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Original article

The cultural landscape of Sintra, a UNESCO World Heritage Site—The balance between forest restoration and carbon stock

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ABSTRACT

Sintra's Cultural Landscape is a World Heritage Site and was the first cultural landscape to be listed in Europe by UNESCO, in 1995. It is a privileged ecosystem with natural and cultural value classified as priorities for conservation. Parques de Sintra-Monte da Lua is a state-owned company established to restore, maintain and promote the public properties in the World Heritage Site. The forest assumes an important role in Sintra's Cultural Landscape with the gradual removal of undesirable species and their replacement with multiple native tree species as one of the goals of forest management. Two aspects should be considered by the forest manager: opposing public opinion in terms of cutting dominant trees, most of the time linked with childhood memories and feelings, and its impact on the ecosystem's carbon stock. Removal and replacement of trees is part of the management of cultural landscapes and concerns like carbon stock and biomass losses cannot be priorities of the forest manager. This work evaluates the carbon stock balance obtained in a 20 ha forest by the removal of undesirable tree species and their replacement by native species. Twenty six inventory plots were measured and carbon stock was estimated to define the baseline of the study. Age-independent individual tree diameter equations, species specific height-diameter equations, and biomass allometric tree equations were used to estimate carbon in a 30-year horizon. Three management scenarios were considered. The results show that, after 30 years, the contribution of the native species to the carbon stock is small compared with the baseline carbon values, compensating only 30% of the carbon losses associated to forest restoration. Conflict management in a context of Cultural Landscape Forest is discussed.

1. Introduction

Cultural landscapes are those where human interaction with natural systems has, over a long time, formed a distinctive landscape (Mitchell et al., 2009). Sintra's Cultural Landscape is World Heritage (http://whc.unesco.org/en/list/723) and was the first cultural landscape to be listed in Europe by UNESCO in 1995. It is integrated into the Sintra-Cascais Natural Park and the Natura 2000 Network (PTCON0008), and is a privileged ecosystem with natural and cultural value classified as priorities for conservation. Parques de Sintra-Monte da Lua (PSML) is a state-owned company established to restore, maintain and promote the public properties in the World Heritage Site of Sintra. Nowadays, parks and monuments under the auspices of PSML attract around 1.5 million visitors per year, corresponding to 88% of the total number of tourists visiting cultural and natural sites in the Sintra Municipality every year.

Forests are complex ecosystems that provide a wide range of value to humans and play a multifunctional role in cultural landscapes that contribute to conserving native biodiversity (Mitchell et al., 2009; Roloff, 2016). Regarding the forest area, the main objectives of PSML are to recover the natural forest, to control the dissemination of invasive species, to reduce the sensitivity of the vegetation to fire as well as the potential risk of fire, to increase the landscape value and to improve the conditions that allow for increasing the number of visitors and the use of the site by the local community. The cultural and ecological sensitivity of visitors to sustainable management of the forest is also among the objectives of the PSML. In this context, the importance of forest tree species as a tool to mitigate CO_2 is explained to the visitors and to the local community, reinforcing the importance of the forest to the reduction of greenhouse gases (GHG) (e.g., Escobedo et al., 2010).

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PSML currently manages approximately 550 ha of forest. This forest is made up of native species and more than 200 exotic species that were introduced intensively in the 19th century, mainly for ornamental purposes. One of them, *Acacia melanoxylon* R. Br., became invasive, and its invasive behavior became more evident after the fires of 1966. This species spread over new areas, often associated with the occurrence of fire, reducing the biodiversity of the ecosystems in which it operates, often leading to inhibition of the germination of native species and also contributing to an increased risk of fire. The gradual removal of undesirable forest species, including invasive species, and their substitution by native forest species is one of the goals of management. Conversion to native broadleaved forests or to mixed forests with a higher prevalence of native tree species increases biodiversity, enhances the aesthetic value and improves biotic and abiotic resilience (Moreira et al., 2012; Roloff, 2016). However, forests with many small trees and few large trees are generally considered to be less appealing than old growth forests where there is a preponderance of large trees; some of these trees may even have a spiritual value (Sands, 2005). In many cases, a relatively minor modification of a planned management activity or the choice of the most appropriate technique to implement a silvicultural intervention as set out in the management plan may be necessary or enough to maintain the landscape visual appeal (Reed and Mroz, 1997; Auch et al., 2016). Forest managers should be able to explain to visitors and the local community that the harvest of undesirable trees, some of them visually dominant, despite changing landscape aesthetics and resulting in a reduction in the carbon stock (Nowak et al., 2002), is essential to break the production of new seeds and to promote the growth of native species. And some of the lost carbon can be offset by these new trees because, through growth processes, trees remove atmospheric CO_2 and store carbon within their biomass.

In this work, the impact of three management scenarios regarding the carbon stock and the dimension of stand trees is analyzed in a 30-year horizon. The carbon removed by harvesting the invasive acacia trees and two other species traditionally associated with production systems in Portugal (eucalyptus and maritime pine trees), as well as the carbon stock associated with the native species planted to substitute the harvested trees is estimated. The estimation is based on a forest inventory that took place in spring 2011, after the harvest of most of the acacia trees but before the plantation of native tree species that occurred in autumn 2011. The results of this study are the basis for information that is provided to the visitors and local inhabitants in order to support the acceptance of the forest management activities that are taking place. Also, findings from this study can be used as indicators for the establishment of integrated management plans of native forests in urban contexts and, particularly, in cultural landscape context.

2. Methods

According to the LULUFC (Land Use, Land-Use Change and Forestry) guidelines (IPCC, 2003) the stock-change method was chosen and the emissions/removals of carbon were evaluated by the difference between the carbon stocks in two successive inventories. In this work, the baseline was obtained by forest inventory used to characterize the forest in spring 2011. In the absence of the second inventory, we used estimates obtained with tree growth models and prediction equations available for the different forest species present in the study area.

2.1. Study area

Serra de Sintra has a Mediterranean climate with an Atlantic influence, with a relatively small annual temperature range (average 19 °C in the warmest month and 10 °C in the coldest month) and a high degree of humidity (INMG, 1991) that arises from the relative proximity to the Atlantic Ocean, the orography and the altitude of the mountain. The condensation of maritime air, favored by tree cover on the mountain, promotes the occurrence of precipitation (860 mm as mean annual value) (INMG, 1991) and fog (Moniz, 2004). Serra de Sintra is presented as the main geological feature of the Lisbon region with a maximum altitude of 528 m. Sintra's Eruptive Massif, of magmatic origin, is formed by eruptive rocks as the most common granite rock (Ribeiro et al., 1997). The forest managed by PSML is distributed over several management units referred as Tapadas. Two of them, Tapada das Roças and Tapada do Mouco, are located side by side and were selected as the study area.

2.2. Forest inventory

Nine forest strata were identified in the study area, as combinations (pure or mixed stands) of *Acacia* Mill. spp., *Eucalyptus* L'Hér. spp., *Pinus pinaster* Aiton, and *Pittosporum undulatum* Vent. A stratum with a mixture of species was identified and designated as Mixed. In some cases, in this stratum, it was only possible to identify the genus of the tree.

The forestry inventory took place in spring 2011 after the harvest of most of the acacia trees; 26 circular plots of 500 m^2 distributed proportionally to the area of the different strata were measured, assuming one plot per hectare but with a minimum of two plots per stratum (see Table 2). Any individual with a height greater than or equal to 2.0 m was considered a tree. In each inventory plot two perpendicular measurements of the diameter at breast height (*dbh*) and total height of each tree with a *dbh* larger than 4.5 cm were measured (Table 1). Trees with a diameter smaller than 4.5 cm were counted (per species) and grouped in one class; average values of diameter and height were assigned this class. Tree age was not evaluated.

Samples of the litter of the forest floor, after the removal of live herbaceous plants, were collected in four areas of 900 cm^2 in each inventory plot, spaced 2 m from the plot center, and defined according to the cardinal directions. Soil samples for organic carbon determination at a depth of 30 cm were obtained at the same location where litter samples were collected. These samples were mixed to obtain one composite per inventory plot. A soil sample of about one kilogram was taken to the laboratory.

2.3. Estimation of carbon stock (baseline)

The estimation of carbon stock in the study area in spring 2011 implied the estimation of the following pools:

(a) Total biomass, defined as the sum of above and belowground biomasses.

Biomass values were initially estimated at tree level using several allometric equations from literature (Nabuurs et al., 2003; Montero et al., 2005; Zianis et al., 2005; Tomé et al., 2007; Faias, 2008; Ruiz-Peinado et al., 2011, 2012; Soares and Tomé, 2012), then summed over each plot and reported to the hectare (Eq. (1)). Biomass at the stratum level was based on the mean biomass value per hectare for the stratum multiplied by the stratum area and biomass in the study area was the sum of the biomasses considering all the strata (Eq. (2)).

$$W_{plot} = \frac{10}{plotarea} \sum\nolimits_{i=1}^{n} (w_{ai} + w_{bi}) \quad (1)$$

$$W_{area} = \sum\nolimits_{j=1}^{nstrata} \left[\left(\frac{\sum_{i=1}^{m} W_{ploti}}{nplots} \right)_j \times area_{stratumj} \right] \quad (2)$$