-1}); T2: high sewage sludge doses (100 kg total N ha^{-1}). Different letters indicate significant differences between treatments. SEM: standard error of the mean.

CONCLUSION

In both studies, the improvement in soil fertility associated with liming and fertilisation with high doses of sewage sludge implied an increase in tree growth and production in the understorey. Tree growth decreased when some herbaceous species such as *Holcus lanatus* L. and shrubs were established in the understorey. The dense canopy of *Pinus radiata* D. Don reduced production in the understorey compared with *Quercus rubra* L.

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Chapter IV

Sistemas silvopastoris como técnica de prevenção de incêndios florestais

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Intensive program Management of agroforestry systems: ecological, social and economic approaches

RESUMO

Os sistemas silvopastoris são métodos de gestão do território agroflorestal que podem ser usados com finalidades diversas, entre elas, a redução do risco de incêndios florestais, que são uma ameaça para as florestas de muitos países, entre os quais Espanha, onde na década de 1991-2000 arderam em média mais de 175 mil hectares por ano, um terço da qual arborizada.

Entre as técnicas de prevenção dos incêndios florestais relacionadas com a gestão do combustível vegetal do sub-bosque destacamos a limpeza mecânica- mediante procedimentos diversos-, o fogo controlado e o pastoreio controlado. O pastoreio no monte pode causar incêndios, mas quando os animais são escolhidos adequadamente e bem geridos podem converter-se num aliado importante na prevenção dos incêndios, reduzindo o combustível vegetal do sub-bosque ao mesmo tempo que incrementam a rentabilidade da floresta, juntando produção de carne à produção de madeira, gerando simultaneamente outros benefícios, como melhoria da paisagem, melhor transitabilidade, maior produção micológica, etc.

Em diversos países, Espanha entre outros, têm-se realizado nas ultimas décadas, com bons resultados, experiências de controle de combustível vegetal do sub-bosque mediante pastoreio, como uma técnica de prevenção de incêndios florestais. O nosso grupo de investigação, trabalha na Galicia (NW Espanha) nessa linha há mais de três décadas, ensaiando o pastoreio de cabras, cavalos, ovelhas e porcos em plantações de *Eucalyptus globulus* Labill., *Pinus pinaster* Ait., *Pinus sylvestris* L., *Pinus radiata* D. Don e *Castanea sativa* Miller com bons resultados desde o ponto de vista do incremento produtivo da floresta e a redução do risco de incêndios.

Neste trabalho apresentamos resultados relevantes da nossa investigação, fazendo também referência a outros grupos, espanhois e de outros países, que trabalham nesta linha de investigação, centrando-nos nunha das nossas experiências, pastoreio de equinos em pinhais de *Pinus radiata* D. Don, comparando dois tipos de gestão -pastoreio continuo e rotacional-, revelando os resultados que, a médio prazo, o controle de combustível do sub-bosque é relevante com os dois sistemas de pastoreio, sem diferenças significativas entre eles.

Os resultados apresentados foram obtidos através dos projetos de investigação AGF1998-0368, AGL2001-2996 e AGL2002-00968, financiados pelo Ministerio de Educación y Ciencia de España.

Palavras chave: combustivel vegetal, incêndios, pastoreio, sistemas silvopastoris.

SILVICULTURA PREVENTIVA DE INCÊNDIOS EM POVOAMENTOS FLORESTAIS

Atualmente, os projetos de repovoamento florestal tendem a usar compassos mais alargados, possibilitando a circulação de máquinas entre as árvores, para realizar desmatações ou lavoras com o objetivo de reduzir a competição entre a vegetação espontânea e as jovens árvores e diminuir o combustível do sub-bosque, mitigando assim o perigo de incêndio florestal, uma vez que um dos objetivos essenciais da silvicultura preventiva é a redução e gestão de combustível vegetal, vivo e morto que se acumula sob as árvores. Nesse sentido, para além do espaçamento, outras questões importantes surgem, como a diversificação das espécies a usar, as podas para dificultar os fogos de copas, etc.

A limpeza pode ser pontual, circunscrita a uma área ou total, e seletiva ou não seletiva. Os métodos mais utilizados são os seguintes:

- Manual: Com ferramentas apropriadas, proibitivo para grandes extensões em muitos países devido ao custo da mão-de-obra.

- Mecânico: Com motoroçadoras (corta-matos) manuais ou acopladas à tomada de força de um trator (eixo vertical e eixo horizontal, correntes ou martelos). As motoroçadoras robustas desagregam o mato, o que facilita a mineralização da matéria orgânica. Quando o declive o permite também se podem aplicar lavouras superficiais com fresa ou grade de discos, produzindo-se uma arranque das espécies herbáceas e arbustivas. No caso de grandes declives, pode-se construir terraços, plantando no limite do terraço e mantendo a plataforma livre de arbustivas ou matos através da passagem de moto-roçadoura, fresa ou grade de disco, embora esta técnica seja cara, agressiva e com notável impacto na paisagem, devido à maior terraplanagem que gera.

A biomassa do sub-bosque, assim como os restos das podas e desbastes, também pode ser usado como combustível, diretamente ou obtendo através de pirólise, combustíveis líquidos ou gasosos.

- Fogo: A queima controlada ou fogos prescritos são técnicas eficazes de prevenção de incêndios florestais mas têm que ser aplicadas com precaução.

- Operações químicas: a eliminação química é cara e negativa do ponto de vista ecológico, de modo que, apenas consideramos viável o uso de produtos fitofarmacêuticos em situações pontuais ou áreas de reduzida superfície. Os princípios ativos recomendáveis são glifosato, hexazinona, triazinas, picloram, 2,4D, triclopir, etc. Os três últimos citados são de ação seletiva, respeitando as espécies de folha estreita (gramíneas, por exemplo). Atualmente, é frequente o emprego de produtos fitofarmacêuticos nas filas de plantação (faixas de 1m de largura aproximadamente) para diminuir a competição da flora espontâneas nos dois primeiros anos de plantação.

- Pastoreio: Usando espécies animais compatíveis com as espécies florestais das plantações que consigam consumir as plantas que constituem o combustível vivo do sub-bosque. Esta técnica pode ser combinada com as anteriores.

Em alguns dos sistemas comentados, os resíduos vegetais podem permanecer no solo e serem incorporados, noutros (aproveitamento energético da biomassa), o material vegetal é extraído, o que pode ter efeitos negativos sobre o solo a médio e longo prazo. Com a queima produz-se uma rápida mineralização da matéria orgânica e o nitrogénio volatiliza-se em maior ou menor grau. Com o pastoreio, extrai-se a vegetação, mas há uma restituição ao solo através das dejecções (Matusz, 1962; Baker, 1979; García Salmerón, 1991; Valette et. al. 1993).

SISTEMAS SILVOPASTORIS

A “agrosilvicultura” é uma pratica ancestral em todo o mundo que consiste na combinação de árvores com culturas agrícolas e/ou animais na mesma unidade de superfície, estabelecendo-se entre os componentes interações ecológicas e económicas (Nair, 1989a,b). As vantagens das práticas agroflorestais são consequência das características que as definem e que segundo Anderson e Sinclair (1993), podem-se resumir em produtividade, estabilidade e sustentabilidade. A produtividade destes sistemas deriva sobretudo da multiplicidade dos produtos obtidos; assim, a partir da mesma área obtém-se madeira, carne, leite, lã, pasto, lenha, mel, produtos medicinais e farmacêuticos, cestaria, resina, flores, bolotas, etc.

Além disso, são sistemas de grande importância ecológica, devido às funções não produtivas associadas: previnem a erosão eólica e hídrica e os incêndios florestais; melhoram o microclima, a fertilidade do solo e a qualidade paisagística; criam habitats para a flora e fauna autóctones; regulam e depuram as águas; favorecem o uso recreativo dos ecossistemas florestais; contribuem para o controle de pragas e doenças; aumentam a biodiversidade; e reduzem a poluição (Hislop e Sinclair, 2000; McAdam e Sibbald, 2000; Sinclair et al., 2000).

A maior estabilidade dos sistemas agroflorestais relaciona-se com os rápidos retornos monetários dos produtos agrícolas e/ou animais que se compatibilizam e complementam com os mais serôdios oriundo das árvores, como a madeira, o que proporciona aos proprietários uma maior continuidade de rendas ao longo da vida da exploração, em comparação com a gestão florestal tradicional (Sharrow, 1999), ao mesmo tempo que se reduz o risco de perdas devido a possíveis evoluções desfavoráveis dos mercados e do clima ou decisões políticas, o que supõe uma redução da vulnerabilidade dos sistemas a curto, medio e longo prazo (Sharrow, 1999; Anderson e Sinclair, 1993).

Por outro lado, do ponto de vista social, estos sistemas contribuem para a melhoria das condições socioeconómicas das áreas rurais, especialmente as mais deprimidas, mediante a criação de emprego, o aumento dos rendimentos e a redução de riscos. Trata-se de sistemas de gestão da terra nos quais se associam as tecnologias modernas com os usos tradicionais, convertendo-os em sistemas compatíveis com as características socioculturais da população local, contribuindo para a sua fixação e facilitando a sua integração, o que confere estabilidade a estes sistemas (Nair, 1991).

Os sistemas agroflorestais são tão abundantes e variados, como as funções e produções que lhe podem estar associadas. Neste trabalho, centrar-nos-emos nos sistemas silvopastoris, que correspondem aos usos agroflorestais mais desenvolvidas nas regiões temperadas e industrializadas, para além de serem os mais antigos (Nair, 1991).

Entre os diversos tipos de sistemas silvopastoris que existem vamos centrar-nos no pastoreio em bosques e áreas florestadas nas quais se pastam as espécies arbustivas e herbáceas que crescem de forma natural no sub-bosque. Este tipo de sistema pode utilizar-se para reduzir o combustível vegetal e diminuir por tanto o risco de incêndios florestais (Rigueiro, 1992, Rigueiro et al. 1997). Um dos melhores exemplos encontra-se na Península Ibérica mediterrânica na “dehesa” espanhola ou montado português (Campos e Martin, 1986; Olea, 1999).

O estrato arbóreo

O estrato arbóreo, importante componente dos sistemas silvopastoris, constitui o tecto vegetal do sistema e pode desempenhar várias funções:

- Produzir madeira.

- Proporcionar diretamente alimento fresco e conservado para o gado (ramos, frutos, etc.). É frequente em “agrosilvicultura” tropical e na zona mediterrânica, onde os sistemas silvopastoris têm o seu maior expoente na dehesa, fazendo-se as podas da árvore em anos nos quais a produção de pasto é baixa, para utilizar os ramos como forragem (Joffre et al., 1989).

- Reduzir “inputs” de fertilização, empregando árvores da familia das leguminosas, que fixam nitrogénio atmosférico, melhorando a produção forrageira e, por tanto, a produção animal.

- Proporcionar sombra ou refugio para o gado.

É desejável que o arvoredo dos sistemas silvopastoris reúna características entre as quais destacamos as seguintes (King, 1980; Rigueiro, 2000):

- É importante que apresentem dominância apical e facilidade de poda natural, ou que tolerem podas intensas (Beaton e Hislop 2000).

- São aconselháveis espécies com uma relação diâmetro de copa / diâmetro do tronco baixa, com copa clara, que permita a passagem de luz para o solo e não intercepte a precipitação em elevadas proporções. Além disso, é desejável que a decomposição da manta morta não tenha efeitos alelopáticos sobre espécies pascicolas do sub-bosque.

- Devem ter boa capacidade de bombear nutrientes e os seus sistemas radiculares devem explorar horizontes profundos do solo, para reduzir a competição com o estrato herbáceo e arbustivo e, assim obter uma maior produtividade dos componentes arbóreo e forrageiros.

- Como é óbvio, as árvores devem ser compatíveis com o tipo de gado usado.

Espécies como *Pinus palustris* Mill, *Pinus elliotii* Engelm., *Pinus radiata* D. Don, *Pinus pinaster* Ait. e *Pinus sylvestris* L., entre outros pinheiros, cumprem muitas das características enumeradas, como a poda natural ou tolerar podas artificiais, facilidade de crescimento com baixas densidades, forte dominância apical e atuam como bombas de nutrientes.

No caso dos eucaliptos, estes apresentam alguns inconvenientes, como os seus efeitos alelopáticos e a tendência para abrir excessivamente a copa quando se plantam em baixas densidades, ainda que tenham a vantagem de permitir a penetração da luz até aos estratos inferiores do sub-bosque (Silva, 1988, Rigueiro, 1992, 2000).

No Reino Unido, foram realizados ensaios para estudar a possibilidade do uso de distintas espécies arbóreas em sistemas silvopastoris, obtendo-se bons resultados com *Acer pseudoplatanus* L., *Fraxinus excelsior* L., *Prunus avium* L., *Pinus sylvestris* L. e diversas espécies do género *Populus* (Beaton e Hislop, 2000; McAdam e Hoppe, 1996; McAdam e Sibbald, 2000).

Na Grécia, são frequentes os sistemas silvopastoris com espécies arbóreas com *Quercus petraea* (Matt.) Liebl., *Quercus frainetto* Ten., *Castanea sativa* Mill., *Pinus halepensis* Mill., *Pinus brutia* Ten., *Pinus pinaster* Ait., *Pinus nigra* Arn., *Quercus ilex* L., *Quercus coccifera* L. e *Quercus suber* L. (Papanastasis, 1996).

Em França estes sistemas são frequentes com *Pinus pinea* L., *Pinus halepensis* Mill., *Quercus ilex* L., *Quercus suber* L. o *Quercus humilis* Mill. (Étienne, 1996).

Em Espanha, para além das dehesas mediterrânicas, no norte e noroeste, zona especialmente castigada pelos incêndios florestais como já foi comentado, são frequentes os sistemas silvopastoris com *Pinus pinaster* Ait., *Pinus radiata* D. Don, *Pinus sylvestris* L., *Eucalyptus globulus* Labill. e *Castanea sativa* Mill., e investigouse a possibilidade do uso nestes sistemas de outras espécies arbóreas, como *Quercus rubra*

L., *Eucalyptus nitens* Maiden, *Castanea x coudercii* A. Camus, *Pseudotsuga menziesii* (Mirbel) Franco, *Fraxinus excelsior* L., *Betula alba* L. o *Populus x canadensis* Moench (Rigueiro, 1999; Ibarra et al., 2000).

Na Nova Zelândia e Chile, a espécie arbórea mais usada em sistemas silvopastoris é *Pinus radiata* D. Don. Foram realizadas plantações com esta espécie em prados já estabelecidos, com um aumento dos benefícios globais até aos 12% (Knowles e Cutler, 1980; Knowles, 1991; Hawke, 1991; Hawke e Knowles, 1997).

Na Austrália, além de *Pinus radiata* D. Don, usam-se diversas espécies do género *Eucalyptus*, como *E. saligna* Sm., *E. maculata* Hook, *E. camaldulensis* Dehnh. e *E. globulus* Labill. Neste caso, os sistemas silvopastoris têm primordialmente um carácter protetor relativamente à produção, sendo importante a sua contribuição na luta contra a erosão e controle da acidez e salinidade do solo.

Na zona noroeste dos EUA, o tipo de sistema silvopastoril mais característico inclui a plantação de *Pinus ponderosa* Dougl. ex Lawson e *Pinus contorta* Dougl. ex Loud. em pastos naturais extensivos chamados "rangelands" (Williams et al., 1997). Contrariamente, no sudeste do país, desenvolveram-se sistemas muito mais intensivos, nos quais se usa *Pinus elliottii* Engelm. ou *Pinus palustris* Mill. (Lewis e Pearson, 1987; Williams et al., 1997).

O gado

Os animais devem ser o mais compatível possível com o tipo de arvoredo e capazes de se de alimentar da vegetação que se desenvolve no sub-bosque (Rigueiro, 1997, 1999, 2000; Silva, 1988).

É necessário ajustar a densidade e composição do efetivo em função da produtividade e composição botânica do pasto. Por outro lado, as cargas iniciais dependerão da função que se atribui ao gado; se se pretender um controle rápido do combustível devem ser usadas cargas muito altas durante um curto período de tempo, se o objetivo for um sistema sustentável ao longo do tempo, as cargas serão menores.

Cabras e cavalos, especialmente de raças rústicas, são animais adequados para controlar o combustível vegetal lenhoso vivo do sub-bosque, reduzindo assim o risco de incêndios florestais. O pisoteio também contribui para reduzir (despedaçar) o combustível vegetal morto, acelerando o processo de decomposição e mineralização do mesmo, ao que também contribui a fertilização aportada com as dejeções (Rigueiro, 1992).

As ovelhas e as vacas consomem bem o pasto herbáceo, por isso é aconselhável introduzi-las quando o sub-bosque se abre devido ao pastoreio de cabras e cavalos ou quando estabelecemos uma pastagem artificial a quando da florestação (Rigueiro, 1992).

Nas situações de instalação de povoamentos em associação com pastagens artificiais, para prevenir possíveis danos que os animais façam nos primeiros anos de plantação, podem ser utilizadas árvores de maior dimensão ou então proteger as árvores por sebes, se estas estiverem agrupadas, ou colocar proteções individuais ao redor de árvores (McAdam, 1991; Fletcher et al., 1993; Mosquera et al., 2001). Outra opção seria o aproveitamento do pasto por corte enquanto existe o perigo de que os animais danifiquem as árvores (Sharrow, 1983).

SISTEMAS SILVOPASTORIS NA PREVENÇÃO DE INCÉNDIOS FLORESTAIS: EXPERIENCIAS NA GALICIA (NW ESPANHA)

O pastoreio na floresta foi uma prática habitual no passado na maioria das regiões ibéricas, e em algumas aldeias continua ainda a ter relevância na atualidade. Geralmente, aproveitava-se ou ainda se aproveita, o pasto natural das áreas de mato, melhorando-o por vezes, substituindo-o mesmo noutros casos por pastagens artificiais.

No norte da Península Ibérica foram realizadas experiências no passado recente, que em alguns casos permanecem, sobre o aproveitamento pascícola das áreas de mato e do seu melhoramento e transformação em pastagens (Sineiro, 1982; Sineiro e Diaz, 1999; Osorio et al., 1999).

A compatibilidade dos animais com o arvoredo tem sido tradicionalmente mais problemática, sendo frequente a proibição pela administração florestal da entrada do gado em bosques e arborizações florestais, por receio dos potenciais danos que os animais possam causar às árvores ou à regeneração dos mesmos, proibição que frequentemente conduziu à rutura entre administração e administrados, considerando-se mesmo que esta atitude está na origem, pelo menos em algumas zonas, da conflitualidade na origem dos incêndios florestais.

O pastoreio das zonas florestais continua a ser um foco de conflito em regiões como a Galiza, pelo que é necessário ordená-lo, e o ordenamento do pastoreio em zonas florestais pode organizar-se através de sistemas silvopastoris.

Os sistemas silvopastoris na Galiza começaram a ser investigados há mais de 30 anos. Estes trabalhos iniciaram-se no Centro de Investigações Florestais de Lourizán (Pontevedra), juntando-se mais tarde a estas linhas de investigação equipas do Centro de Investigações Agrárias de Mabegondo (A Coruña) e do Departamento de Produção Vegetal da Escola Politécnica de Lugo. Diversas publicações testemunham a efetividade destas técnicas, do ponto de vista da redução do combustível vegetal do sub-bosque e, consequentemente da diminuição do risco de incêndios florestais (Rigueiro, 1985, 1986, 1992; Rigueiro et al. 1997; Rigueiro, 1999; Silva, 1988, 1991, 1993). Também se abordou a substituição artificial de vegetação natural que cresce no sub-bosque por espécies herbáceas-mais produtivas, nutritivas, digestíveis e palatáveis para o gado, ou seja, a criação de pastagens arborizadas que, à parte de reduzir o risco de incêndios florestais, melhoraram a produtividade, a paisagem e a facilidade de transitar nestes espaços (Rigueiro, 1985, 1992; Silva, 1993; Piñeiro e Pérez, 1988). As espécies arbóreas que têm sido usadas são *Pinus pinaster* Ait., *Pinus sylvestris* L., *Pinus radiata* D. Don, *Betula pubescens* Ehrh. e *Eucalyptus globulus* Labill. Hai anos realizando-se experiências com cavalos num pinhal de *Pinus radiata* D. Don na província de Lugo, comparando o efeito do pastoreio contínuo e rotacional na redução do combustível vegetal do sub-bosque (Rigueiro et al., 2001).

Seguidamente, faremos uma exposição sucinta dos resultados mais interessantes, fruto de algumas das experiências realizadas na Galiza, centrando-nos especialmente na utilização do gado como "destroçadora”, que se alimenta basicamente do pasto natural do sub-bosque, reduzindo assim a quantidade de combustível vegetal e, por tanto, o perigo de incêndio.

Árvores

Os estudos de controlo de combustível do sub-bosque pelo pastoreio foram realizados principalmente em florestas de pinheiro bravo (*Pinus pinaster* Ait.), pinheiro-silvestre (*Pinus sylvestris* L.) e pinheiro-insigne (*Pinus radiata* D. Don) e eucaliptais de eucalipto branco (*Eucalyptus globulus* Labill.). Pinhais e eucaliptais são as massas arborizadas que cobrem atualmente a maior superfície na Galiza – entre 70% e 80 % da superfície arborizada total- e procedem de reflorestações. A densidade das árvores (número de pés por hectare, cobertura do solo em projecção vertical das copas, área basal) está relacionada com a produtividade do sub-bosque, já que ao aumentar a densidade chega menos luz ao solo, e reduz-se a acumulação de biomassa do sub-bosque (Dodd et al., 1972).

Pasto natural do sub-bosque

O estrato herbáceo sub-arbustivo nos pinhais e eucalipatis galegos geralmente está dominado por espécies fruticosas heliófilas e por herbáceas heliófilas e esciófilas. O que torna importante conhecer a qualidade pascícola das principais espécies herbáceas e arbustivas que crescem em condições de sombra, como algumas monocotiledóneas herbácaes (por exemplo dos géneros *Dactylis*, *Molinia*, *Holcus*, *Agrostis*, *Lolium*, *Briza* e *Pseudoarrhenatherum*), herbáceas dicotiledóneas (por exemplo dos géneros *Achillea*, *Erodium*, *Lamium*, *Plantago*, *Rumex*, *Trifolium*, *Senecio*, *Stellaria*, *Urtica*, *Capsella*, *Mentha*, *Taraxacum* e *Daucus*), arbustos (como os dos géneros *Cytisus*, *Ulex*, *Erica*, *Lonicera*, *Pterospartum*, *Daboecia*, *Rubus*, *Genista* e *Calluna*) e raminhos de árvores de menos de 0,5 cm de diâmetro (por exemplo dos géneros *Alnus*, *Betula*, *Fraxinus*, *Quercus*, *Pinus*, *Fagus*, *Salix*, *Populus*). Os resultados principais dos nossos estudos indicam que as espécies herbáceas têm conteúdos mais elevados de nutrientes, o que as torna mais interessantes em sistemas extensivos (Rigueiro et al., 2002). As dicotiledóneas mostram um conteúdo mais elevado em minerais que as monocotiledóneas (Pinto et al., 2002; Rigueiro et al., 2002).

Espécies dos gêneros *Cytisus*, *Rubus* e *Ulex* têm maior potencial forrageiro que as dos generos *Erica* ou *Calluna*, e *Pterospartum* tem um baixo conteúdo proteico, apesar de ser uma leguminosa. As espécies arbóreas apresentam melhor qualidade pascícola que os arbustos, e durante o verão têm conteúdo similar em proteína, fósforo e minerais às espécies herbáceas, tornando-as interessantes para regiões com baixa produção de pasto durante o verão devido à seca estival.

O pinheiro bravo e o eucalipto branco têm copas claras que deixam passar para o sub-bosque uma proporção importante de radiação, mesmo em condições normais de densidade nas plantações. Como consequência, estas formações apresentam um estrato herbáceo-subarbustivo dominado por espécies fruticosas heliófilas e por herbáceas heliófilas e esciófilas. A produtividade do sub-bosque situa-se entre 2,5 e 3,2 t de MS por ha e ano. Contrariamente, nos pinhais de silvestre e insigne, com as densidades normais de plantação, a passagem de radição solar através do dossel arbóreo é menor, pelo que o mato heliófilo tem maior dificuldade para se estabelecer no sub-bosque, fazendo-o sem dificuldade as herbáceas e lenhosas mais tolerantes à sombra, sendo a produtividade algo menor, entre 1,4 e 2,8 t de MS por há e ano (Silva, 1993).

Nas várias experiências realizadas na Galiza, os sub-bosques das parcelas experimentais apresentavam no estado inicial uma acumulação de biomassa de 25 e 50 t de MS por ha, com domínio de espécies lenhosas. Para favorecer o controle efetivo do mato pelo gado, este deve pastar os rebentos tenros, no estado herbáceo, que é quando são mais palatáveis, nutritivos e digestíveis e, em consequência melhor controlados. Por tanto, antes de introduzir os animais é recomendável realizar um tratamento do sub-bosque: queima ou roça (manual ou mecânica) (Rigueiro et al., 1997).

Gado e sua gestão

Os animais devem ser de raças rústicas e compatíveis com o tipo de árvore, capazes de se alimentar da vegetação que cresce no sub-bosque. Nas fases iniciais, quando a vegetação lenhosa é abundante, é aconselhável introduzir lenhívoros, como as cabras e os cavalos, animais cuja dieta comporta elevadas proporções de lenhosas. Devido á introdução do pastoreio, a vegetação do sub-bosque evoluí, reduzindo-se a cobertura das espécies lenhosas e incrementando-se a das herbáceas, recomendando-se então a substituição do gado lenhívoro por herbívoros (como ovelhas e vacas). No entanto não se deve suprimir totalmente o pastoreio com lenhívoros para evitar que o matorral se recupere (Rigueiro et al., 1997).

O cavalo é compatível com eucaliptos e pinheiros, mesmo ainda quando as árvores são jovens, porque não as come, e controla bem os tojos, retamas e gramíneas duras; com as folhosas só é compatível quando já não chega às copas. A cabra convive com o eucalipto branco, mesmo jovem, sem o danificar, mas isto não acontece com os pinheiros e outras folhosas, cuja copa come se está ao alcance, podendo mesmo ferir os troncos quando a casca não está suficientemente desenvolvida; controla bem os rebentos de tojo, retamas, silvas, urzes pequenas e herbáceas. Ovelhas e vacas consomem bem o pasto herbáceo, e inclusivamente, se são raças rusticas, os rebentos tenros das espécies lenhosas, e consideram-se compatíveis com pinheiro, eucaliptos e outras folhosas quando não conseguem alcançar as copas (Rigueiro, 1992, Rigueiro et al., 1997).

Nas experiências realizadas em Marco de Curra (Monfero, A Coruña), a 550 m de altitude, sob substrato xistoso, com precipitação média anual de 1593 mm e temperatura média anual de 10,6 ºC, em pinhais de *Pinus pinaster* Ait. de 30 anos e uma densidade de 450-700 pés por ha, e em pinhal de *Pinus sylvestris* L. da mesma idade e com 500-800 pés por ha, conseguiram-se bons resultados com uma carga geral inicial de 2 cabras por ha, que foi variando com o aumento das espécies herbáceas no sub-bosque, estabilizando-se a partir do terceiro ano 1 cabra e 3 ovelhas por ha. A gestão do gado é feita segundo um modelo que poderíamos considerar de pastoreio rotacional-extensivo, com o objetivo de conseguir cargas pontuais ou instantâneas altas, que aumentam a efetividade no controle do combustível vegetal, incluídas as espécies de menor palatabilidade. A parcela experimental dividiu-se em 4 parcelas e o tempo de ocupação de cada sub-parcela é de um mês aproximadamente, sendo por tanto o tempo de repouso de 3 meses (Rigueiro, 1992; Rigueiro et al., 1997).

Nas parcelas experimentais de *Eucalyptus globulus* Labill. no monte Coto de Muiño (Zas, A Coruña), propriedade do Grupo ENCE, localizadas a 420 m de altitude e também sobre xistos, a precipitação média anual é de 1640 mm e a temperatura média anual é de 11,9 ºC. A densidade de árvores é de 2000 pés por hectare e os proprietários utilizavam pastoreio livre ou contínuo. A carga animal é de 2 cabras e uma égua por cada 4 ha, pastando conjuntamente. Na Primavera sobra pasto, permitindo-se então a entrada das vacas dos compartes, com uma carga aproximada de 1 vaca/ha (Rigueiro, 1992; Rigueiro et al., 1997).

Outro estudo com cavalos (raça autóctone do cavalo galego de monte), foi desenvolvido num pinhal (*Pinus radiata* D. Don), no monte comunitário de Sambreixo (Parga - Guitiriz - Lugo). A altitude é de 500 metros e os pinheiros têm 25 anos, sendo a densidade no início da experiência de 800 pés por ha, reduzindo-se a 400/ha, após um desbaste. A temperatura média anual é de 10,9 ° C e a precipitação média anual é de 1477 mm. A carga geral foi de 0,5 animais/ha e foram avaliados dois sistemas de pastoreio: contínuo (duas réplicas em duas parcelas de 6 ha) e rotacional (duas réplicas em duas parcelas de 6 ha, divididas cada uma em quatro sub-parcelas de 1,5 ha; o tempo de ocupação é de um mês e três meses de descanso). Espécies abundantes na parcela experimental de Sambreixo são: tojos (*Ulex europaeus* L., *Ulex gallii* Planchon), silvas (*Rubus* spp.), urzes pequenas (*Erica umbellata* L., *Erica cinerea* L., *Erica ciliaris* L., *Calluna vulgaris* (L.) Hull), giesta branca (*Cytisus striatus* (Hill) Rothm.), giesta amarela (*Cytisus scoparius* (L.) link), *Genista florida* (Genista florida L.), carqueija (*Pterospartum tridentatum* (L.) Willk.), feto (*Pteridium aquilinum* (L.) Kuhn), *Daboecia cantabrica* (Hudson) C.Koch, *Halimium lasianthum* (Lam.) Spach., *Pseudoarrhenatherum longifolium* (Thore) Rouy, *Agrostis curtisii* Kerguélen, *Agrostis capillaris* L., *Holcus lanatus* L., *Holcus mollis* L., *Avenula marginata* (Lowe) J. Holub, *Molinia caerulea* (L.) Moench, etc. São frequentes as plântulas de árvores autóctones: carvalho (*Quercus robur* L.), castanheiro (*Castanea sativa* Miller) e bétula (*Betula pubescens* Ehrh.), e praticamente nula a regeneração de pinheiros.

Controle do combustível vegetal

O controle de combustível vegetal vivo pelo gado no eucaliptal do Monte Coto do Muiño (Zas, A Coruña) é muito importante. Numa parcela em que foi feito um desbaste nos três anos anteriores, e posteriormente uma queimada para destruir os restos de exploração e o matorral, introduziu-se gado numa zona e noutra limitou-se o acesso ao pastoreio, tendo-se verificado que a biomassa do sub-bosque é 80% mais baixa nas zonas pastoreadas. Os resultados, do ponto de vista da prevenção de incêndios florestais, são muito positivos neste monte, uma vez que praticamente não incêndios nas últimas décadas, enquanto nas proximidades há registos de superfícies importantes queimadas (Rigueiro, 1992).

Nos pinhais de Marco da Curra (Monfero, A Coruña) previamente ao inicio da experiência, a biomassa do sub-bosque era da ordem das 40-50 t/ha de matéria seca e atingia uma altura média superior a 2 m. O controlo da vegetação do sub-bosque é muito eficaz, predominando atualmente as espécies herbáceas, com uma altura máxima de 10-15 cm e uma biomassa estabilizada de 0,5-2 t/ha de matéria seca (Silva, 1988). Neste monte, a biomassa aérea do sub-bosque recupera-se a uma taxa de 5 t/ha/ano de matéria verde em parcelas de exclusão ao pastoreio (Rigueiro, 1992).

Na experiência de Sambreixo, como já referimos, comparou-se o efeito do pastoreio de cavalos, rotacional e contínuo, num pinhal de *Pinus radiata* D. Don, com a finalidade de reduzir o combustível vegetal do sub-bosque e o perigo de incêndios. A Figura 1 mostra a biomassa disponível em cada rotação (quando o gado entra em cada subparcela em pastoreio rotacional, e estimativa simultânea em contínuo) para o tojo, espécie dominante no sub-bosque. Observa-se que o pasto disponível é inicialmente (duas primeiras rotações) superior nas parcelas submetidas a pastoreio contínuo, invertendo-se a tendência posteriormente, até à quinta rotação, na qual, devido à maior pressão do pastoreio rotacional, o pasto disponível volta a ser maior nas parcelas de pastoreio continuo.

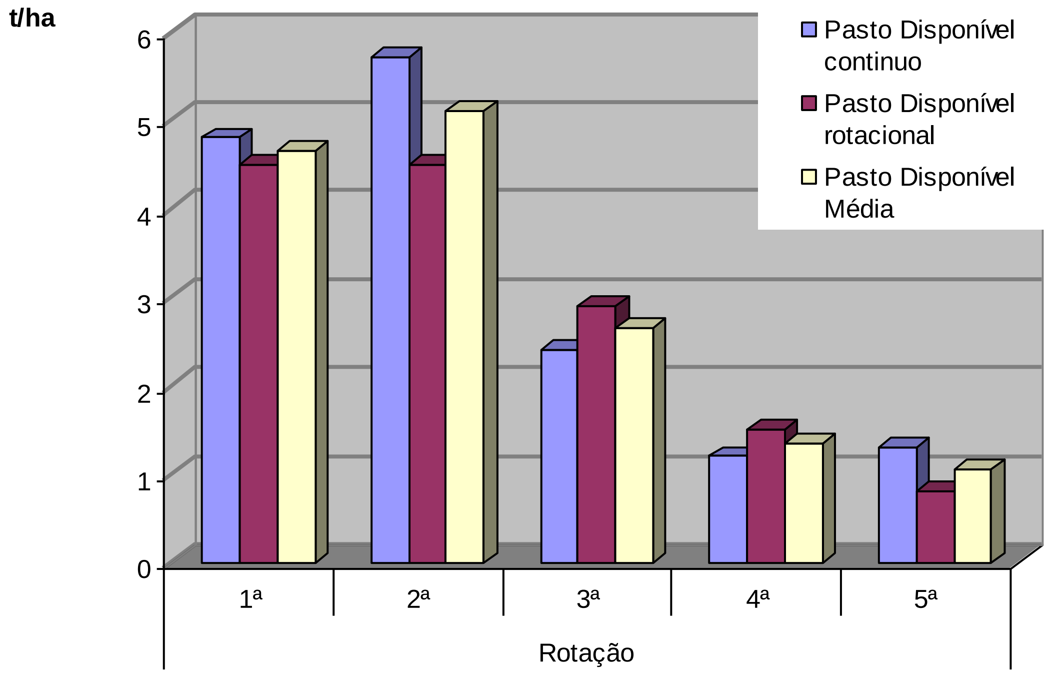

Figura 1. Pasto (biomassa) disponível de *Ulex* spp. no inicio de cada rotação, nas cinco primeiras rotações (20 meses), na experiencia de Sambreixo.

Na Figura 2, podemos observar a biomassa residual (quando o gado sai de cada sub-parcela em pastoreio rotacional, e estimativa simultânea em pastoreio contínuo) para as mesmas espécies de matorral. Nas duas primeiras rotações o pasto residual é maior nas parcelas de pastoreio contínuo tendência que se mantêm, ainda que amortecida nas rotações restantes. Em 20 meses de pastoreio, a biomassa disponível à entrada reduz-se 66% e a residual 87,5%, em média, para os dois sistemas de gestão (pastoreio rotacional e pastoreio continuo), estes dados são indicadores da eficiência do pastoreio na redução de combustível do sub-bosque. O efeito desbroçador é inicialmente mais elevado com pastoreio rotacional, mas tende a igualar-se nos dois sistemas com o tempo. O gado equino controla bem o estrato arbustivo dominado por tojo, mostrando preferência por estas leguminosas, mas quando o efeito do pastoreio dificulta a recuperação destas espécies, os animais consomem e controlam outras que são menos palatáveis.

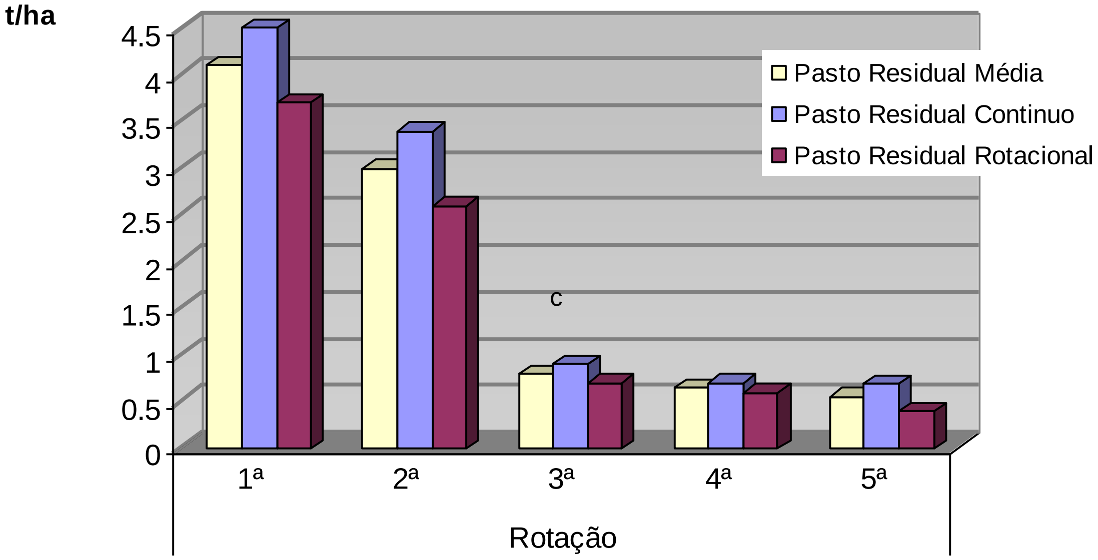

Figura 2. Pasto (biomassa) residual de *Ulex* spp. no final de cada rotação, nas cinco primeiras rotações (20 meses), na experiencia de Sambreixo.

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Chapter V

Productive value of silvopastoral systems established with *Betula pubescens* Ehrh. in abandoned agricultural lands (Galicia-Spain)

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Intensive program Management of agroforestry systems: ecological, social and economic approaches

ABSTRACT

Silvopastoral systems (SPS) are sustainable agroforestry systems characterized by delivering high environmental and economic benefits. As any change, it is necessary to convince farmers to implement it, instead of using more intensive systems broadly extended in Europe in the last decades. Therefore, it is necessary to carry out an economic assessment of forest (FS) and agricultural alternatives to predict their behaviour and provide the owner a basis upon which to select the more adequate alternative. The objective of this study was to present a model to quantify the economic productivity of a SPS established under *Betula pubescens* Ehrh. compared to an exclusively FS with the same tree species. The results obtained showed that initial investments are higher in the SS than in the FS due to the additional cost of the individual tree protectors, which were necessary to avoid after damages caused by sheep. However, SPS resulted more profitable than the FS after 18 years of plantation as SPS net present value (NPV) was positive, being NPV of FS positive after 35 years of plantation. Therefore, from these results we can say that the SPS generate revenues much earlier than timber production systems.

Keywords: Agroforestry systems, downy birch, net present value, forest.

INTRODUCTION

The *Betula* genus is distributed throughout most of Europe, where it is mainly represented by two stand-forming tree species, *Betula pubescens* Ehrh. (downy birch) and *Betula pendula* Roth. (silver birch). In Northern Europe, both species are commercially the most important broadleaved tree species (Hynynen et al. 2010). In Spain, downy birch is mainly found by the northwest of the Iberian Peninsula and western part of the Pyrenees. Downy birch stands currently cover 49,000 ha in northwest Spain, with 32,000 ha in Galicia where the present study was carried out (Xunta de Galicia, 2001). In Galicia, birch has often been treated by foresters as a weed, being under-valued, under-utilised and under-managed. In the present, the interest shown by foresters and private owners is still low. Consequently, the presence of downy birch is much less common than it could be in Galicia as an integral part of the climax vegetation (above 1200 m) and pioneer species (below 1200 m), as a potentially useful species for colonising part of the approximately 635,000 ha (almost the 30% of the forest area in Galicia) that is at present unproductive or colonised by shrubs (Gómez-García et al. 2010). However, recent studies carried out in Galicia have demonstrated the environmental and economic benefices of the use of this tree specie in the establishment of SPS compared with conifer tree species like *Pinus radiata* D. Don (Rigueiro-Rodríguez et al. 2012). In SPS, trees with pasture and livestock production are integrated within the same area and usually *Pinus radiata* D. Don creates less suitable conditions (shading) for the development of understorey vegetation than downy birch. Therefore, the use of autochthonous broadleaved tree species like downy birch should be promoted due to their better sustainability. Moreover, it is important to be aware that in the SPS the pasture component provides an earlier economic return than the exclusively forestry systems (FS). The aim of this study was to present a model to quantify the economic productivity of a SPS established under downy birch compared to an exclusively FS with the same tree species.

STUDY CASES

Silvopastoral system

Betula SPS profitability is going to evaluate based on a long-term experiment established in Lugo (NW Spain) in an abandoned agricultural area. The area of the study belongs to the Atlantic bioclimatic region (EEA 2006) and it is characterized by mean total annual precipitation of 1083 mm and mean annual temperature of 12.2 ºC. In general, the growth of pasture is limited in summer due to drought and in winter due to the low temperatures. The experimental design was a randomized complete block with three replicates. In April 1995, the plots were sown with a mixture of cocksfoot + clovers. Downy birch from bare roots, were planted in May 1995 at 2500 trees ha^{-1} with a tree spatial arrangement of 2 × 2 m (64 m^2 per experimental unit). Fertilization was not applied in order to replicate traditional afforestation practices of agricultural land for this area. The three components of the SS used to estimate the NPV are described below.

<u>Pasture</u>: from 1995 to 2012 annual pasture production (DM) was estimated by cutting the entire surface area delimited by six trees, of the nine trees inner of each plot. Four harvests were made during the experiment in May, June, July and December

except in the first year of the study (1995), when harvests were only carried out in July and December. Pasture samples were weighed in situ, and a representative subsample was taken to the laboratory. At the laboratory, one subsample (100 g) was dried for 72 h at 60 ºC and weighed to estimate annual pasture production by adding up the four harvests. From the annual pasture production we estimated the stocking rate that the system would be able to support.

<u>Livestock</u>: As a result of the climatic conditions described previously, the livestock (sheep for meat production) are in the pasture approximately seven months in a year (grazing period) and stabled for the remaining five months (stables period), during which the animals fed on grass silage complimented with fodder (Zea-Salgueiro 1991). For these reasons, and from the determined nutritional needs of the sheep herd during the grazing and stables periods and on the other side from the annual pasture production obtained from the zone, the stocking rate was determined in the first place through the following equation (Eq1): $SR_p = (PP)/(G_p \times C_p)$

Where: SRp is the stocking rate or number of animals per hectare feeded by the produced pasture during the grazing period on a hectare basis (sheep ha^{-1}), PP is the annual pasture production (kg DM ha^{-1}), G_P was the duration of grazing period (210 days per year; Zea-Salgueiro 1991) and Cp is the consumption of sheep quantified at 1.74 kg DM $sheep^{-1}$ day^{-1} (Zea-Salgueiro 1991). Once the SRpast is determined it is necessary to consider the stables period (150 days per year) and as a consequence we should forecast the annual need for silage. These needs are obtained by applying the following equation (Eq2): $N_{silage} = C_s \times SR_p \times P_{est}$

Where: N_{silage} was the need of silage per year (kg DMsilage $year^{-1}$), C_S was the average consumption of silage per day per sheep quantified at 0.75 kg DM $sheep^{-1}$ day^{-1} (Zea-Salgueiro 1991), SR_P was the number of animals during the grazing period previously estimated (sheep ha^{-1}) and S_P was the days that the animals are kept in the stables per year (150 days per year). Once the annual need of silage was determined, the next step was estimate the area for silage feeding (Eq3): $S_{silage} = N_{silage} / PP_{silage}$

Where: S_{silage} was the surface area of silage (ha) needed to produce, N_{silage} were the needs of silage based on the stocking rate calculated during the grazing period and

PP_{silage} was the production of silage quantified at 7,096 Mg DM silage ha^{-1} year^{-1} (Mosquera and González 1998). This production includes losses that occur in the harvesting process and those that result from the processing of silage as well. Finally, the annual stocking rate (SRann) of the SS was estimated through the following equation (Eq 4): $SRann = SR_p / (1 + S_{silage})$

<u>Tree:</u> Height (h) and diameter at breast height (d) measurements was taken in 2012 from the inner nine trees (to eliminate border effects) and the stand basal are (BA) was estimated (Eq5): $BA = \frac{\pi}{4} \times (N \times d^2)$

Where: BA is stand basal area (m^2 ha^{-1}), N is the number of trees per hectare in 2012 taking into account the reduction by abiotic/biotic damage and d is the mean diameter at breast height. The next step was to estimate the total and merchantable stand volume from the equation developed by Rojo et al. (2005) for birch stands in Galicia, which depends on BA (m2 ha-1) and h (m) (Eq 6): $V = 0.6272 \times BA^{0.9838} \times h^{0.8399}$

Site quality

Site quality in forestry is usually measured indirectly through the relationship between tree height and age, and is known as Site Index (IS). IS, by definition, is the average height of the dominant and co-dominant trees of a given species in a stand at a reference age. IS models provide a convenient and effective tool for determining potential productivity, thus allowing implementation of appropriate forest management practices. From the site quality curves determined by Rojo et al (2005) for birch stands in Galicia (8, 12 and 16 m at a reference age of 20 years) we estimated an IS = 12 meters taking into account that the mean height of SPS under study was 11 meters at 17 years. This IS was used to simulate the FS development as described below.

Forestry system

The model of Rojo et al. (2005) for *Betula* sp. stands (IS = 12 meters) in Galicia was used to simulate stand development. The model uses three transition functions to project each state variable for a given time period. The following stand variables were calculated:

- Dominant height (H0) defined as the mean height of the 100 thickest trees per hectare (Eq7):

$$H_0 = IS\left[\frac{\left(1-e^{-0.0009\times IS^{1.1151}\times t^{1.25}}\right)}{\left(1-e^{-0.0009\times IS^{1.1151}\times 20^{1.25}}\right)}\right]$$

Where IS is the site index (12 m) and t is the stand age (year).

- Number of trees per hectare (N) (Eq8): $N = 78426.086 \times H_0^{-1.60464}$

- Quadratic mean diameter (dg): $dg = 14.14086 \times N^{-0.2731} \times H_0^{0.7355}$ Eq (9)

Finally, the total and merchantable stand volume was estimated via Eq (6).

OBJECTIVE FUNCTION

Net present value (NPV) was used to assess the profitability of a project, as it is the most common method currently used for predict future cash transactions. NPV was determined through the following equation (Eq10):

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+r)^t} - K$$

Where: n is the useful life of the project (years), r is the discounting rate (2%), R is the net cash flow (total of all benefits less all the costs incurred during n (Table 1)), and K is the initial investment that is necessary to start the project (year 0).

NPV of mutually exclusive projects (SPS and FS) with different lives cannot be compared. For this reason, the NPV was estimated considering the real useful life of SPS (n = 18 years).

DETERMINATION OF NPV

To be able to establish and maintain a SPS or FS, it is necessary to carry out a series of activities (Table 1). These activities will result in expenses/incomes on the part of the landowner. In the case of SPS the costs and benefits come from the animals fed by the grass (Table 1). Grass production was converted into feed livestock (lamb and sheep) to calculate the income using data of the annual pasture production obtained in the system along 18 years, and taking into account that each sheep delivers 1.6 lambs per year on an average (Zea-Salgueiro, 1991). Additionally, it is necessary take into account a series of costs and benefits derived from silviculture activities (pruning, thinning, and the final harvesting of trees) due to the presence of tree canopy. The previous tree management technics were also carried out in the case of FS. Once the initial investment and the cash flow were determined, the NPV at each alternative was estimated (Figure 1). The results obtained showed that the initial investment is higher in the case of SPS due to the additional cost of individual tree protectors that are necessaries to avoid the damages that sheep can cause on the trees. However, the results showed that SPS is more profitable than mere timber production when the useful life is 18 years. It is important to highlight that NPV in the case of FS, was negative when the useful life was 18 years and therefore the NPV rule indicates that this alternative should be rejected. For this reason, we estimated the useful life of the FS alternative that generates revenues for the landowner (35 years) (Fig. 1).

Table 1. Initial investment (K), costs and benefits of the alternatives studied within an established period (n =18 years). SPS: silvopastoral system; FS: forestry system.

		Alternative			
		SS		**FS**	
Year (n)	**Activities**	**Costs**	**Benefits**	**Costs**	**Benefits**
0	Land preparation [1]	✓		✓	
	Grass sowing [1]	✓			
	Tree plantation[1]	✓		✓	
	Tree protectors[1]	✓			
	Buying of initial herd [2]	✓			
1-7	Livestock activities[3]	✓	✓		
7	Tree pruning[4]	✓	✓	✓	✓
8-17	Livestock activities[3]	✓	✓		
18	Harvesting4	✓	✓	✓	✓

[1] Included costs from: Land preparation (132 € ha^{-1}), Grass sowing (75 € ha^{-1}), Tree plantation (1200 € ha^{1}), and tree protectors to avoid tree livestock damage (2500 € ha^{-1}).
[2] Buying of initial herd (20 € $sheep^{-1}$).
[3]Annual costs from livestock activities included: shepherd of the herd (210 € 100 $sheep^{-1}$ $month^{-1}$), health maintenance (veterinary 60 € 100 $sheep^{-1}$ $month^{-1}$) and the cost of silage (7 € ha^{-1}). Annual benefits from livestock activities included: selling of the lambs (60 € $lamb^{-1}$) and sheep (20 € $sheep^{-1}$).
[4]The benefits (500 € ha^{-1}) and cots (354 € ha^{-1}) of tree pruning are identified as wood for firewood. Benefits (8 € m^{-3}) and cots of tree harvesting (405 € ha^{-1}).

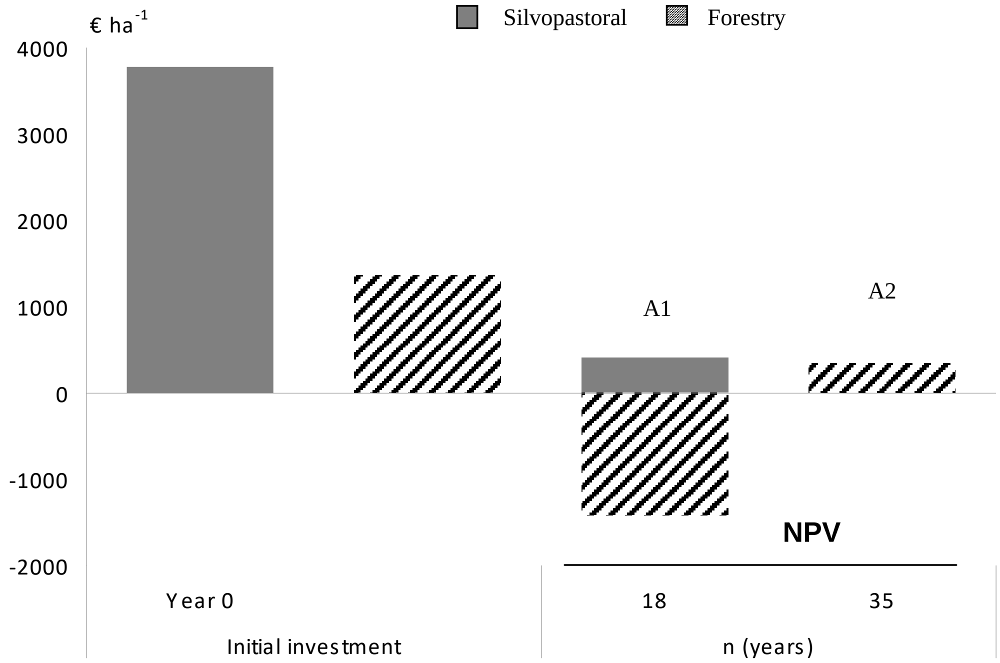

Figure 1. Initial investment and net present value (NPV; € ha^{-1}) estimated from the two alternatives studied. Where n is the useful life of the project; A1-2 was the different alternatives management regimen of forestry system that was evaluated (see Table 3).

These estimations were done taking into account the *Betula* sp. model determinated by Rojo et al. (2005). This model recommended that the first pre-commercial thinning should be carried out after 15 years of establishment and the following thinning should be done every 5 years (20, 25, 30, 35 years). The results showed that on one hand, the NPV obtained in the intermediate years (20, 25 and 30) was negative (data no showed) and, on the other hand, it was necessary an useful life of 35 years to obtain revenues in the case of FS (Fig. 1). From these results we can say that SPS generate revenues much earlier than timber production systems. These results are in accordance with previous studies carried out in the same area with *Pinus radiata* D. Don silvopastoral systems (Fernández-Nuñez et al. 2007; Pasalodos et al. 2009).

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Chapter VI

Landscape management: policy conflicts between silvopastoral systems and biodiversity

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Intensive program Management of agroforestry systems: ecological, social and economic approaches

ABSTRACT

It is known that the compatibility between natural environmental components and traditional human activities is very difficult. Facts concerning old and new conflicts are good examples of these kinds of problems. In this text, the main aims are for students to acquire the sensibility and the perception about the important requirement for compatibility between all of the potential benefits, activities and interests that exists in rural and forest landscapes. One possible process which may achieve more consensual decisions about land use involves the use of public participation methodologies. Public participation has an important role in democracy, once the process strengthens the commitment of citizens to the decisions made regarding the environment. Those decisions could be more robust and less disputed if the methodologies applied are appropriate.

Keywords: landscape, biodiversity, human activities, grazing, conflicts, public participation.

FRAMEWORK AND OBJECTIVES

In Portugal, 7.2% of the country comprises protected areas and 14.1% comprises classified areas according to Natura 2000. Thus, 21.3% of the country is classified and subjected to nature conservation (http://www.icnf.pt/portal/naturaclas/ap).

Forest landscape covers 60% of the Portuguese country (3 500 000 ha of forest stands and 1 900,000 ha of shrublands). About 85% of forest area belongs to private owners, 12% are common’s, and only 3% are from the State domain (Direcção Geral dos Recursos Florestais, DGRF, 2006).

At the environmental level, forests have an important role, with unique natural habitats that ensure the preservation of fauna and flora; forests contribute also to soil conservation, water resources and climate regulation. Also, the multifunctional landscape can facilitate many other human and traditional activities, such as hunting, fishing, pastoralism, recreation and tourism (Marta-Costa et al., 2012). Thus, there is a high potential for benefits, uses, interests and conflicts…

In this session, we presume that students acquire the following: Sensibility and perception about the important requirement of compatibility between all of the potential benefits, activities and interests that rural and forest landscapes can provide, considering that the use of resources is often conflicted.

PROTECTED AREA PROBLEMS IN THE RURAL LANDSCAPE CONTEXT

In this study, we take as our guideline the Natura Network 2000 legislative framework (www.icnf.pt/portal/naturaclas/rn2000), in which some of the main goals are:

a) The preservation of flora and fauna species and of their habitats, for their rarity and scientific value or if they are endangered;

b) The restoration of flora and fauna populations and their habitats when they are threatened;

c) The protection and valorization of landscapes that present interesting scenic and aesthetic values;

d) The establishment of genetic reserves with the warranty of perpetuity of all species;

e) The promotion of sustainable development of the regions that enhance the interaction between the natural environmental components and traditional human activities.

It is easy to understand that the most complex goal is the "promotion of sustainable development of the regions that enhance the interaction between the natural environmental components and traditional human activities". It is true that humans are contradictory, inconsistent and legitimately conflicted. The conflict is symptomatic of policy decisions regarding land use (conservation, production) in confronting legitimate values and social groups with different needs. The compatibility between the natural environmental components and human components is very difficult.

OLD AND NEW CONFLICTS

Commons, Grazing and Forest

In 1936, the organization called “Junta de Colonização Interna” identified 407 500 ha of commons. After that, in 1939, the Afforestation Plan (Plano de Povoamento Florestal) was approved and provided the forest plantations with 420 000 ha using common lands during the next 30 years (1939-68) (Min. Agr., 1940; Devy-Vareta, 1993; Alves, 2000). In this context, the specific provisions of the Administrative Code of 1936 as the distinction between “public affairs” and “common things” were disregarded (Devy-Vareta, 1993).

Grazing was an important activity in the common lands and after the afforestation; people could not use the land for their traditional practices. From 1940 to 1960: 368,374 ha of commons began to be administered by the Forest Services, which planted forests right next to the villages, characterized by a widespread use of pine without fostering diversity.

In the early years after the 1974 Revolution, with the publication of laws nº 39/76 and nº 40/76, better known under the name of “Commons Law”, the Constituent Assembly returned all fields to their lawful owners, referred to as “compartes”. After this event, the Forest Services tried to assist people by improving pastures.

However, depopulation in the mountains had already been observed during this period. Also, the disagreement between the Forest Services and rural communities continued over the years. Thus, the grazing system proposed by the Forest Services was not suited to the traditional systems used by the land users and shepperds. This situation didn´t lead to a good maintenance and persistence of pastures. Those dysfunctional practices resulted in the degradation of improved pastures, as well as a significant increase of shrubby vegetation.

Moreover, between 1950 and 1980, there was a significant increase in areas of shrub and forest, and the number of forest fires managed by the state increased significantly from the 1970s onwards.

All aspects of this process emphasize the importance of sociology, rural extension and dialogue between the different stakeholders in the sense of understanding the traditional habits of the people, in order to be able to intercede more effectively. Therefore, as the rural development policies did not promote the clarification and dialogue, the conflicts persisted almost to the present day (Torres-Manso, 2005).

Production and Conservation

Nowadays, a significant part of the Portuguese landscape submitted to Forest Services management is under the Conservation of Nature authorities, namely the Natural Parks authorities, who have a potential conflict with local residents. The reasons for this conflict are based on the difference between contradictory logics of social groups with legitimate but different needs:

The conservation point of view is based on ecological criteria and aims to maximise the area for conservation of threatened species and their habitats;

The production point of view encopasses economic, social and cultural criteria, and aims to maximise the area for agriculture, wood production, grazing, hunting and tourism, and minimising the area for habitat and species preservation.

What can do landowners when they have a lot of constraints for land use, if no clarification exists regarding compensatory measures? The land use is the means by which landowners obtain their livelihood. Therefore, they look at the land as a view to production of material values. Nevertheless, they are responsible for the landscapes that we want to preserve. The economic infeasibility of farms in terms of agriculture, forestry and livestock activities could lead to their abandonment and consequently, rural depopulation. This context can lead to a serious risk of forest fires, which can undermine biodiversity. At the same time, we have to think about conservation policy with rural inhabitants. It is very important to find technical solutions that were approved by the inhabitants and at the same time are interesting for them and for biodiversity conservation http://www.icnf.pt/portal/naturaclas/rn2000.

WHAT KIND OF SOLUTIONS? PUBLIC PARTICIPATION?

As we discussed previously in the cited examples, technical criteria are not effective enough to solve the different stakeholder problems. Nowadays, in common lands the distrust and conflict persist! Disagreements and fires persist! All these issues are social issues!

How can we reach an understanding? In practice, the dialogue between all stakeholders has not been widely used because it is complex. In this context arises the current concept of public participation, which is based on the Åarhus Convention (http://europa.eu/legislation_summaries/environment/general_provisions/).

The Åarhus Convention is built on the principle that awareness and an improved participation of citizens in environmental problems leads to an improvement of environmental protection. The Convention proposes an intervention in three areas:

- Guarantee public access to information available to public authorities on environment;
- Empower public participation in making decisions with effects on the environment;
- Enlarge the conditions of access to justice in environmental matters.

Public participation has an important role in democracy, once the process strengthens the commitment of citizens to the decisions regarding the environment. Inviting the public to be part of the decision-making processes has been a major objective in European and American environmental policy arenas (Renn, 2006). Environmental decision making requires the integration of complex interactions between ecological, economic and social aspects. This is equally true for evaluating the environmental impacts of a specific project or the development of sustainability pathways. In this process, one has to take into account not only "the facts", but also the values, asking what ought to be honored, protected, sustained, or developed. This constellation requires the active participation of all relevant stakeholders and their early involvement in the process (Forester, 1999).

The kind of decisions resulting from this process could be more robust and less disputed if the methodologies applied are appropriate. Another advantage is the integration of "outsiders" in decision making, extending the scope of the stakeholders.

The dialogue allows the coordination of different types of knowledge, for example, between local and traditional, urban, technical or scientific knowledge (Vasconcelos, 2007).

There are different methods to structure and conduct the participatory processes, which will be applied appropriately to different situations (Vasconcelos, 2007). The classic and most common procedure in a participatory process is conducting breakout sessions for discussion of a document previously prepared. This participatory timing is called “Successive Stage” or “Final Stage” and some negative implications may arise. Accordingly with Vasconcelos and Kaiser (2008), considering the fact that in many cases, stakeholders are faced with a fait accompli, many citizens are far from the process, and some conflicts may be triggered and the difficulties in implementation of the projects are higher.

In contrast, the new formats of interactive methodologies need to be positioned earlier in the stages of the process, where the complexity of the problem increases. Participatory governance is associated with a more interactive format of participation knowledge (Vasconcelos, 2007).

These new participatory methods promote the interactive involvement of stakeholders from the beginning of the participatory process. This participatory timing is called “Preventive Stage” or “Initial Stage”. In this case, the stakeholders are involved in every aspect of the process. From the planning stages and throughout its progress, and when all the options are opened, this is considered to be effective public participation. This effort by the stakeholders, at the initial stage, is relevant to ensure the success of any rural development plan. Several key rules must be considered:

- Stakeholders must be involved in the early phases of the process, allowing opportunity for discussion and time for the participants to understand the process. Also the disseminating of information, learning gradually and contributing with suggestions are important;

- All stakeholders must be committed to creating the conditions to integrate the different interests, adjusting the plan along its development. For example, in protected areas (i.e., rural or forestry areas), public and private organizations, local authorities, associations of commons, forest producers, animal producers, shepherds, hunters, ONG and inhabitants must all participate:

- Interests and values rather than positions should be emphasized to facilitate the search for collaborative solutions that correspond to the interests, avoiding the systematic difficulty of decisions due to considering only previously assumed positions (Innes, 1995 in: Vasconcelos, 1997).

Therefore, stakeholders' involvement in a development plan responds to three important needs:

- Taking full advantage of the knowledge, dynamics and resources at the local level.

- Getting the membership and the support of local actors to overcome problems and achieve consensual solutions that, while they may not be the best solutions. However, they could be good and possibly facilitate further decisions to build a valued landscape from both an environmental point of view and a socio-economical point of view.

- Encouraging local ownership of projects for the development, which can be successful and sustainable.

However, it is important to consider a set of basic conditions, which are central for dialogue to produce emancipatory knowledge. Stakeholders must be:

- Equally informed, listened to, and respected;

- Equal in terms of power (i.e., none can have more power than others to speak or make decisions);

- Able to discuss different ideas or opinions, without being constrained from questioning the status quo;

- Sincere, comprehensible, accurate and have a legitimate basis (Innes et al., 1999 in: Vasconcelos, 1997).

Thus, participatory processes are needed that combine technical expertise, rational decision making, public values and preferences. This model of participation attempts to meet two major objectives: first, to enhance the competence in the decision-making process, and second, to assign a fair share of responsibility to manage environmental affairs to those who are or will be affected by the potential consequences. Special emphasis is given to the link between participation and formal models of decision making (Renn, 2006).

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Chapter VII

Utilização recreativa de paisagens agroflorestais

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Intensive program Management of agroforestry systems: ecological, social and economic approaches

RESUMO

Os atuais sistemas de uso do solo de tipo agroflorestal têm as suas raízes fundadas em modelos tradicionais, autóctones e de autoabastecimento. Embora desenvolvidos anteriormente à disponibilidade e vulgarização dos combustíveis fósseis e respetiva tecnologia representam ainda hoje uma parcela muito significativa do espaço rural. A sua utilização como espaço para lazer está intimamente ligada à prosperidade dos seus detentores e/ou usufrutuários. A sua crescente procura por uma sociedade cada vez mais urbana implica o seu planeamento e desenho por forma a não colidir com as restantes funções destes espaços, mas antes otimizar as sinergias da sua utilização multifuncional.

Palavras-chave: recreação, paisagem rural, sistemas agro-florestais.

INTRODUÇÃO

Os sistemas agroflorestais caracterizam-se pela diversidade de recursos que mobilizam quer ao nível subterrâneo quer ao nível aéreo. A exploração dos diferentes andares, quer abaixo quer acima da superfície da terra, é conseguida por uma escolha criteriosa dos recursos vegetais a utilizar e por uma, igualmente criteriosa, gestão do seu desenvolvimento no tempo e no espaço (Nair, 1985, 1993). Esta diversidade produtiva acrescenta igualmente uma superior diversidade biológica relativamente aos restantes sistemas de utilização do solo. Fundamental que foi para uma economia eminentemente local de autoabastecimento, esta maior diversidade é hoje também a base das funções de conservação da natureza e de proteção do ambiente e, cada vez mais, também recreativas da paisagem rural. O reconhecimento desta realidade leva a que hoje as funções recreativas sejam consideradas no ordenamento jurídico da gestão do território, quer a nível nacional quer a nível regional e local. Tal como vem sucedendo com o diverso normativo que valoriza, protege e remunera, a manutenção das estruturas fundamentais para assegurar as funções de conservação da natureza e de proteção do ambiente, importa agora também desenvolver modelos de adaptados à função recreativa. Embora se possa pensar que a diversidade estrutural e funcional destes sistemas possa ser uma mais-valia para a sua utilização recreativa, não deixa de ser fundamental acautelar a monotonia e repetição que muitas vezes está associada à grande dimensão das propriedades e das parcelas dos sistemas agroflorestais mais importantes. Importa por isso que o planeamento e desenho das atividades de lazer nestes casos persigam precisamente as situações de exceção, quer em termos de circulação que em termos de estadia. A diversidade de recursos que comporta um sistema agroflorestal aconselha a que se valorize a dimensão estacional dos seus componentes de modo a aportar motivação e atratividade acrescida a estas situações.

O PLANEAMENTO DA ATIVIDADE RECREATIVA EM SISTEMAS AGROFLORESTAIS

Anteriormente reservada apenas às classes previligiadas, à aristocracia inicialmente e à burguesia industrial posteriormente, a procura do espaço rural e natural para lazer nos países desenvolvidos tem vindo a massificar-se nas últimas décadas. De facto, a evolução da humanidade, fruto de importantes conquistas sociais e consequente melhoria das condições de vida das populações, consubstancia-se num quotidiano com mais tempo disponível para atividades de livre escolha (Castro, 2009). Tal evolução é indissociável também de uma demografia em urbanização acelerada que conduziu a que nos dias de hoje, a população residente em cidades seja já superior há que ainda habita o meio rural. No sentido de obviar um quotidiano feito de rotinas e ambientes construídos, procurando atividades que tanto física como intelectualmente sejam gratificantes, o espaço não urbano de carácter rural ou natural, é cada vez mais sítio de eleição para lazer com carácter mais ou menos ativo.

No caso europeu, esta realidade caracteriza-se por uma elevada diversidade de situações, diversas em termos do grau de urbanização, da proporção do espaço rural e natural, da legislação e dos sistemas de planeamento e de gestão destes espaços, e das associações simbólicas da cultura de cada nação(Bell *et al.*, 2009a).

No caso concreto de Portugal, as funções recreativas tem vindo a ser integradas no ordenamento jurídico às mais variadas escalas por via dos instrumentos de gestão territorial. A Estratégia Nacional para as Florestas (Figura 1) refere o Recreio como valor de uso direto para as Áreas Costeiras, embora outros valores igualmente ligados a funções recreativas como a caça e a pesca, apareçam associados às Áreas de Gestão Multifuncional que englobam a grande maioria do espaço ocupado pelos principais sistemas agroflorestais do nosso País (Direcção-Geral dos Recursos Florestais, 2007).

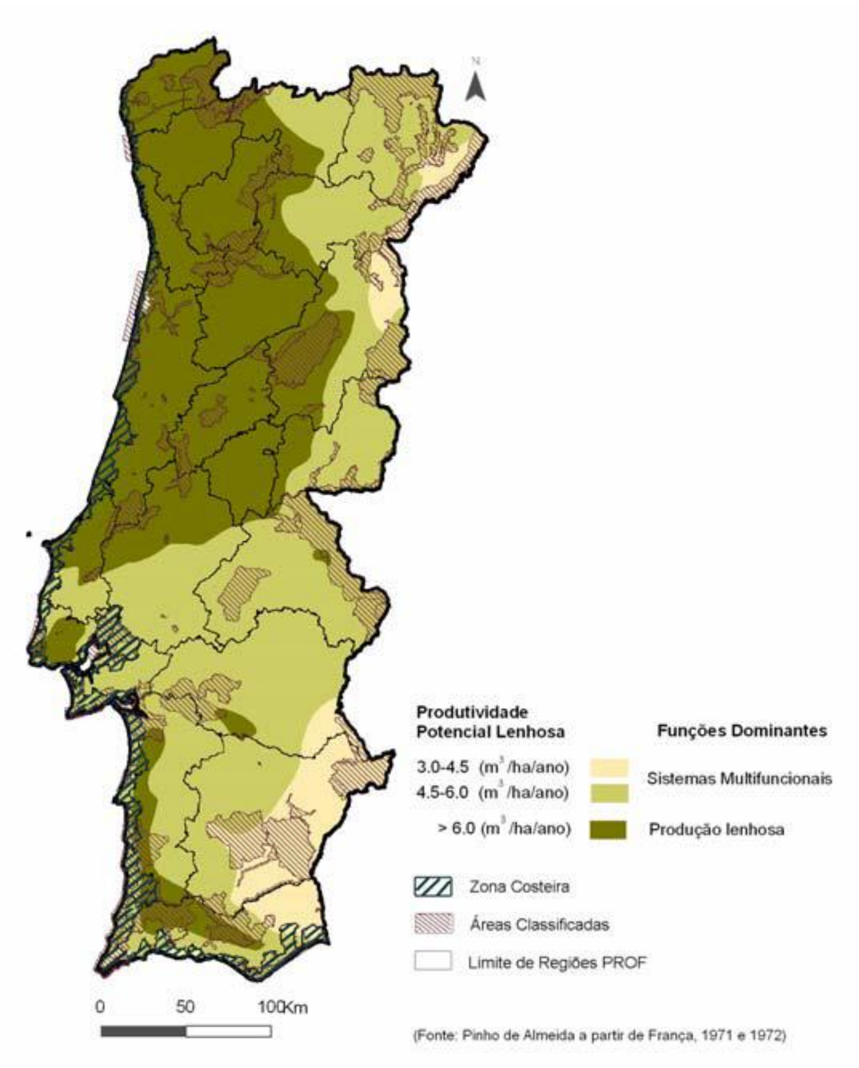

Figura 1. Zonamento das Funções Dominantes da Estratégia Nacional para as Florestas em função do potencial lenhoso.

No caso concreto dos Planos Regionais de Ordenamento Florestal, a especialização do território associada a atividades de lazer traduzida pela prioridade principal atribuída à função “Recreio e Enquadramento, Estética da Paisagem”, reparte-se pelas áreas metropolitanas do Porto e Lisboa, pela Serra da Estrela, e pelos vales do Douro Vinhateiro e do Guadiana/Alqueva (Figura 2, direita). Precisamente nestes dois últimos casos, a prioridade secundária é atribuída à “Silvopastorícia, Caça e Pesca” que englobam a maior área ocupada por sistemas agroflorestais (Figura 2, esquerda).

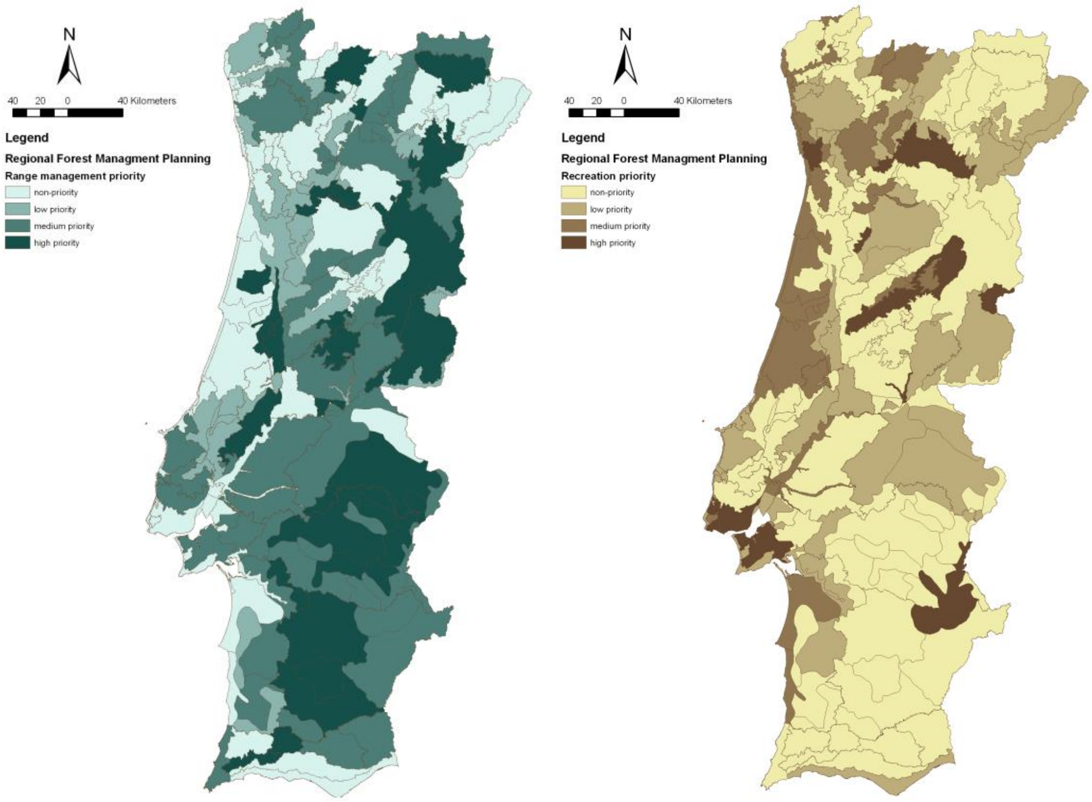

Figura 2. Prioridades das funções "Silvopastorícia, Caça e Pesca" (esquerda) e "Recreio e enquadramento paisagístico" (direita) definidas nos Planos Regionais de Ordenamento Florestal.

O DESENHO DE ESPAÇOS DE LAZER EM SISTEMAS AGROFLORESTAIS

Uma paisagem agroflorestal traduz, em primeiro lugar, a interpretação humana de uma natureza produtiva. O homem vem ordenando os espaços agroflorestais mediante a preferência por certas plantas em detrimento de outras, aproveitando e beneficiando indivíduos que entende como "corretos" relativamente a outros que interpreta como nefastos para si. O objetivo assim definido é, em primeiro lugar, o benefício produtivo. Ao longo dos tempos, a incorporação de novos elementos, ou de novos níveis de exploração de recursos, esteve sujeita a processos de tipo tentativa-erro, assegurando a sua sustentabilidade mediante a introdução de medidas corretoras para os casos em que pudesse estar em causa a sua perpetuação. A relação atenta do homem com o seu funcionamento com base na qual foi delineando a sua gestão, consolidou uma dimensão patrimonial que hoje ultrapassa aquela mais imediata, a económica, para se converter numa realidade cultural identificadora de toda uma comunidade. O apego inerente a esta identificação está na base da preferência por estes espaços para a fruição de momentos de lazer mediante atividades recreativas individuais ou em grupo, de carácter mais ativo ou mais passivo. A evolução das economias rurais de subsistência e autoabastecimento para sistemas abertos de amplas trocas com o exterior acarretou também a abertura à fruição destes espaços a outros extratos da população não diretamente ligados à realidade local. Ao longo das últimas décadas, a sociedade apercebeu-se a apropriou-se dos valores que estes espaços aportam ao funcionamento de realidades mais amplas e abrangentes, desde o nível regional, ao nacional e transnacional(Castro, 2009). A conservação da natureza primeiro, e a sua fruição pelo homem nas mais variadas dimensões mais tarde, estão hoje perfeitamente assumidas como serviços prestados por estes espaços e que sendo devidos, deveriam por isso ser também remunerados. Se no primeiro dos casos – a conservação da natureza – o ordenamento do espaço é algo que deve ser deixado ao "cuidado" das biocenoses envolvidas, já a fruição exige génio humano para ordenar o espaço a contento do homem sem perigar as demais dimensões e funções envolvidas. Tal como em qualquer intervenção conducente à valorização recreativa de um espaço natural, também nos sistemas agroflorestais a não intervenção deve ser sempre a proposta de trabalho inicial (Bell *et al.*, 2009b). De facto, atividades de natureza passiva e/ou contemplativa que requerem apenas espaços de circulação pedestre e locais simples de estadia, podem ser adaptados a elementos físicos e contextos de vegetação existentes desde que os percursos delineados se enquadrem e ajustem corretamente a cada situação (Figura 3). O exercício de ordenamento seria apenas o de sequenciar habitats, sítios para percorrer, observar e interpretar, num exercício de arquitetura paisagista que permite aceder e mostrar tanto quanto possível, com uma intervenção mínima para comodidade à deslocação. A diversificação e multiplicação das atividades recreativas, bem como o seu alargamento com caracter organizado a públicos determinados implicam o seu acautelamento com intervenções suscetíveis de ordenar o espaço agroflorestal e orientar a sua fruição.

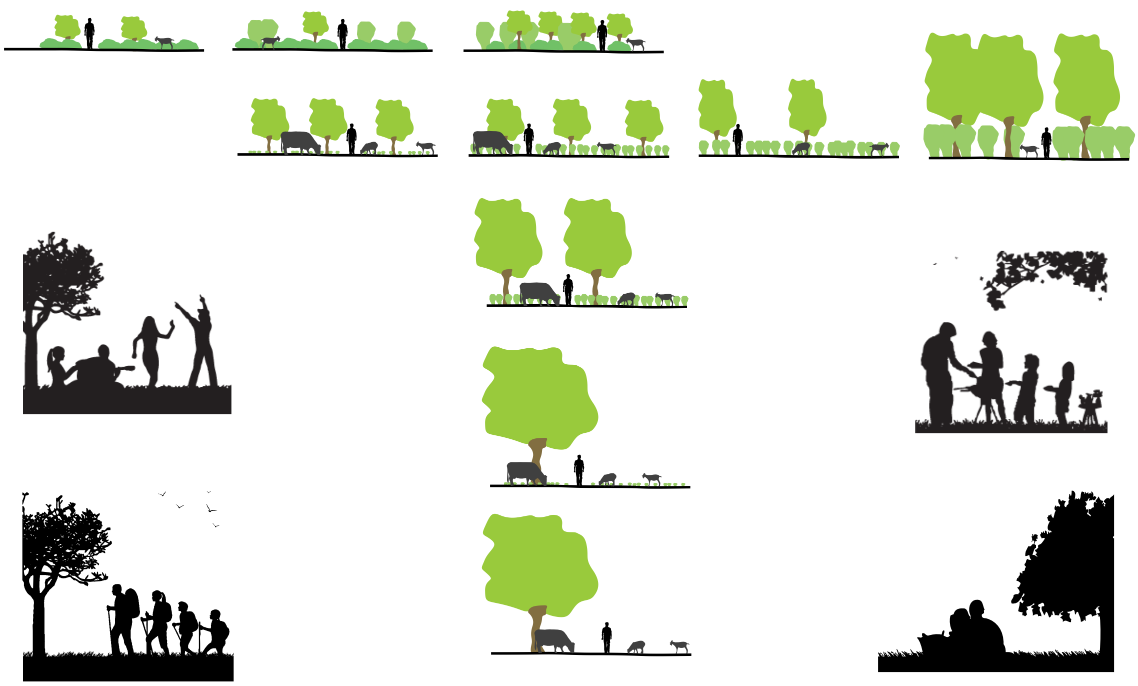

Figura 3. O desenho para apoio à recreação deve integrar um sistema de circulação que una locais de estadia individual ou em grupo, dedicados a atividades de caracter ativo e contemplativo que não se afetem mutuamente.

A realidade patrimonial e o seu valor, sobretudo cultural e histórico, devem estar sempre subjacentes a qualquer proposta de intervenção. Ainda que não deva mermar a criação do seu autor, a intervenção num espaço agroflorestal de valor patrimonial significativo deve valer-se de um conceito que permita destacar os seus elementos mais marcantes e, dessa forma, acentuar o carácter da sua paisagem (Castro, 2012). Qualquer determinante da paisagem que se destaque – litologia, relevo, hidrografia, vegetação – podem ser uma fonte de inspiração. Qualquer particularidade da sua história geológica, ecológica ou social, pode servir também de base à formulação de um conceito unificador para uma intervenção.

O programa de uma intervenção num sistema agroflorestal deve ser claro e determinar, de forma mais induzida ou mais compulsiva, o público-alvo a que se destina e as atividades recreativas preconizadas.

Os sistemas agroflorestais, e as paisagens que na generalidade dos casos os enquadram, não são os mais adequados a proporcionar atividades recreativas em regime intensivo de carácter iminentemente físico, como o arborismo, a orientação ou o *paintball*; a dispersão e/ou a dimensão do arvoredo não lhes confere especiais características para essas atividades. Num outro extremo, de carácter mais passivo ou contemplativo, também atividades do tipo da observação de fauna selvagem, quer em percurso quer localizada, não é favorecida pelo carácter aberto da vegetação destes sistemas. A grande abertura de horizontes que os sistemas agroflorestais proporcionam favorecem antes a fruição de percursos do mais variado tipo – pedestres, cicláveis ou equestres – que podem proporcionar ao praticante amplas vistas para interpretação da paisagem.

A diversidade de situações multiestrato, a variação na repetição dos elementos arbóreos, a sazonalidade da vegetação do sobcoberto, ou o pisoteio do pastoreio, entre outras, são oportunidades intrínsecas aos sistemas agroflorestais. Os diferentes tipos de circulação requerem ritmos de vegetação diferentes; a velocidade da atividade, menor nos percursos pedestres ou equestres do que nos circuitos cicláveis, requer um ritmo maior na variação de estratos de vegetação sob pena de se tornarem monótonos e pouco gratificantes. Por outro lado, os sistemas agroflorestais são, pela sua natureza agrológica, situações com relevos mais favoráveis do que os sistemas iminentemente florestais, nomeadamente nas formações mais densas e de carácter mais remoto. A circulação vê-se assim beneficiada, e sobretudo a ciclável, por relevos e pisos mais favoráveis e regulares. O caminho de tipo "pé posto", vulgo trilho, com largura de 0.60 a 1 metros de largura é suficiente para circular e aceder às diversas estruturas preconizadas, sem facilitar a sua utilização motorizada, sempre de evitar.

Uma boa proposta de circulação num sistema agroflorestal deve comtemplar tipologias diferentes que em conjunto com as diferentes situações atravessadas – pequenos bosquetes, perfis de tipo savana ou estepe, formações arbustivas e pastagens– conferem uma diversidade e uma comodidade adaptada a cada tipo de circulação (Figura 4, intermédia). Embora, o piso em terra batida seja sempre o mais indicado pelo conforto e integração paisagística que proporciona, o recurso a outras tipologias pode ser aconselhada em situações particulares: a calçada em pedra irregular para permitir atravessamentos pontuais por automóvel ou para locais sujeitos a encharcamento por linhas de água de carácter efémero; o caminho rural existente que evite a proliferação de acessibilidades; o passadiço em madeira para locais de atravessamento de linhas de água ou pastagens frequentemente encharcadas, permitindo comodidade, segurança, e não perturbar as propriedades desses habitats (Figura 4, inferior). Amenidades como bancos, sinalética interpretativa e áreas de observação da paisagem devem estar também previstas assim como pequenos abrigos na vegetação devem também ser programados para proteção dos utilizadores de eventuais tempestades ou de sol intenso (Castro, 2012).

Os locais de estadia deverão estar preparados para paragens de descanso e contemplação, paragens para tomada de refeições ou paragens de pernoita. Os primeiros, de descanso, estadias mais curtas que os restantes, não devem comtemplar mais do que locais de acento simples, integrados na paisagem e com design e material coerente com a situação (Figura 4, superior). Já os locais para tomada de refeições devem contemplar para além de estruturas de acento e mesas, ainda local para fazer fogo e instalações sanitárias básicas devidamente integrados no contexto As estruturas para fogo deverão ser construídas em pedra da região, e devidamente equipadas com chaminé anti-faúlha, em localização favorável aos ventos dominantes para contrariar o fumo junto das restantes estruturas. Para a sua localização dever-se-á acautelar a limpeza da vegetação num raio de pelo menos cinco metros. As instalações sanitárias deverão ser construídas ou revestidas a madeira com as tonalidades da vegetação local, e colocada em local dissimulado na vegetação circundante, a nunca menos de quinze metros das restantes estruturas. Por último, caso se pretenda um sítio de pernoita, a situação anterior de tomada de refeições deverá ser completada com um abrigo de pernoita ou bivaque, no qual se poderá passar a noite, e observar o nascer e o pôr-do-sol, momentos em que a generalidade da fauna aproveita para saciar a sede.

Figura 2. A intervenção de apoio à recreação não deve alterar o carácter da paisagem agro-florestal recorrendo a estruturas de estadia (fotografia superior) e circulações integradas com a vegetação (foto intermédia) e que preservem as situações de maior fragilidade (fotografia inferior).

CONSIDERAÇÕES FINAIS

A procura do espaço natural para actividades de lazer de carácter mais activo ou mais passivo é hoje uma realidade em toda a Europa, assim como um pouco por todo o Planeta. Em Portugal, a função recreativa dos espaços florestais, e nomeadamente dos espaços agro-florestais, é hoje reconhecida, e está já consagrada ao nível dos principais instrumentos de gestão do território florestal a nível nacional e regional.

A multiplicipade de formas de que se podem revestir estas actividades tem implicações directas com a preservação das restantes funções dos espaços florestais. Da mesma forma que as actividades de carácter mais desportivo podem colidir com a função de conservação ou protecção numa determinação situação, também as actividades de carácter mais informativo podem ser prejudicadas quando realizadas em situações de produção florestal intensiva. Assim, o planeamento e desenho destes espaços para fruição deverão considerar o conjunto de funções estabelecidas para cada situação concreta. A estrutura e o funcionamento dos sistemas agroflorestais contemplam características intermédias entre estes dois casos.

A generalidades dos sistemas agroflorestais portugueses dizem respeito a espaços abertos que previligiam a contemplação de horizontes amplos, bem como condições de relevo que permitem a circulação pedestre e ciclável sem grandes obstáculos ou dificuldades. Os montados de sobro (*Quercus suber* L.), azinho (*Quercus ilex* L.) e similares são sistemas maduros de grande longevidade traduzida em riqueza de fauna e flora que beneficia o tipo de actividades motivadas pela busca de informação e enriquecimento científico. O quotidiano das actividades associadas, nomeadamente o pastoreio, processam-se a um ritmo que favorece a sua interação com o visitante e seu enriquecimento cultural.

Pese embora a consagração da função recreativa no ordenamento jurídico nacional e a crescente procura por visitantes destes espaços, são escassos ainda os casos que possam hoje ser já considerados como boas práticas a seguir. De modo, apontam-se apenas linhas e princípios gerais que se podem considerar como orientadores para as intervenções que venham a ser realizadas.

Os espaços agroflorestais podem ser preparados e mesmo potenciados mediante infraestrutras que se traduzem em mais conforto e gratificação para o visitante. No entanto, estas deverão ser planeadas e desenhadas sem que interefiram com as restantes funções nem retirem carácter à paisagem em causa. O delineamento de locais de estadia permite concentrar, e assim vigiar e ordenar melhor, a actividade humana. Os seus equipamentos – abrigos, sanitários, fogo –deverão ser desenhados e construídos em materais coerentes com o solo e a vegetação do local, integrados no arvoredo e localizados em situações priveligidas em termos visuais. As circulações deverão afastar-se das vias motorizadas de serviço e desenhadas com um perfil que estimulem o tipo de circulação pretendida – pedestre, ciclável ou equestre – e desaconselhar os restantes tipos de utilização susceptíveis de prejudicar a actividade pretendida.

A implementação de estas linhas muito gerais de actuação para ordenar e/ou potenciar a utilização recreativa dos sistemas florestais poderão no longo prazo aportar experiência própria para definir com mais acuidade, as respectivas normas de projecto.

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Chapter VIII

Economic impact of forest fires: methodologies for assessing losses

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Intensive program Management of agroforestry systems: ecological, social and economic approaches

ABSTRACT

The forest industry is a strategic sector for countries' national development, particularly for rural areas, given its economic, social and environmental functions. Fires are among the biggest threats to Portuguese forests. The main objective of this study is to contribute to the understanding of the economic impact of forest fires and its importance for an efficient management of costs. Thus, we discuss optimal level of fire protection and the economic and social impacts of fire, and present some methodologies for assessing losses caused by forest fires. Social and economic impacts of fires can be extensive, long-lasting and difficult to identify and assess. We address the assessment of losses by forest fire on tradable and non-tradable services and goods. The concept of present value is used to assess the losses on tradable goods, such as wood and other forest products; including recreational services and equipment and infrastructures, and the concept of economic value of environmental resources is used to assess the losses on non-tradable goods. Several examples are presented of the assessment of the economic impact of forest fires using market prices, hedonic prices, travel costs, transference of benefits and contingent valuation methods to value losses on non-tradable assets and, finally, a practical work exercise assessing the costs of a forest fire is illustrated.

Keywords: forest fires; economic impact; losses in tradable and non-tradable goods.

INTRODUCTION

Worldwide the forest industry is a strategic sector for countries' national development, mainly for rural areas. The Portuguese forest, in particular, occupies 38% of the national territory with 3,450 million hectares, the 12th largest forest area in the European Union, and almost one-quarter is a protected area. Portuguese forestry plays a crucial role regarding the three pillars of sustainability:

a) Economically, as it contributes to the improvement of the national economy and external balance equilibrium. The forest industry is an important exporting sector of tradable goods, contributing positively to the trade balance of the country: forest products account for 12% of total national exports, corresponding to a surplus of €2,395 million; and it has a high gross value added (GVA) – 5.3% of the GVA of the overall economy and 14% of manufacturing gross domestic product (GDP).

b) Socially, the forest has the function of a 'family saving insurance' and it contributes directly and indirectly to job creation, particularly in disadvantaged areas, contributing to the settlement of populations in these territories. The Portuguese forest sector represents 400,000 owners; 260,000 workers; i.e., 2% of the active population and 9% of industrial employment respectively.

c) Environmentally, forest ecosystems ensure a set of services such as carbon absorption, enhancing of landscape, conservation of biodiversity, regulation of water quality and the water cycle, curbing of land degradation; the value of which should be on the horizon of sustainable forest management.

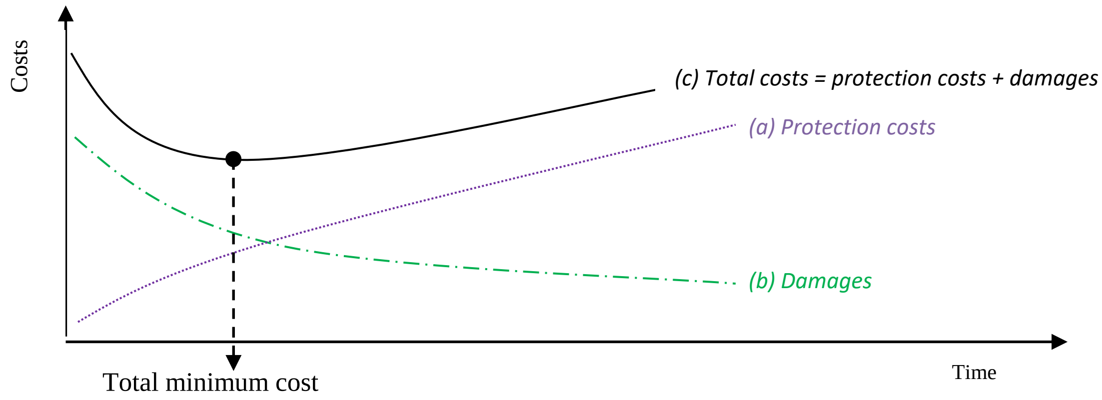
Fires are among the biggest threats to Portuguese forests, despite the progress seen in recent years. Indeed, between 2000 and 2009, 35% of the total burnt area in southern European countries (Portugal, Spain, France, Greece and Italy) was in Portugal; additionally, the likelihood of a forest fire in Portugal rose by around 2%, an estimation four times greater than the probability in the other southern European countries; moreover, the resulting cost of fire (27€ per hectare) is 50% higher than the average cost experienced by southern European countries.

The main objective of this study is to contribute to the understanding of the economic impact of forest fires and its importance for an efficient management of fire costs. The essay begins, in section 2, by discussing the optimal level of protection and the economic and social impacts of forest fires; section 3 offers some methodologies for assessing fire-derived losses in tradable and non-tradable services and goods; and section 4 concludes with a practical work exercise.

COST MANAGEMENT OF FOREST FIRES

The management of forest fires is a matter of efficacy as well as efficiency. As with any other decision regarding the use of limited resources, the efficient management of forest fires must keep its focus on economic principles. Economics says that given the scarceness of resources, economic analysis should be based on choices and the comparison of alternative uses of resources for the choice selection. This comparison can be carried out by applying cost–benefit analysis or other efficiency analysis, as the criteria of total minimum cost.

Criteria of total minimum cost: $Min\ CT = f(protection\ costs,\ damages);$
$\rightarrow protection\ costs = f(prevention,\ fire\ fighting\ costs)$



Source: Adapted from Macedo and Sardinha (1993)

Figure 1. The fire total costs function.

When the total cost is at the minimum any increase in investment in prevention and firefighting expenses is not offset by an equivalent reduction in losses, so the difference between benefits and costs is maximized; reaching the point where the marginal costs (prevention + firefighting costs) are equal to the marginal benefits (reduction of losses). In other words, an increase in prevention and firefighting expenses is balanced by an analogous decrease in damages, thus; at that point, the level of protection is optimal.

In summary, the efficient management of forest fire costs should not be primarily focused on the minimization of fire damage but instead the focus should be on the minimization of total costs. In this way, sometimes a decrease in the level of protection, although implying an increase in damage suffered can often be the best economic decision. As an example, in the 1970s, in Britain, the public authorities took the decision to reduce expenses in forest protection, since they were ten times higher than the direct losses caused by fires, and consequently, although experiencing an increase of damage due to the reduction of protection levels, the average total annual costs remained almost unchanged.

An important question in the management of forest fire costs is often the difficulty in assessing their economic impact (Morton et al., 2003). Indeed, forest fires create a diversity of economic, social and environmental, direct and indirect, short- and long-term impacts, an understanding of which is essential for risk assessment, policy formulation and effective fire management.

Social and economic impacts of fires can be extensive, long-lasting and difficult to identify and assess; e.g. the reduction in property value, tax and income losses for business's, damage to the health of individuals and associated costs, costs due to increased need for water treatment, and costs of non-tradable goods, such as the scenic quality of the landscape, damage to habitats, reduction of biodiversity, climate change, etc. Thus, these have received less attention from researchers than ecological aspects.

In general, only quick statistical data are available, such as the number of fires, how many acres or structures were burnt, and the firefighting costs, which provide an incomplete picture of the total impact of forest fires. Indeed, in the case of large forest fires the environmental, social and economic impacts of the fire can be substantial, particularly when these fires occur in the vicinity of urban areas.

As mentioned, the impact of forest fire can be diverse, including the alteration of wildlife habitat, damage to groundwater and the water supply, damage to public recreational facilities, the evacuation of nearby communities, the breakdown of tourism, destruction of cultural and archaeological sites, the costs of rehabilitation and restoration, and impacts on public health and on transport. However, usually, the more expensive costs are the firefighting costs, damage to residences and the infrastructure and to wood and other forest products. In the next section we will address the question of the assessment of forest fire losses on tradable and non-tradable services and goods.

ASSESSMENT OF FOREST FIRE LOSSES

Losses on tradable goods

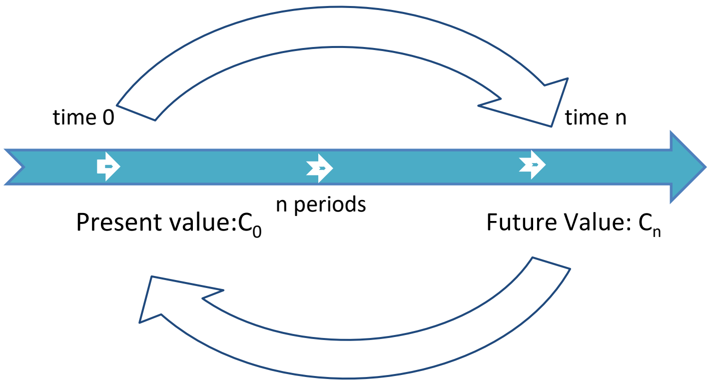
Wood and other forest products; recreational services and equipment and structures.

Fundamental concepts

We begin this section by reviewing some forestry and actual fundamental concepts.

a) Types of stands: we use the term 'young forest stands' if, at the time of the fire, the burnt timber has not yet reached the minimum size to be considered as having commercial value; we use the term 'aged stands' or 'near to the term of exploitability, if, at the time of the fire, the timber is large enough to have commercial value.
b) Revolution is the lifetime of a stand in years and corresponds to the age of the stand at its final cut.
c) The term of exploitability refers to the moment when the stand achieves the optimal of economic and / or biological exploitability.
d) The time value of money principle says that money value can vary over time. For example, a given sum of money today might have a different purchasing power than the same sum of money a couple of years later. The value of money at a future point in time might be calculated by accounting for interest earned or inflation accrued. For example, £100 invested for one year, earning 5% interest, will be worth £105 after one year; therefore, £100 paid now and £105 paid exactly one year later both have the same value to a recipient who expects 5% interest.

Thus, the equivalence between capitals can be achieved through the knowledge of two processes (the inverse of each other): capitalization – the process of finding the future value of a sum (C_n) by evaluating the present value (C_0); and discounting – the process of finding the present value is using the discount rate (t) (see Figure 2 below).



Future value of a present sum (or capital): $C_n = C_0\,(1+t)^n$
Present value of a future sum: $C_0 = C_n\,(1+t)^{-n}$
Given that:
C_0 is the value at time = 0 (present value)
C_n is the value at time = n (future value)
n is the number of periods
t is the discount rate, or the interest rate at which the amount will be compounded in each period.

Figure 2. Discounting *versus* capitalization: the time value of money principle.

e) Soil capital (S), is the potential value of 1 hectare of forest soil. The value of S depends on its use ability, the commercial value of the forest species it sustains and the type of exploration and techniques employed. It presumes stands settled accordingly with the techniques appropriate to the season and forest species and are managed according to the appropriated practices and timelines.

The monetary value of 1 ha of forest soil (S) is defined as the capital it would yield during a revolution (N years) plus the interest per ha equal to the difference between actual revenue (R) and expenditures (D) incurred until the term of exploitability, and the discount rate corresponds to the technical growth rate of the forest species installed.

This is: $$S = \frac{R-D}{(1+t)^N - 1}$$

R – Revenues of the woods at the term of exploitability:

$$R = P + \sum_{n=1}^{N} (d_n + a_n)(1+t)^{N-n}$$

D – Expenses of the woods at the term of exploitability:

$$D = C_0 (1+t)^N + \sum_{n=1}^{N} e_n (1+t)^{N-n}$$

where:

- a_n = commercial value of accessory products sold in year n;
- C_0 = installation cost (or initial capital) of 1 ha of burnt forest stand;
- d_n = commercial value of thinning done in year n;
- e_n = maintenance and exploration expenses of 1 ha of forest stand in year n;

  $$\text{if } e_n \text{ constante}(e_n = e) \Rightarrow \sum_{n=1}^{N} e_n (1+t)^{N-n} = e\frac{(1+t)^N - 1}{t}$$
- P = market value of the main product at the term of exploitability per ha of forest stand; t = discount rate (see Tables 1 and 2).

Losses of cork, resins and fruits

In the case of forestry products that are periodically renewed, once trees have reached a certain age, such as cork, resins and fruits, the losses by area (ha) of forest stand affected by the fire can be calculated, applying one of the following formulas, in case a fire occurs:

Before the start of production:

$$P_P = P_a \times p \frac{(1+t)^a \left[(1+t)^i - 1\right]\left[(1+t)^{N-b} - 1\right]}{(1+t)^N \left[(1+t)^a - 1\right]}$$

After the start of production:

$$P_P = P_a \times p \frac{(1+t)^a \left[(1+t)^b - 1\right]\left[(1+t)^{N-i} - 1\right]}{(1+t)^{N+b-i} \left[(1+t)^a - 1\right]}$$

where:

- P_P = product loss caused by fire;
- P_a = annual production per area (ha);
- p = unit price of the product;
- a = the period of product renewal: 9 years, in the case of cork; 1 year, in the case of resins or fruits;
- i = average age of the forest stand at the time of the fire;
- b = age of the stand at the beginning of production;
- t = annual growth rate of installed forest species;
- N = normal revolution of the type of forest stand installed (years).

Table 1 - Technical Growth Rate: Hardwoods

Revolution (years)	Rapid Growth		Normal Growth		Slow Growth	
	State-owned forests	Private-owned forests	State-owned forests	Private-owned forests	State-owned forests	Private-owned forests
10≤N≤20	0.05	0.06				
20≤N≤30			0.045	0.055		
30≤N≤60					0.04	0.045
60≤N					0.025	0.025

Source: Adapted from Macedo and Sardinha (1993).

Table 2 - Technical Growth Rate: Softwoods

Revolution (years)	Rapid Growth				Normal Growth			
	P. radiata *P. pinaster*		*P. pinaster*		*P. pinaster* *P. sylvestris* *P. larício* *P. canriensis* *P. uncinata*		*P. pinea* *P. halepensis*	
	State-owned forests	Private-owned forests	State-owned forests	Private-owned forests	State-owned forests	Private-owned forests	State-owned forests	Private-owned forests
10≤N≤20	0.055	0.065						
20≤N≤30			0.045	0.050				
30≤N≤60					0.035	0.040	0.025	0.03
60≤N					0.025	0.015	0.015	0.015

Source: Adapted from Macedo and Sardinha (1993).

Losses of wood

Losses of wood can occur in young stands or in forest stands near to the term of exploitability. In the first case the wood burnt has no commercial value but in the second case the burnt wood includes saleable salvages.

Fire in forest stands without commercial value

In the case of a fire event in a young forest stand, Capital losses (C_L) and Losses for delay of surplus value (SV_D) are the commonly used criteria to assess losses. The first one is the criteria used by the Portuguese Institute for Nature Conservation and Forestry (ICNF).

C_L - Capital losses per area (ha) of forest stand affected by the fire. It includes the return on soil capital, the capital invested in the setting up and maintenance of the forest stands and respective returns until the fire incident.

$$C_L = K\left[(S+I)(1+t)^i - S + \sum_{n=1}^{i} e_n (1+t)^{i-n}\right]$$

SV_D – Losses for delay of surplus value, partially or completely destroyed by premature cutting, per area (ha) of forest stand affected by the fire. These losses derive from the fact that gains in woody material resulting from the forest stands' growth in the period between planting and the fire event had been destroyed, thus postponing the term of exploitability in i years.

$$SV_D = K \times P_N \times V_N \frac{\left[(1+t)^i - 1\right]}{(1+t)^N}$$

where:

$$\text{if } e_n = e \Rightarrow \sum_{n=1}^{i} e_n (1+t)^{i-n} = e\frac{(1+t)^i - 1}{t}$$

- e_n = maintenance and exploration expenses of 1 ha of forest stands in year n;
- i = average age of forest stand (years) at the time of the fire event;
- I = current cost of setting up 1 ha of the same type of forest stand;
- K = coefficient of cover (ratio between actual and normal forest stand density for the species, age and season considered);
- N = normal revolution for the type of forest stand installed (years);
- P_N = price of wood (m^3) at the end of exploitability;
- S = value of 1 ha of soil capital for forestry use;
- t = annual growth rate of the forest species installed;
- V_N = volume of wood per ha obtained during a revolution.

Fire in forest stands with commercial value

In case of a fire event in an aged forest stand, **Losses of wood** (L_W) and **Expectation value** losses (E_V) are the commonly used criteria to assess losses. The last one is the criteria used by the ICNF.

L_W - Losses of wood includes the losses resulting from wood commercial depreciation (Dw) and from speeding up it's cut (Vw), by area (ha) of forest stand affected by the fire incident.

$$Loss\ of\ Wood = D_w + P_w$$

Dw - Commercial wood depreciation as a result of damage caused in the trunks, which reduce wood value.

$$D_W = P_i \times V_i - P_i^{'} \times V_i^{'}$$

Vw – Losses in wood volume from the anticipation of its cut down due to the fire incident.

$$V_W = K \times P_N \times V_N \frac{\left[(1+t)^{N-i} - 1\right]}{(1+t)^{N-i}}$$

E_V – Expectation value criteria considers the loss of the expectation value of the forest stand at the time of the fire incident, per area (ha) of forest stand affected by the fire:

$$EV = \frac{K \times R_I - D_I}{(1+t)^{N-i}}$$

R_I and **D_I** - revenue and expenditure values for the period between the fire and the term of exploitability:

$$R_I = P + \sum_{n=i}^{N} (d_n + a_n)(1+t)^{N-n} \qquad D_I = S \times \left[(1+t)^{N-i} - 1\right] + \sum_{n=i}^{N} e_n (1+t)^{N-i}$$

Where:

- a_n = commercial value of accessory products sold in year n;
- d_n = commercial value of thinning done in year n;
- e_n = maintenance and exploration expenses of 1 ha of forest stands in year n; if $e_n = e \Rightarrow \sum_{n=i}^{N} e_n (1+t)^{N-i} = e\frac{(1+t)^{N-i}-1}{t}$
- i = average age of forest stand (years) at the time of the fire event;
- K = coefficient of cover;
- N = normal revolution to the type of forest stand installed (years);
- P = market value of the main product at the term of exploitability per ha of forest;
- P_i '= commercial price (per m^3) of wood damaged by fire (at most equals to P_i);
- P_i = price of m^3 of standing wood with bark, undamaged and with the average characteristics of forest stand burnt;
- P_N = price of wood (m^3) at the term of exploitability;
- S = value of 1 ha of soil capital for forestry use;
- t = annual growth rate of the forest species installed;
- V_i '= viable volume of wood that can extract of stems damaged by the fire (m^3 / ha) (at most equals to V_i);
- V_i = volume of wood of stems damaged by the fire (m^3 / ha);
- V_N = volume of wood per ha obtained during a revolution.

Losses of firewood and brushwood

The losses of firewood in forest stands are obtained by estimating the ratio of the volume of woody stems and crowns and calculating the losses of firewood for the same fraction of wood losses. The assessment of damage for loss of wood is done by calculating the depreciation due to the fire.

Losses of grasslands

The losses of grasslands are determined according to the location, the normal load, annual income, etc., and include the accumulated annual income of the defence period.

Losses in hunting

The lack of inventories and the fact that the effect of fires on hunting extends to five years make it difficult to estimate the hunting losses caused by fire. Moreover, the recreational character of hunting activity inhibits the estimation of the commercial value or the number of pieces culled annually. In the case of having such estimates the huntable losses caused by fire can be calculated by:

$$H_n = \frac{\sum_{i=n-4}^{n} Am_i}{A_m} \times V_n$$

where:

- H_n = damage caused by brushwood fires on hunting in year n;
- Am_i = area of burnt brushwood in year i;
- A_m = total area of brushwood in the region or country;
- V_n = commercial value of the hunting in year n.

Losses in recreational services

Forest fires produce, among others, effects on soil, vegetation, fauna and microclimate, some of which last for decades. The recovery of the landscape and its recreational and touristic value, after a fire, is a task for the long term and may even take as long as 20 years, especially in forests with slow-growing species. Losses in recreational services can be determined by:

$$P_{rn} = 0{,}65 \times \left[R_{fn} \sum_{i=n-19}^{n} A_{fi} + R_{mn} \sum_{i=n-4}^{n} A_{mi} \right]$$

where:

- P_{rn} = damage caused by the fires in recreational values in year n;
- R_{fn} = annual revenues of 1 ha of forest in year n;
- R_{mn} = annual revenues of 1 ha of bushes in year n;
- A_{fi} = area of burnt forest in year i;
- A_{mi} = area of bushes burnt in year i.

Losses in infrastructure and equipment

In the case of repairable damages, the losses are evaluated by the cost of the repair. In the case of destruction, damages are determined by:

$$P_b = (1 - \frac{i}{v}) \times p$$

where:

- P_b = damage caused by fire to the infrastructure or equipment;
- i = age of the infrastructure or equipment at the time of the fire;
- v = standard lifetime of the equipment or the infrastructure (see table 3 next page);
- p = original cost of the infrastructure or equipment.

Table 3 – Infrastructures and equipment's average lifetime			
Property	**Average lifetime (years)**	**Property**	**Average lifetime (years)**
Transportation		Buildings	
- Aircraft	6	- Factories, garages, warehouses, offices, etc.	45
- Passenger cars, motorcycles, trailers	3	- Recreational facilities	20
- Buses	9	- Countryside residences	25
- Light trucks	4	Crops and Livestock	
- Heavy trucks, tank trucks, tractors	6	- Annual crops	1
Betterments		- Orchards, vineyards, etc..	10
- Roads, canals, ditches, piers, bridges	20	- Livestock	1
- Fences	10		
Infrastructure and Equipments			
- Buildings (excluding residences)	25		
- Agricultural machinery	10		
- Mining constructions	10		
- Machinery and equipment for forestry	6		
- Sawmills and other permanent units	10		
- Pulp industries	15		

Source: Adapted from Macedo and Sardinha (1993).

Losses on non-tradable goods: The economic value of environmental goods and resources

As mentioned, the impacts of forest fire can be diverse, including losses of non-tradable goods, such as the scenic quality of the landscape, damage to wildlife habitats, and reduction of biodiversity. The economic assessment emerges as a measuring tool of environmental goods and services and of the impacts of environmental degradation and depletion, determining the direct and indirect costs of qualitative and quantitative changes. It is gathering importance in the evaluation of forest fire economic losses on non-tradable goods.

The economic value of a good refers to the maximum quantity of other goods and services that people are willing to give in exchange of a good, a service or a ‘state of the world’ (e.g. environmental quality). This definition highlights that goods or services only have value if people assign it to them, and that value concept is relative and is measured through an exchange (of goods and services).

The economic value of an environmental good consists of the estimate of a monetary value for this good, in opposition to other available goods. However, sometimes, it is difficult to aggregate all the effects in a single indicator. The economic value of environmental resources (EVER) results from their attributes, and these can be associated to the use (direct, indirect and option) or non-use of the resource, i.e., its simple existence (Figure 3). EVER proposes a fee for environmental resources’ use and/or preservation. The genesis is the protection of current and future generations’ interests. Thus, use value (UV) is the value attributed by people who use or have the usufruct to the environmental good to satisfy their needs. The non-use value (NUV) is dissociated from the use because it derives from a moral, cultural, ethical or altruistic position regarding the rights of existence of other living species or the preservation of natural assets even if they do not represent current or future use for them. While slightly different classifications exist, these produce the same result. Still, controversy exists regarding existence (EV) and option (OV) values, since the EV represents the individual will to preserve a set of environmental resources for future generations’ direct and/or indirect use. Thus, the conceptual question is whether a value defined in this way is closer associated with the OV or the EV. Equally, the legacy value (in this definition mixed with the EV) can be independent (Figure1). However, for EVER it is important that the individuals point out the most trustworthy values possible, independently of the current or future use.

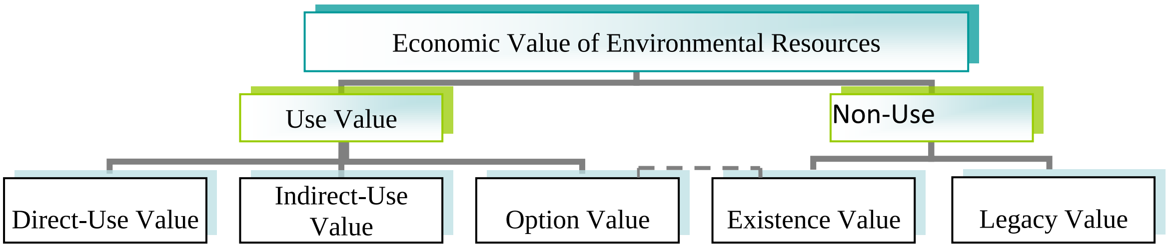


Figure 3. Different economic values of environmental resources

How to quantify an intangible asset such as ‘air quality’? The answer to this question resides in the concepts of:

a) Sacrificed Production – this measures the value, at market prices, of the production that ceases to be produced as a result of actions harmful to the environment caused by other activities;
b) Willingness to Pay – this refers to individuals’ willingness to pay for the additional consumption of the environmental good; it is used when the environment good has not only a current market value but also a future use value (VO) and an existence value (VE).

There are several methods of economic valuation of environmental goods and resources; the most commonly used for assessing forest fire impacts are market prices, hedonic prices, travel costs, transference of benefits and contingent valuation methods. Table 4 presents a summary of these methods.

Table 4 – Methods of economic valuation of environmental goods and resources

Market prices	Estimation based on the price at which goods and services are traded in markets. It can be used to assess changes in the quantity or quality of a good or service. Example: losses in wood, structures and equipment; carbon exchange market.
Hedonic prices	This is based on the premise that the market price of a given product reflects the set of characteristics or the services it provides. It values individual characteristics by analysing the variation in market price to changes in their characteristics. Example: losses in non-tradable assets such as the scenic quality of a landscape can be measured through variations in the market price of a given house located in a burnt area prior and after the fire event.
Travel costs	The time and expenses that a person spends in travelling, for example, to a recreational area, represents a measure of the price that individuals paid to access that location. It's usually used in the valuation of environmental resources such as parks and other recreation areas.
Transference of benefits	This method produces an estimate of benefits using existing information concerning studies at other locations and / or settings. It is often used when it is too expensive and / or there are strong constraints to a specific study of a certain place.
Contingent valuation	This method consists of asking people directly, through a questionnaire, how much they are willing to pay for a particular environmental good or service or, in some cases, how much they are willing to accept to give up the usufruct to a particular environmental service. It is a way to allocate money value to the non-use of environmental goods; i.e. goods and resources that do not involve market transactions and that may not involve direct participation, only 'passive use' value. Example: The value of enjoying the scenic landscape and observing wildlife; the value given to the possibility of future fishing or watching birds, and the right to bequeath these options to future generations, or the value that people attach to simply knowing that there are whales or giant pandas.

Table 5 presents some examples of the economic impact of forest fires.

Table 5. Economic impact of forest fires

Damage Category	Asset	Value (€)	Method Used	Country	Reference
Forestry Goods and Resources	Timber	€322–551 million	Market prices	USA	Mercer et al. (2000)
	Timber	€467 million	Market prices	Indonesia	EEPSEA (1998)
	Direct forest benefits	€667 million	Transference of benefits	Indonesia	EEPSEA (1998)
	Indirect forest benefits	€1.019 million	Transference of benefits	Indonesia	EEPSEA (1998)
	Biodiversity	€28.4 million	Contingent valuation	Indonesia	EEPSEA (1998)
	Carbon absorption	€257.4 million	Market prices	Indonesia	EEPSEA (1998)
	Habitats	€43 and €74	Contingent valuation	USA	Loomis and Gonzalez-Caban (1998)
Property Losses		9-11 million €	Market prices	USA	Mercer et al. (2000)
	Private property	20 million €	Market prices	USA	Mercer et al. (2000)
	Infrastructures	742.900 €	Market prices	USA	Kent et al. (2003)
Losses in Economic Activity	Tourism	70.3 million €	Market prices	USA	Mercer et al. (2000)
	Sales	Increased 1,000 million €	Official statistics	USA	Mercer et al. (2000)
	Salaries	Decreased 3%	Official statistics	USA	Kent et al. (2003)
	Sales	Increased 4%	Official statistics	USA	Kent et al. (2003)
Other Damage	Health problems	€ 946 million	Market prices, contingent valuation	Indonesia	Ruitenbeek (1999)
	Emergency calls	Increased from 91% to 132%		USA	Mercer et al. (2000)
Rehabilitation after Fire	Emergency rehabilitation	€11.8 million	Market prices	USA	Kent et al. (2003)
	Long-term rehabilitation	€31.2 million	Official statistics	USA	Kent et al. (2003)

Source: Adapted from Riera et al. (2006).

PRACTICAL WORK EXERCISE

A wildfire has devastated a mixed forest comprising 5 ha of pinewood from natural regeneration, and 10 ha of cultivated land of chestnut trees located on private property. The pinewood was aged 12 years and there was no commercial recovery of the burnt wood. The chestnut trees were aged 25 years and it was possible to recover €750 per ha of salvaged wood. The damage suffered included losses of wood and fruits.

1. Determination of chestnut tree wood losses

Chestnut tree summary table:

Area = 10 ha	C_0 = €500 /ha	N = 40 years	i = 25 years	$e_n = e$ = €25 /ha
V_N = 100 m^3 /ha	P_N = 37.5€	V_i = 55.5 m3 /ha	P_i = €20	Salvages = €750 /ha
t = 0.04		a_n = 0	K=0.6	

	Year (n)	Volume/ha (m^3)	Price / m^3
Thinning scheduled	15	15	10
	20	18	15
	25	20	22.5
	30	25	27.5

→ **Loss of Wood**

<u>Commercial wood depreciation</u> – Fires in forests aged near to the term of exploitability cause damage to trunks, which can substantially reduce the commercial value of the wood.

The commercial depreciation of the wood is given by:

In the present case salvages $\text{salvages} = P_i' \times V_i' \Rightarrow D_W = 55.5 \times 20 - 750 = 360€$

$$D_W = P_i \times V_i - P_i' \times V_i'$$

Losses in wood volume from the anticipation of its cut down due to the fire

$$V_W = K \times P_N \times V_N \frac{\left[(1+t)^{N-i} - 1\right]}{(1+t)^{N-i}} = 0.6 \times 37.5 \times 100 \times \frac{\left[1.04^{40-25} - 1\right]}{1.04^{40-25}} = 2{,}250 \times \frac{0.8009}{1.8009} = 1{,}000.60€$$

Loss of Wood = D_w+ P_w =1,360.6 per ha, making a total of about €13,606.25 for the 10 ha of chestnut trees burnt.

→ **Expectation value (EV)**

$$EV = \frac{K \times R_I - D_I}{(1+t)^{N-i}} = \frac{0.60 \times 5{,}578.04 - 878.46}{1.8009} = 1{,}370.63€$$

The revenue and expenditure planned for the period between the fire and the term of exploitability are:

$$R_I = P + \sum_{n=i}^{N} (d_n + a_n)(1+t)^{N-n} = 3{,}750 + 810.40 + 1{,}017.64 = 5{,}578.04€$$

$$D_I = S \times \left[(1+t)^{N-i} - 1\right] + e \times \frac{(1+t)^{N-i} - 1}{t} = 471.81 \times \left(1.04^{15} - 1\right) + 25 \times \frac{\left(1.04^{15} - 1\right)}{0.04} = 878.46€$$

Determination of Soil Capital: $S = \frac{R - D}{(1+t)^N - 1} = \frac{6{,}569.51 - 4{,}776.14}{1.04^{40} - 1} = \frac{1793.34}{3.801} = 471.81€$

$$R = P + \sum_{n=1}^{N} (d_n + a_n)(1+t)^{N-n} = 3{,}750 + 2819.51 = 6{,}569.51€$$

$$P = 100 \times 37.5 = 3{,}750€$$

$$\sum_{n=1}^{N} (d_n + a_n)(1+t)^{N-n} = 2{,}819.51$$

Year (n)	Volume (m^3)	Price / m^3 (€)	d_n (Volume x Price)	$(1+t)^{N-n}$	$d_n \times (1+t)^{N-n}$
15	15	10	150€	$1.04^{40-15} = 2.6658$	399.87€
20	18	15	270€	$1.04^{40-20} = 2.1911$	591.60€
25	20	22,5	450€	$1.04^{40-25} = 1.8009$	810.40€
30	25	27.5	687.5€	$1.04^{40-30} = 1.4802$	1,017.64€
Total					2,819.51€

$$D = C_0(1+t)^N + e \times \frac{(1+t)^N - 1}{t} = 500 \times 1.04^{40} + 25 \times \frac{1.04^{40} - 1}{0.04} = 24{,}776.14€$$

Expectation Value Losses: $EV\text{ - }Salvages = 1{,}370.63 - 750 = 620.63€$ per ha, making a total of about €6,206.3 for the 10 ha of chestnut trees burnt.

2. Determination of chestnut fruit losses

Chestnut fruits summary table:

P_a = 7,500 kg	a = 1 years	b = 10 years	p = 2€	N = 40 years	i = 25 years	t = 0.04

→ **Chestnut fruit losses**

$$P_P = P_a \times p \frac{(1+t)^a\left[(1+t)^b - 1\right]\left[(1+t)^{N-i} - 1\right]}{(1+t)^{N+b-i}\left[(1+t)^a - 1\right]} = 7{,}500 \times 2 \frac{(1.04)\ \left[(1.04)^{10} - 1\right]\left[(1.04)^{15} - 1\right]}{(1.04)^{25}\left[(1.04) - 1\right]} = 562{,}723.710€$$

Chestnut fruit losses equal €112.54 per ha, making a total of about €5,627,237.10 for the 10 ha of chestnut trees burnt.

3. Determination of pinewood losses

Pinewood summary table

A = 5 ha	K = 0.8	e_n = e = 25 € /ha	d_n = 0; a_n = 0	N = 50	i = 12 years
V_N = 200 m^3 /ha	P_N = 35 € /m^3	I = 5,000 € /ha	C_0 = 0	t = 0.04	

→ **Capital losses (C_L)**

$$C_L = K \times \left[(S+I)(1+t)^i - S + e\frac{(1+t)^i - 1}{t}\right] = 0.8 \times \left[(521.28 + 5{,}000) \times 1.04^{12} - 521.28 + 25 \times \frac{1.04^{12} - 1}{0.04}\right]$$
$$= 6{,}955.13€$$

<u>Determination of Soil Capital</u>: $S = \frac{R - D}{(1+t)^N - 1} = \frac{7{,}000 - 3{,}816.68}{1.04^{50} - 1} = 521.28€$

$$R = P + \sum_{n=1}^{N} (d_n + a_n)(1+t)^{N-n} = 200 \times 35 = 7{,}000€$$

$$D = C_0(1+t)^N + e \times \frac{(1+t)^N - 1}{t} = 25 \times \frac{1.04^{50} - 1}{0.04} = 3{,}816.68€$$

Capital losses equals €6,955.13 per ha, making a total of about €34,775.70 for the 5 ha of pinewood burnt.

→ **Losses for delay of surplus value (SV_D)**

$$SV_D = K \times P_N \times V_N \times \frac{\left[(1+t)^i - 1\right]}{(1+t)^N} = 0{,}8 \times 35 \times 200 \times \frac{\left[1.04^{12} - 1\right]}{1.04^{50}} = 56{,}000 \times \frac{0.601}{7.107} = 473.56€$$

Losses for delay of surplus value equals €473.56 per ha, making a total of about €2,367.81 for the 5 ha of pinewood burnt.

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