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A Spatial-Based Decision Support System for wood harvesting management in mountain areas

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ABSTRACT

In this paper, a spatial-based economic model is proposed with the aim of estimating the most likely harvest cost of a forest block in relation to its particular morphological and operating features. This work, which is based on the classical stumpage price assessment method, presents an economic balance of a forest cut, attained by conducting a cost analysis of each logging phase of the different standard harvesting strategies. The study area is in the North-West of Italy, in the Mount Cotolivier forest compartment, in Oulx, Piedmont. The map of the stand structure, which is included in the Oulx Forest Management Plan, was used to locate blocks (areas considered homogeneous according to the stand structure and forest typology) where silvicultural cuts could be scheduled. The feasibility of the selected logging strategies was mapped considering six conditioning factors, of both a topological and a topographic nature. Their influence was weighted by means of a score assignation and integrated in a Multi-Criteria Decision Making procedure. The scores were mathematically combined to calculate a spatial dependent cost-function (*Block Exploitation Aptitude, BEA*) in which the suitability of each block to be harvested was mapped through a specific strategy. The obtained *BEA* was then used to estimate the most suitable productivity rate of the harvests of each block. The unitary costs of the strategies were estimated and then compared to find the most profitable one for each block.

This model has proved to be effective in generating objective economic results concerning harvest cuts in productive stands in mountainous areas. The proposed methodology simultaneously takes into account different factors and generates feasibility scenarios, in the space domain, for the considered harvesting strategies. The proposed model represents a prototype on which an operational *Decision Support System* could be based to assist forest managers over the short-medium term.

1. Introduction

Evaluating the exploitation costs of a forest harvest is a basic step in the stumpage price[1] estimation, and requires several skills in different work fields, such as economy, silviculture and exploitation planning (Carbone and Ribaudo, 2005; Picchio et al., 2011). Stumpage price evaluation is generally considered to be the most appropriate methodology to evaluate mature or close-to-mature stands (López Torres et al., 2016). It has been used frequently at both international (Chang, 1983; Sessions and Sessions, 1992; Mei et al., 2010) and national level (Serpieri, 1917; Patrone, 1947; Borghese and Venzi, 1990), and it is usually adopted in forest evaluations (Carbone and Ribaudo, 2005; Carbone, 2009).

Although several works have focused on particular aspects of this estimation, such as the definition of all its components (Brun et al., 2009; Carbone, 2009) or its relationship to the purchase cost of public auctions (Brannman et al., 1987; Pettenella, 1998), only a few have attempted to relate the economic aspects to the spatial features. Few works have evaluated the Total Economic Value[2] (Pearce, 1990; Plottu and Plottu, 2007) of a territory considering both its productive functions and ecosystem services provided, at either local (Giau, 1998; Häyhä et al., 2015) or regional level (Grêt-Regamey et al., 2008; Bernetti et al., 2013; Felardo and Lippitt, 2016). Other works, such as those by Adams et al. (2003) and Huth et al. (2005) have proposed spatial-based models that were focused on harvesting risks and impacts; on selecting the most suitable harvesting method (Yoshioka and Sakai,

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[1] Stumpage is a partial balance defined as: $S = p\,x - c(x)$, where: p is the "price" of timber, that is, its market value per unit of timber assortment; x is the quantity of timber, and $c(x)$ is the cost of felling a unit of timber and transporting it to the market.

[2] The total economic value (TEV) of a resource is the sum of its direct, indirect, option and existence values.

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2005 Kühmaier and Stampfer, 2010), on addressing forest management and policies over large areas (Linehan and Corcoran, 1994; Puttock, 1995); or on evaluating timber availability and its harvesting costs at a regional level (Nakahata et al., 2014). However, none of these works has dealt with the estimation of the harvesting cost of logging operations at a stand level. A similar spatially explicit approach, aiming at optimising forest management from an economic point of view, was already presented in Hartl et al. (2013). There, the stumpage price of harvests was computed in relation to the achievable timber volume, without taking in account alternative strategies of work organization and environmental aspects of stands. Similarly, the Biomasfor model (Sacchelli et al., 2013b) stands for its ability to match ecological and technical data, assessing the economic results of harvest with the stumpage price method. On the other hand, harvests are analysed at regional level, not identifying each considered stand.

The present work, which is based on the classical assessment method, presents a cost analysis for each logging phase of a forest cut, and achieves an economic evaluation of an area managed by a local forest consortium. In order to make the economic evaluations consistent for management purposes, a GIS-based Decision Support System (DSS) was set up. DSSs are becoming common tools in the environmental planning context, as they are able to integrate spatial information, economic evaluations and operational issues (Thompson and Weetman, 1995; Segura et al., 2014) to optimise managers' choices (Diaz-Balteiro and Romero, 2008). Many works concerning land use and land management (Geneletti, 2004; Borgogno-Mondino et al., 2015a; Romano et al., 2015) reported the effectiveness of these systems, and the positive consequences from their adoption have been pointed out (DE Meyer et al., 2013). Their application can be very versatile depending on the aim and territorial level. For example, Sacchelli et al. (2013b) and Puttock (1995) related harvest costs to forest biomass while Pussinen et al. (2001) and Nakahata et al. (2014) analysed cost dependently from spatial scale (national to locacl). Moreover, to avoid subjectivity effects that can occur when non-homogeneous parameters are simultaneously evaluated (Bottero et al., 2013 Sánchez-Lozano and Bernal-Conesa, 2017), DSSs are often supported by Multi-Criteria Decision Making approaches, which allow factors pertaining to both the territory and the environment to be considered simultaneously.

In this context, an operational DSS in form of a *Spatial-based Economic Model* (hereafter called SEM), was developed. To create an effective operational tool able to consider the productive aspects of forest management in a mountainous environment some essential conditions had to be fulfilled. Particularly, our DSS is supposed to supply forest managers of local level information, (Costa et al., 2010); to evaluate the particular silvicultural aspects of a mountainous areas (Spinelli et al., 2013); to support harvest planning in the short-medium term and to favour positive outcomes for landowners and benefits for the local community (Carvalho-Ribeiro et al., 2010 Brukas and Sallnäs, 2012). The present model aims at describing the whole estimation process, considering territorial features and standard logging strategies. The economic results are expressed as the most likely harvest cost, in consideration of the operating features of the compartment. The adoption of SEM at a local level would represent an effective tool to support local forest managers' decisions (West et al., 2013), and would lead to several benefits concerning planning and management activities (Angehrn and Jelassi, 1994; Hung et al., 2007).

2. Materials and methods

2.1. Study area

The study area where *SEM* was built is located in the upper Susa valley, in the Piedmont Region, North-West Italy. The compartment, part of the town of Oulx (Fig. 1), extends over 455.62 ha, and it is included in the local Forest Management Plan (FMP), which is the current forest planning instrument. This area has a widespread road network (average density of 55 m ha^{-1}); its altitude ranges from 1200 to 2100 m a.s.l. and the main forest category is represented by larch stands (*Larix decidua* Mill.), even though Norway Spruce (*Picea abies* (L.) H. Karst.) and Scots Pine (*Pinus sylvestris* L.) stands can be found at lower, north-facing sites. Larch reforestation is at present underway on the south-facing slopes.

This compartment was selected as a case study because of the productive destination of its forests, its favourable orographic and fertility conditions and a long-standing active management. The latter condition is due to the Consorzio Forestale Alta Valle Susa, a forest management consortium that operates in the whole Upper Susa Valley. Its presence in the area has to be considered positively, since in the Italian Alps, in spite of the steady spread of woods of the last decades (Gasparini and Tabacchi, 2011), the forestry sector supplies only 1% of the national primary sector income (Secco et al., 2017), with a wood increment exploitation of 24% (http://eurostat.ec.europa.eu). This is one of the lowest rates in Europe, even though the data should not be considered completely reliable because of illegal selling on the local firewood market (Pettenella, 2009). This general situation is leading to an increasing number of abandoned forests and under-exploited timber resources (Bätzing et al., 1996; Coppini and Hermanin, 2007), negative aspects that can be faced through an effective management and a steady timber market, two conditions ensured by the consortium.

2.2. Data

Since SEM was set up as an operational tool for forest managers, the considered spatial features were modelled in a GIS so they could be mapped and then related to economic and operational data.

The *Map of the Stand Structure,* which is included in the FMP and supplied in polygon vector format, depicts the vertical and horizontal organization of forest stands, according to their past management and stage of development (IPLA, 2003); it also divides them into blocks (Armitage, 1998). These blocks share a common stand structure, and represent the smallest management unit located by the FMP (Bagnaresi et al., 1986). Because of their dimensions and homogeneity, the blocks were assumed as the harvesting units on which silvicultural cuts are scheduled. The topographic features of the area were mapped using the Regione Piemonte Digital Terrain Model (DTM), supplied in raster format with a 5-m grid size and a height tolerance = 1.44 m (http://www.geoportale.piemonte.it). Qualitative data related to the assortments, orography, road network and timber volume of the forest blocks were obtained from the current FMP. Since the data were supplied as a text document (report), the relevant information was selected and organised in a relational database. Other inputs were obtained from: a) literature, regarding for example, technical and economic data on the organization of the logging operations, productivity and hourly costs for machines and manpower (Hippoliti and Piegai, 2000; Lubello, 2008; Blanc, 2010), and b) interviews with forest managers and workers, to define the features and limits of the considered harvesting techniques.

From an economic perspective, the stumpage price method was considered as most effective to evaluate the harvesting costs of mature forest stands, while other elements, such as ecosystem services, were not included, since they were not considered relevant for this work. Similarly, any revenues derived from timber selling were not computed either, as they are not influenced directly by the forest managers' decisions.

Several logging strategies were included in this model to identify the most suitable harvesting method. With the support of the aforementioned forest consortium, it was possible to define accurately all the fundamental technical and economic parameters in consideration of the forest and area features. The use of constant and standard values allowed the most likely estimate of the standard economic operator strategies to be built for standard market conditions (Merlo, 1993).