Ecological Economics 143 (2018) 210–217

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Evaluating the Economic Potential of Uneven-aged Maritime Pine Forests

Renato Rosa [a,*], Paula Soares [b], Margarida Tomé [b]

[a] CENSE—Center for Environmental and Sustainability Research, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Lisbon, Portugal
[b] Universidade de Lisboa, Instituto Superior de Agronomia, Centro de Estudos Florestais, Tapada Ajuda, 1349-017 Lisboa, Portugal

ARTICLE INFO

Article history:
Received 8 November 2016
Received in revised form 29 April 2017
Accepted 8 July 2017
Available online xxxx

Keywords:
Uneven-aged management
Maritime pine
Economic optimization
Matrix growth model

ABSTRACT

Continuous cover practices are likely to better respond to the increasing demand for social, aesthetic and environmental values provided by forest ecosystems than even-aged forest plantations. Also, uneven-aged forestry may be especially attractive for non-industrial private forest owners, as it provides more regular revenues and, by taking advantage of natural regeneration, reduce installation costs. Knowledge on alternative regimes to even-aged forestry is therefore in high demand. We first add to the literature by proposing a new maritime pine forest growth model that can be readily used in optimization studies. Second, we are the first to analyze optimal uneven aged forest management for this species. Highlighting the contribution of this study, a comparison of our results with currently suggested silvicultural management scenarios is provided. We show that the economic profitability of this species significantly increases under optimal forest management and may thus present a viable alternative to rotation forests. In particular, we show that optimal forest management may entail harvesting cycles.

1. Introduction

The Faustmann rotation model (Faustmann, 1849) plays a dominant role in the history of forest economics. While the use of this framework proved successful to consider various economic and ecological issues (for a review, see Newman, 2002), management under such a formulation is restricted to even-aged forestry. In fact, even if in its more general framework silvicultural practices may include thinnings, management under the rotation model is characterized by clearcut cycles. As a result, the number of economic studies on continuous cover forest practice is relatively small and knowledge of the economics of uneven-aged forestry is thus comparatively incipient. The preponderance of the Faustmann model in forest economics may have actually favoured the establishment of even-aged forest plantations, while its economic performance over uneven-aged forestry is still open to question (Tahvonen, 2009). Additionally, a growing interest in alternative forest management regimes to even-aged forestry has recently emerged to satisfy the increasing demand for social, aesthetic and environmental values provided by forest ecosystems (see e.g. Weetman, 1996; Gamborg and Larsen, 2003; Puettmann et al., 2009). Uneven-aged forestry is, however, usually modelled through size-structured models, whose higher complexity with respect to the standard one-stand Faustmann model demands economic analysis by means of numerical methods.[1] Increasing knowledge of the economics of continuous cover forestry therefore inevitably demands for applied studies focusing on different regions and species. In this context, an increasing body of literature has emerged but, to the best of our knowledge, it is still mainly restricted to northern European countries, particularly to Scandinavia (see e.g. Tahvonen et al., 2010; Rämö and Tahvonen, 2014). This paper adds to that body of work by providing an application to a key forest species in southwestern Europe.

Maritime pine is distributed along vast areas of Italy, France, Portugal, Spain and North Africa (EUFORGEN, 2009), playing a vital role in some of their regional economies. The Landes de Gascogne in Aquitaine, France, contains the largest monospecific woodland area in southwestern Europe: a one-million-hectare maritime pine forest (IFN, 2010). In Spain, maritime pine is the predominant coniferous species, covering 1,680,000 ha of land with mixed and pure stands (Anta et al., 2006). In Galicia alone, this species covers 217,281 ha of pure stands (MAGRAMA, 2011) and is the most important commercial species in northwestern Spain (Sanz et al., 2006). In Portugal, maritime pine has historically been the predominant species, occupying the largest share of forested land. However, in the last 15 years, pine forest area is steadily decreasing due to the desertification of the country inland, the frequency and re-occurrence of forest fires, the presence of pests and diseases, and the replacement of the species by eucalyptus (ICNF, 2013; Santos

* Corresponding author at: DCEA FCT-UNL, Campus de Caparica, 2829-516 Caparica, Portugal.
E-mail addresses: renato.rosa@fct.unl.pt (R. Rosa), paulasoares@isa.ulisboa.pt (P. Soares), magatome@isa.ulisboa.pt (M. Tomé).

[1] The exception to this is Tahvonen (2015). Given the complexity involved in economic optimization, where forest growth description is provided by size-structured models, analytical solutions are derived for a more simplified version of two-size classes only.

http://dx.doi.org/10.1016/j.ecolecon.2017.07.009
0921-8009/

et al., 2013). Nonetheless, maritime pine still occupies the largest area of forest land in both central and northern regions of Portugal (AFN, 2010).

The majority of forest land ownership in France, Spain and Portugal is private (Pulla et al., 2013). In France, the average size of private forest land equals 2.7 ha, a fragmentation often associated with passive management (Petucco et al., 2015). Private forest amounts to 74% of total forest land, but when considering maritime pine species only, this number increases to 88% (CNPPF-IDF, 2015). In Galicia, only 2.2% of total forest land is public. Land properties are typically small (67.9% of total forest area is held by approximately 672,000 owners) and widely distributed (Rodríguez-Vicente and Marey-Pérez, 2009). In Portugal, 92.3% of woodland is under private ownership (FAO, 2010) and 61% of the forest owners have woodland of <5 ha, which corresponds to 26% of the national forest area (DGRF, 2007).

Given its relevance for the forest sector in these regions, several empirical growth models have been developed for this species, the large majority of which were designed for pure even-aged plantations. Rodríguez Soalleiro (1995) developed the first growth model for even-aged stands of maritime pine in Galicia, a model later improved by González et al. (2005) with new ecoregional site index curves. More recently, Arias-Rodil et al. (2015a) developed a growth model based on the state-space approach for the region of Asturias in northwestern Spain. For Portugal, Páscoa (1987) and Fonseca (2004) developed diameter distribution models for even-aged stands with data from the National Forest of Leiria (central coast) and north Portugal respectively (see also Fonseca et al., 2012). Falcão (1998) also offers a stand-level growth model for the National Forest of Leiria. Finally, Nunes et al. (2011) developed individual tree-growth models for even-aged stands. For France, a stand growth model was developed by Lemoine (1991, see also Salas-González et al., 2001). To the best of our knowledge, only two models are available for uneven-aged maritime pine forests: Alegria and Tomé (2013) for pure stands and Orois and Soalleiro (2002) for mixed stands. More details about these models are available on the Institut Européen de la Forêt Cultivée (IEFC) website.

Even-aged stand models for this species have been applied in several papers, either simulating the impact of different silvicultural scenarios (see e.g. Salas-González et al., 2001; Alegria, 2011) or using optimization techniques (see e.g. Arias-Rodil et al., 2015b; Ferreira et al., 2014; Pasalodos-Tato et al., 2010). On the other hand, only two papers have analyzed management of uneven-aged mixed stands including maritime pine species. Orois and Soalleiro (2002) and Orois et al. (2004) simulate the results of different silvicultural scenarios for this species and, while Rojo and Orois (2005) optimize conversion paths from even to uneven-aged maritime pine stands in Galicia, the final uneven-aged stand structure is imposed as a constraint. Pure maritime pine uneven-aged growth models have thus not yet been applied in optimization studies to investigate optimal forest management, which remains largely uncharted. Knowledge of managing uneven-aged stands is therefore in high demand for this species, as in both Galicia and Portugal a large share of the maritime pine forest structure is already uneven-aged. These are typically held by small private forest owners whose harvesting practices are not grounded in technical silvicultural principles, resulting in an understocked uneven-aged forest structure with trees of poor growth and low quality (Molina, 1988; Orois et al., 2004; Rojo and Orois, 2005; Baptista and Santos, 2005; Alegria and Tomé, 2013). In addition, uneven-aged forestry may be especially attractive for non-industrial private forest owners, as it provides more regular revenues and, by taking advantage of natural regeneration, reduces installation costs.

This paper develops a size-structured forest growth model, a framework typically applied in uneven-aged management forest studies, and applies it to obtain optimal forest management maximizing economic returns for this species. We add to the literature firstly by proposing a new maritime pine forest growth model – the UPine model – that can be readily used in optimization studies. Secondly, we are the first to analyze optimal uneven-aged forest management for this species. In order to highlight the contribution of this study, we provide a comparison of our results with current silvicultural management scenarios. We show that the economic profitability of this species significantly increases under optimal forest management and may therefore present a viable alternative to rotation forests. In particular, we show that for high productivity stands, optimal forest management may involve harvesting cycles, a result that, to the best of our knowledge, is new in the literature.[2]

2. Model

Forest dynamics are modelled using a size-structure matrix stand-growth model (Usher, 1966, 1969) and the notation closely follows Tahvonen et al. (2010). There are n size classes. Let $\phi(\boldsymbol{X}_t)$, denote forest ingrowth as a function of stand density. The number of trees in size class $s=1,\dots,n$ in year $t=0,1,\dots$ is denoted by $x_{s,t}$ and the number of harvested trees by $h_{s,t}$. Let $\alpha_s(\boldsymbol{X})$ $s=1,\dots,n$ in year $t=0,1,\dots$ denote the fraction of trees that moves to the next size class in period $t+1$ and $\beta_s(\boldsymbol{X}_t)$ the natural mortality rate. The share of trees remaining in the same class in period $t+1$ can thus be written as $1-\alpha_s(\boldsymbol{X}_t)-\beta_s(\boldsymbol{X}_t)$. Forest stand dynamics can therefore be described through a set of difference equations:

$$x_{1,t+1}=\phi(\boldsymbol{X}_t)+(1-\alpha_1(\boldsymbol{X}_t)-\beta_1(\boldsymbol{X}_t))x_{1,t}-h_{1,t} \tag{1}$$

$$x_{s+1,t+1}=\alpha_s(\boldsymbol{X}_t)x_{s,t}+\left(1-\alpha_{s+1}(\boldsymbol{X}_t)-\beta_{s+1}(\boldsymbol{X}_t)\right)x_{s+1,t}-h_{s+1,t},s=1,\dots,n-2, \tag{2}$$

$$x_{n,t+1}=\alpha_{n-1}(\boldsymbol{X}_t)x_{n-1,t}+(1-\beta_n(\boldsymbol{X}_t))x_{n,t}-h_{n,t} \tag{3}$$

Revenues, R_t, are defined as follows:

$$R_t=\sum_{s=1}^{n}(\omega_{s,1}p_1+\omega_{s,2}p_2+\omega_{s,3}p_3)h_{s,t} \tag{4}$$

where $\omega_{s,j}$ and $p_j, j=1,2,3$ denotes the tree volumes (m^3) and prices of three categories of wood: top, chipping and sawmill. The maximization problem, where r denotes the discount rate, can finally be specified as follows:

$$\max_{h_{s,t}\ s=1,..n,\ t=1,\dots}\sum_{t=0}^{\infty}\frac{R_t}{(1+r)^t} \tag{5}$$

subject to (1–4), the non-negativity constraints $h_{s,t}\geq0$ and $x_{s,t}\geq0$, for $s=1,\dots,n$ and $t=0,1,\dots$ and the initial forest size distribution.

3. Data Inventory and Model Estimation: The UPine Model

With the objective to evaluate mortality, growth and recruitment in uneven-aged naturally regenerated maritime pine stands in the central inland region of Portugal, 30 circular semi-permanent plots of 1000 m^2 were installed by Alegria (2004). The installation and the first inventory were carried out from September 1996 to March 1997. Tree coordinates were measured in all plots. Plots were re-measured twice at approximately annual intervals. The following variables were measured in all trees with a diameter at breast height (dbh) larger than 5 cm: dbh, total height, height to the live crown base, and crown width. A concentric sub-plot of 500 m^2 was considered within each plot and a set of sample trees was selected for additional measurements, including, age at 1.30 m height and diameter increment without bark in the past 5

[2] Tahvonen (2009) also found optimal harvesting cycles under an uneven management framework. In those cases, however, regeneration was either artificial or depended on the gaps left by harvested trees. Additionally, the existence of harvesting cycles was not linked to site productivity in Tahvonen's study, meaning that harvesting cycles in our study are determined by different factors.