**Assessing the timber value: A case study in the Italian Alps**



*Published version:*

DOI:10.1016/j.forpol.2018.05.010



(Article begins on next page)

# Assessing Timber Value: a case study in the Italian Alps

Cristian Accastello*, Simone Blanc, Angela Mosso, Filippo Brun

University of Turin, Department of Agriculture, Forest and Food Science (DISAFA), Largo Paolo Braccini 2, 10095 Grugliasco, Italy

∗ Corresponding author. E-mail address: cristian.accastello@unito.it (C. Accastello).

## Abstract

In the Piedmont region, in North-West Italy, the abundance of unmanaged woods has led to negative environmental and economic consequences, generating a decrease in the ecosystem services supplied and in the provision of low-value timber products. In this context, increased logging activities could create new development opportunities for the rural areas in which most of the abandoned stands are situated.

This work analyses a forest harvest by creating a model to evaluate its Timber Value. The economic results were analysed to investigate the structural and logistic factors influencing the profitability of a harvest. The results obtained revealed that a small profit margin is achievable for small local logging companies, even if strongly influenced by the hourly costs of labourers.

To quantify the influence of each factor of the model on the timber value, a sensitivity analysis was performed. Then, to test the robustness of the results a Monte Carlo simulation was carried out simultaneously varying the factors involved. Finally, a scenario analysis was performed, in which the standard conditions referring to the most common private forest company typologies were examined.

Overall, these methods were found to be suitable for our aims and capable of supplying important results to analyse a forest harvest from an economic perspective.

## Keywords

Timber value; sensitivity analysis; forest harvest; Monte Carlo simulation; Italian Alps

## Highlights

- A model to compute the Timber Value of a harvest in chestnut coppice was built
- The model was statistically analysed to measure the influence of factors on its results
- Sensitivity Analysis, Monte Carlo simulation and Scenario analysis were performed
- Results support logging companies in improving their economic performance

## Introduction

It is commonly accepted how the active management of forests can enhance the liveability of local communities in rural areas both from a socio-economic and environmental perspective, supporting local timber markets and ensuring the provision of several valuable Ecosystem Services, such as protection from natural hazards, recreation and biodiversity (Frank et al., 2015, Fürst et al., 2010). Therefore, in some European countries characterized by low rates of forest exploitation (as is the case in Italy, where the harvest rate is 23% of the growth rate) (Secco et al., 2017), measures and instruments capable of assisting forestry operations could play an important role in supporting the forestry sector at both policy and economic levels. In this context of under-exploitation of forest resources, enhancing the value of the existing coppice forests can represent a consistent opportunity, where these new measures and instruments could be adopted.

Coppice forests, that cover more than 18M ha in Europe (19% of which are in Italy) (Angelini et al., 2013) represent a paradigmatic example of a natural environment which has been profoundly shaped by human intervention. Past management has modified the species composition and structure in order to mainly provide small-sized fuelwood production (Fabbio, 2016). Due to this close relationship with the surrounding human settlements, exploitation of coppices has followed the evolution of society. In Italy, over the last 70 years, these rural areas, where most of these forests are located, have suffered a vast depopulation (Pelleri and Sulli, 1997), that has led to the abandonment of large areas of agricultural land and actively managed forests, allowing secondary woodlands to proliferate (Bätzing et al., 1996, Coppini and Hermanin, 2007). These phenomena, occurring mainly in the Alpine areas, consequently caused a decrease of the ability of forests to cope with natural hazards (Vogt et al., 2006) and reduced the quality and quantity of the harvested timber (Fonti and Giudici, 2001), which is still not sufficient to satisfy national demand (Secco et al., 2017).

In order to support the development of the forestry sector in Italy, many political efforts have been undertaken on both national and regional scales (Quatrini et al., 2017, Marchetti, 2018), with several measures focusing on coppices (Mairota et al., 2016). In addition to these policy measures, the scientific community produced several works addressing this topic, including among others: the benefits deriving from the sustainable active management of coppices studied from the perspective of biodiversity (Mattioli et al., 2016, Müllerová et al., 2015), natural risk reduction (Vogt et al., 2006), logging impacts (Venanzi et al., 2016) and policy solutions (Fabbio, 2016). Nonetheless, this current discussion seems lacking in the evaluation of economic aspects: for this reason, this paper is an attempt to rectify this shortcoming, by establishing a model to analyse the harvesting operations in a coppice forest, in order to define the main factors influencing their economic results.

The selected study area is a chestnut (*Castanea sativa* L.) coppice located in the Piedmont Region, in the Western Italian Alps. In Italy, this typology of coppice covers almost 1M ha, equal to 27% of all Italian coppices (Angelini et al., 2013) and represents a valuable example of the effects of the different societal trends that influenced forest management over the last decades. In the past, thanks to the many different products that chestnut stands were able to provide (Mariotti et al., 2008), society favoured their presence throughout all the mountainous areas in the country, generating a veritable "Chestnut culture" (Conedera et al., 2004). Then, from the Seventies onwards, the spread of some virulent pathogens, such as Ink Disease (*Phytophthora cambivora* (Petri) Buisman) and Chestnut Blight (*Cryphonectria parasitica* (Murrill) Barr.) (Turchetti and Maresi, 2006, Turchetti et al., 2008), and the related physiological problems, such as Ring Shake, limited their use (Macchioni and Pividori, 1996, Fonti et al., 2002). Consequently, these limitations provoked a clear change in their management, shifting from coppice to high forest, or frequently to abandonment (Arnaud et al., 1997, Conedera et al., 2001). From an economic perspective, this change also influenced the profitability of these stands: in fact, the lower value of the achievable wood products, made the economic return of their exploitation uncertain. Currently, chestnut stands are the most common forest type in the Piedmont Region, covering an area of 205,000 hectares, equal to 23% of the forests covering the regional territory (Gottero et al., 2007), and also one of the most common in Italy, but their fate is still uncertain. Therefore, the framework we developed aims to illustrate the potential revenues that can be achieved through a return to the active management of these stands, by providing a reliable economic analysis of the forest harvesting process, taking into consideration both the revenues that can be obtained from the different timber products and the costs associated with logging operations.

To reach this goal, we i) set up a model to evaluate, from an economic perspective, the most likely timber value of a harvest and then tested it on a representative case study located in the Western Italian Alps; ii) assessed the effect and intensity of the variation of the economic and technical factors on the results of the model, through a sensitivity analysis of its parameters and the evaluation of their elasticity; iii) proved the robustness of the results, by applying a reiterative probabilistic analysis based on a Monte Carlo simulation model; and finally, iv) built a scenario analysis with the standard features of the two most common types of private logging companies in the study area, whose characteristics are also well suited to the Italian context. This set of analysis is intended to be employed to compare and analyse the drivers which most profoundly affect the profitability of a harvest in different areas and when adopting different work methods. Moreover, its application with real data from the standard logging companies in the area will also be relevant for entrepreneurs, in order for them to evaluate the management of their logging operations from an economic perspective and to support the definition of the most suitable business strategies to implement their company performance.

## *2 Materials and Method*

*2.1 Case study*

The data needed to build the timber value (TV) model was obtained from a case study conducted in the Ormea territory of the Piedmont Region, a small municipality in the Western Italian Alps, 800 m above sea level. The analysed chestnut stand is an over-mature coppice stand, with sporadic sycamore (*Acer pseudoplatanus* L.), European ash (*Fraxinus excelsior* L.) and rowan (*Sorbus aucuparia* L.) trees, covering a total area of 0.42 ha. A forest road, suitable for use as a bunching site, where the timber can be collected before its extraction, constitutes the lower boundary of the stand. This area, whose features are consistent with most of the privately-owned coppice forests of the Region (Gottero et al., 2007), can also be considered as an example of the most common state of Italian coppices, where the lack of management has negatively influenced the profitability of the harvest (Moscatelli et al., 2007). In Piedmont, at least 30% of chestnut stands are either abandoned (Manetti et al., 2006) or over-aged and under-exploited (Gasparini and Tabacchi, 2011). Moreover, 89% of these stands in this Region are privately-owned (Gottero et al., 2007), and generally affected by a fragmentation of ownership that negatively influences harvesting activities (Brun et al., 2009). This phenomenon is clearly evident in the statistical data collected from the Italian Statistics Institute (ISTAT), which states that the average harvest area in the Western Alps is equal to 0.46 ha (Istat, 2015), while the area of forest operations in coppice forests, referring to the Piedmont Region, varies from 0.43 to 0.78 ha (Brun et al., 2014a). Therefore, this study can be considered representative of the current forestry situation in the area, securing validity to the results.

The dendrometric data was collected through field surveys with complete callipering of the trees and measurement of a relevant number of tree heights. This data allowed us to employ the Italian Forest National Inventory (IFNI) log rules (Castellani et al., 1984) to estimate the total wood volume of the area, equal to 494 $m^3$/ha.

The stand is an over-aged chestnut coppice stand; since the production of new sprouts for this species is only marginally influenced by the age of the stump (Conedera et al., 2001), the current Regional Forest Law defines specific rules for its management (art. 56; Law 8/r – 2011). In particular, for chestnut stands, no maximum rotation period is defined by law, but a minimum crown cover percentage after harvesting, equal to the 10% of the initial volume, is required. Moreover, it should be noted that pathogens such as ink disease and chestnut blight resulted to be widespread in the stand, negatively influencing the quality of the products.

*2.2 Timber Value model*

To understand how the structural and logistic features of logging companies operating in the Piedmont Region influence the TV of a forestry operation, a model capable of describing and analysing the whole process was developed. TV is the most common measure used to estimate the value of a mature forest stand (Faustmann, 1995, Chang and Gadow, 2010, Navarrete and Bustos, 2013) and is defined as the value of standing timber, as determined from the sales price at the landing location, minus all harvesting costs (Armitage, 1998, Nieuwenhuis, 2000, Amacher et al., 2009). The model we created examines all the positive and negative items in the economics of the logging operation. Regarding timber revenues, the quantities and market values of the assortments were estimated. As for costs, all the segments of the logging operations needed to perform the harvest were analytically considered, and subsequently formalized into a framework able to take into account different harvest types. The TV per cubic meter was then obtained by dividing this value by the extracted wood volume: this value was used as the reference value in this study and in the following analyses. The data acquisition of all the information necessary to build the TV model, e.g. wood volume, achievable products, hourly yields, machinery costs, manpower costs and market prices, is a complex and accurate operation. In fact, all technical and economic data was collected both in the field or by means of a literature review of relevant studies (Picchio et al., 2011, Brun and Blanc, 2017). This data can be divided into three categories: a) ordinary objective data, namely the organization of the logging operations; b) complex objective data, such as the collected and elaborated dendrometric data; c) estimated information, such as the hourly yield and the opportunity costs from the logging company internal data.

### *2.2.1 Revenues*

The main data source concerning timber revenues is the timber market itself, pertaining to both the features of the most common assortments and their price. According to the literature on chestnut timber (Nosenzo, 2007), its products are usually divided into: i) first grade poles, which are straight logs without knots and can be used for natural engineering works; ii) second grade poles, which are mostly straight logs with a limited number of knots that do not affect their technical qualities and are generally used for vineyards and other plantations; and iii) chipping wood for local biomass energy plants. Considering these constraints, the overall amount of the revenues is derived from the product of the *n* product and its respective price (Eq. (1)).

$$R_{ass} = \sum_{i=1}^{n} p_i \cdot q_i \qquad (1)$$

where $R_{ass}$ is the revenue originated by the trees equal to the sale of the assortment (€) at the landing site; $n$ is the number of the considered assortment; $p_i$ is the price of the $i$ assortment (€ $m^{-3}$) and $q_i$ is its volume ($m^3$).

### *2.2.2 Costs*

In order to compute the costs of the harvest, it is first necessary to define the characteristics of the logging operations and their organization, on which the hourly yield depends (Gautam et al., 2014). Despite recent innovations in terms of harvest mechanization and the development of machines that are able to perform different operations over a wide range of conditions (Cavalli, 2008), a traditional organization of harvesting operations still prevails in Piedmont (Picchio et al., 2011). Therefore, a "Short Wood System" was adopted for the harvest. This traditional system, characterized by low mechanization, low budget machinery, often derived from agriculture, and a limited number of employees for each company (Spinelli et al., 2004, Gautam et al., 2014), represents the standard method adopted in the area. In fact, most private companies cannot afford to employ more than two workers, or buy highly mechanized machines, such as harvesters and forwarders (Blanc et al., 2017).

In order to properly compute the costs of the harvest and since different hourly yields and timber volumes were involved, it was necessary to consider the different phases of the logging operations separately, because each phase requires different machinery and manpower. In addition, the wood volume is also influenced by the considered phases. The extracted volume is often lower than the felled one, due to the processing operations, which assume a certain percentage of wood waste. The wood waste value adopted in this study was the 10% of the felled volume, a value consistent with other similar works (Giordano, 1981, Carbone et al., 2013).

According to the Short Wood system employed, the required logging operations are: i) felling and processing, where trees are cut, delimbed, topped and bucked in merchantable lengths; ii) bunching, when poles are transported to the landing site; iii) extraction, when the trunks are hauled to a truck road. The cost of each phase includes machinery and labour costs, where the work hours were computed in consideration of the characteristics of the harvest and of the working strategy adopted (Picchio et al., 2011). It should be pointed out that the number of machinery and labour work hours may not be identical, since some operations can be performed without the need to employ machines. Moreover, as far as the hourly labour costs are concerned, it is important to underline how this amount changes greatly in relation to their source. In this context, two options were defined. The first option is when the workers' wage is considered as external to the company, the price is defined by national agreements, and considered as a full cost for the company (Blanc, 2010). The second option is when it is internal to the company, e.g. because it is performed by the entrepreneur himself or a member of his family, the workers' wage can be evaluated as an opportunity cost (Posnet and Ian, 1996, Brun and Mosso, 2014), that is, the salary of the alternative activity the worker decides to forgo. By contrast, the hourly machinery costs were computed analytically, considering both the fixed costs (capital recovery, interest and depreciation, taxes and insurance) and the variable costs (fuel, lubricant, repair and maintenance costs) that contribute to the final cost amount (Miyata, 1980, Sierra-Pérez et al., *in press*).

The harvesting costs of the general *i* phase were thus obtained by multiplying the number of hours of work of the *j* machines utilized by their cost per hour, then adding the hours of work of each worker multiplied by the respective unitary costs (2):

$$Cp_i = \sum_{j=1}^{n} q_j \cdot uc_j + \sum_{k=1}^{m} q_k \cdot uc_k \quad (2)$$

where $Cp_i$ is the cost of a general *i* phase (€); $q_j$ is the number of hours of employment of the general *j* machine (h); $uc_j$ is the average unitary cost of the *j* machine (€ $h^{-1}$); $q_k$ is the number of hours of employment of the *k* typology of worker (h); $uc_k$ is the average unit cost of the *k* typology of worker (€ $h^{-1}$); *i* is the number of considered phases; *j* is the number of employed machines and *k* is the number of employed workers.

The number of the employed $q_j$ and $q_k$ factors is influenced by both the wood volume of the harvest and the productivity rate of each phase, namely (3):

$$q = \frac{V}{r} \quad (3)$$

where *q* is the number of employed factors (h), *V* is the wood volume processed by a machine in a general *i)* phase ($m^3$) and *r* is the productivity rate ($m^3$ $h^{-1}$).

The volume is a complex objective datum, and its amount was obtained after processing the dendrometric data using volume tables, whereas the productivity rates were estimated following a literature review (Hippoliti and Fabiano, 1997, Hippoliti and Piegai, 2000, Blanc, 2010). This data was then adapted to the conditions of this study, including environmental adaptations such as slope, road network and terrain roughness, and logistic adaptations such as the extraction distance and harvest intensity, which are determined by features of the harvest site (Accastello and Brun, 2016).

The harvesting costs were computed by summing the amount of each phase, using equation [2]. According to other authors (Carbone, 2008, Picchio et al., 2011), the administrative costs, interest and earnings of the logging company were then added and subsequently evaluated as 5% of the cost of the operations. The TV is the difference between the revenues obtained from the sale of the timber and this sum of costs; the TV per cubic meter is then obtained by dividing this difference by the felled wood volume (4):

$$TV = \frac{R_{ass} - C_{tot}}{V} \quad (4).$$

where *TV* is the Timber Value (€·$m^{-3}$); $R_{ass}$ is the revenues obtained from the sale of the assortments (€); $C_{tot}$ is the overall amount of costs (€) and *V* is the felled wood volume ($m^3$). This set of operations constitutes the model to calculate the TV of the harvest. This constitutes the starting point for all the following statistical elaborations, which were performed by employing this model and its results.

### *2.2.3 The TV of the case study*

Once the model had been built, it was used to estimate the TV of the case study. According to the environmental characteristics of the stand and the logistic features of the logging operations, all the values required for the model were measured or estimated, depending on the type of data. A market survey (Piedmont Region personal communication, 2017) was performed to define the type and price of each assortment; the collected data is reported in Table 1.

| Assortment | Price (€·m$^{-3}$) |
|---|---|
| 1st grade poles | 70 |
| 2nd grade poles | 60 |
| Chipping wood | 45 |

Source: market survey, 2016.

**Table 1** – The assortments and their price

The logging operations considered to calculate the harvesting costs were: i) felling and processing with chainsaw; ii) manual bunching along the slope; iii) extraction with a tractor and trailer along the existing road. These operations are summarized in Table 2, which also includes the employed machinery as well as its estimated hourly cost and productivity rate.

| Phase | Adopted technique | Productivity (m$^3$ h$^{-1}$) | Employed machine | Hourly cost of the machine (€ h$^{-1}$) |
|---|---|---|---|---|
| Felling and processing | Processing at the felling site | 1.3 | Chainsaw | 3.10 |
| Bunching | Manual along the slope | 1.4 | - | 0.00 |
| Extraction | Forwarding with trailer | 2.9 | Tractor, grapple loader and trailer | 31.90 |

**Table 2** – Description of the features of the logging operations

The most common private logging company structure in the area was adopted for this evaluation: namely, a craftsman enterprise composed of the entrepreneur and one salaried worker. The hourly wage of the former was estimated as an opportunity cost for the company as 15€ h$^{-1}$, while the retribution of the latter was defined, according to national agreements, as a cost of 18.63€ h$^{-1}$. This value was considered the most suitable in relation to the skills required to perform the harvest and the average characteristics of these workers, in terms of years of employment and experience.

### *2.3 Sensitivity analysis*

The Sensitivity Analysis (SA) allows the effects on the result to be evaluated in relation to fixed variations of the variables (Grubbs, 1969, Sobol, 1990, Saltelli et al., 2004). This procedure is also known as a "what if" analysis (Himmelblau and Bischoff, 1968), since it evaluates what happens when a default variation of a factor is hypothesized. A specific SA methodology was developed, according to the features of the variables, in order to measure the TV ranges. The results of the performed SA can supply useful information to optimize the decision process of the harvest, to foster the robustness of the decisions that are made and to highlight the main factors that influence the results of the model (Brainard et al., 2006, Navarrete and Bustos, 2013). Consequently, these factors are also those on which it is appropriate to focus during the estimation process (Koller, 1999).

A local SA has been performed in this study. This technique evaluates the effect of each single input variable on the result through a "one factor at a time" approach (Saltelli et al., 2000). The factors were made to vary singularly over a default range of values, while the other input values were kept fixed. The reciprocal independence of the involved variables is a basic element that ensures the reliability of the results, since they cannot influence each other (Zhang et al., 2012). For this reason, a relevant variable such as the fuel price was excluded from the analysis: in fact, since its variation directly influences the hourly costs of machinery, its inclusion would not have maintained the condition of independence of the variables.

The SA performed on the TV model included 6 independent variables: 3 related to the economic parameters of the model (namely the hourly costs of the machines and the workers involved), and 3 related to technical parameters (namely the productivity rates of the different logging operations) (Hanewinkel et al., 2014). These parameters were made to vary over specific ranges, as defined in the literature (Hippoliti and Fabiano, 1997, Hippoliti and Piegai, 2000, Blanc, 2010), and then adapted to the conditions of the hypothesized harvest, that is, the conditions that were investigated during the field surveys (Moore et al., 2011). The features of each variable are summarized in Table 3, together with their variation range, which was defined following a literature review (Logan, 2011, Picchio et al., 2011).

| **Variable** | **Measurement unit** | **Minimum value** | **Maximum value** |
|---|---|---|---|
| Worker's hourly cost | € $h^{-1}$ | 8.00 | 25.00 |
| Hourly cost of the chainsaw | € $h^{-1}$ | 2.00 | 6.00 |
| Hourly cost of the tractor | € $h^{-1}$ | 20.00 | 45.00 |
| Felling and processing productivity rate | $m^3 h^{-1}$ | 0.75 | 1.75 |
| Bunching productivity rate | $m^3 h^{-1}$ | 0.88 | 1.88 |

| | | | |
|---|---|---|---|
| Extraction productivity rate | $m^3 h^{-1}$ | 1.25 | 3.75 |

**Table 3**– Input variables involved in the SA

The TV variations were then analysed using descriptive parameters to allow a comparison of the considered variables. More specifically, the results were analysed by: i) defining the Break Even Point (BEP) of the variable (Singh and Deshpande, 1982), that is, the value that is able to ensure equilibrium between the revenues and costs (where its position can supply important information about the trend of the variable and the possibility of achieving a profitable harvest); ii) comparing the gradient of the lines, which describes the trend of the relationship between the variables and the results (this elaboration was only possible for the variables that showed a linear trend); iii) calculating the elasticity of this relationship (Pannell, 1997), that is, a parameter that can be used to measure the influence of a variable on the TV (eq. [5]):

$$e = \frac{\Delta Y/Y}{\Delta x/x} \quad [5]$$

where *ΔY/Y* is the variation of the result and *Δx/x* is the variation of the parameter in relation to the value assumed in the estimation. Performing these elaborations on the results of the SA, allowed more information to be obtained about the typology and intensity of the influence of each variable on the TV.

## *2.4 Monte Carlo Simulation*

The Monte Carlo Simulation (MCS) is a reiterative analysis of the results of a model in relation to random and simultaneous variations of its independent input factors, in which a normal distribution of the frequencies of the latter is hypothesized (Saltelli et al., 1999). It is commonly adopted to analyse a model and evaluate the robustness of the results (Confalonieri, 2010, Moore et al., 2011). This methodology allows a greater in-depth analysis of the results and the relationship of the model with the input variables, which are investigated together simultaneously. This technique allows the stability of the results of a model, including a stochastic element in its input variables, to be tested in order to simulate the intrinsic uncertainty of the operative conditions. Due to their characteristics of uncertainty, the productivity rates of the logging operations and the average price of the timber products were investigated. Their features were included in the model by defining a random variability, in terms of standard deviation, equal to 10% of the mean value of each considered variable. This analysis was reiterated 10,000 times to simulate the random variation of the variables.

## *2.5 Scenario analysis*

A Scenario analysis was the last investigation to be performed on the TV model. It consists of the development of hypothetical conditions of interest, characterized by input variable values chosen by the stakeholder, inserted into the model to study the corresponding result (Saltelli et al., 1999). Therefore, it can be considered as a particular case of sensitivity analysis, since a predetermined modification of the factors is established. The creation of these predefined situations can be useful to understand, for example, which of a group of options is the most suitable for the aims of the stakeholder, in order to support his decision-making processes with objective results supplied by the model (Hoogstra-Klein et al., 2016). Actual data pertaining to the two most represented private forest company typologies in Piedmont were introduced as parameters into the model to build the hypothesized scenarios. The comparison of these scenarios makes it possible to highlight how the structural and logistic features of the logging companies can affect the profitability of the harvest. The data necessary to accurately describe the standard conditions of the private companies operating in the area were obtained from the Regional Register of Forest Companies (http://www.sistemapiemonte.it/aifo), which includes organizational, economic and management information about the enterprises operating in the regional territory (Blanc et al., 2017).

The craftsman logging company, which had previously been considered to estimate the TV, and a logging company owned by a farmer are the two enterprises that were tested in the scenario analysis. These two typologies of entrepreneurs constitute more than 90% of the logging companies operating in Piedmont (Brun et al., 2014b). The differences in these two enterprise structures lie within the adopted machinery and labour costs. As far as the farmer's enterprise is concerned, the agriculture sector is supported by fiscal subsidies distributed to purchase fuel, which consequently costs much less, than fuel sold at the market price (almost 50% less). Moreover, the annual number of hours of machine employment is generally higher than the number reached by craftsman enterprises, leading to a lower hourly incidence of fixed costs. As far as labourer's wages are concerned, workers employed in the agricultural sector have lower salaries than those of qualified craftsman workers, as stated in their respective national agreement. Moreover, the entrepreneur's wages have to be considered differently as it is viewed as an opportunity cost, which is defined by comparing these activities with others they cannot accomplish. While harvesting is the main employment of a craftsman, a farmer usually performs forest activities during the winter, when his agricultural activities are less compelling and profitable. These conditions mean that the farmer should be assigned a lower opportunity cost than the craftsman. Finally, because of the simple technical requirements needed to perform the considered harvest, a delta in terms of productivity rate, cannot be precisely defined for the enterprises. The characteristics of the two considered scenarios are described in Table 4, where the differences between the craftsman enterprise (Scenario 1) and the farmer enterprise (Scenario 2) are listed and compared.

| Cost of item | Scenario | Scenario | Measurement |
|---|---|---|---|

| | 1 | 2 | unit |
|---|---|---|---|
| Entrepreneur’s wage (opportunity cost) | 15.00 | 13.00 | € $h^{-1}$ |
| Employed worker’s wage | 18.63 | 14.98 | € $h^{-1}$ |
| Fuel price (11/2016) | 1.06 | 0.65 | € $l^{-1}$ |
| Hourly cost of the tractor | 31.90 | 21.30 | € $h^{-1}$ |

**Table 4** – Characteristics of the two scenarios

## *3 Results*

### *3.1. Timber value*

The revenues derived from the products sale are mainly obtained from the sale of chipping wood, which represents 72% of the wood volume and generates 64% of the revenues. This is because the characteristics of the main species of the stand are not suitable for more profitable utilization, such as construction beams, and pathogens present in the stand had depreciated the value of the majority of the stems. These conditions are, in fact, quite common in these stands, and only a local energy station, to which the chipping wood can be sold, can make the harvest profitable. In this harvest, 440 trees were felled, and a volume of 187 $m^3$ of processed wood was obtained, whose sale ensured the enterprise a total revenue of €9,533 (Tab. 5).

| **Assortment** | **Volume** | | **Revenue** | |
|---|---|---|---|---|
| | **$m^3$** | **%** | **€** | **%** |
| 1st choice poles | 18.99 | 10 | 1329.30 | 14 |
| 2nd choice poles | 34.17 | 18 | 2050.20 | 22 |
| Chipping wood | 136.74 | 72 | 6153.30 | 64 |
| Total | 187.00 | 100 | 9532.80 | 100 |

**Table 5 –** Assortments and their related revenues

The cost of the logging operations were computed according to the methodology illustrated in equations (2) and (3). Administrative costs, interest and earnings of the company were added, and the total cost of the harvest was obtained (Tab. 6).

| **Phase** | **Cost (€)** |
|---|---|
| Felling and processing | 3231.68 |
| Bunching | 2322.99 |
| Extraction | 3218.06 |
| **Cost of logging operations** | **8772.73** |
| Administration cost (5%) | 438.64 |
| **Overall harvesting cost** | **9211.37** |

**Table 6**– Overall harvesting costs

The difference between the revenues (€9532.80) and the overall harvesting costs (€9211.37) led to a positive value of €321.43, for a TV of 1.72 € $m^{-3}$. This demonstrates that the harvest resulted in a positive outcome even though its profit margin is somewhat limited. In this sense, the robustness of the estimation and its sensitivity to the variables that compose it become fundamentally important information to be acquired, as this enables an in-depth evaluation of the achieved economic results.

### *3.2 Sensitivity analysis*

The six variables listed in Table 3 were analysed one by one by means of a local SA. The variables were inserted into the model according to the previously described default ranges of variation. Given the different nature of the relationship between the variables and the result of the model, they were divided into two groups. The first group was formed by the 3 variables related to costs. In fact, they all generate a linear relation to the result of the model, which steadily grows as they increase. The trend that these variables originate is shown in Figure 1. The black dots in Figures 1 and 2 represent the values that were assumed in the economic estimation of the hypothesized harvest. As is evident, they are generally close to the negative values of the y-axes, with each variable ensuring wide improvement margins to its performance.

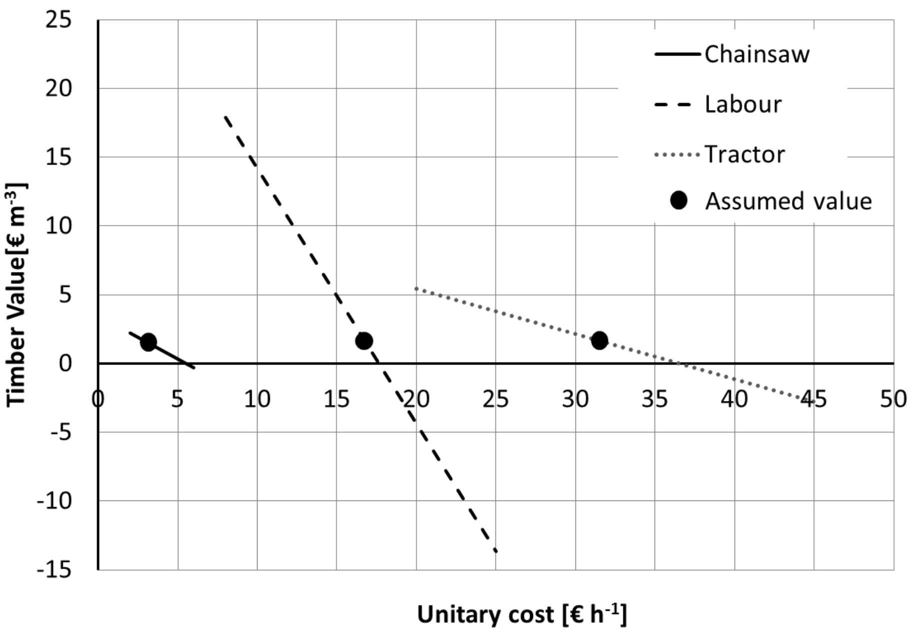


**Figure 1** –The relationship between the hourly operation costs and the TV

The graph clearly shows the influence of each variable on the outcome. In fact, there is a noticeable different width of variation and the gradient they assume. The results of Figure 1 are expressed in terms of BEP, gradient and elasticity in Table 7.

| **Variable** | **Break-even point (€ h$^{-1}$)** | **Gradient** | **Elasticity (%)** |
|---|---|---|---|
| Hourly cost of the chainsaw | 4.27 | -0.63 | -0.7 |
| Hourly cost of the worker | 17.22 | -1.86 | -22.8 |
| Hourly cost of the tractor | 36.54 | -0.33 | -6.8 |

**Table 7** – Analysis of the results achieved with the SA for the three linear variables

In relation to the chainsaw hourly cost, it is apparent how its limited width does not allow the TV to vary extensively, even if, due to its gradient, it has already an influence on the profitability of the harvest, making it vary between positive and negative values. An opposite situation can be observed for the labour cost factor, whose high trend slope and wide range influence the TV to a greater extent, and allow very positive (17 € m$^{-3}$) to very negative (-14 € m$^{-3}$) monetary results to be reached. Finally, the hourly costs of a tractor represent an average situation, since the effects of its wide range are softened by its low slope, which greatly limits the variations of the TV.

The break-even point, whose values are influenced to a great extent by the range width and the unit of measure of each variable, varies between 4.27 and 36.54 € h$^{-1}$. The gradient always resulted in negative values, as also evidenced in Fig. 2. Since the slope of the hourly cost of a worker is the lowest negative value (-1.86), it can be hypothesized to have a greater influence on the result, while the hourly cost of a tractor assumes the highest value (-0.63). This situation is confirmed by the elasticity, where the decrease in the TV as a consequence of a 1% growth in the considered variable, ranges from very low (-22.8%) to nearly zero (-0.7%), in relation to the nature of the relationship between the variables and the results. Therefore, we can assume the results depict a close bond between labour costs, which represent 68% of the overall harvesting costs, and the TV of the intervention, as shown by elasticity values higher than 20%.

The variables related to productivity rates, whose trend is shown in Figure 2, are linked to the result of the model by a non-linear relation, in which steady variations of the variables generate a more than proportional increase in the result before the inflection point, and a less than proportional increase after it.

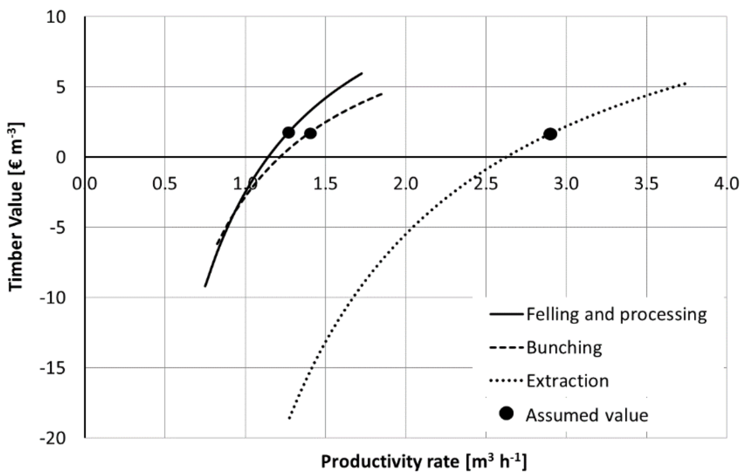


**Figure 2** – Relationship between productivity rates and TV

The significant influence of the extraction phase on the final result clearly emerges in Figure 2. In fact, the width of its variation range and the trend of the curve can be seen to clearly affect the TV, which varies from 5 to -18 € m$^{-3}$. The other two variables regarding the felling, processing and bunching phase, assume a similar trend, whose influence on the TV is limited and mostly ensures positive TV values.

Further analysis was performed in order to quantify the relationship between the variables and the TV, as shown in table 8. The values of the break-even point and the elasticity of the relation are listed for each variable, whereas it was not possible to compute the gradient for them.

| **Variable** | **Break-even point (m$^3$ h$^{-1}$)** | **Elasticity (%)** |
| --- | --- | --- |
| Felling and processing productivity rate | 1.14 | 10.1 |
| Bunching productivity rate | 1.21 | 7.6 |
| Extraction productivity rate | 2.63 | 10.1 |

**Table 8** – Analysis of the results achieved through the SA for the three non-linear variables

The break-even point is very similar for the first two variables, close to 1 m$^3$ h$^{-1}$, while the productivity rate of the extraction phase assumes a value of 2.63 m$^3$ h$^{-1}$; in any case, it results much lower than the values reported in table 7. Concerning elasticity, the bunching phase has the lowest value, at 7.6%, while the other two factors report the same percentage; all of them have a positive influence on the result, allowing it to increase substantially even with 1% variations.

## *3.3 Monte Carlo simulation*

The Monte Carlo simulation took into consideration the simultaneous variation of the three productivity variables of the logging operations and the mean price of the products. While the former were left free to range over a delta of 10% of the standard deviation of their mean value, precise boundaries were fixed for the prices. In fact, the minimum value was set at the price of the least valuable assortment, that is, chipping wood, in order to simulate realistic market conditions, while the maximum was set at the price of the second grade poles. The results of the 10,000 simulations performed are shown in Figure 3, which shows the trend of the function on the cumulated frequency percentage of the TV.

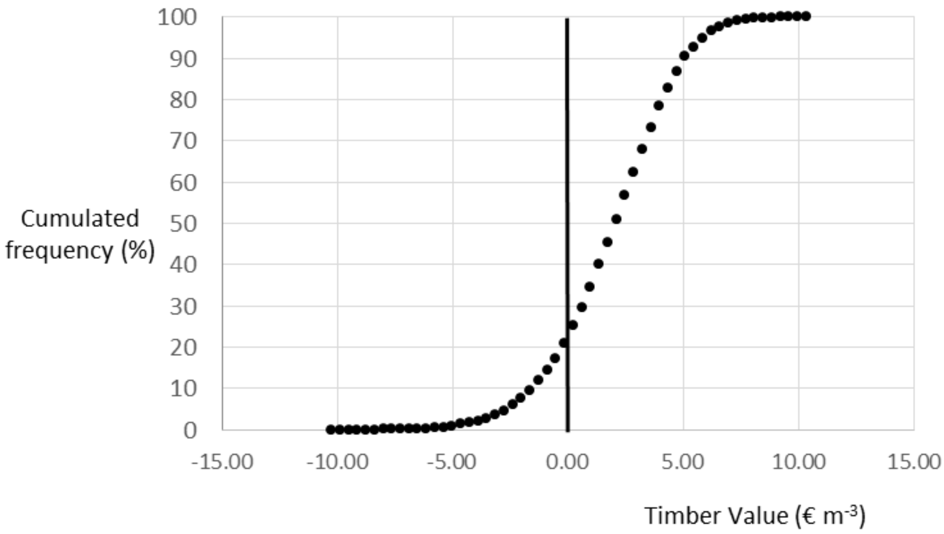


**Figure 3** – Distribution of the cumulated frequency (F%) of the TV

As can be noticed, the TV varies from -12 to 10 €$m^{-3}$, due to the simultaneous variation of the productivity factor, thus confirming its great dependence on the input variables of the model. The graph supports the robustness of the results of our estimation, since the most frequent output is a positive economic result. In the MCS, 68% of the cases led to a profitable harvest.

### *3.4 Scenario analysis*

The economic results of the harvest were computed for the two hypothesized scenarios based on the values reported in Table 4, which lists the differences between the two types of enterprises considered (Table 9).

| **Scenario** | **Enterprise typology** | **Overall unitary harvesting cost (€ $m^{-3}$)** | **TV (€ $m^{-3}$)** |
|---|---|---|---|
| 1 | Craftsman | 49.26 | 1.72 |
| 2 | Farmer | 35.87 | 9.31 |

**Table 9 –** Comparison of the main economic parameters achieved for the two scenarios

As shown in table 8, the enterprise run by the farming entrepreneur achieves better results in terms of economic profitability of the harvest, with a lower harvesting cost of 7.59 € $m^{-3}$. This positive result is also evident when compared to the craftsman, when the TV value is approximately six-fold. This favourable situation, as previously mentioned, is mainly due to the lower hourly costs of the machinery and of labour. Moreover, it can be hypothesized that the results achieved for the farm enterprise are much more robust than the ones represented in Figure 3, since the Monte Carlo simulation performed on the values of scenario 2 led to a probability of obtaining negative economic results close to 0%.

## *4 Discussion and Conclusions*

In this study, a model was developed to estimate the Timber Value of a forest harvest in a chestnut stand under standard operative conditions. Each phase of the logging operations has been analysed and included in the model in relation to the standard working protocols of the local companies (Spinelli et al., 2004, Picchio et al., 2011, Gautam et al., 2014). Our case study, characterized by easy accessibility of the stand and organization of the harvest operations, has allowed all the relevant technical and economic factors to be defined and analysed. Even though the analysis only focused on one harvest, given the representativeness of its features, we believe the results of this economic and statistical analysis can be considered to be relevant at Regional and Alpine level and useful to provide some insights related to the management of most of the over-aged chestnut stands in these areas, also thanks to the simulations and to scenario analysis performed. Moreover, since the framework of the model is versatile and able to employ input data that reflects the standard conditions of new study areas (e.g. with further market timber price surveys, or collection of data regarding the most common working organizations and technologies for the area,) it could be used to a great extent for other case studies, allowing the comparison between multiple scenarios.

The approach we adopted to evaluate the TV of the harvest is classic, however, to our knowledge, the manner in which we analysed it from a statistical point of view is innovative and could be adopted in other contexts. Other previous Italian studies (Magagnotti and Spinelli, 2011, Picchio et al., 2011, Spinelli et al., 2012), performed an economic analysis of forest interventions, but the reasons underlying those results were in general little investigated. On the other hand, in this paper the computed TV is a stepping-stone for further analysis that leads to both theoretical and operational insights on their influence on the final result.

More specifically, the sensitivity analysis we conducted, in which all the variables included in our economic model have been considered, enabled the measurement of their influence on the TV (O'Neill et al., 1980, Koller, 1999). This technique has already been adopted in several papers starting from Grubbs (1969) and Sobol (1990) who were the first to focus on this aspect and to define its main framework and rules. More recently, similar research was published by Saltelli (1999) and Saltelli, et al (2004), who focused on describing the different analysis typologies that can be used in relation to the aims of the research and the available data. Similarly, the Monte Carlo simulation also allowed more information to be gained on the profitability of the harvest and on the robustness of our evaluation (Dieter, 2001, Maarit and Kallio, 2010), even though negative economic results were observed for 32% of all the evaluated cases.

At international level, some other studies adopted similar approaches. Among these Whittock et al. (2004) and Oliveira et al. (2012) evaluated the influence of some variables on the incomes derived from plantations by performing a reiterative analysis, while Yoshioka et al. (2002) studied the variation of the cost of biomass production in different harvesting sites. More related to our research are Van Gardingen, et al. (2003), who studied the causes of the variations of the incomes derived from harvesting in relation to different silvicultural management procedures, while other authors have studied the parameters that have the highest influence on the harvest operations, and their effects on productivity (Vangansbeke et al., 2015). This latter work is the most interesting because it adopts a similar approach, combining SA with different scenarios; in our study however, a different scale was considered in order to better reflect the current Italian conditions of the forestry sector and in particular the features of its logging companies.

These aspects were then specifically investigated in the scenario analysis conducted on the data taken from the Regional Register of the Forest Companies, allowing the two most common types of private enterprises in the forest harvest sector to be analysed. This data clearly highlighted the specific features of each of these companies, whose characteristics influence the profitability of the performed harvests to a great extent. In fact, farming enterprises that are able to harvest forest stands clearly emerge to be supported by favourable conditions in terms of labour and fuel costs, which are two elements that do not depend on the personal entrepreneurship skills of the owners. More favourable conditions are also derived from the opportunity of employing the same machines for both the agricultural and forestry activities of these companies, which results in a significant decrease in their fixed costs. On the other hand, this situation entails strong limitations due to the peculiar features of the forestry operations performed in the Alps. While the farmer's enterprise proved to be very well adapted to a context made of small forest blocks of low quality products situated in favourable orographic conditions, we can assume that on higher slopes with fewer available roads, the lack of professional skills and proper forestry machinery would strongly decrease their economic competitiveness. In those cases, the skills of the craftsman enterprise would represent a decisive aspect in ensuring a positive economic outcome from the harvest.

At policy level, even if this research has illustrated the economic potential ensured by the Chestnut stands of the Italian Alps for harvests on small forest stands, several limitations still remain for this sector. They are mainly related to a weak connection with the wood industry, where the demand of Italian wood products is lacking, or even absent, due to their low quality (Ciccarese et al., 2015), and to the territorial governance guidelines, which over previous years have resulted to be confused and discontinuous (Carbone and Savelli, 2009, Secco et al., 2017). While different governance addresses were pursued in the last decades, causing inefficient resource management, in more recent years, some positive initiatives have addressed the forestry sector, promising to deliver a positive outlook for harvest rates and profitability trends. In the Piedmont Region, an innovative law was passed in 2017 to promote the establishment of associations of forest owners, supporting the shared management of private forest areas (Marandola and Romano, 2012, Beltramo et al., 2018). Similarly, within the application of the last period of the Rural Development Fund, 15 Italian Regions out of 20 funded measures to improve the management of coppiced forests (Quatrini et al., 2017) and a new National Forest Law was recently issued (Marchetti, 2018). Finally, decisive progress was made in the development of management guidelines for coppices in order to reduce the influence of the diseases affecting the chestnut in the achievable assortments (Spinelli et al., 2017, Fabbio, 2016).

Overall, the methodologies included in this study can be considered suitable for our aims and capable of supplying important results to analyse a forest harvest from an economic perspective. The model we built considers all the logging operations and makes it possible to simulate variations of its input factors, whose influence on the TV has been evaluated through SA, MCS and scenario analyses. The latter can be particularly useful to support the evaluation of forest entrepreneurs, since they often operate in very heterogeneous contexts, in which there is a lack of predetermined parameters, and often suffer wide profitability variations due to the variation of single factors. The novelty of this study is represented by both the adopted workflow, combining different economic and statistical analyses, and the study area: to our knowledge, other examples of this kind of analysis in the Alpine area have not yet been undertaken.

In the future, our aim is to further develop the model in order to increase the complexity of the harvests examined so more options can be evaluated and compared. This would include the organization of the logging operations and the machinery involved, allowing more useful information about the profitability of the harvest to be supplied to forest entrepreneurs.

## 5 Funding

This work was not supported by external funding.

## 6 Acknowledgments

The Authors wish to thank Marguerite Jones for the English editing and the two anonymous reviewers who contributed to the improvement of the manuscript with their comments and suggestions.

## 7 Conflict of interest statement

None declared.

## 8 References

ACCASTELLO, C. & BRUN, F. 2016. Un modello spaziale per l'analisi dei costi di utilizzazione in un'area montana. *Dendronatura,* 37, 38-54.

AMACHER, G., OLLIKAINEN, M. & KOSKELA, E. 2009. *Economics of Forest Resources,* Cambridge, Massachussets, The MIT Press.

ANGELINI, A., MATTIOLI, W., MERLINI, P., CORONA, P. & PORTOGHESI, L. 2013. Empirical modelling of chestnut coppice yield for Cimini and Vicani mountains (Central Italy). 26, 3037-3049.

ARMITAGE, I. 1998. *Guidelines for the Management of Tropical Forests,* Rome, FAO.

ARNAUD, M. T., CHASSANY, J. P., DEJEAN, R., RIBART, J. & QUENO, L. 1997. Economic and ecological consequences of the disappearance of traditional practices related to chestnut groves. *Journal of Environmental Management,* 49, 373-391.

BELTRAMO, R., ROSTAGNO, A. & BONADONNA, A. 2018. Land Consolidation Associations and the Management of Territories in Harsh Italian Environments: A Review. *Resources,* 7, 19.

BLANC, SIMONE, ACCASTELLO, C., MOSSO, A. & BRUN, F. 2017. L'albo delle imprese forestali come strumento conoscitivo e di aumento della competitività. *AgriRegioniEuropa*, *Article in press*.

BLANC, S. 2010. *Analisi e valutazioni sull'impiego della manodopera e delle macchine nel comparto agro-forestale,* Grugliasco, DEIAFA.

BRAINARD, J., LOVETT, A. & BATEMAN, I. 2006. Sensitivity analysis in calculating the social value of carbon sequestered in British grown Sitka spruce. *Journal of Forest Economics,* 12, 201-228.

BRUN, F. & BLANC, S. 2017. *Aspetti metodologici per la realizzazione della stima del prezzo di macchiatico,* Torino, Italy, Università di Torino.

BRUN, F., GIAU, B. & MOSSO, A. La gestione del patrimonio forestale attraverso forme associate: aspetti economico finanziari. Produzioni agroalimentari tra rintracciabilità e sicurezza. Analisi economiche e politiche d'intervento, 2009 Taormina, Italy. FrancoAngeli, 357.

BRUN, F. & MOSSO, A. 2014. Confronti di reddivitità di cultivar di lampone. *Dendronatura,* 35.

BRUN, F., MOSSO, A. & BLANC, S. 2014a. Analisi delle istanze di taglio presentate in Piemonte nelle ultime stagioni silvane. Torino, Italy: Piedmont Region.

BRUN, F., MOSSO, A. & BLANC, S. 2014b. Utilizzazioni boschive e valore dei prelievi legnosi in Piemonte. *In:* FORESTALI, A. I. D. S. (ed.) *Second International Congress of Silviculture - Designing the future of the forestry sector.* Florence.

BÄTZING, W., PERLIK, M. & DEKLEVA, M. 1996. Urbanization and depopulation in the Alps. *Mountain research and development*, 335-350.

CARBONE, F. 2008. Costi di esercizio delle macchine, delle operazioni e degli interventi selvicolturali. *L'Italia Forestale e Montana,* 63, 333-350.

CARBONE, F. & SAVELLI, S. 2009. Forestry programmes and the contribution of the forestry research community to the Italy experience. *Forest Policy and Economics,* 11, 508-515.

CARBONE, F., SCHIAVONI, L. & SCOCCHERA, C. 2013. Valore di macchiatico: analisi comparativa dei principali schemi di calcolo presenti nella letteratura economico-estimativa nazionale. *Forest@-Journal of Silviculture and Forest Ecology,* 10, 316.

CASTELLANI, C., SCRINZI, G., TABACCHI, G. & TOSI, V. 1984. Inventario Forestale Nazionale Italiano (IFNI) Tavole di cubatura a doppia entrata. *Istituto Sperimentale per l'Assestamento Forestale e per l'Alpicoltura, Trento*.

CAVALLI, R. 2008. Linee evolutive nel settore delle utilizzazioni forestali e dell'approvvigionamento del legname. *L'Italia Forestale e Montana,* 64, 297-306.

CHANG, S. J. & GADOW, K. V. 2010. Application of the generalized Faustmann model to uneven-aged forest management. *Journal of Forest Economics,* 16, 313-325.

CICCARESE, L., PELLEGRINO, P. & PETTENELLA, D. 2015. A new principle of the European Union Forest Policy: the cascading use of wood products. *Italian Journal of Forest and Mountain Environments,* 69, 285-290.

CONEDERA, M., KREBS, P., TINNER, W., PRADELLA, M. & TORRIANI, D. 2004. The cultivation of Castanea sativa (Mill.) in Europe, from its origin to its diffusion on a continental scale. *Vegetation History and Archaeobotany,* 13, 161-179.

CONEDERA, M., STANGA, P., OESTER, B. & BACHMANN, P. 2001. Different post-culture dynamics in abandoned chestnut orchards and coppices. *For Snow Landsc Res,* 76**,** 487-492.
CONFALONIERI, R. 2010. Monte Carlo based sensitivity analysis of two crop simulators and considerations on model balance. *European Journal of Agronomy,* 33**,** 89-93.
COPPINI, M. & HERMANIN, L. 2007. Restoration of selective beech coppices: a case study in the Apennines (Italy). *Forest Ecology and Management,* 249**,** 18-27.
DIETER, M. 2001. Land expectation values for spruce and beech calculated with Monte Carlo modelling techniques. *Forest Policy and Economics,* 2**,** 157-166.
FABBIO, G. 2016. Coppice forests, or the changeable aspect of things, a review. *Annals of Silvicultural Research,* 40**,** 108-132.
FAUSTMANN, M. 1995. Calculation of the value which forest land and immature stands possess for forestry. *Journal of Forest Economics (Sweden)*.
FONTI, P. & GIUDICI, F. 2001. Quantità e qualità della massa legnosa ottenibile da un ceduo di castagno invecchiato. *Schweizerische Zeitschrift fur Forstwesen,* 152**,** 417-424.
FONTI, P., MACCHIONI, N. & THIBAUT, B. 2002. Ring shake in chestnut (Castanea sativa Mill.): state of the art. *Annals of Forest Science,* 59**,** 129-140.
FRANK, S., FÜRST, C. & PIETZSCH, F. 2015. Cross-sectoral resource management: how forest management alternatives affect the provision of biomass and other ecosystem services. *Forests,* 6**,** 533-560.
FÜRST, C., LORZ, C., VACIK, H., POTOCIC, N. & MAKESCHIN, F. 2010. How to Support Forest Management in a World of Change: Results of Some Regional Studies. *Environmental Management,* 46**,** 941-952.
GASPARINI, P. & TABACCHI, G. 2011. *L'Inventario Nazionale delle Foreste e dei serbatoi forestali di Carbonio INFC 2005,* Bologna, Edagricole.
GAUTAM, S., LEBEL, L. & BEAUDOIN, D. 2014. Value-adding through silvicultural flexibility: an operational level simulation study. *Forestry,* 88**,** 213-223.
GIORDANO, G. 1981. Tecnologia del legno, vol. 1. *UTET Torino***,** 938-939.
GOTTERO, F., EBONE, A., TERZUOLO, P. G. & CAMERANO, P. 2007. *I boschi del Piemonte, conoscenze ed indirizzi gestionali,* Torino, Regione Piemonte.
GRUBBS, F. E. 1969. Procedures for detecting outlying observations in samples. *Technometrics,* 11**,** 1-21.
HANEWINKEL, M., KUHN, T., BUGMANN, H., LANZ, A. & BRANG, P. 2014. Vulnerability of uneven-aged forests to storm damage. *Forestry,* 87**,** 525-534.
HIMMELBLAU, D. M. & BISCHOFF, K. B. 1968. *Process analysis and simulation: deterministic systems,* New York, Wiley.
HIPPOLITI, G. & FABIANO, F. 1997. *Appunti di meccanizzazione forestale,* Firenze, Studio Editoriale Fiorentino.
HIPPOLITI, G. & PIEGAI, F. 2000. *Tecniche e sistemi di lavoro per la raccolta del legno,* Arezzo, Compagnia delle Foreste.
HOOGSTRA-KLEIN, M. A., HENGEVELD, G. M. & DE JONG, R. 2016. Analysing scenario approaches for forest management—One decade of experiences in Europe. *Forest Policy and Economics*.
ISTAT 2015. Sistema informativo su agricoltura e zootecnia. *In:* ISTAT (ed.). Roma, Italy.
KOLLER, G. 1999. *Risk assessment and decision making in business and industry: A practical guide,* Boca Raton, Florida, CRC press.
LOGAN, M. 2011. *Biostatistical design and analysis using R: a practical guide,* Chichester, John Wiley & Sons.
MAARIT, A. & KALLIO, I. 2010. Accounting for uncertainty in a forest sector model using Monte Carlo simulation. *Forest Policy and Economics,* 12**,** 9-16.
MACCHIONI, N. & PIVIDORI, M. 1996. Ring shake and structural characteristics of a chestnut (Castanea sativa Miller) coppice stand in northern Piedmont (northwest Italy). *Annales des Sciences Forestières,* 53**,** 31-50.
MAGAGNOTTI, N. & SPINELLI, R. 2011. Financial and energy cost of low-impact wood extraction in environmentally sensitive areas. *Ecological Engineering,* 37**,** 601-606.

MAIROTA, P., MANETTI, M. C., AMORINI, E., PELLERI, F., TERRADURA, M., FRATTEGIANI, M., SAVINI, P., GROHMANN, F., MORI, P. & TERZUOLO, P. G. 2016. Opportunities for coppice management at the landscape level: the Italian experience. *iForest-Biogeosciences and Forestry,* 9, 775.
MANETTI, M. C., AMORINI, E. & BECAGLI, C. 2006. New silvicultural models to improve functionality of chestnut stands. *Advances in Horticultural Science,* 20, 65-69.
MARANDOLA, D. & ROMANO, R. 2012. More associations to enhance the efficacy of RDP forestry measures. *Sherwood - Foreste ed Alberi Oggi*, 41-45.
MARCHETTI, M. 2018. The new National Forest Law, a very encouraging step forward. *Forest@,* 15, 18-19.
MARIOTTI, B., MALTONI, A. & MARESI, G. 2008. Tradizione, innovazione e sostenibilità: una selvicoltura per il castagno da frutto. *III Congresso Nazionale Selvicoltura per il miglioramento e la conservazione dei boschi italiani.* Taormina (ME): Accademia Italiana di Scienze Forestali.
MATTIOLI, W., MANCINI, L. D., PORTOGHESI, L. & CORONA, P. 2016. Biodiversity conservation and forest management: The case of the sweet chestnut coppice stands in Central Italy. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology,* 150, 592-600.
MIYATA, E. S. 1980. Determining fixed and operating costs of logging equipment. *In:* U.S. DEPT. OF AGRICULTURE, F. S., NORTH CENTRAL FOREST EXPERIMENT STATION (ed.) *General Technical Report (GTR).* St. Paul, Minnesota.
MOORE, T. Y., RUEL, J.-C., LAPOINTE, M.-A. & LUSSIER, J.-M. 2011. Evaluating the profitability of selection cuts in irregular boreal forests: an approach based on Monte Carlo simulations. *Forestry,* 85, 63-77.
MOSCATELLI, M., PETTENELLA, D. & SPINELLI, R. 2007. Produttività e costi della lavorazione meccanizzata dei cedui di castagno in ambiente appenninico. *Forest@-Journal of Silviculture and Forest Ecology,* 4, 51.
MÜLLEROVÁ, J., HÉDL, R. & SZABÓ, P. 2015. Coppice abandonment and its implications for species diversity in forest vegetation. *Forest Ecology and Management,* 343, 88-100.
NAVARRETE, E. & BUSTOS, J. 2013. Faustmann optimal pine stands stochastic rotation problem. *Forest Policy and Economics,* 30, 39-45.
NIEUWENHUIS, M. 2000. Terminology of forest management. *IUFRO World Series,* 9.
NOSENZO, A. 2007. Determinazione degli assortimenti ritraibili dai boschi cedui di castagno: l’esempio della bassa Valle di Susa (Torino). *Forest@-Journal of Silviculture and Forest Ecology,* 4, 118.
O'NEILL, R. V., GARDNER, R. H. & MANKIN, J. B. 1980. Analysis of parameter error in a nonlinear model. *Ecological Modelling,* 8, 297-311.
OLIVEIRA, A. D. D., REZENDE, J. L. P. D., MELLO, J. M. D. & SCOLFORO, J. R. S. 2012. Economic feasibility and rotation age for stands of candeia (Eremanthus erythropappus). *Cerne,* 18, 695-706.
PANNELL, D. J. 1997. Sensitivity analysis of normative economic models: theoretical framework and practical strategies. *Agricultural economics,* 16, 139-152.
PELLERI, F. & SULLI, M. 1997. Campi abbandonati e avanzamento del bosco. Un caso di studio nelle Prealpi lombarde (Comune di Brinzio, Provincia di Varese). *Annali dell'Istituto Sperimentale di Selvicoltura,* 28, 89-125.
PICCHIO, R., SPINA, R., MAESANO, M., CARBONE, F., MONACO, A. L. & MARCHI, E. 2011. Stumpage value in the short wood system for the conversion into high forest of a oak coppice. *Forestry Studies in China,* 13, 252-262.
POSNET, J. & IAN, S. 1996. Indirect cost in economic evaluation: the opportunity cost of unpaid inputs. *Health Econ,* 5, 13-23.
QUATRINI, V., MATTIOLI, W., ROMANO, R. & CORONA, P. 2017. Caratteristiche produttive e gestione dei cedui in Italia. *L’Italia Forestale e Montana,* 72, 273-313.
SALTELLI, A., CHAN, K. & SCOTT, E. M. 2000. *Sensitivity analysis,* New York, Wiley.
SALTELLI, A., TARANTOLA, S., CAMPOLONGO, F. & RATTO, M. 2004. *Sensitivity analysis in practice: a guide to assessing scientific models,* Chichester, John Wiley & Sons.
SALTELLI, A., TARANTOLA, S. & CHAN, K.-S. 1999. A quantitative model-independent method for global sensitivity analysis of model output. *Technometrics,* 41, 39-56.

SECCO, L., FAVERO, M., MASIERO, M. & PETTENELLA, D. M. 2017. Failures of political decentralization in promoting network governance in the forest sector: Observations from Italy. *Land Use Policy,* 62, 79-100.

SIERRA-PÉREZ, J., GARCÍA-PÉREZ, S., BLANC, S., GABARRELL, X. & BOSCHMONART-RIVES, J. *in press*. The use of forest-based materials for the efficient energy of cities: environmental and economic implications of cork as insulation material. *Sustainable Cities and Society*.

SINGH, S. P. & DESHPANDE, J. V. 1982. Break-Even Point. *Economic and Political Weekly,* 17, 123-128.

SOBOL, I. Y. M. 1990. On sensitivity estimation for nonlinear mathematical models. *Matematicheskoe Modelirovanie,* 2, 112-118.

SPINELLI, R., MAGAGNOTTI, N. & RELANO, R. L. 2012. An alternative skidding technology to the current use of crawler tractors in Alpine logging operations. *Journal of Cleaner Production,* 31, 73-79.

SPINELLI, R., MAGAGNOTTI, N. & SCHWEIER, J. 2017. Trends and Perspectives in Coppice Harvesting. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering,* 38, 219-230.

SPINELLI, R., OWENDE, P. M. O., WARD, S. M. & TORNERO, M. 2004. Comparison of short-wood forwarding systems used in Iberia. *Silva Fennica,* 38, 85-94.

TURCHETTI, T., FERRETTI, F. & MARESI, G. 2008. Natural spread of Cryphonectria parasitica and persistence of hypovirulence in three Italian coppiced chestnut stands. *Forest Pathology,* 38, 227-243.

TURCHETTI, T. & MARESI, G. 2006. Management of diseases in chestnut orchards and stands: a significant prospect. *Advances in Horticultural Science,* 20, 33-39.

VAN GARDINGEN, P. R., MCLEISH, M. J., PHILLIPS, P. D., FADILAH, D., TYRIE, G. & YASMAN, I. 2003. Financial and ecological analysis of management options for logged-over Dipterocarp forests in Indonesian Borneo. *Forest Ecology and Management,* 183, 1-29.

VANGANSBEKE, P., OSSELAERE, J., VAN DAEL, M., DE FRENNE, P., GRUWEZ, R., PELKMANS, L., GORISSEN, L. & VERHEYEN, K. 2015. Logging operations in pine stands in Belgium with additional harvest of woody biomass: yield, economics, and energy balance. *Canadian Journal of Forest Research,* 45, 987-997.

VENANZI, R., PICCHIO, R. & PIOVESAN, G. 2016. Silvicultural and logging impact on soil characteristics in Chestnut (Castanea sativa Mill.) Mediterranean coppice. *Ecological Engineering,* 92, 82-89.

VOGT, J., FONTI, P., CONEDERA, M. & SCHRÖDER, B. 2006. Temporal and spatial dynamic of stool uprooting in abandoned chestnut coppice forests. *Forest Ecology and Management,* 235, 88-95.

WHITTOCK, S. P., GREAVES, B. L. & APIOLAZA, L. A. 2004. A cash flow model to compare coppice and genetically improved seedling options for Eucalyptus globulus pulpwood plantations. *Forest ecology and management,* 191, 267-274.

YOSHIOKA, T., ARUGA, K., SAKAI, H., KOBAYASHI, H. & NITAMI, T. 2002. Cost, energy and carbon dioxide (CO2) effectiveness of a harvesting and transporting system for residual forest biomass. *Journal of forest research,* 7, 157-163.

ZHANG, L., YU, G. R., GU, F. X., HE, H. L., ZHANG, L. M. & HAN, S. J. 2012. Uncertainty analysis of modeled carbon fluxes for a broad-leaved Korean pine mixed forest using a process-based ecosystem model. *Journal of Forest Research,* 17, 268-282.

## 9 Web references

http://www.sistemapiemonte.it/aifo