

Introducing the *montado*, the cork and holm oak agroforestry system of Southern Portugal

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Abstract The Portuguese *montado* is an agro-silvo pastoral system quite similar to the *dehesa* in Spain, and covering in Portugal most of the Southern region of the country, Alentejo. The trees in the *montado* are cork oh holm oak, and the system is mostly acknowledged due to the cork production, but also due to its singular savanna like land cover pattern, its multiple and complementary productions, the support of a diversity of ecosystems services and its biodiversity. The present special issue covers the diversity of components of the *montado* and of perspectives required to understand and assess the functioning of the system. This Editorial introduces the *montado* system, describes its extension and similarities to the *dehesa* in Spain, and addresses the multiple productions and externalities of the *montado*. It also refers to the several components of the system. It focus on the uniqueness and values of this system, stressing its potential and threats, and the requirements for integrated knowledge production. In the end of the Editorial, each one of the papers that compose the special issue are presented.

Keywords Agro-silvo pastoral system · Agroforestry · *Montado* · *Dehesa* · Multifunctionality

The *montado*

The Portuguese *montado*, evergreen oak parklands consisting of a multifunctional silvo-pastoral system that covers about 800,000 ha in Portugal, mainly in the region of Alentejo, where it covers 730,000 ha (Costa et al. 2009). A similar system can also be found in South–East Spain, the *dehesa*, mostly in Extremadura (1.25 M ha) and Andalucía (700,000 ha). Thus, according to Olea and San Miguel-Ayanz (2006), the *montadoldehesa* agroforestry systems may cover an area of about 3.5–4.0 M ha in the southwestern Iberian Peninsula, and is for the most part, still under production today. The area covered by this land use system is thus of large relevance in the Southern European context.

The international acknowledgement of this system stems originally from cork production, with Portugal contributing about 33% of the world cork oak area, and 54% of the mean annual world cork production (Ribeiro et al. 2010). Most important today, in international terms, the *montado* is also acknowledged due to its specificity and value as a particular landscape, its biodiversity support, aesthetic and identity values, attractiveness for recreation and environmental balance (Berrahmouni and Regato 2007; Costa et al. 2009; Surová and Pinto-Correia 2008; Surová et al. 2011). The *montado* is considered a High Nature Value Farming System, according to the European classification proposed by the European Environmental Agency (Paracchini et al. 2008),

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related to the required targeting of public policies, concerning the provision of public goods through agriculture and forestry (Berrahmouni and Regato 2007; Olea and San Miguel-Ayanz 2006).

In the Alentejo region, the dominant *montado* landscape represents one of the best Mediterranean examples of the development of the social, environmental, and economic functions of an agrosilvopastoral system, maintained over hundreds of years (Costa et al. 2009; Martín-Vicente and Fernández-Alés 2006; Pinto-Correia and Fonseca 2009). The most singular characteristic of the *montado* is its savanna-like physiognomy, spread throughout a large scale mosaic, in changing densities, of cork (*Quercus suber*) and holm oak (*Quercus ilex rotundifolia*) trees.

Montado systems can be considered complex agroforestry systems, in which complexity increases with the conjunction of production activities (agriculture, pasture, grazing, animal stock, etc.), that share the same growing space in a landscape characterised by its site variability, especially at the soil/climate/topography levels (Pinto-Correia 1993). The economic sustainability of the system has so far, and since some centuries ago, been based on a diversity of products, not just cork, but also livestock, and complementary products such as wood and charcoal (Berrahmouni and Regato 2007; Díaz et al. 2003; Pinto-Correia and Fonseca 2009; Plieninger and Wilbrand 2001).

Production activities in the undercover are cereal crops cultivated in long rotations, combined with fallowing, and extensive livestock grazing/raising of cows, sheep, goats, cattle and the Iberian pig (Gaspar et al. 2007; Plieninger 2007). Associated activities are bee-keeping and mushroom picking. The open tree cover is maintained through natural regeneration and trees are seldom planted. Nevertheless, trees have a direct value as fodder crop, providing acorns and leafy branches in autumn and winter, when the herbage production is low, and an indirect value as shelter against cold in the winter and heat in summer (Cañellas et al. 2007; Moreno-Marcos et al. 2007). Furthermore, the trees create the ecological characteristics that are fundamental to the sustainability of all activities occurring at stand level (Ribeiro et al. 2003, 2006). The sustainable management of the combination sets of production activities requires a good knowledge of the resilience and elasticity of the forest components, in each particular soil/climate/topographic conditions (Ribeiro et al. 2004, 2006).

Besides multiple production outcomes, the *montado* supports a rich biological diversity that evolved from the ingenious and dynamic adaptation of humans to their environment (Plieninger and Schaar 2008). Most plant and fungi species in these landscapes are valued as non-timber forest products for human use, many of them with aromatic, culinary or medicinal properties. In terms of biodiversity, *montado* landscapes reach levels of 60–100 flowering plant species per 0.1 ha (Díaz et al. 2003). Plant diversity may be improved through shrub clearing (every 3 years), favouring a mosaic of micro-environments (Canteiro et al. 2011). Furthermore, canopy cover strongly shapes the composition of macrofungal communities (Santos-Silva et al. 2011). Management options determine diversity at the soil level: greater losses in sporocarps production and taxa composition are registered where shrub density is controlled by permanent grazing or involving cutting practices followed by soil tillage (Azul et al. 2011).

The tree crown coverage and distribution has been shown to be a major factor in determining the diversity and population density of many animal groups. The *montado* is an extremely well-adapted habitat for wild ungulates, especially red deer (*Cervus elaphus hispanicus*) and wild boar (*Sus scrofa*), which are nowadays regarded as expensive renewable natural resources (Vargas et al. 1995). In addition, small and medium mammals are abundant in the *montado* as a consequence of low human disturbance, including the endangered Cabrera vole *Microtus cabreræ* (Mira et al. 2008; Rosalino et al. 2009). The wild rabbit (*Oryctolagus cuniculus*), abundant in the *montado*, is still the basic prey of many predators (including endangered species, such as the Iberian imperial eagle, *Aquila adalberti*, or the Iberian lynx, *Lynx pardinus* and necrophages e.g. black vulture, *Aegypius monachus* (Olea and San Miguel-Ayanz 2006). Among other Mediterranean land cover classes, the *montado* shows the highest richness in the breeding of passerine birds, seemingly as the presence of border and open-habitat birds (Tellería 2001). The variables that reflect tree and shrub density and cork removal are the most important predictors of bird assemblages (Godinho and Rabaça 2011). With regard to lizards, a positive correlation with cork management areas, and negative with high livestock grazing, has also been demonstrated (Godinho et al. 2011).

As for the role of the *montado* as support of recreation activities, aesthetic appreciation and identity

preservation, its importance is widely recognised today in the Southern European context (Aronson et al. 2009; Emanuelsson 2009; Pinto-Correia and Vos 2004; Pedroli et al. 2007; Plieninger and Wilbrand 2001; Terwan et al. 2004). Still, much improvement is needed in methodological approaches to assess public preferences in relation to the different types of *montado*, resulting from different local conditions, but mainly from different management options (Pinto-Correia et al. 2011), so that detailed information can be used in decision support systems.

Changes in the *montado* system and knowledge production needs

As described above, the *montado* production system results from the integration of conflicting activities in the same space, creating the need for a constant search of equilibrium among its components in order to achieve sustainability (Pinheiro et al. 2008; Ribeiro et al. 2004). Threats to the balance of the system are currently of various kinds (Costa et al. 2009; Eichhorn et al. 2006; Ribeiro et al. 2004).

The most acknowledged threats are, on one hand, the over-exploitation of the tree cover, as cork harvest and pruning for charcoal production, in non-balanced terms, which will harm and weaken the trees (Cañellas et al. 2007). On the other, intensification of the activities in the undercover, such as overgrazing and mechanised ploughing, may hinder tree regeneration, so that the long-term regeneration of the tree cover is not guaranteed (Plieninger and Wilbrand 2001; Plieninger 2007). As natural regeneration is unreliable, and artificial planting has been beset by serious setbacks, regeneration is absent in many situations, therefore threatening the future maintenance of the system. Mechanised and deep ploughing also affects the root system and weakens the trees. Overgrazing may result in compaction of the soil and higher erosion risks.

Finally, in more peripheric and more fragile areas, there has been a trend of extensification or abandonment, that allows an invasion of shrubs and other oaks increasing the competition (reducing cork production), resulting in shrub encroachment and the risk of forest fires (Pinto-Correia and Mascarenhas 1999; Pinto-Correia 2000). Actually, cultivation

tends to diminish under the trees, and the undercover is solely used for grazing, in varying intensity.

Furthermore, ongoing climatic change may presumably induce more repeated and severe droughts, while the spread of wildfires may force the turnover of *montado* mosaic into large and persistent shrublands (Acácio et al. 2009).

Montado systems can be conceptualised as open forest systems with a set of external variables, and a feedback loop comprising stand structure → growth → tree size and shape → stand structure (Pretzsch 2009) that controls its stability. The elasticity and resilience of these systems is good, but can be disturbed by extreme changes of various kinds. This may happen both by (1) random, external variables that relate to tree mortality, tree damage and intensity of natural regeneration, and (2) management-based variables that can affect the system at tree level physiology (debarking, crown pruning and root pruning) and at site level mainly by soil structure modifications (soil mobilisation, erosion risk, organic matter depletion, fertility loss, etc.) (Ribeiro et al. 2004). These disturbances are incorporated in the multilevel feedback loops, resulting in observed system responses. Presently, the observed reduction of density by mortality results from a debilitating interaction caused by the combination of external variables: over grazing → soil mobilisation → soil erosion → soil organic matter depletion → lack of natural/artificial regeneration → climate change. The response from the feedback loop is the loss of tree/stand vitality through loss of resilience and consequently, loss of elasticity (Ribeiro and Surovy 2008).

For the preservation of the *montado* with the valuable characteristics it is known for, it is crucial to enhance good practices focused on long-term objectives and to promote its regeneration as a whole system. Adaptive management techniques are required. Such techniques require growth models and decision support systems, constructed in knowledge-based monitoring systems. In a context where the main economic objectives of management may change according to new market balances, new social demands and related public policies, such systems need to integrate many different forms of knowledge production and domains, barely incorporated thus far (Costa et al. 2009; Plieninger and Schaar 2008).

An integrated research approach

The Research Group on Mediterranean Ecosystems and Landscapes (EPM/ICAAM), from the Institute of Mediterranean Agricultural and Environmental Sciences, at the University of Evora (<http://www.icam.uevora.pt/>), has been developing research on cork oak and holm oak woodlands, using a trans-disciplinary approach and aiming at producing integrative knowledge as a support for decision making. The group is located in Évora, in the region of Alentejo, where the *montado* is the dominant land-use system, and therefore most research on each dimension of the rural areas is related, in some way, to the *montado* system. Research domains stretch from tree physiology, the root system, fungi role, natural vegetation and conservation biology, cork production and grazing potentialities, public goods provision and users demand, and finally to modelling approaches to tree growth and the balance of the system. The latter ones use and combine the information and data provided by other groups and specialists, thus increasing interaction and further knowledge-integration. Integration of the various types of research and knowledge production is a main goal of the EPM/ICAAM, and this issue reflects the possible domains for further integration, based on a study object, the *montado*, that greatly demands such integration in order to be fully understood and consequently managed. For this reason, all papers are by multiple authors, most of them being members of EPM/ICAAM, while others are external colleagues with whom the EPM/ICAAM team collaborates, in other research centres in Portugal.

Contents of this special issue

The main objectives of the present special issue are to gather the results of research developed on different perspectives of the *montado* in the Alentejo, and to establish a diversified and complementary knowledge-base for the definition of management options in this system. It is as such a highly interdisciplinary special issue, in the diversity of perspectives considered in each paper, but also in the combined disciplinary approaches applied in some of the papers.

This Editorial aims to present and describe the *montado* system, stressing its potential and threats,

and the requirements for integrated knowledge production. Paper 1, by Peter Surový et al., “Evaluation of coarse cork-oak root system by means of digital image”, deals with methodological contributions for the assessment of the *montado* composition and its root systems, fundamental for the balance of the whole system. Paper 2, by Margarida Vaz et al., “Leaf-level responses to light in two co-occurring *Quercus* (*Q. ilex* and *Q. suber*) species: leaf structure, chemical composition and photosynthesis”, deals with the physiology of the tree cover, and describes the results of studying leaf acclimation to incidental light in cork and holm oaks. Paper 3, by Carla Canteiro et al., “Conservation of Mediterranean oak woodlands: understorey dynamics under different shrub management” relates to experimental disturbances and its effects on the shrub physiognomy, composition and structure; closely linked and therefore relevant to the role of the *montado* in biodiversity conservation. Paper 4, by Celeste Silva et al., “Canopy cover influence on macrofungal richness and sporocarp production in Montado ecosystems”, refers to the diversity of macrofungi in the *montado* as a result of its composition, that relates to the balance of the system but also to its multiple uses and attractions for users. Papers 5 and 6 refer to the soil level, and both assess the impact of management options and practices in soil biodiversity. Paper 5, by Anabela Marisa Azul et al., addresses “Fungal fruitbodies and soil macrofauna as indicators of land-use practices on soil biodiversity in the Montado”. Paper 6, by Sara Mendes et al., is “Assessing the impact of understorey vegetation cut on soil epigeic macrofauna from a cork-oak Montado in South Portugal”. Papers 7 and Paper 8 are of another nature, as they focus on the management effects of various *montado* types on animal diversity. Paper 7, by Sergio Godinho et al., “Montado management effects on the abundance and conservation of reptiles in Alentejo, Southern Portugal”, is about reptiles and the effect of livestock grazing. Paper 8, by Carlos Godinho and João Rabaça, “Birds like it Corky: the influence of habitat features and management of ‘montados’ in breeding bird communities”, enhances the relationship between bird assemblages with tree and shrub density, and cork removal. Paper 9, by Teresa Pinto-Correia et al., “The fuzziness of Montado landscapes: progress in assessing user preferences through photo-based surveys”, addresses a far

different, more methodological issue, in relation to approaches for assessing public preferences. Paper 10, by Diana Surová et al., “Integration of landscape preferences to support the multifunctional management of the Montado system”, deals with the integration of preference values by multiple groups of users, in a decision-support system. Paper 11, by Peter Surovy et al., “Observations on 3-dimensional crown growth of Stone pine”, is also methodological, as it addresses advanced techniques for the detailed monitoring of Mediterranean silvo-pastoral systems, applied in this paper to pine stands, but possible to adapt for application in cork or holm oak stands. This special issue should be considered by the reader as an overarching set of contributions to the understanding of the full complexity of the agro-silvo-pastoral land use systems still existing today in Europe, as the *montado*, and of the methodological challenges raised by addressing each one or a complex of the components of the *montado* system and integrating them.

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