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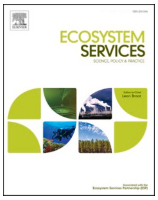

Full Length Article

Farming for nature in the Montado: the application of ecosystem services in a results-based model

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ABSTRACT

The Montado is a silvopastoral system with a tree cover of predominantly *Quercus suber* but also *Quercus rotundifolia*, where cattle or sheep graze the understory. It occupies more than one million hectares in southern Portugal, and a similar landscape, the Dehesa, covers ca. three million hectares in Spain. These silvopastoral systems can simultaneously benefit the environment and socio-economic activities by providing a bundle of ecosystem services (ESs). However, an ongoing trend of decline in tree density and the covered area is threatening such provision. Policies are needed to motivate farmers to secure the ESs that they provide. One possible format is the development of a results-based model (RBM) for agri-environment schemes (AES), implemented under the Common Agricultural Policy. In an RBM, farmers are paid when they deliver specific environmental results (ERs) (e.g. healthy and functional soils), that are linked with the provision of different (and often multiple) ESs. This study defines possible ERs for the Montado and details how these results are linked to the provision of ESs. It then considers management actions that can allow the achievement of these ERs and the costs of these actions. Our methodological approach is based on a transdisciplinary dialogue involving researchers, practitioners (i.e farmers), public authorities and policy makers. The results of the process include the identification of four main ERs: a healthy soil ecosystem, a biodiverse native-Mediterranean pasture, an oak tree layer where regeneration exists (i.e. trees of different ages), and preserved or enhanced landscape elements, for example riparian galleries with vegetation. These ERs increase the supply of provisioning services (e.g. cork production), of regulating services, (e.g. carbon sequestration), and cultural services (e.g. aesthetic inspiration). RBMs allow farmers to use any management practice they choose as the focus is on the results. Nonetheless, to estimate costs we identified 12 potential strategic management practices (and their cost) along with the technical support that farmers would need. We conclude that an RBM could be an affordable solution for public policies in the Montado system, given the limited government budget for supporting AES.

1. Introduction

Land use systems that combine trees with pastures and animal grazing (silvo-pastoral systems) are agro-ecosystems that can simultaneously create environmental, economic and social benefits (Röhrig, Hassler and Roesler 2020). They are a type of agroforestry that combines

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the management of trees or other woody perennials, forage and livestock on the same site (Jose et al., 2019; Moreno and Rolo 2019). Such vertical and horizontal heterogeneity results in a landscape with high natural values (Acebes et al., 2016; Pinto-Correia et al. 2018). These systems are unique examples of diversification in land use that enhance a bundle of ecosystem services (ESs) such as carbon storage, biodiversity enhancement, wildfire prevention or erosion control and efficient nutrient cycling, thereby reducing leaching, without compromising yield (Sales-Baptista and Ferraz-de-Oliveira 2021; Tamburini et al. 2020). In addition, they offer a diversity of income streams and are a source of cultural heritage and high-quality landscapes (Ahammad et al., 2021; Guerra et al., 2014; Moreno et al. 2018; Surová and Pinto-Correia 2016). This is exemplified in the Montado in the Alentejo region of Portugal (Bugalho et al., 2011; Guerra et al., 2014).

The Montado and Dehesas (on the Spanish side) are Europe's largest silvopastoral systems. When properly managed, they provide a high nature value farmland (HNVf), where the production ensures high levels of other ESs (Lomba et al., 2020). These nature conservation values are highly dependent on maintaining specific (traditional) agricultural practices (Godinho et al. 2016; Pinto-Correia et al. 2018). Silvopastoral systems have been developed over millennia as a long-term adaptation to natural scarcities (Ferraz-de-Oliveira et al., 2016; Pinto-Correia and Fonseca 2009; Sales-Baptista and Ferraz-de-Oliveira 2021). When these systems are in balance, they provide ESs that secure production goals. The optimum levels of provision of these ESs depend on the capacity for simultaneously securing production, the ecological balance and landscape quality (Lomba et al. 2020; Teixeira et al. 2018). While the market remunerates some provisioning services, it does not reward other regulatory or supportive services or some cultural services. They are difficult to trade, mainly because they cannot be individually owned or exclusively used (Röhrig et al. 2020). As such, the ESs that fall outside the market are not a priority for farmers (Camilli et al. 2018). Despite this, for a long time, the silvopastoral systems of Iberia have provided provisioning services without reducing other ESs (Bugalho et al. 2011; Pinto-Correia and Vos 2004). This balance has been disturbed in recent decades, due to a combination of factors: including the globalisation of markets and technologies, farming intensification and specialisation. The implementation of a centralised agricultural policy across Europe further promoted specialisation (CAP, the Common Agriculture Policy) (Almeida et al. 2016; Guimarães et al. 2018).

In the present context, failing to compensate farmers for the ESs that do not contribute to their incomes can contribute to the simplification of the whole farm system which, in turn, reduces its high nature value (Pinto-Correia et al. 2018; Röhrig et al. 2020). The economic valorisation of these multiple ESs could be an incentive for farmers in the Dehesa and Montado to maintain and enhance their mixed farming systems with multiple positive externalities (Ahammad et al. 2021; Torralba et al. 2018). New (European) public policies should play a key role in this process (Blackstock et al., 2021; Guerra et al. 2016; Otero et al. 2020). One such mechanism, being piloted in different settings in Europe, are Results-based models (RBMs) (Herzon et al. 2018; Targetti, Schaller, and Kantelhardt 2019). RBMs are strategies that link payments with the delivery of desirable ESs (e.g. healthy and functional soils): a departure from the current practice-based agri-environment schemes (AES) implemented under the CAP. The existing AES compensate farmers for certain practices with the expectation of achieving environmental benefits. In an RBM, the management practices that allow the ESs to be maintained are identified and the costs of their implementation estimated. Yet, payment is calculated considering the environmental outcomes, not the practice. Hence, RBMs are considered a strategy for payments for ESs (Bennett and Gosnell, 2015; Cullen et al., 2018; Blackstock et al., 2021). When applying an RBM the order of magnitude of anticipated changes is estimated, along with the management alternatives available to farmers. As such, RBMs are an evidence-based analysis of the relationship between agricultural practices and the delivery of ESs that are applied at an appropriate spatial scale (i.e., at the farm level). In this paper we present a cost analysis of the application of an RBM for the Montado in southern Portugal (Fig. 1).

In this paper we present and discuss the changes in management practices necessary to secure a selection of ESs in a Montado area, as well as the foreseen costs of changing from existing standard management practices to practices that provide the targeted ESs. The paper includes the contextualization of the analysis within the framework of RBMs, followed by a description of the methodology used in the study, and a presentation of the results obtained. The discussion and conclusion mainly focus on the implication of this analysis for the development of new policy instruments for supporting sustainable agriculture.

2. Result-based models

The AES, implemented under the CAP, are a key policy framework for integrating environmental concerns within European agriculture and are the largest source of EU funding for applied nature conservation (Batáry et al. 2015; O'Rourke and Finn 2020; Pe'er et al. 2020). The EU payments for AES that link agriculture with the protection of natural resources are based on the principle of compensation for both income foregone and additional costs incurred, compared to conventional farming practices (Sainte Marie 2014). This means that public agencies need to ensure that operational and investment costs, foregone production, profits and private transaction costs are all covered by the payment (Hejnowicz et al., 2016).

Over the last 30 years, there has been some debate over the ecological performance and cost effectiveness of the AES (Cullen et al. 2018; O'Rourke and Finn 2020; Pe'er et al. 2020). Thus, calls to integrate the ES framework into AES have gained prominence in the policy and scientific debate, which implies assessing the value of the regulatory, supportive and cultural ESs provided by farming systems (Herzon et al., 2018; Moran et al., 2021). This poses a significant challenge in complex farming systems such as silvopastoral systems, which deliver a diverse range and high level of ESs (Bennett and Gosnell 2015; Kay et al. 2019; Santos et al. 2020).

ESs can be evaluated in different ways. There are different paradigms and distinctions to define the value of ESs, such as the instrumental, or anthropocentric, perspective and the intrinsic, or biocentric perspective (Röhrig et al. 2020). Moreover, because of the intangible nature of many such services, it is difficult to assign them a value (Bennett and Gosnell 2015). With farm systems producing both marketable and non-marketable goods and services, the value of an ES can remain underestimated (or ignored) by the market place (Blackstock et al., 2021; Röhrig et al. 2020). Yet, valuing ESs, for example through stated preference survey techniques can, through hypothetical bias, lead to an overestimation of their economic value (Bennett and Gosnell 2015). To better inform public policies and make them more efficient in supporting the provisioning of ESs, robust evaluation procedures are needed.

Within CAP and more specifically the AES, the number of pilots RBMs is increasing and showing promising results (Dupraz and Guyomard 2019; Moran et al. 2021; Targetti et al. 2019). In order to implement an RBM it is necessary to identify the farm management practices in place and those that can replace them to improve ESs provision. Although farmers have a choice over the management practices they adopt (if any) it is important to identify them first in order to gauge whether they will enable farmers to achieve the desired ESs and if they are practical for the farmer. In addition, the costs to be incurred also need to be calculated so the level of payment can be defined. In the current AES, payments for the costs incurred are based on the extra costs of the practices associated with each specific measure, combined with an estimation of the loss of income, usually related to decreases in production. Likewise, in an RBM the payment rate can be derived by quantifying the opportunity costs of the management option that is considered most likely to achieve the ESs, and not on a valuation of the results *per se* (Herzon et al., 2018). As such, one of the main challenges in setting an appropriate payment level for an RBM is to assure that this

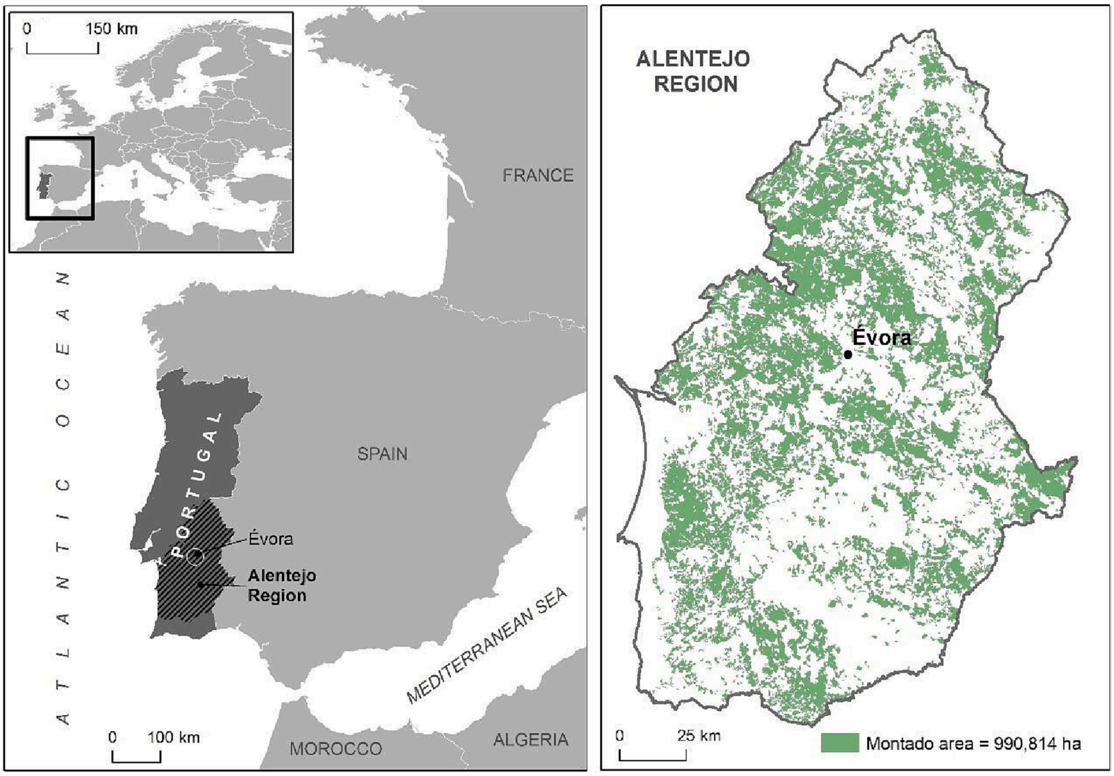

Fig. 1. The distribution of Montado in the Alentejo region, Portugal (Source: Guimarães et al. 2018).

payment is cost effective in the sense that it reflects the full cost of achieving the ESs, including the time spent by farmers and any possible decrease in production related income (Cooper et al., 2009).

3. Methodological approach

The analysis of costs we present was derived from the analysis of scientific evidence to support the implementation of a pilot RBM for the Montado, applied within a specific local area close to Évora (see Fig. 1), where the Montado is the dominant farming system. This analysis was built as a transdisciplinary effort between researchers, farmers and public authorities, following a structured design, as detailed in the rest of this section (see Fig. 2).

3.1. *The transdisciplinary arena*

The transdisciplinary (TD) arena is a multi-actor approach that we adopted to provide an ongoing process of interaction between our multidisciplinary research team and other key stakeholders (Table 1).

The researchers were mainly from University of Évora and the key regional stakeholders were farmers and technical staff from the public authorities (a total of 22 participants).

The TD arena was the space where individuals from different disciplines, backgrounds and roles interacted for 5 years to co-produce the knowledge necessary for the future development of an RBM for the Montado. The TD arena involved regular meetings, coordinated by a skilled facilitator who was also available to be contacted by the participants, by phone or email, whenever required. In the TD arena we discussed data, clarified the rationale behind different proposals and validated the best compromise to move forward (details in Pinto-Correia et al. 2022). At different steps in the process, the research team would prepare the baseline information and send it out to all participants before they met to discuss it. At each meeting the goal was to discuss the data made available, decide if it was sufficient and reach a consensual decision. At the end of each meeting the next steps were defined and a short summary of the advances was made available to all. Consensus was always reached, even if sometimes decisions were postponed to the next meeting because there was insufficient information available or the proposals needed further development.

3.2. *Identification of the environmental results*

In a RBM ESs are clustered and designated as environmental results (ERs). Work on defining the most relevant ERs to be achieved by a future RBM for the Montado dates back to 2013 (details in Guimarães et al. 2019) when a vision for the future of Montado in the Alentejo region was developed through a TD setting. This work identified the elements within the productive ecosystem that needed to be maintained or enhanced (e.g. the soil ecosystem). It was subsequently complemented by later studies that detail the Montado as a high nature value farmland (Ferraz-de-Oliveira et al. 2016; Pinto-Correia et al. 2018; Serrano et al. 2018) and allowed the identification of a first tentative list of ERs. This list was discussed, refined and agreed in the TD arena by all those involved. The definition was done under the premise that the provision of these ERs could be achieved by adaptations or changes in management practices. As such the ERs presented in this paper merely provide a sub-set of the ESs that the Montado can provide.

3.3. *Management practices required to achieve the identified ERs*

After accomplishing a consensual list of ERs we then moved to the definition of the management practices that could achieve these results. This was carried out separately for each defined ER. As specialised knowledge was required for this step, two task forces were established, the first targeting ERs related to soil, pastures and tree layers and the second targeting ERs related to water and biodiversity.

In each task force, the relation between targeted ER and farm management practices was defined by a triangulation between a literature review, expert knowledge and validation by farmers. Each task force met regularly. When needed, experts from outside the TD arena were

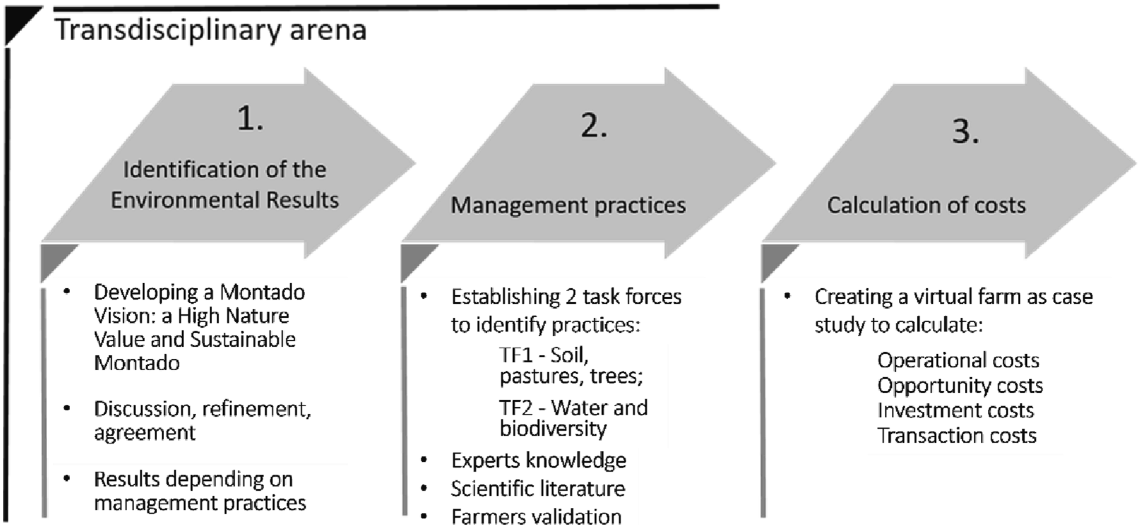

Fig. 2. The methodological approach. Three sequential actions were taken, all of them involved consensus building of the main desired outcomes between the actors involved. The arrows indicate actions and below each arrow we describe the steps to achieve each outcome.

Table 1
Details of the stakeholders participating in the TD arena.

Type of stakeholder	Number of people	Role
Researchers in ecology/ conservation/botany/ zoology	5	Define the environmental results (ER), bring the scientific knowledge to define the results-based indicators (RBI), and the management practices that can allow farmers to reach the defined ESs
Researchers in animal science	2*	
Researchers in economy/ management/policy/ transdisciplinarity	4*	Define the likely costs and required payment levels, the design, facilitate and coordinate the TD arena, transpose the scientific content into the policy framework
Montado producers and managers	8	Define the ESs, the RBI, calculate costs and identify the most appropriate management practices
The Ministry of Agriculture: General Bureau of Planning and Policy	3	Interface between the work developed in the TD arena and decision makers. The identification of possible adjustments needed so that the outcomes can be used at the policy and decision-making level

Note: * These researchers are also part of the core group of the project so in addition their research role, they were also involved in the coordination of the project.

recruited. These meetings were also facilitated and systematised by the skilled facilitator. The experts' knowledge was shared at the task force meetings, through one-to-one discussions and through their revision of the documents that the project researchers had prepared. The practices identified by each task force were presented, discussed and validated (or challenged) by farmers at the TD arena meetings, which usually led to agreements being reached. In some cases, agreement was not possible and more work had to be done before a consensus could be reached. Hence validation by farmers was sometimes postponed to the following meeting in cases where farmers felt that new information and/or other alternatives needed to be considered.

The final list of possible management practices for each ER was discussed within the TD arena, considering the scientific robustness of each practice and the practicality of its implementation.

3.4. *Calculation of the costs of changing management practices*

The final activity was the calculation of the costs. Such an exercise in the Montado must reflect the fact that it is a heterogeneous land use system with different spatial attributes, such as the slope of the terrain, soil type, distance to main roads, etc. The development of an RBM in such a context has to be done in concrete spatial locations to reduce variability as much as possible. To obtain a cost estimation, the first step was to define an example of a virtual, mainstream farm, with beef cattle as livestock, where Montado is the dominant land use (Fig. 3). The structure and details of this virtual farm were derived from a literature review, a review of statistical data and the combined knowledge within the team about Montado farms in the region. All the details of the virtual farm and its core characteristics, in terms of land cover, land use and management practices, were discussed in the TD arena before being agreed upon. The stakeholders, including the public authorities, agreed that using this virtual farm was an acceptable approach for dealing with the heterogeneity within the Montado. Working with a virtual farm allowed us to simplify and generalise the characteristics, to simplify the estimation of costs and avoid the necessity of providing ranges of values. Montado farm income depends primarily on beef production and cork harvesting with complementary income obtained from game rights, charcoal and firewood from pruning or dead trees. Costs for changing management practices were calculated per hectare (2020 values). We acknowledge that some costs per hectare may be scale dependent, hence the virtual farm represents only a reference point. Yet, this is the same methodology for cost calculations that is used by Portuguese (and the other EU member states) authorities within the AES, as explained below (using the principle of compensation for additional costs or loss of income), allowing comparison between our model and present-day practice.

We adopted the model of a 500 ha farm divided in 10 paddocks of equal size (i.e. 50 ha each). Six paddocks (300 ha) were Montado woodpastures, (mixed *Quercus suber* and *Quercus rotundifolia)* with a tree density of 40 trees/ha and an understory of native Mediterranean pasture, rotationally grazed by a suckler herd that would stay in each paddock for 45 days. The remaining 200 ha of our virtual farm were open swards (treeless) of annual native pasture. A suckler herd of 300 Livestock Units (LSU) grazed the Montado paddocks for 9 months a year and spent the remainder of the year grazing on the 200 ha of open

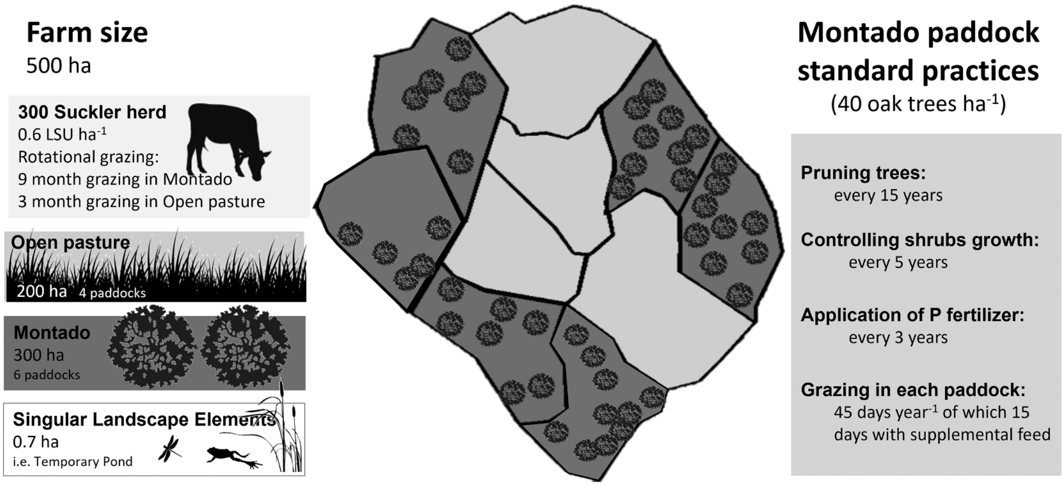

Fig. 3. How the virtual Montado farm was used to calculate costs.

pastures. The stocking density was 0.6 LSU/ha. It is generally considered that around 1.4 %[1] of the total Montado area is occupied by singular landscape elements: remnants of natural habitats that generally are protected by the European Habitat Directive (Council Directive 92/43/EEC). These might be small forest patches of *Quercus* and *Pinus*; patches of shrubs, riparian galleries, rocky outcrops and temporary or permanent ponds.

Standard management practices for the Montado that we defined included: pruning trees every 15 years, shrub clearance using a disk harrow every 5 years and the application of phosphate-based fertiliser every 3 years (200 kg/ha). The herd is moved between paddocks regularly (every 45 days). Supplementary feeding is commonly practiced due to seasonal variations in pasture quantity and quality (García de Jalón et al. 2018). In the most demanding periods, concentrates for suckler cows (with 15% crude protein and 13% crude fibre) and/or forages (hay and silage) are used to meet the livestock's nutritional requirements. The concentrates are acquired in the market, from national feedstuff factories, and the forages from neighbouring farmers.

The principle of compensation for additional costs or loss of income is common practice within the EU's AES. This led us to include the operational and opportunity costs of any change in management practices, alongside with investments and private transaction costs. The operational costs represent the extra costs (or foregone income) of changing management practices (e.g. grazing patterns). Changes in management practices also involve each farm developing a specific plan after an evaluation of the existing conditions. This implies private transaction costs, i.e., the costs related to the acquisition of knowledge, travelling and the time spent by the farmer and the advisor on evaluation visits, the elaboration of the farm plan, participation in training activities or other meetings. Finally, investment costs are those required to introduce new capabilities, to procure or replace equipment or to provide for major modifications of an existing capability. These types of investments are 'one-offs' and so need to be amortised over time. We do not include opportunity costs of converting the Montado to other more profitable systems because it is not an option as *Quercus suber* and *Quercus rotundifolia* are protected tree species under national and international laws (Guimarães et al. 2018) and, in addition, the Montado itself is a semi-natural habitat protected under the European Habitats Directive (Council Directive 92/43/EEC). This prevents landowners from converting Montado areas to other farming systems. In the virtual farm, we do not foresee changes in the quantity of livestock in the farm. Nonetheless, as we will later discuss, in certain scenarios of strong intensification in the Montado, a decrease in livestock density or a change of livestock type (e.g. from cattle to sheep) might be considered as a means of regenerating oak trees. In such a situation the opportunity costs should be considered.

The income of an actual Montado farm varies considerably, depending on the business model used, which may range from a model more focused on cork production, in areas dominated by cork oaks, to a model based on livestock, in areas dominated by holm oaks, or a balance of the two (Guimarães et al. 2018). However, to provide an order of magnitude for the ERs cost calculated, for readers not familiar with agricultural production activities' results in Portugal, it is necessary to have income data related with these two main products. The figures issued by the General Bureau of Planning and Policy within the Ministry of Agriculture, based on data from the Farm Accountancy Data Network (FADN) of the European Commission, show the following.

1) Bovine production with a Gross Added Value of 123€/ha, based on an income of 400€/ha (with no public payment support) and a consumption of variable costs of 277€/ha
2) Cork is only harvested every nine years and income from cork production can vary considerably. Several biotic and abiotic processes can influence its quantity and quality. Arosa et al. (2017) identify cork production per tree as between 36 kg and 70 kg and the income from cork between 1.33€ and 3.33€/kg. Among the participants in the TD arena, income from cork ranged from 18.70€ to 100€/ha.

4. Results

4.1. Environmental results

The four identified ERs aim to ensure the long-term conservation of the Montado, guaranteeing that the system can endure disturbances without changing its basic (vertical and horizontal) structure and functions. Response to multiple, interacting disturbances varies between species (Buma and Wessman 2012), thus environmental heterogeneity, secured through the diversity in type and arrangement of elements is a key feature in promoting the attainment of ERs in the Montado. The typical patch-mosaic of Montado land use/land cover (Mulatu et al. 2016), with denser patches of trees intermingled with more open grasslands, harbours a diversity of habitats and species (Mulatu et al. 2016; Simonson et al. 2018). Biodiversity is known as the cornerstone of ecosystem functions and services (Cardinale et al. 2012; Harrison et al. 2014; Kremen and Merenlender 2018). Thus, maintaining biodiversity is

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[1] This percentage represents the average area occupied by singular landscape elements in the 8 paddocks where the RBM were tested (all details in Pinto-Correia et al., 2022). The paddocks are part of the farm owned by the farmers taking part of the TD arena.

mandatory for securing the Montado in a productive sustainable way (Kremen and Merenlender 2018). An important criterion in the selection of the ERs was the link between provisioning and regulating ecosystem services. Another criterion was the need to increase the quantity and quality of the habitats existing within the Montado. Within this broad framework four ERs were detailed and these are summarised in Table 2. The ERs described in this section were validated by experts and farmers in the TD arena.

The first ER is a healthy soil ecosystem. Healthy soil allows a functional soil biome, which prevents erosion, increases water retention and water quality, supports all other Montado components and improves the capacity to sequester carbon (Sardans and Peñuelas 2013; Eddy and Yang 2022).

Biodiverse pasture is the second ER and involves enhancing a biodiverse plant understory cover. It is known that mixtures of several plant species in pastures increase the provision of ecosystem services in comparison to pastures with only few plant species (Sanderson et al. 2007). A biodiverse pasture provides habitat for wildlife (reptiles, birds, mammals and pollinator insects) and, simultaneously, promotes water infiltration and protects soil from erosion. Additionally, pasture also acts as a carbon sink (Hussain et al. 2009). Native plant species have developed survival strategies and are better adapted to the Mediterranean environment, particularly climate disturbances, such as water scarcity, and the region's shallow acidic soils (Bergmeier et al., 2010; Paço et al. 2009; Porqueddu et al. 2016).

The third ER is a diversified vertical structure of the tree cover which permits oak regeneration. Such a structure is key for the functioning and the long-term resilience of oak trees to multiple disturbances (Acácio et al. 2007; Arosa et al. 2017). In a sustainable Montado system, natural tree regeneration is present at different stages of development, from seedlings and saplings to juvenile and mature trees. When the adult trees decay and finally disappear, it is fundamental that the replacement of the old trees is already under way, so that the new trees have sufficient capacity to persist alone. Trees are also the habitat for several bird and mammal species (Catarino et al. 2016).

Finally, the fourth ER is the presence of diversified habitats formed by terrestrial and aquatic landscape elements that are hotspots of biodiversity *per se* (Pinto-Cruz et al., 2009; Godinho and Rabaça, 2011; Pereira et al., 2014). The presence of these remnants of natural habitats can be verified in each paddock when its characteristics are noted (details in Pinto-Correia et al., 2022). We have grouped them in a category designated as singular landscape elements that include: small forest patches of Quercus and Pinus (Decocq et al. 2016), patches of shrubs (Oksuz et al. 2020), riparian galleries (Lind et al., 2019), rocky outcrops (Fitzsimons and Michael 2017), and temporary and permanent ponds (Bolpagni et al. 2019). All of these small patches of natural habitats constitute steppingstones and corridors that increase connectivity within the Montado, as well as, environmental heterogeneity, a feature that supports the HNV of the Montado.

After defining the ERs for the RBM we then needed to define results-based indicators (RBI) that allow their assessment. We selected 10 RBI that have been tested in 8 pilot paddocks. Details of this work can be found in Pinto-Correia et al. (2022).

4.2. *The management practices and costs of achieving each environmental result*

The change in practices to deliver these desired ERs are listed in Table 3. Most of the identified practices have multiple objectives and are linked to the delivery of more than one ER. There may be other practices which could lead to similar results – but the ones selected are those that are most commonly used and do not require a radical paradigm shift in day-to-day farm management.

Seven practices were identified that promote a healthy and functional soil, five of which also contribute to other ERs, such as biodiverse Mediterranean pastures and oak tree regeneration (Table 3). To increase

Table 2
The environmental results to be achieved in the Montado.

Environmental Result/ Aims	Detailed consequences and benefits	References
A healthy soil ecosystem/ To increase organic matter To decrease toxicity To avoid bare soil	A healthy soil that supports vegetation growth. When the soil is covered by vegetation, its roots help to hold the soil. Without plant cover the soil organic matter will be lost. In bare soil the soil temperature will be higher, killing the soil microbiome and reducing the soil's functions. Without a deep and well-established plant root system, water will not infiltrate into the soil and without plant cover water will not be retained and added to the aquifers. When soil fertility is reduced the plant root system is affected and plant growth is reduced, thus affecting pasture biomass and plant cover, indirectly increasing the risk of erosion. When toxicity is present, the competition between plants favours plants more adapted to acidic pH, affecting herbage mass and reducing plant biodiversity.	Marcos et al., 2007; Sardans and Peñuelas 2013; Carvalho et al., 2015; Sales-Baptista et al., 2016; Serrano et al., 2018; Serrano et al., 2020
A biodiverse native-Mediterranean Pasture/ To preserve or increase the vegetation biodiversity and to avoid over or under grazing	Legumes capture nitrogen (N), thus improving soil fertility and reducing the need for N fertiliser inputs. Heterogeneity in plant species composition provides different microhabitats, shade and protection due to the differences in canopy architecture and the diversity of vertical strata that better supports pollinator insects. A biodiverse pasture allows more palatable and nutritional alternatives and contributes to better distributing the grazing pressure over the pasture both spatially and temporally. The grazing of animals contributes to the dispersal of both seeds and dung, increasing soil N and organic matter. Organic matter helps to retain water in the soil and improves the soil structure. A biodiverse pasture will better promote the sequestration of carbon.	Bergmeier, Petermann, and Schröder 2010; Hussain et al., 2009; Paço et al. 2009; Porqueddu et al. 2016; Sanderson et al., 2007
Oak trees layer with regeneration/ To preserve and increase regeneration	The survival of Montado depends on tree regeneration. A balanced Montado will have trees at different developmental stages. The diversity of ages in a population is a guarantee of the persistence of the tree layer and the replacement of old trees. Diverse multi-layered canopies, tree heights and	Acácio et al. 2007; Arosa et al. 2017; Catarino et al. 2016.

(*continued on next page*)

Table 2 (*continued*)

Environmental Result/ Aims	Detailed consequences and benefits	References
	trunk diameters provide diversified wildlife habitats, which supply shelter and food resources (e.g. acorns).	
Preserved or enhanced habitats and landscape elements/ To promote biodiversity and heterogeneity	The presence of natural habitat patches is essential to promote the multifunctionality of the Montado, providing support to a wide diversity of faunal groups and resilience to the ecosystem itself. A diverse matrix of habitats enhances the presence of birds, insects and other wildlife, providing food, protection from predation, shelter during breeding seasons, and ensuring landscape connectivity.	Godinho and Rabaça, 2011; Pereira et al., 2014; Pinto-Cruz et al., 2009.

oak tree regeneration six practices were identified, while four and two practices were identified to preserve Mediterranean biodiverse pastures and to preserve and enhance single landscape elements respectively.

Montados generally have poor, highly acidic, soils with low organic matter content and, often, a reduced cation exchange capacity (Serrano et al. 2020). The practices identified to promote soil conservation include pH and toxicity correction using calcitic limestone or, when Mn toxicity is identified, using dolomitic limestone which raises soil pH and simultaneously increases the Mg/Mn ratio (Carvalho et al., 2015). Such investment can be necessary and costs 90€/ha with 5-year useful life, using a 75 hp tractor with 2-wheel drive and considering a tractor driver's salary of 20267.94€/year. The application of fertilisers, particularly phosphates, improves soil quality, benefits pasture growth, and consequently soil cover, and may benefit oak tree nutrition (Rodrigues et al. 2020). In regard to the virtual farm, an increase in the frequency of phosphate fertilisation was considered necessary. Currently, this action normally takes place every 3 years and should increase to every year, implying an added cost of 93.1€/ha/year. This cost was calculated considering 1 h/ha for fertiliser distribution, 0.5 h/ha for transport and 200 kg/ha of fertiliser, using the same type of tractor identified above. All these figures were agreed upon within the TD arena. Further, it was agreed at the TD arena, that this action should be based on soil sampling diagnosis so that quantities are defined rationally. Soil loss and degradation is identified as an important problem, particularly on medium to steep slopes in the Montado. Practices to avoid soil loss include the creation of drainage ditches that promote the growth of pasture around the existing furrows, which slows the flow of runoff water while promoting its infiltration. The cost per hectare of such practice varies considerably depending on a number of conditions of the paddock, therefore, we illustrate such cost by presenting the hourly cost of a backhoe, (27€/h). Such an intervention has a 5-year useful life.

Cattle grazing activity also impacts soil health and its functioning through trampling, creating areas of bare soil especially where animals gather, such as at water points and feeding points (Sales-Baptista et al., 2016). Providing additional drinking points as well as improving grazing management through rotational grazing reduces these negative impacts on the soil (*ibid*). The timing and frequency of moving grazing animals between different paddocks, according to pasture and soil conservation needs, is a key management practice. This can help avoid over and under grazing and help achieve the identified ERs. Grazing management is also relevant for the protection of oak regeneration. The grazing management in the virtual farm and for each paddock of 50 ha, consumes 2.5 h/per day with the cattle. Additionally, two journeys of 8 h each per year are needed to move cattle to and from the different paddocks. These movements are made by the herdsman accompanied by another worker, representing a cost of 26.4 €/ha/year. To increase the cattle movement another full day of work, dedicated to moving the cattle between the paddocks, and two half days work, guiding movements within the paddocks, are needed. Such modification implies a cost increase of 10.9€/ha/year. To avoid overgrazing an increase in the cattle feed supplementation period should also be considered. In the virtual farm the extra supplementation implied a 10% increase in supplementation for the existing stocking rate (0.6 LSU/ha/year), which represents a cost of 12€/ha/year. As mentioned before, additional drinking points for cattle are needed. To estimate this cost, we took the unit cost of a

Table 3
Possible management practices and costs to achieve the targeted environmental results for the virtual farm.

Management practices	Operational Costs/ha/year	Investment costs (per unit)	Useful life (years)	Environmental Results			
				Healthy soil ecosystem	Tree regeneration	Mediterranean biodiverse pastures	Singular landscape elements
Increase frequency of phosphate fertilisation	93.1€	–		X	X		
Improve grazing management	10.9€	–		X	X	X	
Increase cattle feed supplementation period	12€	–		X	X	X	
Increase frequency of surveillance to identify invasive species *	3.6€	–					X
pH and toxicity correction	–	90€/ha	5	X			
Creation of drainage ditches	–	27€/hour backhoe	5	X			
Provide additional drinking points (2 tanks/50 ha)	–	5500€/unit	10			X	
Plant new trees **		37.2€/ha	–	X	X		
Shrub clearance using a shredder	–	22€/ha	3	X	X	X	
Protect young trees (50 individual plant protectors/50 ha) **	–	16.25€/unit	10		X		
Install fences to exclude cattle (62.3 m/50 ha)	–	3030€/km	10				X
Removal of invasive species *	–	6.03€/ha	5				X

Note: All costs were discussed and validated in the Td arena.
(*) Each ha of Montado has (on average) 1.4% of singular landscape elements that promote biodiversity and the costs/ha reflects this.
** The objective is to reach a Montado with 80 trees/ha, which is twice the existing tree density. This will be done through an equal contribution of natural regeneration and plantation. Planted trees have a higher mortality rate so we estimated that 30 new trees will be needed for 20 to survive after 5 years.

5000 L mobile water tank installation, 5500€ with 10-year useful life. In our example, two tanks are required to respond to a 10% increase in water needs in a 50 ha paddock.

In some Montado areas where natural regeneration is very scarce and does not compensate for the loss of trees, plantation of new trees or even better, sowing acorns from selected trees in the area (so that adaptation to the local contextual conditions is secured), might be necessary, since natural regeneration may not occur at all in low tree density areas (Godinho et al., 2018; Moreno et al. 2014). In both cases, protecting young trees using either artificial thorny protectors or natural thorny protectors (shrubs) is required to increase the regeneration rate (Rolo et al., 2013). In our example, an increase of 40 trees/ha was considered to double the tree population over time to the target of 80 trees/ha. We considered that this ER could be achieved by both natural regeneration (50%) and plantation (50%). Since planted trees in Montado have a high mortality rate (Moreno and Rolo 2019), we estimate that 30 plants (at 1.24€/sapling) are needed to establish 20 new trees after 5 years. This led us to arrive at a cost of 37.2€ per hectare with useful life larger than 100 years. Such activity also promotes a dense root system that increases the organic matter and functional biodiversity (Sardans and Peñuelas 2013). The management of shrub encroachment to avoid increased fire risk and to reduce vegetation (tree, shrub and pasture) competition for natural resources is a common practice in the Montado. Shrub control is currently carried out by harrowing which negatively affects the tree root system and also promotes soil erosion (Guerra and Pinto-Correia 2016). Shrub clearing with a shredder, following the marking of young trees so as to protect them, has been shown to avoid soil degradation while preserving oak tree root systems (Sardans and Peñuelas 2013; Simões et al. 2016). Shrub control using a shredder costs 22€/ha and lasts up to 3 years, a period that can vary according to each paddock's characteristics and the climatic conditions. In this cost estimation we have not considered the opportunity costs of setting the paddock aside from grazing to allow natural regeneration to occur. This option was not considered ideal by the TD arena and priority was given to management practices that allow compatibility between economic activities. The more acceptable option was to protect young trees. This involves purchasing and installing individual plant protectors, at a cost of 16.25€/protector which have 10 years of useful life. For the 50 new trees (20 from natural regeneration and 30 planted trees) that would be achieved in 5 years, the investment cost estimated is 812.5 €/ha in tree protectors.

To achieve the conservation and improvement of the singular landscape elements we considered surveillance to identify preservation needs was to be an appropriate management practice to produce the targeted ERs. Other agreed required practices were fencing to exclude cattle and the removal of invasive species, so that the native vegetation can evolve. Considering the existence of a maximum of 1.4% area with natural habitat patches (singular landscape elements), the discussion in the TD arena led to an agreement that three full days (24 h) of work would be needed for 50 ha. The workload includes the inspection of the protections, cutting old and dry branches and identifying spots where invasive species need to be removed. Surveillance means a cost of 3.6€/ha/year. Removal of invasive species represents a cost of 6.03€/ha every 5 years. The costs of fencing singular landscape elements is derived from the cost per km of fencing (including labour costs): 3030€/km with 10 years of useful life.

In addition to the operational and investment costs described above we also included 25.2€/ha/year for transaction costs to cover the farmers' and the technical advisors' time investments in defining an action plan for the farm and attending meetings and training activities. These transactions costs include the following time estimates:

- 4 days' work by the advisor to develop the plan;
- 2 days' work by the advisor and the farmer to discuss the plan;
- 2 h/month of the farmer's time (on average) to attend meetings;
- 8 h per year to participate in 2 training sessions per year.

All these estimates were discussed in the TD arena that included technical staff from the Ministry of Agriculture General Bureau of Planning and Policy (GPP), who made all the payment calculations for the support policies and investments. By following the same cost estimation principles as for the AES payments, we maintained comparability with existing policies.

5. Discussion

In this paper we first defined a desirable state for a mainstream Montado area and specified four attainable ERs that need to be achieved and maintained. We then identified a set of management actions that will allow the achievement of the desirable state and, then, estimated the costs of making such changes.

Previous studies have listed the most significant ESs that the Montado can provide (Bugalho et al. 2011; Guerra and Pinto-Correia 2016; Torralba et al., 2018; Kay et al. 2019). However, very few studies attempt to link farm management directly with the provision of ESs in the Montado (Fonseca et al. 2019; Guerra and Pinto-Correia 2016). In order to develop an RBM programme it is essential to make this link explicit. In RBM, each farmer needs to agree with those who manage the scheme, upon the ESs that he or she will purposively try to provide. Our study proposes a set of ERs for the Montado that act as indicators of the provision of several ESs (Table 2). These ERs were validated by a set of different stakeholders who worked together in a TD arena (Table 1 and Pinto-Correia et al. 2022). To the best of our knowledge, our study is the first to describe a set of ERs appropriate for the Montado, that were mutually agreed upon by a range of stakeholders, and which explicitly considered farmers' capacity to achieve those results by changing their management practices. Pinto-Correia et al. (2022) provide a detailed description of a set of indicators and metrics that were defined and tested in a pilot study. Although an upscaling of this is needed, the pilot study indicates that these ERs are quantifiable and can be achieved by farmers' actions (see details in Pinto-Correia et al. 2022).

In Table 3 we identify a set of management practices that reflect the almost unique complexity of the Montado system. In simpler production systems this type of management overview and overall cost calculation would be much simpler, but in a silvopastoral system a balance between its components needs to be considered. Both the tree layer and pastures in the undercover have to be considered, along with the conditions for a well-distributed grazing pressure and the presence of singular landscape elements responsible for distinct habitats. Farmers already deal with such complexity and have done so for centuries. Recently, external pressures such as market globalisation and public policy incentives, have led to a simplification of the system. In the case of the Montado, this trend is leading to the loss of one of the main components of this silvo-pastoral system which can be spatially identified by the loss of tree cover (Godinho et al. 2016). We have considered management practices that will counteract the simplification of the system and allow its complexity to be recovered. This is the reason why several of the management practices in Table 3 are linked to the provision of more than one distinct ER: being part of the same system they are naturally linked with each other (Mulatu et al., 2016; Fonseca et al. 2019). All the practices presented in Table 3 are sustainable management practices that consider the particularities of the Mediterranean region and the capacities of farmers (Ruiz et al., 2020). An RBM programme which implements such practices will provide an opportunity for testing and monitoring practices such as no-till technology, the application of organic fertilisers and reseeding, considered by Ruiz et al. (2020). No-till technology involves the use of a shredder to clear bushes (Table 3), while the use of organic fertilisers and reseeding can be alternatives to some of the management actions described in this study. In an RBM, farmers are free to define the best way to arrive at a certain level of ER. The cost estimation is needed to define payment levels, but it's the farmer who decides which is the most cost-effective manner of securing the ERs.

The management practices increasingly in use that negatively impact

Montado are described in the literature (Pinto-Correia and Vos 2004; Almeida et al., 2016; Guerra and Pinto-Correia 2016). Such practices can be summarised as: (a) an increase of livestock density without a corresponding investment in the system's primary productivity, (b) changes in the type of cattle breed, from endogenous light live-weight breeds adapted to the feed resources of the Montado to heavier and resource intensive breeds; (c) the introduction of new, often more impacting, shrub clearing methods (e.g., soil disking and soil mobilisation); and (d) the expansion of fodder crop areas and irrigated pastures. These management practices imply a disruption of the balanced state of the Montado. Their growing use by farmers is linked to the pressure on all agricultural systems to specialise, the structure of payments in the Portuguese implementation of the CAP, the globalisation of markets and technologies and the increased difficulty in maintaining a cost-effective business model in the Montado (Fragoso et al. 2011; Pinto-Correia et al. 2019; Pinto-Correia and Azeda 2017). A market system that reflects agroforestry's real market value can result in land use changes that favour multifunctional agroforestry by promoting a financially profitable system (Kay et al. 2019).

The current AES, based on supporting specific management practices, does not seem to prevent the declining trend detected in the Montado (Godinho et al., 2014). Moreover, many farmers are unwilling to participate in AES, partially due to the restrictions imposed on livestock grazing density (Faria and Morales 2020; Santos et al. 2015). Thus, new approaches are urgently needed to halt the decline of these unique silvopastoral systems and to make better use of public funding. An RBM model can overcome several of the obstacles towards farmers' participation in the current AES: the imposition of management practices, low financial compensation and a lack of technical support (Santos et al. 2015). A system in which the provision of ERs is made economically viable, by their integration within the farm business, needs to be tested.

The present study provides the baseline information needed by the identification of key ERs and possible cost of achieving them. The weight of such costs will vary considerably between farms and additional work is needed to define a representative average; yet, the numbers presented in Table 3 allow us to draw some conclusions. Santos et al. (2015) report that the current financial compensation within AES for changing cattle and tree density does not compensate for the revenue losses. The financial compensation needed for farmers to vary cattle and tree density and change the contract length of the current AES, is six times higher than what they currently receive, approximately 825€/ha/year. Santos et al's (2015) analysis is based on the AES as business as usual, which means providing financial support for management actions. If more farmers were willing to participate in the current AES this would imply a substantial budget increase, and indicates the difficulty in maintaining the AES in its current format. Moreover, it is difficult to evaluate the outcomes of the current AES (Pe'er et al., 2020). Hence, changes in AES need to occur. Integrating an RBM approach within AES would imply that several ES are targeted, achieved and quantified. That *per se* is an advantage in relation to the current approach. In addition, a RBM approach would include the provision of the technical support farmers call for and give farmers back their decision-making capacity, which may also contribute to the programme's attractiveness. Hence an RBM could be a viable alternative given the limited government budgets for supporting AES and the shortcomings of the existing programme.

Other studies have described the importance of CAP payments in farm accounts (Escribano, Díaz-Caro, and Mesias 2018). Without policy intervention, it is unlikely that farmers will incorporate the costs identified in this study into their existing business models. The role of agriculture as a supplier of public environmental goods justifies economic incentives to encourage farmers to shift their activities to embrace the provision of these public goods, which implies extra costs for them and/or income forgone (Cooper, Hart, and Baldock 2009). The costs shown in the present study will differ according to the state of the Montado in each actual farm. With the list of possible management actions and their likely costs, it would be possible to estimate and integrate a payment range for an RBM for the Montado that does not risk being too far from the real costs incurred by land owners. This should be a progressive payment, according to the ERs achieved on a yearly basis.

Finally, an important aspect of this study that needs to be highlighted is the transdisciplinary process that was used in this pilot case. From the identification of the ERs to the identification of costs, a combination of scientific and empirical knowledge was used and all the stakeholders came to a consensus over the decisions described. Such participation is relevant and can make the difference if and when an RBM is implemented. Other studies have previously shown farmers' willingness to take part in policy design, including the possibility of proposing their own measures (Santos et al. 2015). Therefore, this work, that considers farmers' preferences is an important achievement in itself.

6. Conclusions

In the framework of RBMs we have defined four ERs for the Montado; 1) a healthy and functional soil ecosystem, 2) a biodiverse native-mediterranean pasture, 3) an oak tree layer with regeneration (i.e. tree with different ages) and 4) preserved and enhanced habitats and landscape elements. These ERs have been defined in a TD setting and simultaneously contribute to nature conservation and to the Montado agro-silvo-pastoral productivity.

In an RBM farmers are free to choose how they achieve the maximum level of the ERs. Yet, management practices need to be identified to secure options for farmers' own decisions. Hence, we defined 12 possible management practices: 1) increase frequency of phosphate fertilisation, 2) pH and toxicity correction, 3) create drainage ditches, 4) improve grazing management (by moving the cattle more frequently), 5) increase cattle feed supplementation period, 6) provide additional drinking points for the cattle, 7) plant new trees, 8) protect young trees 9) clear shrubs using a shredder, 10) increase frequency of surveillance to identify invasive species, 11) install fences to exclude cattle and 12) remove invasive species.

Finally, we presented the cost that farmers might have if they opt for the above management practices. To secure the willingness of farmers to improve ERs, payment needs to cover the incurred costs; hence, quantifying costs is fundamental if an RBM is to become a policy instrument.

The Montado is a productive agroecosystem which corresponds perfectly to many of the present-day requirements for sustainable agriculture and use of natural resources, as defined in the European Green Deal and in the UN Sustainable Development Goals. Public policy has a strong influence on agricultural management practices and business models, not only in Europe but all over the world. It is a major contributor to the problems faced in the Montado and needs to become part of the solution. The present study was integrated in the development of a new agro-environmental measure for the Montado that is currently being implemented. The monitoring of this measure will be fundamental to understand if an RBM is an effective policy solution to the challenges faced by the Montado and similar agroforestry ecosystems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

Acácio, V., Holmgren, M., Jansen, P.A., Schrotter, O., 2007. Multiple recruitment limitation causes arrested succession in Mediterranean cork oak systems. Ecosystems 10 (7), 1220–1230.

Acebes, P., Pereira, D., Oñate, J.J., 2016. Towards the identification and assessment of HNV Dehesas: a meso-scale approach. Agrofor. Syst. 90 (1), 7–22.

Ahammad, R., Stacey, N., Sunderland, T., 2021. Analysis of forest-related policies for supporting ecosystem services-based forest management in Bangladesh. Ecosyst. Serv. 48, 101235.

Almeida, M., Azeda, C., Guiomar, N., Pinto-Correia, T., 2016. The effects of grazing management in Montado fragmentation and heterogeneity. Agrofor. Syst. 90 (1), 69–85.

Arosa, M.L., Bastos, R., Cabral, J.A., Freitas, H., Costa, S.R., Santos, M., 2017. Long-term sustainability of cork oak agro-forests in the Iberian Peninsula: A model-based approach aimed at supporting the best management options for the Montado conservation. Ecol. Model. 343, 68–79.

Batáry, P., Dicks, L.V., Kleijn, D., Sutherland, W.J., 2015. The role of agri-environment schemes in conservation and environmental management. Conserv. Biol. 29 (4), 1006–1016.

Bennett, D.E., Gosnell, H., 2015. Integrating multiple perspectives on payments for ecosystem services through a social – ecological systems framework. Ecol. Econ. 116, 172–181.

Bergmeier, E., Petermann, J., Schröder, E., 2010. Geobotanical survey of wood-pasture habitats in Europe: diversity, threats and conservation. Biodivers. Conserv. 19 (11), 2995–3014.

Blackstock, K.L., Novo, P., Byg, A., Creaney, R., Juarez Bourke, A., Maxwell, J.L., Tindale, S.J., Waylen, K.A., 2021. Policy instruments for environmental public goods: Interdependencies and hybridity. Land Use Policy 107, 104709.

Bolpagni, R., Poikane, S., Laini, A., Bagella, S., Bartoli, M., Cantonati, M., 2019. Ecological and conservation value of small standing-water ecosystems: a systematic review of current knowledge and future challenges. Water (Switzerland) 11 (3), 402.

Bugalho, M.N., Caldeira, M.C., Pereira, J.S., Aronson, J., Pausas, J.G., 2011. Mediterranean cork oak savannas require human use to sustain biodiversity and ecosystem services. Front. Ecol. Environ. 9 (5), 278–286.

Buma, B., Wessman, C.A., 2012. Differential species responses to compounded perturbations and implications for landscape heterogeneity and resilience. For. Ecol. Manage. 266, 25–33.

Camilli, F., Pisanelli, A., Seddaiu, G., Franca, A., Bondesan, V., Rosati, A., Moreno, G.M., Pantera, A., Hermansen, J.E., Burgess, P.J., 2018. How local stakeholders perceive agroforestry systems: an Italian perspective. Agrofor. Syst. 92 (4), 849–862.

Cardinale, B.J., Emmett Duffy, J., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., MacE, G.M., Tilman, D., Wardle, D.A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S., Naeem, S., 2012. Biodiversity loss and its impact on humanity. Nature 486 (7401), 59–67.

Carvalho, M., Goss, M.J., Teixeira, D., 2015. Manganese toxicity in Portuguese Cambisols derived from granitic rocks: causes, limitations of soil analyses and possible solutions. Revista de Ciências Agrárias 38 (4), 518–527.

Catarino, L., Godinho, C., Pereira, P., Luís, A., Rabaça, J.E., 2016. Can birds play a role as high nature value indicators of Montado system? Agrofor. Syst. 90 (1), 45–56.

Cooper, T., Hart, K., Baldock, D., 2009. The Provision of Public Goods through Agriculture in the European Union. London, UK.

Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

Cullen, P., Dupraz, P., Moran, J., Murphy, P., O'Flaherty, R., O'Donoghue, C., O'Shea, R., Ryan, M., 2018. Agri-environment scheme design: past lessons and future suggestions. EuroChoices. EuroChoices 17 (3), 26–30.

Decocq, G., Andrieu, E., Brunet, J., Chabrerie, O., De Frenne, P., De Smedt, P., Deconchat, M., Diekmann, M., Ehrmann, S., Giffard, B., Mifsud, E.G., Hansen, K., Hermy, M., Kolb, A., Lenoir, J., Liira, J., Moldan, F., Prokofieva, I., Rosenqvist, L., Varela, E., Valdés, A., Verheyen, K., Wulf, M., 2016. Ecosystem services from small forest patches in agricultural landscapes. Curr. Forestry Rep. 2 (1), 30–44.

Dupraz, P., Guyomard, H., 2019. Environment and climate in the common agricultural policy. EuroChoices 18 (1), 18–25.

Eddy, W.C., Yang, W.H., 2022. Improvements in soil health and soil carbon sequestration by an agroforestry for food production system. Agr. Ecosyst. Environ. 333, 107945.

Escribano, M., Díaz-Caro, C., Mesias, F.J., 2018. A participative approach to develop sustainability indicators for dehesa agroforestry farms. Sci. Total Environ. 640–641, 89–97.

Faria, N., Morales, M.B., 2020. Farmland management regulates ecosystem services in Mediterranean drylands: Assessing the sustainability of agri-environmental payments for bird conservation. J. Nat. Conserv. 58, 125913.

Ferraz-de-Oliveira, I., Azeda, C., Pinto-Correia, T., 2016. Management of Montados and Dehesas for high nature value: an interdisciplinary pathway. Agrofor. Syst. 90 (1), 1–6.

Fitzsimons, J.A., Michael, D.R., 2017. Rocky outcrops: a hard road in the conservation of critical habitats. Biol. Conserv. 211, 36–44.

Fonseca, A.M.P., Marques, C.A.F., Pinto-Correia, T., Guiomar, N., Campbell, D.E., 2019. Emergy evaluation for decision-making in complex multifunctional farming systems. Agr. Syst. 171, 1–12.

Fragoso, R., Marques, C., Lucas, M.R., Martins, M.B., Jorge, R., 2011. The economic effects of common agricultural policy on Mediterranean Montado/Dehesa ecosystem. J. Policy Model 33 (2), 311–327.

García de Jalón, S., Graves, A., Moreno, G., Palma, J.H.N., Crous-Durán, J., Kay, S., Burgess, P.J., 2018. Forage-SAFE: a model for assessing the impact of tree cover on wood pasture profitability. Ecol. Model. 372, 24–32.

Godinho, S., Guiomar, N., Machado, R., Santos, P., Sá-Sousa, P., Fernandes, J.P., Neves, N., Pinto-Correia, T., 2016. Assessment of environment, land management, and spatial variables on recent changes in Montado Land Cover in Southern Portugal. Agrofor. Syst. 90 (1), 177–192.

Godinho, S., Guiomar, N., Gil, A., 2018. Estimating tree canopy cover percentage in a mediterranean silvopastoral systems using Sentinel-2A imagery and the stochastic gradient boosting algorithm. Int. J. Remote Sens. 39 (14), 4640–4662.

Godinho, C., Rabaça, J.E., 2011. Birds like it Corky: the influence of habitat features and management of 'montados' in breeding bird communities. Agroforest. Syst. 82, 183–195. https://doi.org/10.1007/s10457-010-9345-4.

Guerra, C.A., Metzger, M.J., Maes, J., Pinto-Correia, T., 2016. Policy impacts on regulating ecosystem services: looking at the implications of 60 years of landscape change on soil erosion prevention in a mediterranean silvo-pastoral system. Landsc. Ecol. 31 (2), 271–290.

Guerra, C.A., Pinto-Correia, T., 2016. Linking farm management and ecosystem service provision: challenges and opportunities for soil erosion prevention in mediterranean silvo-pastoral systems. Land Use Policy 51, 54–65.

Guerra, C.A., Pinto-Correia, T., Metzger, M.J., 2014. Mapping soil erosion prevention using an ecosystem service modelling framework for integrated land management and policy. Ecosystems 17 (5), 878–889.

Guimarães, H., Esgalhado, C., Ferraz-De-Oliveira, I., Pinto-Correia, T., 2019. When does innovation become custom a case study of the Montado, Southern Portugal. Open Agriculture 4(1).

Guimarães, M.H., Guiomar, N., Surova, D., Godinho, S., Pinto-Correia, T., Sandberg, A., Ravera, F., Varanda, M., 2018. Structuring wicked problems in transdisciplinary research using the socialecological systems framework: an application to the Montado System, Alentejo, Portugal. J. Clean. Prod. 191, 417–428.

Harrison, P.A., Berry, P.M., Simpson, G., Haslett, J.R., Blicharska, M., Bucur, M., Dunford, R., Egoh, B., Garcia-Llorente, M., Geamănă, N., Geertsema, W., Lommelen, E., Meiresonne, L., Turkelboom, F., 2014. Linkages between biodiversity attributes and ecosystem services: a systematic review. Ecosyst. Serv. 9, 191–203.

Hejnowicz, A.P., Rudd, M.A., White, P.C.L., 2016. A survey exploring private farm advisor perspectives of agri-environment schemes: the case of England's Environmental Stewardship Programme. Land Use Policy 55, 240–256.

Herzon, I., Birge, T., Allen, B., Povellato, A., Vanni, F., Hart, K., Radley, G., Tucker, G., Keenleyside, C., Oppermann, R., Underwood, E., Poux, X., Beaufoy, G., Pra, J., 2018. Land use policy time to look for evidence : results-based approach to biodiversity conservation on farmland in Europe. Land Use Policy 71 (December 2017), 347–354.

Hussain, M.Z., Otieno, D.O., Mirzae, H., Li, Y.L., Schmidt, M.W.T., Siebke, L., Foken, T., Ribeiro, N.A., Pereira, J.S., Tenhunen, J.D., 2009. CO2 exchange and biomass development of the herbaceous vegetation in the Portuguese Montado ecosystem during spring. Agr. Ecosyst. Environ. 132 (1–2), 143–152.

Jose, S., Walter, D., Kumar, B.M., 2019. Ecological considerations in sustainable silvopasture design and management. Agrofor. Syst. 93 (1), 317–331.

Kay, S., Graves, A., Palma, J.H.N., Moreno, G., Roces-Díaz, J.V., Aviron, S., Chouvardas, D., Crous-Duran, J., Ferreiro-Domínguez, N., García de Jalón, S., Măcicăşan, V., Mosquera-Losada, M.R., Pantera, A., Santiago-Freijanes, J.J., Szerencsits, E., Torralba, M., Burgess, P.J., Herzog, F., 2019. Agroforestry is paying off – economic evaluation of ecosystem services in European landscapes with and without agroforestry systems. Ecosystem Services 36, 100896.

Kremen, C., Merenlender, A.M., 2018. Landscapes that work for biodiversity and people. Science 362 (6412).

Lind, L., Hasselquist, E.M., Laudon, H., 2019. Towards ecologically functional riparian zones: a meta-analysis to develop guidelines for protecting ecosystem functions and biodiversity in agricultural landscapes. J. Environ. Manage. 249 (August), 109391.

Lomba, A., Moreira, F., Klimek, S., Jongman, R.HG., Sullivan, C., Moran, J., Poux, X., Honrado, J.P., Pinto-Correia, T., Plieninger, T., McCracken, D.I., 2020. Back to the future: rethinking socioecological systems underlying high nature value farmlands. Front. Ecol. Environ. 18 (1), 36–42.

Marcos, G.M., Obrador, J.J., García, E., Cubera, E., Montero, M.J., Pulido, F., Dupraz, C., 2007. Driving competitive and facilitative interactions in Oak Dehesas through management practices. Agrofor. Syst. 70, 25–40. https://doi.org/10.1007/s10457-007-9036-.

Moran, J., Byrne, D., Carlier, J., Dunford, B., Finn, J.A., Huallacháin, D., Sullivan, C.A., 2021. Management of high nature value farmland in the Republic of Ireland: 25 years evolving toward locally adapted results-orientated solutions and payments. Ecol. Soc. 26 (1), 20.

Moreno, G., Franca, A., Pinto-Correia, T., Godinho, S., 2014. Multifunctionality and dynamics of silvopastoral systems. Options Mediterranéennes A(109):421–36.

Moreno, G., Rolo, V., 2019. Agroforestry practices: Silvopastoralism. In: Mosquera-Rosada, M.R., Prabhu, R. (Eds.), Agroforestry for Sustainable Agriculture. Burleigh Dodds Science Publishing, Cambridge, UK.

Moreno, G., Aviron, S., Berg, S., Crous-Duran, J., Franca, A., García de Jalón, S., Hartel, T., Mirck, J., Pantera, A., Palma, J.H.N., Paulo, J.A., Re, G.A., Sanna, F., Thenail, C., Varga, A., Viaud, V., Burgess, P.J., 2018. Agroforestry systems of high nature and cultural value in Europe: provision of commercial goods and other ecosystem services. Agrofor. Syst. 92 (4), 877–891.

Mulatu, T., Bastos, R., Santos, M., Sousa, J.P., da Silva, Pedro Martins, Cabral, João Alexandre, 2016. Do the passerine traits' dynamic patterns indicate the ecological status of agro-forestry ecosystems? A modelling approach for 'Montado' management assessments. Global Ecol. Conserv. 8, 154–169.

O'Rourke, E., Finn, J.A., 2020. Farming for Nature: Result-Based Agri-Environment Schemes.

Oksuz, D.P., Aguiar, C.A.S., Tápia, S., Llop, E., Lopes, P., Serrano, A.R.M., Leal, A.I., Correia, O., Matos, P., Rainho, A., Branquinho, C., Correia, R.A., Palmeirim, J.M., 2020. The contribution of small shrubby patches to the functional diversity of wood-pastures. Acta Oecol. 108 (August), 103626.

Otero, Iago, Katharine N. Farrell, Salvador Puello, Giorgos Kallis, Laura Kehoe, Helmut Haberl, Christoph Plutzark, Peter Hobsonm, Jaime García-Márquez, Beatriz Rodriguez-Labajos, Jean-Louis Matin, Karl-Heinz Erb, Stefan Schindlerq, Jonas Nielsen, Teuta Skorin, Josef Settele, Franz Ess, Erik Gómez-Baggethun, Lluis Brotons, Wolgang Rabitsch, François Schneider, and Pe'er Pe'ers. 2020. Biodiversity policy beyond economic growth. Conserv. Lett. in press(August 2019):1–18.

Paço, T.A., David, T.S., Henriques, M.O., Pereira, J.S., Valente, F., Banza, J., Pereira, F.L., Pinto, C., David, J.S., 2009. Evapotranspiration from a Mediterranean Evergreen Oak Savannah: the role of trees and pasture. J. Hydrol. 369 (1–2), 98–106.

Pe'er, Guy, Bonn, Aletta, Bruelheide, Helge, Dieker, Petra, Eisenhauer, Nico, Feindt, Peter H., Hagedorn, Gregor, Hansjürgens, Bernd, Herzon, Irina, Lomba, Ângela, Marquard, Elisabeth, 2020. Action needed for the EU Common Agricultural Policy to address sustainability challenges. People and Nature 2, 305–316.

Pereira, P., Godinho, C., Gomes, M., Rabaça, J.E., 2014. The importance of the surroundings: are bird communities of riparian galleries influenced by agroforestry matrices in SW Iberian Peninsula? Ann. For. Sci. 71, 33–41. https://doi.org/10.1007/s13595-012-0228-x.

Pinto-Correia, T., Vos, W., 2004. Multifunctionality in Mediterranean Landscapes - Past and Future. Pp. 135–64 in The New Dimensions of the European Landscape, edited by R. H. G. Jongman. Dordrecht,NL: Springer Netherlands.

Pinto-Correia, T., Azeda, C., 2017. Public policies creating tensions in montado management models: insights from farmers' representations. Land Use Policy 64.

Pinto-Correia, T., Guiomar, N., Ferraz-de-Oliveira, M.I., Sales-Baptista, E., Rabaça, J., Godinho, C., Ribeiro, N., Sá Sousa, P., Santos, P., Santos-Silva, C., Simões, M.P., Belo, A.D.F., Catarino, L., Costa, P., Fonseca, E., Godinho, S., Azeda, C., Almeida, M., Gomes, L., Lopes de Castro, J., Louro, R., Silvestre, M., Vaz, M., 2018. Progress in identifying high nature value Montados: impacts of grazing on hardwood rangeland biodiversity. Rangel. Ecol. Manage. 71 (5), 612–625.

Pinto-Correia, T., Muñoz-Rojas, J., Thorsøe, M.H., Noe, E.B., 2019. Governance discourses reflecting tensions in a multifunctional land use system in decay; tradition versus modernity in the Portuguese Montado. Sustainability 11 (12), 3363.

Pinto-Correia, T., Ferraz-de-Oliveira, I., Guimarães, M.H., Sales-Baptista, E., Cruz, C., Godinho, C., Santos, R., 2022. Result-based payments as a tool to preserve the high nature value of complex silvo-pastoral systems: progress towards farm-based indicators. Ecol. Soc.

Pinto-Correia, T., Fonseca, A., 2009. Historical perspective of montados: the example of Évora. In: Aronson, J., Santos Pereira, J., Pausas, J. (Eds.), Cork Oak Woodlands on the Edge: Ecology, Adaptative Management, and Restoration. Island Press, pp. 49–54.

Pinto-Cruz, C., Molina, J.A., Barbour, M., Silva, V., Espírito-Santo, M.D., 2009. Plant communities as a tool in temporary ponds conservation in SW Portugal. Hydrobiologia 634, 11–24. https://doi.org/10.1007/s10750-009-9885-7.

Porqueddu, C., Ates, S., Louhaichi, M., Kyriazopoulos, A.P., Moreno, G., del Pozo, A., Ovalle, C., Ewing, M.A., Nichols, P.G.H., 2016. Grasslands in 'old world' and 'new world' mediterranean-climate zones: past trends, current status and future research priorities. Grass Forage Sci. 71 (1), 1–35.

Rodrigues, A.R., Costa e Silva, F., Correia, A.C., Bicho, M.C., Madeira, M., Coutinho, J., 2020. Do improved pastures enhance soil quality of cork oak woodlands in the Alentejo Region (Portugal)? Agrofor. Syst. 94 (1), 125–136.

Röhrig, N., Hassler, M., Roesler, T., 2020. Capturing the value of ecosystem services from silvopastoral systems: perceptions from selected Italian farms. Ecosyst. Serv. 44 (July), 101152.

Rolo, V., Plieninger, T., Moreno, G., 2013. Facilitation of holm oak recruitment through two contrasted shrubs species in mediterranean grazed woodlands. J. Veg. Sci. 24 (2), 344–355.

Sainte Marie, Christine, 2014. Rethinking agri-environmental schemes. A result-oriented approach to the management of species-rich grasslands in France. J. Environ. Plan. Manag. 57 (5), 704–719.

Sales-Baptista, E., d'Abreu, M.C., Ferraz-de-Oliveira, M.I., 2016. Overgrazing in the Montado? The need for monitoring grazing pressure at paddock scale. Agrofor. Syst. 90 (1), 57–68.

Sales-Baptista, E., Ferraz-de-Oliveira, M.I., 2021. Grazing in silvopastoral systems: multiple solutions for diversified benefits. Agrofor. Syst. 95 (1), 1–6.

Sanderson, M.A., Goslee, S.C., Soder, K.J., Skinner, R.H., Tracy, B.F., Deak, A., 2007. Plant species diversity, ecosystem function, and pasture management – a perspective. Can. J. Plant Sci. 87 (3), 479–487.

Santos, R., Clemente, P., Brouwer, R., Antunes, P., Pinto, R., 2015. Landowner preferences for agri-environmental agreements to conserve the Montado ecosystem in Portugal. Ecol. Econ. 118.

Santos, J.L., Moreira, F., Ribeiro, P.F., Canadas, M.J., Novais, A., Lomba, A., 2020. A farming systems approach to linking agricultural policies with biodiversity and ecosystem services. Front. Ecol. Environ. 1–8.

Sardans, J., Peñuelas, J., 2013. Plant-soil interactions in mediterranean forest and shrublands: impacts of climatic change. Plant and Soil 365 (1–2), 1–33.

Serrano, J., Shakib Shahidian, J., Marques Da Silva, E., Sales-Baptista, I.F., De Oliveira, J., De Castro, L., Alfredo Pereira, M., De Abreu, C., Machado, E., de Carvalho, M., 2018. Tree influence on soil and pasture: contribution of proximal sensing to pasture productivity and quality estimation in Montado ecosystems. Int. J. Remote Sens. 39 (14), 4801–4829.

Serrano, J., Shahidian, S., Marques, J., da Silva, F., Moral, F.-R., Carreira, E., Pereira, A., de Carvalho, M., 2020. Evaluation of the effect of dolomitic lime application on pastures – case study in the Montado Mediterranean Ecosystem. Sustainability (Switzerland) 12 (9).

Simões, M.P., Belo, A.F., Fernandes, M., Madeira, M., 2016. Regeneration patterns of Quercus Suber according to Montado management systems. Agrofor. Syst. 90 (1), 107–115.

Simonson, W.D., Allen, H.D., Parham, E., de Basto e Santos, Eduardo, Hotham, Paul, 2018. Modelling biodiversity trends in the Montado (wood pasture) landscapes of the Alentejo, Portugal. Landsc. Ecol. 33 (5), 811–827.

Surová, D., Pinto-Correia, T., 2016. A landscape menu to please them all: relating users' preferences to land cover classes in the Mediterranean Region of Alentejo, Southern Portugal. Land Use Policy 54.

Tamburini, G., Bommarco, R., Wanger, T.C., Kremen, C., van der Heijden, M.G.A., Liebman, M., Hallin, S., 2020. Agricultural diversification promotes multiple ecosystem services without compromising yield. Sci. Adv. 6 (45).

Targetti, S., Schaller, L.L., Kantelhardt, J., 2019. A fuzzy cognitive mapping approach for the assessment of public-goods governance in agricultural landscapes. April Land Use Policy 1–17.

Teixeira, H.M., Vermue, A.J., Cardoso, I.M., Claros, M.P., Bianchi, F.J.J.A., 2018. Farmers show complex and contrasting perceptions on ecosystem services and their management. Ecosyst. Serv. 33 (April), 44–58.

Torralba, M., Fagerholm, N., Hartel, T., Moreno, G., Plieninger, T., 2018. A social-ecological analysis of ecosystem services supply and trade-offs in European wood-pastures. Sci. Adv. 4, 1–13.