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Research article

Sustainability assessment in forest management based on individual preferences

Susana Martín-Fernández*, Eugenio Martinez-Falero

Escuela Técnica Superior de Ingenieros de Montes, Forestal y del Medio Natural, Technical University of Madrid, Ciudad Universitaria s n, 28040, Madrid, Spain

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ABSTRACT

This paper presents a methodology to elicit the preferences of any individual in the assessment of sustainable forest management at the stand level. The elicitation procedure was based on the comparison of the sustainability of pairs of forest locations. A sustainability map of the whole territory was obtained according to the individual's preferences. Three forest sustainability indicators were pre-calculated for each point in a study area in a Scots pine forest in the National Park of Sierra de Guadarrama in the Madrid Region in Spain to obtain the best management plan with the sustainability map. We followed a participatory process involving fifty people to assess the sustainability of the forest management and the methodology. The results highlighted the demand for conservative forest management, the usefulness of the methodology for managers, and the importance and necessity of incorporating stakeholders into forestry decision-making processes.

1. Introduction

Since the introduction of Sustainable Forest Management (SFM), forest owners and managers have required effective and efficient decision-support tools in order to produce management plans that are realistic, practical and sustainable (Reynolds et al., 2007). It became necessary to define a SFM framework to monitor, measure and assess these plans. This framework consists of a number of criteria and indicators based on the proposals of the Montréal Process (Montréal Process Working Group, 2007) and the Ministerial Conference on the Protection of Forests in Europe (Ministerial Conference on the Protection of Forests in Europe, 2007).

These criteria and indicators are currently used for a number of purposes (i.e. forest biological diversity, productive capacity or/and maintenance of forest ecosystem health, social aspects), and have emerged as a powerful tool for implementing sustainable forest management and assessing sustainability (Vacik et al., 2007; Wijewardana, 2008).

However, as sustainability is a complex concept, no single assessment of sustainability can be globally accepted (Ness et al., 2007; Reynolds et al., 2007). In this paper, we consider sustainability assessment as the measurement of the result of management practices on sustainability. This measurement will depend on how these indicators are integrated.

The opinion of most stakeholders involved in the process must also be taken into account in order to make the sustainability assessment acceptable and applicable by society (Vainikainen et al., 2008). These stakeholders may include forest owners, corporate or government forest managers, local inhabitants, and private individuals.

These participatory processes are usually conducted through negotiations with stakeholders, voting systems and multiple choice experiments (Berninger et al., 2010; Kouplevatskaya, 2007; Sheppard and Meitner, 2005), or by applying multicriteria decision-making methods (Mendoza and Prabhu, 2005; Mustajoki et al., 2011; Ocampo-Melgar et al., 2017).

When the study is done at the stand level, these participative processes also offer an opportunity to find the most sustainable management plan for each participant. This requires a value function to obtain the sustainability value for each point in the territory. The methodology developed by Fishburn (1985) allows sustainability to be assessed and ensures the existence of this value function. It is based on utility theory, which enables people's preferences to be represented in numerically useful ways and orders the alternatives. The individual compares the alternatives in

* Corresponding author.
E-mail addresses: susana.martin@upm.es (S. Martín-Fernández), eugenio.mfalero@upm.es (E. Martinez-Falero).

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pairs, and the analysis of the matrix of preferences reveals the type of preference and the structure of the value function.

The aim of the present work was to apply Fishburn's developments to assess the sustainability of current forestry operations in the Fuenfría Valley in the Sierra de Guadarrama National Park in Madrid in a participatory process, in order to devise the management plan which best suits the sustainability preferences of each individual. A second aim was to evaluate the methodology.

2. Methodology

The sustainability of forestry management was assessed based on Fishburn's methodology following the steps below:

1. Identify the forest locations to be compared in the pairwise comparison process.
2. Develop a pairwise comparison process: obtain the ranking of the forest sites according to the individual's preferences and identify the type of preference.
3. Extend the sustainability value to the rest of the points in the area of application.
   The steps to design the best management plan according to these preferences were:
4. Estimate the objective optimisation function from the sustainability indicators.
5. Design the management plan which maximises sustainability for each individual.

The steps to assess the methodology were:

6. Design a questionnaire to evaluate the results of this process, and conduct a survey.

The methodology was implemented in a computer application called Silvanet (Martínez-Falero et al., 2010). The application starts by asking the user for his/her personal data, education level and job, then shows the pairs of the different forest management alternatives to determine which one is preferable. The users are shown images and a description of each alternative, information about indicators, and forest management. As output, Silvanet shows the map of sustainability of the forest area in the case study, and the best management plan according to the user's preferences. The algorithms for the analysis of preference and optimisation are transparent for the user. The application also saves all this information in a database for use by the forest manager.

2.1. Assessment of the sustainability of a current forestry operation

2.1.1. Description of the study area

The study area is located in the Fuenfría Valley in the Sierra de Guadarrama National Park (Madrid, Spain). This park protects 34,000 ha located in the autonomous regions of Madrid and Castile-León. The Regional National Parks Authority and the Departments of the Environment in the two autonomous regions are responsible for their management.

The Fuenfria Valley is located in the central zone of the Sierra de Guadarrama, in the northwest of the Madrid Region. This valley was declared an area of conservation and preservation of traditional uses in the "Declaration of the Sierra de Guadarrama National Park " Law 7/2013. The potential uses of the Fuenfria Valley are recreational, conservative and productive.

The study area covers 127.10 ha (40°45′N, 4°5′W), and its altitude ranges from 1310 to 1790 m. It is south facing, with an average annual temperature of 9.4° C, and average annual rainfall of 1180 mm. Its primary vegetation is Scots pine (*Pinus sylvestris* L.), grouped in five different types of structure (Pascual et al., 2008):

- Type 1: Uneven-aged forest (multi-layered canopy) with very high crown cover. Area: 26 ha.
- Type 2: Multi-diameter forest with high crown cover. Area: 24 ha.
- Type 3: Multi-diameter forest with medium crown cover. Area: 29 ha.
- Type 4: Even-aged forest (single-story) with low crown cover. Area: 37 ha.
- Type 5: Zones with scarce tree coverage. Area: 11 ha.

A LIDAR image was used to compute the spatial value of the sustainability indicators. The Digital Canopy Height Map (DCHM) obtained from the LIDAR image had a pixel of 1 m. The procedure for acquiring the image is described in Pascual et al. (2008).

Finally, field data were used to validate the indicators. Ten plots were obtained by systematic sampling, two for each type of forest structure. Table 1 shows the respective values of the indicators measured both directly from the field data and calculated solely from the LIDAR image.

2.1.2. Stakeholders

The study area is managed by the government authorities as it belongs to a National Park. In our research, we focused on one group of stakeholders, namely, the visitors to the park, for two reasons. First, they are beneficiaries of the park (Wallace et al., 2016), and second, we could validate the methodology with people from different backgrounds.

2.1.3. Selection of the indicators

According to Thomson (2005), any set of criteria and indicators can be used in public participation; i.e. the criteria and indicators proposed in the Report on the Montréal Process (Montréal Process Liaison Office, 1997) or the Pan European Forest Process. Both sets of indicators fall into three general categories: vital functions and attributes (biodiversity, productivity, forest health, the carbon cycle, soil and water protection), socio-economic values and benefits, and forest policy and regulatory framework. We have used three indicators: structural diversity, I_1; timber yield, I_2, and amount of biomass, I_3, selected according to the objectives of the 2009–2019 Sierra de Guadarrama Management Plan. These objectives include the improvement of the forest structure, measured by indicator I_1, and the regulated exploitation of natural resources –indicator I_2. One of the objectives of this plan and of the Spanish Forest Law (Ley de Montes 43/2003) is to reduce CO_2 in the atmosphere by

Table 1
Values of the indicators obtained with field measurements and measurements from the LiDAR forest (in % regarding maximum sustainability conditions).

Type of structure-plot	Indicator I1 Structural diversity (%)		Indicator I2 Timber yield return (%)		Indicator I3 Biomass (%)	
	Terrain	Image	Terrain	Image	Terrain	Image
T1-P1	63.29	49.26	53.49	49.82	53.15	47.01
T1-P2	55.32	41.47	69.26	55.57	64.45	49.61
T2-P1	49.08	41.06	88.4	89.18	83.8	82.38
T2-P2	44.11	44.15	74.44	72.54	66.19	66.4
T3-P1	58.41	54.47	33.68	33.68	33.88	33.9
T3-P2	49.01	54.37	30.14	28.85	28.06	29.23
T4-P1	57.93	56.16	10.68	15.23	10.99	19.01
T4-P2	56.78	59.55	15.85	10.09	15.99	11.28
T5-P1	61.47	56.77	2.49	8.74	2.69	9.03
T5-P2	62.11	62.07	3.13	4.64	3.83	5.88