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Optimization of Scots pine (*Pinus sylvestris*) management with the total net return from the value chain

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ABSTRACT

Constant unit prices for sawlogs and pulpwood are commonly used in the valuation of a forest stand. We analyzed the optimal management strategy at the stand level in even-aged pine stands in the case where stems are valued based on the prices and predicted quantities of the end products of the sawing process at the stand level (QualityPremiumCase). The QPC was then compared to the base case (BC) in which quality indifferent unit prices are used.

We used a simulation-optimization system OptiFor in which a process-based growth model PipeQual provides growth predictions that include input variables for models that predict the lumber grades and by-products percentages of the total volume of stems. Growth model predictions, harvesting cost function, and models for predicting the yield of various sawn wood grades and by-products of the sawing process, in addition to exogenous unit prices and processing costs were used for calculation of the bare land value as a function of the decision variables. Numerical optimization, by Osyczka's direct and random search algorithm was used to determine the management regime that maximized the bare land value for both cases.

Fewer thinnings in the QPC were optimal compared to the BC. Thinnings were heavier, and time intervals between thinnings were longer in the QPC than in the BC. The yield of sawn wood was significantly higher and the quality distribution of sawn wood better in the QPC. It was also found that optimal management regimes obtained by constant unit prices may lead to raw material supply, which is not profitable for sawmills to process.

Introduction

Determining optimal management at the stand level is a widely studied branch of forest economics. How roundwood price is expressed is one of the main factors that define the value of a particular forest management regime. General formulation for the bare land value (BLV), commonly referred as the Faustmann formula, entails that the amount of wood is given as a function of time and then multiplied by a constant price (Eq. (1)) (e.g. Johansson and Löfgren, 1985; Amacher et al., 2009).

$$V = \frac{[pf(T)e^{-rT} - c_0]}{(1 - e^{-rT})} \quad (1)$$

where p is the constant price, $f(t)$ stand volume at time t, T the rotation age, r the interest rate, and c_0 the regeneration cost. Although it is easy to solve analytically for the optimal rotation age, the formulation as such does not fit well for defining optimal management regimes (Valsta, 1999). The constant mean price for timber without dependence on the dimensions of the timber at age T (or at the time of thinning) causes unrealistically short rotation ages, when the roundwood trade dimensions are the primary determinators for the market value of roundwood. Empirical studies that aim to determine the optimal management regime, especially in Finland, have used constant prices for sawlogs and pulpwood, since statistical data for market prices are widely available. However, when a single price for all size and quality classes of logs is used in the analyses, the results may differ drastically from those cases in which more information on the quality premium is used. Several light thinnings from above may become optimal in analyses where the only price threshold is met when trees pass the lower dimension limit for logs.

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Scots pine (*Pinus sylvestris* L.) is the most important species for the saw milling industry in Finland. During the last decade pine sawn wood production has ranged from 4.8 to 6.7 billion m^3 from which clearly more than half have been exported (Finnish Statistical Yearbook of Forestry, 2013). The value of roundwood for processing industry is strongly dependent on the properties of stems, thus the pricing system should effectively carry the information down from the buyers to the forest owners so that the price is indicative of the value of certain quality attributes. Price guides the decision making at three different levels, specifically: (1) it values different forest management options and guide forest management decisions in the long run. (2) it defines the value of a certain stand for wood procurement and (3) it controls the bucking procedure (Gjerdrum, 2009). Almost all Finnish roundwood is traded as standing sales so that the owner sells the permission to operate and the buyer then carries out all the activities from harvesting to logistics and timber is usually measured by the measurement unit used by the harvester. The prevalent pricing method involves assortment pricing where assortments are sawlogs and pulpwood and price is indicated per solid cubic meter with bark. Typical requirements for sawlogs are: at least 15 cm top diameter, maximum sound knot size 6 cm and dry knot 4 cm and sharp crooks, rot, blue stains or worm holes are not accepted (Malinen et al., 2010). The sawmill industry has lately expressed concern that processing small diameter logs has not been profitable since the unit price used in roundwood acquisition is constant for all log sizes and qualities and have not reflected the end-product prices or processing costs (K. Merivuori, Director of Finnish Sawmills Association, Personal Communication, 14th March 2016). In addition, pine was strongly favored in the regeneration from 1960s to early 1990s, in near future a bigger share of final fellings will therefore be conducted in pine dominated stands. Pine was planted in all site types, including sites where soil was too fertile or impermeable to be optimal for pine production (Vuokila, 1982). This potentially causes challenges for processing industry and heightens the need for a pricing mechanism that include incentives for forest managers to achieve higher quality and larger diameter logs. It has been showed (i.e. Hudson et al., 1998) that incorrect price information on quality differentials results in suboptimal production decisions along the whole production chain.

Roundwood quality from the perspective of raw material supply for manufacturing has attracted relatively little research interest, despite its importance to the total value of the production chain from forest management to wood processing industry (Malinen et al., 2015). Since roundwood pricing has not been commonly based on quality attributes in Finland, price data of different quality classes of logs is scarce for empirical studies. Beyond that, studies that utilize the specific prices of end-products for roundwood valuation in stand level forest management optimization is to the best of our knowledge non-existent and thus this study is the first attempt to fill that gap. As a next step from the formulation of the forest management problem without intermediate costs or revenues [Eq. (1)], the effect of thinning for the optimal forest management regime was considered in several early studies (e.g. Brodie et al., 1978; Kao and Brodie, 1979; Bullard et al., 1985). However, in these studies the quality of roundwood was only related to the size of the stems removed. Only few studies have considered timber quality and its value in detail in stand level management optimization. Haight et al. (1995), predicted stem sweep (curvature) in loblolly pine trees following wind damage and used predictions to value stems given stumpage prices that depend on diameter, height, crown length, and sweep. They used that valuation method to determine optimal stand management following damaging storms. Möykkynen and Miina (2002) combined a distance-dependent spatial growth model and a model for the spread of the fungus that causes butt rot in spruce stands in order to optimize the management of infected stands. Some studies have successfully examined the effects of silvicultural treatments on the quality aspects of timber, by using detailed information on branches and crown structure and then used the various techniques for evaluating the quality at the stand level in case study-type settings (e.g. Väisänen et al., 1989; Mäkelä et al., 2000; Ikonen et al., 2003). Cao et al. (2008) took a different approach to quality and compared the value of roundwood by using the process-based growth model in simulations when the attributes of fibers of spruce had different value classes, based on their suitability for pulping.

Predicting the value of timber by taking into account its quality entails a very detailed description of the growth and development of the stand. The linkage of management decisions to their effects on the quality of timber, necessitates that the growth model should be able to react dynamically through physiological processes affected by these decisions. Process-based growth models based on the theories of ecological processes and structural regularities fit well the purpose of studying forest management when the causal effects on quality attributes are crucial for recognition. Hyytiäinen et al. (2004) were the first to incorporate a process-based growth model in economic optimization at the stand level and applied the approach by taking into account the quality distribution of roundwood in pine-dominated forests. Their quality classification was based on external features such as the size and number of external knots of cut-to-length logs. Logs had four quality categories whose valuation was based on price estimates provided by timber sale professionals. They found that at higher interest rates (3 or 5%), superior quality butt logs were not produced at all in optimal management schedule. Price used for superior butt logs was 71.52 € m^{-3} and 52.98 € m^{-3} for ordinary butt logs. Hyytiäinen et al. (2004) also found that several light thinnings (i.e. four thinnings in *Vaccinium*-type site) would maximize the value of bare land, the thinning type was found to be less important factor.

We analyzed in this study how the valuation of quality attributes of sawlogs affected stand management that maximize soil expectation value. Quality is understood here as the suitability for producing different sawn wood grades and it was valued at sawn wood prices, taking into account the production costs. The objective is to demonstrate the pricing system, which signals the value of each sawn wood quality class, in addition to by-products. Calculations that use the mean prices for timber and pulp wood were performed to determine how the traditional approach differs from management maximizing the net value of sawn products. The inner quality was, in the present study, taken into account, using the yields of sawn wood grades in computing the value of sawlogs. Multinomial logistic regression models for predicting sawn wood quality distribution (Lyhykäinen et al., 2009) were linked to the simulation-optimization tool OptiFor (Cao et al., 2015), which uses the process-based growth model PipeQual (Mäkelä and Mäkinen, 2003). OptiFor uses Osyczka's (1984) implementation of Hooke and Jeeves' direct and random search algorithm to determine the number of thinnings, thinning intensities, and rotation periods that maximize the net present value of sawn wood and by-products (pulpwood, sawdust, chips, and bark) of the sawing process. The analysis also takes into account the costs of forest management.

Materials and methods

Initial stands

Computations of optimal treatment were conducted for 11 sample Scots pine stands (Table 1). The same stands have been used in background calculations for silvicultural recommendations in Finland (Hyytiäinen et al., 2010) and by Cao et al. (2015). Stands data were generated using the data from permanent sample plots. Diam-