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Selecting the best forest management alternative by aggregating ecosystem services indicators over time: A case study in central Spain

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ABSTRACT

Sustainable forest management has been approached on many occasions by defining and subsequently measuring a set of initially accepted indicators. This methodology permits the aggregation of multiple goods and services with heterogeneous characteristics into forest management. However, the calculation of these indicators has usually been static. When we find ourselves in situations in which there is a need to make long-term evaluations of the effects of possible scenarios affecting forest management, a procedure has to be set up to define and aggregate the different indicators over time, as well as to integrate the preferences of the stakeholders involved in management.

This study shows a goal programming-based methodology, which permits to select the best management alternative in 6 climate change scenarios when different indicators are aggregated over 100 years in a mountain forest in Central Spain. The results revealed the predominance of one management alternative (no management) when the preferences of the stakeholders were aggregated. However, when the preferential weights corresponding to some stakeholders were included separately, the solution may notably vary, especially in the case of forest owners. It was concluded that the methodology proposed allows a dynamic aggregation of diverse sustainable forest management in addition to presenting a great flexibility at the moment of selecting various solutions proposed by the goal programming model, and the preferences of the different stakeholders.

1. Introduction

Nowadays, there are different definitions of sustainable forest management. There is a consensus that sustainable forest management involves a process of managing forests that are economically feasible, environmentally concerned and socially valuable, balancing present and future needs (Higman et al., 2005). The current idea of sustainable forest management is not only associated with production objectives (Bettinger et al., 2009, chap. 9), and it veers away from the mere achievement of classic conditions ensuring sustained yield (Recknagel and Bentley, 1919).

On the other hand, there is currently a certain unanimity in the premise that defining an initial set of multidisciplinary criteria and indicators may well come nearer to the idea of sustainable forest management (Raison et al., 2001). However, many of these studies have paid more attention to the definition and measurement of the indicators than to their aggregation, which has failed to answer the immediate question of whether forest management is sustainable or not (Diaz-Balteiro et al., 2016a).

Given that multidimensionality is intrinsic to the sustainable forest management idea, some studies have attempted to use diverse MCDM (Multiple Criteria Decision Making) techniques. Thus, starting from several years ago, some forest management case studies have incorporated sustainability by applying MCDM techniques (Diaz-Balteiro and Romero, 2008). Under the MCDM umbrella, goal programming has been one of those most widely used methods to build synthetic indexes in forest management applications, integrating several indicators and criteria (Diaz-Balteiro and Romero, 2004; Giménez et al., 2013; Aldea et al., 2014; Diaz-Balteiro et al., 2016b). Other studies employing other MCDM techniques in similar sustainable forest management issues are Wolfslehner and Vacik (2008), Balana et al. (2010), Jalilova et al. (2012) or Hernández et al. (2014). Finally, it has recently been shown how the combination of MCDM tools with other techniques may be valid for integrating the ecosystem services (ES) associated with a forest system (Uhde et al., 2015).

The above methodologies allow the aggregation of a battery of different indicators into synthetic indexes that measure the overall

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sustainability of a forest management alternative. However, this methodology can be applied to the aggregation of indicators for sustainable forest management without really taking into account the above idea of sustainability. That is, you can aggregate a set of indicators without trying to define a sustainability index. This multi-indicator approach can help to establish a ranking of different forest management alternatives, even integrating the preferences of diverse decision-makers (Nordström et al., 2009; Diaz-Balteiro et al., 2013).

In this study, we have focused on *Pinus sylvestris* mountain forests in the Sierra de Guadarrama in Spain. We used the hybrid patch model PICUS v1.6 (e.g., Seidl et al., 2005) to analyse the provision of multiple ES over a 100-year simulation scenario, providing related ES indicators (Seidl et al., 2011; Pardos et al., 2015). Planning and implementing multifunctional forest management is challenging because ES could be affected differently by changes in climate and management. In this sense, the model PICUS assesses the impact of climate change and allows to design management alternatives.

Since forest management is, in general, of an inherently dynamic nature, the primary objective of this study was to show a methodology which aggregates a set of indicators with different values over the time, to obtain the most preferred management alternative throughout the planning horizon. This idea has been applied to a mountain forest case study where the objective was to select the optimal forest management alternative under several climate scenarios, introducing the preferential weights of different stakeholders. A secondary objective of this study was to examine whether the results obtained over time were affected by changes in the stakeholders' preferential weights attached to the different indicators analysed.

Although there is an extensive literature on the aggregation of indicators (Pollesch and Dale, 2015), in not many studies is this aggregation has been carried out over time. Thus, many of them usually offer methods for building composite indexes, but from a static point of view. However, when assessing the sustainability of different systems, it is essential to integrate a dynamic component (Schlaepfer and Elliot, 2000, pp. 14). Some examples of the calculation of a set of indicators at different times over time are found in Le et al. (2010), and Butler et al. (2012). In the latter study, the authors have defined a synthetic biodiversity index (farmland bird index) with values taken between 1970 and 2006. Finally, in Briceño-Elizondo et al. (2008), a multi-attribute utility model in a stochastic context has been employed to select the best stand treatment programme under different climate scenarios and using a physiological growth model to simulate the value of different criteria throughout 100 years. However, no preferential stakeholders' preferences have been integrated into the model.

2. Material and methods

2.1. Case study: Pinar de Valsaín forest

Pinar de Valsaín is a 7622 ha public forest located on the North facing slopes of the Sierra de Guadarrama (Central Mountain Range of Spain, 40° 49′N, 4°1′ W). At elevations between 1400 and 1900 m a.s.l. the forested area is clearly dominated by pure even-aged *Pinus sylvestris,* while mixed *Pinus sylvestris-Quercus pyrenaica* stands (10% of the forested area) are found at below 1400 m a.s.l. Above 1900 m a.s.l., alpine shrubs is the prevailing vegetation type. The climate is sub-Mediterranean, with a mean annual temperature of 8.5 °C at 1500 m, average annual rainfall of 1275 mm, and precipitation between May and September of 651 mm. Moderately deep dystric cambisols and ferric luvisols have developed over acidic bedrock as major soil types.

Table 1
Baseline climate and climate change scenarios at 1500 m a.s.l.

Baseline climate			Climate scenarios				
	C0		C1	C2	C3	C4	C5
T (°C)	7.2	ΔT	+3.7	+3.8	+3.9	+4.6	+5.9
P (mm)	1366.3	ΔP	−17%	−10%	+4%	−11%	−17%
P_{summer} (mm)	337	ΔP_{summer}	−25%	−30%	−24%	−38%	−58%

The lack of any formal planning for centuries led to overexploitation, regeneration failure and severe degradation of the forest. The situation changed with the implementation of the first management plans in 1889. Since then, even-aged forest management based on natural regeneration has been the common practice. For decades, the use of a uniform shelterwood system with a rotation of 120 years and a 20-year regeneration period favoured timber production as the main ES. Starting from the 1980's, multifunctionality gained importance and the silvicultural system was changed to a shelterwood group system that extended the regeneration period to 40 years, to ensure sufficient natural regeneration. Currently, this is the "business as usual" management approach for *Pinus sylvestris* stands. The main ES demanded currently at Pinar de Valsaín are timber, carbon storage, biodiversity and habitat conservation, recreation and game. Since 2013, 3326 ha of the Valsaín forest (above 1875 m a.s.l.) are included in the "Sierra de Guadarrama" National Park, where management is highly regulated and even restricted in some areas.

2.2. Climate scenarios

We used a baseline climate (C0) and five transient climate change scenarios (C1 to C5). Each climate consisted of a 100-year time series that included daily data for temperature, precipitation, radiation and vapour pressure deficit. Data available between 1961 and 1990 (*Puerto de Navacerrada* weather station, 40°47′N, 4°01′W) were used to generate the baseline climate at 1500 m a.s.l. The five climate change scenarios were based on regional climate model simulations from the ENSEMBLES project (Hewitt and Griggs, 2004; www.ensembleseu.org). Climate scenarios increase mean temperature between 3.7 °C and 5.9 °C, decrease summer precipitation (May–September) between 25% and 58%, while changes in annual precipitation are not so marked (Table 1).

2.3. Forest management alternatives

Forest management alternatives have focused only on *Pinus sylvestris*, both in the pure and mixed stands. The business-as-usual management regime (BAU), an alternative management (AM1) and a "no management" alternative (NM) have been defined. The alternative management AM1 focuses on changes in the thinning regime to favour more diverse stand structures and to trigger tree vigour while promoting quality timber, at the same time maintaining the multifunctionality of the stands.

In the BAU alternative, the focus is on the production of valuable timber while keeping up a satisfactory level of other ES. Three light thinnings from below are applied at ages 40, 60, and 80 years. Four regeneration fellings are applied during a 20-year period. In the final regeneration cut after 20 years, some residual trees per hectare are kept standing to provide a nesting habitat for birds. Rotation length is 120 years. In the AM1 alternative, the management objective is to promote quality timber similarly to BAU. However, in contrast to BAU, selective crown thinnings (35–40% of standing volume is removed) are applied to promote growth and vigour of good quality trees. The rotation consists of 120 years employing the irregular shelterwood as in BAU for natural regeneration. The main objective of the NM alternative is to allow natural processes,