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# OPTIMIZING THE WOOD SUPPLY CHAIN IN CALABRIA: FROM HARVEST SITE TO THE MILL OF WOOD PROCESS
**(s.s.d. AGR/09)**


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***Short Abstract***

This PhD thesis aims to develop, through innovative approaches, and to integrate systems to make competitive and environmentally compatible logistics, harvesting and transport of wood assortments up to destinations in treatment and industrial processing. During recent years, novel technologies and methods for the utilization of wood have been suggested and introduced so as to enhance the wood supply chain. The phases of harvesting and wood processing can provide decisive technological innovations to improve quality, to reduce costs, to create new types of products to enhance the end-uses of the raw material and wood. In particular, wood harvesting has always represented one of the most important management interventions, not only in meeting production objectives but also to favour the biodiversity of the forests. The efficiency and functionality of a particular harvesting system depends on a number of characteristics. For this reason, along with technical analysis in production processes, this study have conducted a thorough analysis of the productivity and economy related to the technical-technological solutions proposed in the various production processes for the entire wood supply chain. After the highlighting of the most critical points of wood supply chain, in the results possible actions have been indicated to overcome them.

**Keywords:** Wood Supply chain, Wood Quality, Mechanization Forestry, Harvesting, Sawmill.

***Abstract***

This PhD thesis aims to develop, through innovative approaches, and to integrate systems to make competitive and environmentally compatible logistics, harvesting and transport of wood assortments up to destinations in treatment and industrial processing. In this PhD thesis a three-step experimental procedure was set up by performing in sequence the following independent tests: (i) Acoustic evaluation of wood quality using non-destructive technologies; (ii) Monitoring and to determine of the productivity and cost in the innovative work sites using Skidders, Forwarders and Cable Crane; (iii) Determination of the parameters in the wood processing to the sawmill.

During recent years, novel technologies and methods for the utilization of wood have been suggested and introduced so as to enhance the wood supply chain. The demands for sustainably produced wood as a raw material for a variety of end uses is placing increased pressure on the forest resource. Knowledge of the timber properties of trees and logs is important to ensure that harvested wood is directed to its most appropriate end use. Current harvesting practice in the Italy means that trees are often felled, processed and dried before the timber is strength graded by machines at the sawmill. The phases of harvesting and wood processing provide decisive technological innovations to improve quality, to reduce costs, to create new types of products to enhance the end-uses of the raw material and wood. In particular, wood harvesting has always represented one of the most important management interventions, not only in meeting production objectives but also to favour the biodiversity of the forests. Several harvesting methods was monitored: the full-tree, tree-length, and cut-to-length systems. The applicability of each one system has depended on several variables related to stand characteristics (such as trees density, average tree volume or thinning intensity), by every single tree (volume, height, branch size and state of pruning) or terrain (slope, soil or state of roughness).

For the purpose of an overall improvement in the efficiency of labour, economic analysis and comparison of solutions, this study has been conducted using the interaction between operating costs of labour of machinery but also the analysis to the overall consumption resources participating in the process chain. After the highlighting of the most critical points of wood supply chain, in the results possible actions have been indicated to overcome them. The activity aims to disseminate the most appropriate classification techniques within forest to reach a classification of wood assortments evaluated by a qualitative characterization.

## *1. Introduction*

### *1.1 Definition of supply chain*

A supply chain is defined as an "integrated process wherein a number of various business entities (i.e. *suppliers, manufacturers, distributors, retailers*) work together in an effort to (1) acquire raw materials, (2) convert these raw materials into specified final products, and (3) deliver these final products to retailers" (Beamon, 1998). This definition can be interpreted to describe the typical forest industry supply chain, from the forest (raw material) to the final consumer (finished wood product). The participants in a typical wood industry supply chain include landowners, loggers, sawmills, manufacturers, and retailers. For many years, the philosophy behind successful companies has been the concept of mass production, whereby a company produces as many units as quickly and cheaply as possible. In such a system, "the company is built around the plant and all internal transactions that make up the order-to-cash cycle (*order entry, purchasing, transportation, and distribution*) all revolve around the manufacturing function" (Kuglin, 1998). Within the last twenty years, the term 'supply chain management' (SCM) has been established. The supply chain can be defined as: "the manufacturer and its suppliers, vendors, and customers- that is, all links in the extended enterprise- working together to provide a common product and service to the marketplace that the customer is willing to pay for. This multi-company group, functioning as one extended enterprise, makes optimum use of shared resources (people, processes, technology, and performance measurements) to achieve operating synergy. The result is a product and service that are high-quality, low cost, and delivered quickly to the marketplace" (Kuglin, 1998). Schonsleben (2004) defines supply chain management as coordination of strategic and long-term cooperation in logistics networks. In order to better monitor and manage the flow of goods and information, and to work towards efficient use of enterprise resources in the supply network, managers have started to introduce supply chain management systems (SCMS)

(Davenport and Brooks, 2004). Schonsleben (2004) notes that “SCMS” just like logistic software in general – portrays products, actors, and processes of orders, and supports administration activities and accounting”. Shared databases are integral parts of SCMS as they provide network members with detailed and timely information (Symon, 2000).

### *1.2 Wood supply chain*

Forest-wood supply chain (FWSC) (Figure 1) applies the concepts of logistics and supply chain management to the field of forestry, and in particular to the area of logging and transport operations. FWCs can be seen as a set of processes by which forest resources are converted into products and services. FWSC deals with all processes within this chain, starting from the management of a new forest to the valorization of the wood product; covering forest organization, logging and transport, and forest industry to end-use (Vötter 2009). Processes in FWSC are not separated and single processes but are linked together and interact with each others, creating entire and full system to supply wood from forest to sawmill in an expected way. Depending on a number of factors such as the level of harvesting and transport industry development in a country, forest and terrain condition, and the investment capacity of the harvesting contractor, the methods used in the processes of a wood supply chain are not the same. This means that the level of integration and dependency of the processes with each other also varies within the chain. The forestry wood supply chain is a complex process. In fact, each provider involved in the wood supply chain can take independent decisions.

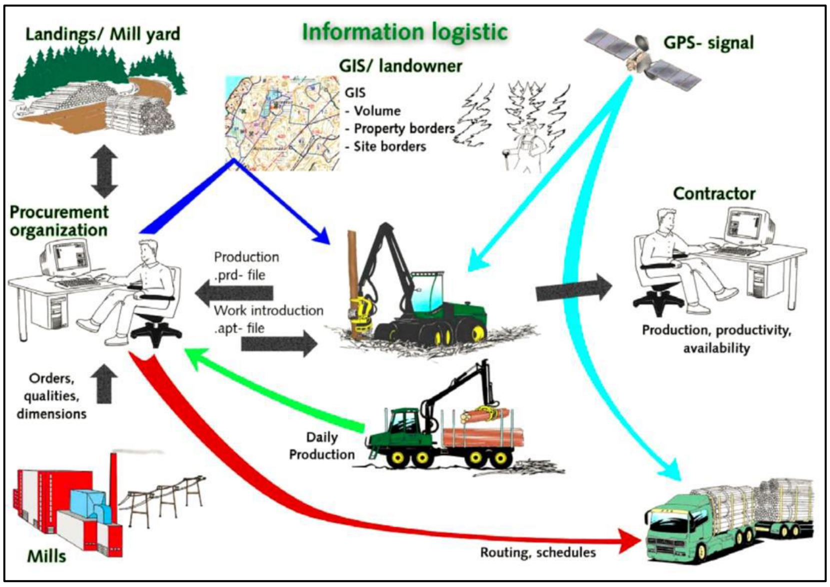


Figure 1 - Main components in Forest-wood supply chain

Forestry operations, the wood processing industry and other actors involved in the process chain have organized their activities according to their own, usually functional criteria and spheres of responsibility (e.g. buying, logistics, marketing). Moreover, the fragmented structure of the timber supply chain makes it extremely difficult to optimize timber value added from supply in the forest through processing in a factory. For instance, no suitable procedures or tools exist to forecast the revenue from the sale of intermediate and finished products of the processed lumber (veneer wood, sawn and barked wood, lumber, industrial lumber, wood chips, etc). There is also no procedure available to project the costs of transportation logistics, influenced by a multitude of parameters (timber assortment, lot sizes, transport distance, truck utilization, etc.), along the entire supply chain and beyond. The market for timber products has changed from a sellers' market (push system) into a buyers' market (pull system); Gunter (2006) states that "it is not possible anymore to produce timber for an anonymous market". Timber production has to take market requirements into account (Heinimann, 2000). Companies have to be able to react quickly and flexibly to customer's demands. In response to these changes and needs, supply networks and supply chain management systems (SCMS) have been introduced in forestry and many other industries

(Heinimann, 1999). A supply chain can be considered as a complex system of processes and related materials, in the case of wood fuel processes such as harvesting, extraction and transport and wood in different states of processing. Entrepreneurs often have to decide which type of supply chain to employ for a certain operation. Therefore, machinery has to be selected and its operations coordinated and balanced. During recent years, novel technologies and methods for the utilization of wood have been suggested and introduced so as to enhance the wood supply chain. Basically, innovations have been grouped into two main classes: radical innovations that change the operating principle of a system and lead to a technology leap, and incremental innovations that improve the existing systems by enhancing their resource efficiency or reducing their costs in gradual steps. In wood harvesting, radical innovations have been the introduction of the bow saw in wood felling and cross cutting in the 1930s, the chain saw in the 1950s and 1960s and mechanization of the felling, delimbing and cross cutting by using the single grip harvester principle in the 1980s. Once introduced, these technologies have been gradually improved so that their performance levels have risen and e.g. fuel consumption has been reduced markedly. Moreover, wood characteristics and some specific measurements collected at each step of the wood chain process are diverse. An example of forestry wood supply chain is illustrated in Figure 2.

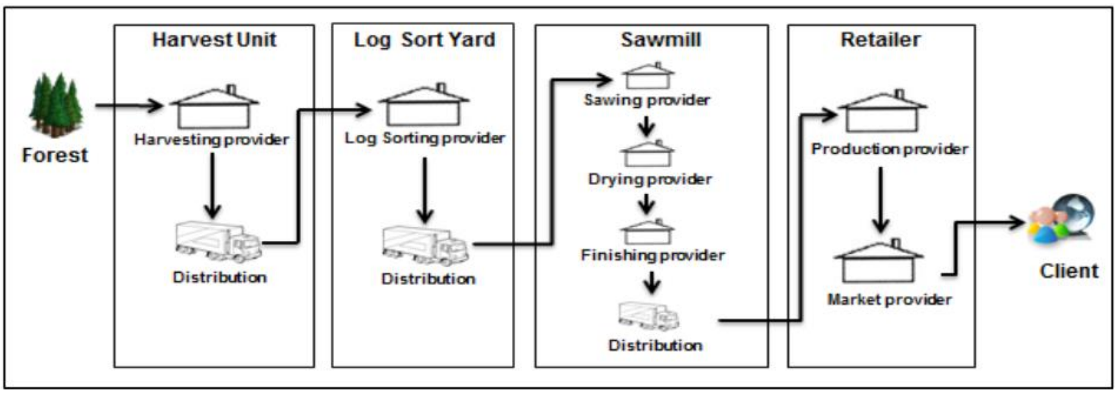


Figure 2 - Forestry supply chain

This figure shows the different stages in the wood production process, starting from the extraction of the forest raw material and finishing by sale to a consumer. In addition, for simplification purposes, the proposed wood supply chain is composed of four types of providers: Harvest Units, Log Sort Yards, Sawmills and Retailers. To extract the raw material from the forest, the tree is felled and cut to logs by a “Harvester”. Thereafter, the logs are transported to the Sawmill. In the mill, logs are sawn, drying, sorted, finished and then transported to the retailer for sale to clients.

### *1.3 Forest Surface in Italy*

Italian’ forest resource base occupies an area of 10.467.533 ha (NFI 2007) and it represents 35% of the Italian territory. These forests fall into two categories; public and community/private forests. In addition, Italy has an aggressive farm forestry program that is credited with a high proportion of trees on farmlands and within this study supply from these trees resources is considered within the supply analysis. In table 1 are reported the data of forestry in Italy.

*Table 1 - Surface forestry in Italy*

| **REGION** | **Areas at Cover forestry (ha)** |
|---|---|
| TUSCANY | 1,151,539 |
| SARDINIA | 1,213,250 |
| PIEDMONT | 940,116 |
| TRENTINO ALTO ADIGE | 779,705 |
| LOMBARDY | 665,703 |
| **CALABRIA** | **612,931** |
| EMILIA ROMAGNA | 608,818 |
| LAZIO | 605,859 |
| VENETO | 446,856 |

| | |
|---|---|
| CAMPANIA | 445,274 |
| ABRUZZO | 438,590 |
| UMBRIA | 390,255 |
| LIGURIA | 375,134 |
| FRIULI V.G. | 357,224 |
| BASILICATA | 356,426 |
| SICILY | 338,171 |
| MARCHE | 308,076 |
| APULIA | 179,040 |
| MOLISE | 148,641 |
| AOSTA VALLEY | 105,928 |
| **ITALY** | **10,467,533** |

In these last years, as reported of the National Inventory confirms the growth of forestry land, with an increase of 5.8% over 2005. Specifically, there are 9,297,078 hectares of forest and 1,813,237 hectares of other wooded lands, for a total of 11,110,315 ha, that is 35% of the national land area (30,132,858 ha). The rate of increase, is approximately 54,000 ha/year, and includes natural regeneration and afforestation, while the average annual rate of deforestation between 2005 and 2015 was just over 3,500 ha/year. The forest area has increased by more than 600,000 hectares in 10 years, about 2% of the national land area. More than 86.6% of the forest area is under hydrogeological constraint.

The increase in forest area was not followed by an increase in operating investments in the territory. Forestry management is the main tool to enhance the environmental, social and economic functions of the forest and ensure the protection, conservation and production. Only 15.7% of the Italian forests (1.3 million ha) is subjected to a detailed planning (multi-year management plans), essential tool for ensuring the provision of ecosystem services in balance with that of commercial products (timber for industrial use and firewood).

In Europe the production of forest based raw material (work timber, firewood and energy uses) amounts to approximately 484 million $m^3$ per year, while the annual growth of forests (annual increase) is about 768 million $m^3$. In this context, the Italian industry of wood products imports more than 80% of raw materials from abroad.

Public forests are managed by the government for provision of forests goods and services. These forests cover an area of 1,043,509 ha; plantations covering 138,152 ha and natural forests occupying an area of 905,357 ha. Public plantation forests are managed for the supply of industrial wood requirement, construction and other timber requirements, and for wood fuel. Public natural forests, in particularly in protected areas (National Parks), are explicitly managed for provision of environmental services such as biodiversity, water catchment protection, climate amelioration etc. Forests in community and private lands cover an area of 6,699,221 ha. These forests comprise both natural forests and plantations forests. These forests are managed by respective communities and private land owners according to their respective management objectives which are mainly provision of both goods and services. Community forests are important sources of building poles and wood fuel in the country (firewood, biomass). Private plantations and wood lots are owned by private individuals or firms investing in wood production for commercial purposes mainly for roundwood and wood fuel (short rotation forestry).

### *1.4 Forest Surface in Calabria*

Forests in Southern Italy (Calabria) are an important area in terms of forest production ranking among the regions of the country with the largest forest cover even though the highest concentration of woodlands remain confined to the northern regions of Italy. Actually forests cover 1,517,836 ha (NFI 2005) of the southern Italy territory mainly with beech, chestnut, Corsican pine and silver fir high forests (more than 300,000 ha combined) with a woodland rate of 31.8%.

Every year, the average increase in wood volume in Calabria (equal to 6-8 $m^3$ $ha^{-1}$) exceeds and sometimes doubles the estimated increase in other forests in and around Southern Italy (Marziliano *et al.* 2012*;* Proto and Zimbalatti, 2015). As a result, the forest in Calabria supplies numerous wood industry sectors in Southern Italy. The annual amount of harvested timber in 2015 was 668,912 $m^3$ (ISTAT 2013), about 8.5% of the national total and 37% of the total amount of timber harvested in Southern Italy, where, according to the National Statistical Database (ISTAT 2013), firewood harvesting has increased more than roundwood harvesting (Proto and Zimbalatti, 2015). Wood from Calabria is mainly destined for the production of energy or for building and packing materials. However, some wood products are sent for processing firms in other regions, where they are converted into quality products (Zimbalatti, 2005; Proto *et al.* 2016).

***1.5 Management of forest in Calabria***

The forest management has evolved over time according to the interests and needs of human population with respect to the use of natural resources. In the modern age (the late 15th century and 16th, 17th centuries) the multi-products forest (Silvopastoral economics) came to be replaced with the traditional agricultural forest. Medieval forest management, based on selective cutting and uneven-aged stands (Agnoletti, 2006), was replaced by tillage and the intensification of clearcutting (Thomas, 1983). The current management of forest in Calabria region is Sustainable Forest Management (SFM), accepted as the overriding objective for forest policy and practice. SFM is a concept developed over time, for the increasing needs to find new strategies and methods for a rational management of forest resources (Paletto, 2008). The SFM was elaborated in the report of the World Commission on Environment and Development (WCED, 1987), better known as the Brundtland Report (1987). In this report, sustainability was defined as: “Meeting the needs of the present generation without compromising the ability of future generations to meet their needs”. This definition represents the conceptual basis of a new forest management paradigm that changed radically the traditional forest management in Sustainable Forest Management (SFM).

The term, sustainable forest management asserts that: “Forest resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual human needs of present and future generations. These needs are for forest products and services, such as wood and wood products, water, soil, food, fodder, medicine, fuel, shelter, employment, recreation, habitats for wildlife, landscape diversity, carbon sinks and reservoirs, and for other forest products”.

In order to achieve these objectives, managers must avoid traumatic actions against the forest ecosystem (for examples: clear cutting on wide surface, artificial regeneration with exotic species, etc.).

The four major criteria for the sustainability of a forest ecosystem are: maintenance of biological diversity, viability of ecological processes, productivity of soil, water and air and the ability to provide for sustained human use (Georgia Forestry Commission, 2000). Contemporary sustainable forest management aims to ensure that goods and services derived from forests meet present-day needs while at the same time securing the forests' continued viability and contributions to long-term development. As such, forest management itself requires prudent management in order to conserve essential ecosystem services such as soil fertility, water quality, as well as, carbon sequestration, maintenance of biodiversity, and recreational values.

## 2. State of the Art

### 2.1 Cover Forestry in Calabria

In Italy woodlands are very important not only for the surface that occupy, but also for the variety of typical landscapes that they form; their potentiality is considerable thanks to the favourable seasonal conditions which allow a prolongation of the vegetative time, with consequent increase of productivity levels. Calabria is a region in Southern Italy with a forest cover equal to 31.8%. More than a third of Italy is covered by arboreal and shrub vegetation, equivalent to 35% of the national surface. Calabria forest are also highly productive since every year the average increase in wood volume (6-8 $m^3$ $ha^{-1}$), exceeds and sometimes doubles the increase estimated for other forest in Southern Italy.

In order to make useful indications about the systems used for forest use, it is necessary to consider the main stationary characters in which wood businesses in Calabria are located. 52% of the wooded area is between the second and third gradient, while slope values of less than 20% are found in about 88,000 ha of forest. As for the accident of the Calabrian forests, it is noted that 57% of the wooded areas are not rough, while 43% of the surface varies between the rugged and the very rugged. Finally, according to the degree of accessibility of forest areas, i.e physical access to the forest and ease of access, most of the surface is accessible (88%). The territory is characterized by a wide network of natural forest tracks, especially in areas where the land is prevalent and where in the past there have been repainting and forest reconstruction financed by the 1st and 2nd Calabrian Special Law. Unfortunately, these road networks are not always easily accessible due to lack of maintenance (Barreca *et al.* 2008).

### 2.3 Wood Quality

Wood products from Calabria are mainly destined for the production of energy or for building and packing materials, they are often sent to processing firms in other regions, which will then transform them into quality products (Zimbalatti, 2005).

In order to determine the quality of wood assortments, acoustic technologies have been well established as material evaluation tools in the past several decades, and their use become widely accepted in the forest products industry for on-line quality control and products grading. Recent research developments on acoustic sensing technology offer further opportunities to evaluate standing trees logs for general wood quality and intrinsic wood properties (Carter *et al.* 2005; Wang *et al.* 2007). This method presents the fundamentals of acoustic wave in tress propagation in trees and logs and discusses two different mechanism of acoustic velocity measurement, time of flight (TOF) approach for standing trees and resonance – based approach for logs (Carter *et al.* 2005; Wang *et al.*2007).

Assessing wood quality in standing trees has been a long – time interest to wood products manufactures end forest managers worldwide. A significant effort has been devoted to develop to environmentally friendly agriculture and forestry for future generations develop robust NDT technologies that are capable of predicting intrinsic wood proprieties of individual trees and assessing wood quality by stands and forest.

In particularly acoustic tomography is an emerging NDT technology for tree decay detection in both urban community and production forest. Many field studies have been conducted to assess the applicability and reliability of the technique in such applications. Although investigations on urban trees showed great success using acoustic tomography to detect moderate to severe internal decay within the trunk, detection of early stage of decay using such technology still constitutes a challenge.

Internal decay is a major structural defect on trees of many species. The economic loss caused by internal decay is most significant for the hardwood trees that are used to produce appearance- grade veneer and other high value engineered wood products. Because of the exceptionally high prices paid for high quality hardwood trees, undetected decay can cause a substantial monetary loss to timber buyers and wood manufacturers (Wiedenbeck *et al.* 2004). Early detection of internal decay in hardwoods could provide a significant benefit to the industry in terms of making accurate quality assessments and volume estimates and use of the resource. It can also help foresters in prescribing silvicultural treatments for improved management decision-making and thus help maintain a healthy forest (Wang *et al.* 2009). Acoustic tomography is an emerging NDT technology for tree decay detection in both urban community and production forest. It allows the users to visualize the velocity distribution of the acoustic waves as the waves propagate through the cross section of a tree trunk. Because acoustic velocity is directly related to density and dynamic modulus of elasticity of wood, acoustic velocity mapping of a cross section could be used as a diagnostic image to detect internal decay in trees (Bucur, 2003).

### *2.3 Logging Operation in Calabria*

In the region there are about 2,500 companies operating in the woodworking sector, divided into forestry and first-processing businesses (Zimbalatti *et al.* 2005). From the data shown in Figure 1 there is a clear gap between the number of forestry companies and the use of forest areas compared to those involved in processing woody sorts and their transformation into marketable products.

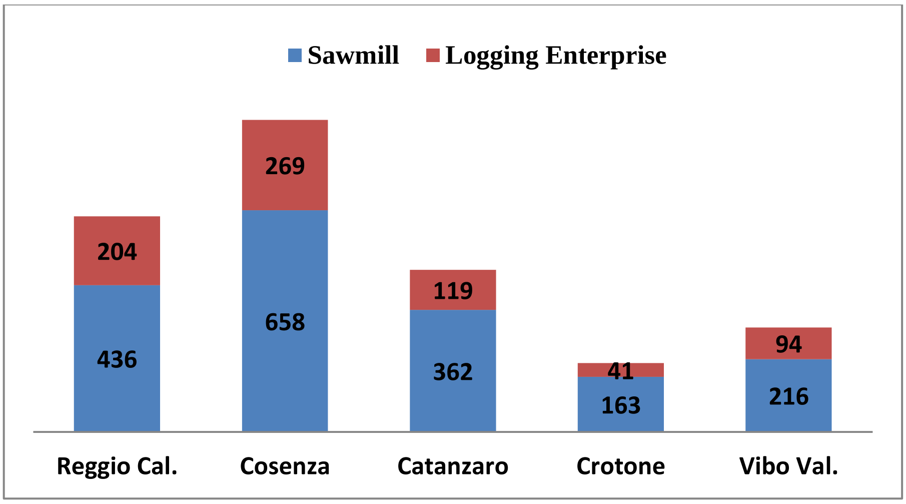


Figure 1 - Enterprise in Wood Supply Chain in Calabria Region

This means that in Calabria, forestry companies, knowing the data on timber volumes processed annually, fail to ensure a constant supply of raw materials to the processing industries which are often obliged to buy and work timber coming mainly from the Eastern Countries Europe (Proto and Zimbalatti, 2008).

In Calabria, the average working time of wooded enterprises is 198 days/year; exactly 58% of companies work for 100-150 days / year, 16% for 150-200 days / year, 14% for 200-250 days / year, while the remaining 12% for more than 250 days. Climatic conditions, which are certainly not prohibitive during the winter season, encourage businesses not to do any forestry activities during that time of the year for only two or three weeks. Forest companies employ a very small number of workers; on average, they have 2.6 units and in 90% they have only one team of workers. The characteristics of the teams for use, however, often depend on the types of intervention to be made in the woods. In fact, in the particular context in which they work, the number of different staff and their field experience influences the establishment of such teams. Considering the total staff employed in Calabrian woodland businesses, 65% is made up of fixed-term workers; 53% of them are in the age range of 36 to 50 years.

Despite such a conspicuous density of woodland resources, the most common working method in Calabria, can be considered as begin traditional and at an early stage of mechanisation (Hippoliti, 1997). It is based mainly on agricultural tractors, sometimes with specific forest machines like winches, hydraulic cranes, log grapples but also, the use animal for gathering and yarding is a widely used technique, There are few highly specialized machines for forest exploitation, and can be traced to the use of skidder, forwarder and some cable crane, where the low level of mechanisation in Calabrian forests is due to their site features, the characteristics of the propriety, the small dimensions of many enterprises, scant knowledge of modern machinery, and the scarcity of studies relating to the use of modern machinery.

Chainsaws are the most common machinery for timber cutting operations (Verani and Sperandio, 2003). There are few companies that own cable and forwarder cranes despite the orography of the Calabrian forests that are well suited to their use. With respect to the type of work carried out, 12% of forestry enterprises execute timber felling, set up and exhumation while the remaining 88% carry transport, thus completing the entire production cycle from the abatement operation plant until timber transfer to first processing plants or for direct sale in the case of firewood. The product ranges consist of timber and firewood in 65% of wood enterprises; 26% of companies are only burning firewood, while the remaining 9% only produce lumber. For the work in a woodland many categories of operators are necessary, but they are not always fitted for the required job. Some categories are engaged in goods productions, other in both of them. The characteristics of teams for utilizations, however, depend on the kind of the operation they have to carry on in the forest. Often in happens that, in particular work contexts, the number of operators is variable and their experience in the field has a great influence upon the constitution of these teams. The forest firms which operate in the central and southern regions are often associated with the idea of backward organizing conditions and, in particular, with the use of out-to-date utilization methods. During the last years the technological gap between means and methods applied in the Apennines and Alps areas is considerably shortened, thanks to the firms witch want to be competitive in local markets, and also thanks to the recent boost initiatives connected to the rural development politics (Moscatelli *et al.* 2007). Starting from these considerations, the main purpose of this research is to look into the reality of forest utilizations in some regions of southern Italy, with a special attention to the study of the mechanization level used in forest utilizations. All this, in order to start (formulating an hypothesis of a possible future development of the research) a process of progressive divulgation and spreading, among the forest entrepreneurs, of knowledge about the most modern and rational techniques and technologies of forest utilization, so that workers can operate with greater economy and respect for the environment and for their own health (Verani and Sperandio, 2005).

### *2.4 Sawmill in Calabria*

In Calabria, timber processing employs over 20.000 labours (Istat, 2013), and it is mainly concentrated in the provinces of Cosenza and Reggio Calabria. Timber industries should ensure high quality products, services and processes to improve their competitiveness in the market. The sector of wood working is a specific sector where the environmental challenge is an important factor of competitiveness for the production value added.

Many chain wood working companies in Italy are investing in new productive methods at a low environmental impact. The wood working sector represents a good resource for the economy in Calabria. The companies are based on a first and a second processing of wood working and they are mostly settled in the province of Cosenza followed by the province of Reggio Calabria which has a relatively high position , while the main city Catanzaro is placed in the middle of a series that decreases with the provinces of Vibo Valentia and Crotone (Zimbalatti *et al.* 2009). To yield sawing normally means the volume of sawn timber and semi-finished you get from sawing round wood. This is the quantitative yield and is expressed as a percentage of the volume of the round.

If you wish to highlight the quality of the boards or semi obtained, according to a classification, a habit or an intended use, reference is made to surrender sawing quality. The round provides the sawing through different products which can be divided according to the kinds qualitative as follows: i) primary products, ii) secondary products and iii) 'waste' or more properly by products. They are defined primary products assortments of greater value, such as for example the sawn timber of commercial length, which in the customary productive local and national corresponds to lengths not less than 4 m. Secondary products are those of the less valuable and which sometimes are recovered by a second sawing; they are separated into short pieces (elements of length less than 15 cm, minimum thickness 20 mm) and round wood (elements 350 cm, width 8 of length less than 390 cm, minimum width 6 cm, without dimensional limitations nor quality). Finally among the products are distinct slabs (outer part of the tree stump), the trims (elements resulting from the trimming of the table) and the sawdust, which have a commercial value low, but not negligible.

### *2.5 Objectives*

This PhD thesis aims to develop, through innovative approaches, and to integrate systems to make competitive and environmentally compatible logistics, harvesting and transport of wood assortments up to destinations in treatment and industrial processing. In this PhD thesis a three-step experimental procedure was set up by performing in sequence the following independent tests: (*i*) Acoustic evaluation of wood quality using non-destructive technologies; (*ii*) Monitoring and to determine of the productivity and cost in the innovative work sites using Skidders, Forwarders and Cable Crane; (*iii*) Determination of the parameters in the wood processing to the sawmill.

The objective of the first study (*Acoustic evaluation*) was to determine if the effects of silvicultural practices on wood quality can be identified using acoustic measurement to assess the wood quality with non-destructive method in standing trees of Calabrian pine and chestnut. For this purpose, two different instruments were applied and five hundred and ten standing trees in six sites were non-destructive tested using a time-of-flight acoustic wave technique. The first instrument was TreeSonic™ while the second was Ultrasonic Tomography™. The results obtained will show in this thesis as Activity 1 and Activity 2.

The second test was to provide sound data for permitting the formulation of models of the cycle time for extraction operation (skidder, forwarder and cable crane) in a small-scale forestry. The specific objectives were: (1) to calculate production rates ($m^3$ $h^{-1}$) and costs (€ $m^{-3}$) of wood harvesting in southern Italy, (2) to develop models of cycle time and productivity, and (3) to determine the most influential factors for each work phase. In addition, only for the study of forwarder productivity, have been compared different results obtain in different Country. In fact, during the third year of my PHD, I studied the same methodology in NZ at School Forestry in Christchurch (New Zealand). For this purpose, several sites were tested, located in Calabrian region. Furthermore, skidder and forwarder machines were monitored by using GPS/GSM technology. The results obtained will show in this thesis as Activity 3, Activity 4, Activity 5, and two papers (An investigation in roundwood extraction of Fagus Sylvatica and Calabrian pine by Greifenberg TG700) and (Measuring the mobility parameters of tree-length forwarding systems using GPS technology in the Southern Italy forestry).

The objective of the third study was the study of the parameters in the wood processing to the sawmill. In fact, to complete the study of Calabrian wood supply chain this third activity has determined a good model for the wood raw material predicting quality distribution of the sawn products resulting from the volume of trees. In particular, in all kind of production the efficiency of the process is crucial. This applies both in terms on how efficient the people producing the products are and on how efficient the process itself is. In the latter case one important parameter is how efficient the use of the raw material is. For this purpose, this study was conducted in a midsize sawmill, with a production 8,000 – 10,000 $m^3$/year of lumber, located in Calabrian Region. This study showed that the factors influencing the production yield are various and random between the sawing of logs with human operational decisions, errors along the sawing line and in measuring that affect the sawing yields. The results obtained will show in this thesis as Activity 6.

## *3. Materials, Methods, Results and Conclusion*

### *3.1 Activity 1 - Assessment wood quality in coniferous (Calabrian Pine)*

#### *Introduction*

Assessing the wood quality of individual trees and overall forest stands has become an important procedure in forest operations, as forestry and wood processing industries are under increasing economic pressure to maximize extracted value (Wang *et al.* 2007a). For this reason, the estimation of timber species, quantity, and quality is critical for quantifying the productive value of a forest (Marziliano *et al.* 2012; Proto *et al.* 2014). The worldwide shift in the wood supply from old-growth forests resources to intensively managed plantations increases the value of evaluating tree quality prior to harvest (Wang and Ross, 2008).

Significant efforts have been made to develop robust, non-destructive technologies (NDT) capable of predicting the intrinsic wood properties of individual trees and assessing wood quality by stand and forest. In addition, more recently, non destructive technologies including (mini) rhizotrons and ground-penetrating radar have been proposed to more recently assess plant rooting distribution and growth (Sanesi *et al.* 2013; Marziliano *et al.* 2015). The use of such technologies not only leads to greater profitability for the forest industry, but can also help foresters to make economic and environmental management decisions for treatment of individual trees and forest stands, improve thinning and harvesting operations, and efficiently allocate timber resources for optimal utilization (Wang *et al.* 2007a; Proto *et al.* 2015). Acoustic technologies have become well established as material evaluation tools, and their use has become widely accepted for quality control by the wood industry (Wang *et al.* 2007b). With the development of portable and simple-to-use, time-of-flight and resonance-based tools, the use of acoustics in the forestry sector has increased, particularly in countries such as New Zealand (Walker and Nakada, 1999; Tseheye *et al.* 2000; Chauchan and Walker, 2006), Australia, the United States (Wang *et al.* 2000; Wang *et al*,. 2001a; Wang *et al.* 2001b;

Wang *et al.* 2002; Wang *et al.* 2004), Hungary (Brashaw *et al.* 2009; Divos, 2010) and the United Kingdom (Searles and Moore, 2009). In Japan, Nakamura (1996) used ultrasonically-induced waves to assess larch trees and observed significant differences in acoustic velocities and MOE for trees in forest stands at different locations and trees of different density. The non-destructive technologies (NDT), equipment, and evaluation procedures that resulted from those efforts are now in widespread use. This technology is beginning to be used more by the European forest industries, and this paper reports a case study using these tools in managed conifer forests in Italy.

The objective of the study was to determine if the effects of silvicultural practices on wood quality can be identified using acoustic measurement to assess the MOEd of trees with non destructive method in standing trees of Calabrian pine (*Pinus nigra* Arnold ssp *calabrica*).In Calabria, where the tests were conducted, forest cover is 40.6% compared to the national average of 34.7%. Each year, the average increase in wood volume in this region (equal to 6-8 $m^3$ $ha^{-1}$) exceeds and sometimes doubles the estimated increase in other forests in and around Southern Italy (Proto and Zimbalatti 2015, Zimbalatti and Proto 2009). A secondary aim was to determine if the effects of silvicultural practices on wood quality can be identified using this technique.

***Materials and methods***

***The time-of-flight method***

The system used for measuring acoustic velocity in trees involves inserting two sensor probes (a transmit probe and a receiver probe) into the sapwood for few centimetres in a vertical plane according to the manufacturer's instructions and introducing acoustic energy into the tree through a hammer impact. Wave propagation velocity in a standing tree is determined by measuring time-of-flight for a single pulse wave. Time-of-flight (TOF) essentially measures the time for the stress wave to travel from the transmit probe to the receiver probe. Piezoelectric sensors inside the two probes are used to sense the passing of the wave.

The acoustic velocity is then calculated from the span between the two sensor probes and the TOF data using (eqn 1):

$$CT = S/\Delta T$$

where CT is acoustic velocity (m/s), S is distance between the two probes (sensors) (m), and Δt is time-of-flight (s).

The FAKOPP TreeSonic™ (Fakopp Enterprise, Agfalva, Hungary) is an acoustic tool designed to study standing trees (Booker and Ridoutt, 1997; Lindstrom *et al.* 2002; Huang, 2005, Chauchan and Walker, 2006; Brashaw *et al.* 2009, Divos, 2010; Wang 2011; Wang, 2013). The tool is comprised of a hand-held hammer and two probes, a transmitting accelerometer, and a receiving accelerometer. The vibration transducers, patented by the Weyerhaeuser Company, are equipped with a sliding hammer, resulting in quick operation (Huang ad Lambeth 2006). To measure the acoustic velocity wave on the tree, the start and stop sensors are driven through the bark at a 45° angle into the wood of the standing tree; in fact, FAKOPP TreeSonic™ was developed to operate in the longitudinal direction of the stem (Fig. 1) unlike to several tools (Hitman Resonance Tool, IML Impulse Hammer and Microsecond FAKOPP) specifically modelled for radial measurement. During field acoustic measurements, the probes are aligned within a vertical plane on the same face.

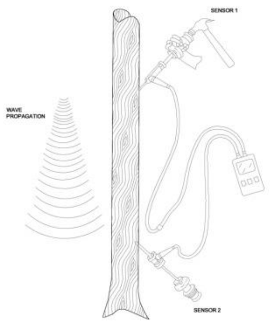


Figure 1 - Acoustic wave system for field-testing of standing trees.

For this study, a 1.00-meter testing span was roughly centred at breast height. The lower probe was placed about 40–60 cm above the ground. In conjunction with the acoustic measurement, the diameter at breast height of each tree was measured according to the common practice in forestry measurement (Proto *et al.* 2015). Four readings in the same position were obtained for each tree. Stress wave times were then converted to mean acoustic velocity for each tree.

***The Modulus of Elasticity equation***

After obtaining the acoustic velocity, the next step is to determine the most important parameter in estimates of wood quality: the modulus of elasticity. This parameter can be estimated from the velocity of acoustic waves (acoustic velocity, CT) that pass through wood according to the following formula (eqn 2):

$$\text{MOEd} = \text{wood density x acoustic velocity}^2$$

where density is typically expressed in $kg \cdot m^{-3}$, and velocity in $km \cdot s^{-1}$ (Pellerin and Ross 2002, Chauhan *et al.* 2005; Lasserre *et al.* 2007). Wood density was determined by volumetric method, which required measuring the volume and mass of dry wood in the laboratory. The density was computed starting from basic density measured on 10 mm large diameter by roughly 10 mm depth cores, removing the bark. To compute the basic density, the oven-dry mass (MC0%) was divided by its green volume, was measured via the Archimedes' law, using a beaker with distilled water placed on a lab electronic balance (0,001 g of resolution) set to zero, with a mechanical arm connected to the needle able to correctly immerse the wood specimen in the water, the top of the wood being just below the meniscus, avoiding a significant immersion of the needle. A small specimen from the core was devoted to get the moisture content of the wood via gravimetric test (ISO 3130). Although the specimens were green, they had been stored in distilled water for 48 hours in order to saturate the wood. From basic density raw data, by taking into account the shrinkage percentage (Sh% = 100 * decrease in size/original size, applying a shrinkage rate of 0.14 and 0.25 % for every % of mc, respectively for radial and tangential direction, according to Sell *et al.* 1990) from fibre saturation point down to 12%MC, the normal density (kg/m$^3$12%) was computed. The velocity, kept as measured on green timber, was not corrected according to the moisture content, following the manufacturer's specification. One small wood cylinder was taken from the same area of the stem of each tree as the NDT measurement. When MOE is estimated using this formula, it is called dynamic modulus of elasticity (MOEd) (Urhan *et al.* 2014). Stress wave propagation in wood is a dynamic process that is internally related to the wood physical and mechanical properties (Wang *et al.* 2001a).

***Study sites and tree samples***

Field tree measurements were conducted from October 2014 to February 2015 and included measurements of acoustic wave tests on each sample tree. Trees on each site were listed in ascending order of acoustic velocity. A total of 450 trees were tested and each one was tagged with a unique number. The tree samples were stratified by diameter at breast height to determine the diameter range present.

Four Calabrian pine (*Pinus nigra* Arnold ssp *calabrica* (Land) E. Murray) research installations were chosen for the study. The thinning trials were conducted in 60-year-old plantations of Calabrian pine, in the Cosenza Tyrrhenian Presila, located at Varco San Mauro in the municipality of Rose. The study was conducted on the average value measured in four dissimilar sites under different treatments (Fig. 2): Control (T), light thinning (A), intermediate thinning (B), and heavy thinning (C).

For each of the thinning treatments, there were 8 years between the first and second cuts, and 10 years between the second and third. The resulting crops consisted of 800, 600, and 400 plants per hectare (for plots A, B, and C, respectively), which were subsequently targeted for final harvest and regeneration.


Figure 2 - The four treatments in the study area.

The historical information and the silvicultural data of these plots are reported in Table 1.

*Table 1 - Sites and stands selected for nondestructive evaluation*

| **Years** | **Sites** | **Total number of trees** | **dbh** | **hg** | **hg/dbh** | **basal area ha $^{-1}$** | **volume ha $^{-1}$** |
|---|---|---|---|---|---|---|---|
| | | **n. ha $^{-1}$** | **cm** | **m** | **----** | **$m^2$** | **$m^3$** |
| 1985 | T | 1651 | 22.0 | 14.45 | 66 | 62.71 | 477.84 |
| | A | 1769 | 21.2 | 15.50 | 73 | 62.72 | 476.05 |
| | B | 1699 | 22.1 | 15.07 | 68 | 65.42 | 497.85 |
| | C | 1757 | 21.5 | 14.98 | 70 | 63.62 | 482.86 |
| 1995 | T | 1460 | 25.4 | 18.12 | 70 | 74.26 | 674.98 |
| | A | 1339 | 26.0 | 19.87 | 76 | 71.12 | 648.35 |
| | B | 1176 | 27.4 | 19.35 | 71 | 69.39 | 636.48 |
| | C | 1103 | 27.6 | 19.63 | 71 | 66.07 | 606.58 |
| 2005 | T | 1460 | 27.5 | 22.25 | 81 | 86.87 | 796.39 |
| | A | 1001 | 30.5 | 22.70 | 74 | 73.14 | 677.62 |
| | B | 827 | 32.0 | 22.97 | 72 | 66.62 | 619.79 |
| | C | 664 | 32.9 | 23.04 | 70 | 56.54 | 527.26 |
| 2015 | T | 1315 | 30.9 | 27.79 | 90 | 97.55 | 905.84 |
| | A | 803 | 34.2 | 28.13 | 82 | 72.58 | 670.30 |
| | B | 605 | 36.6 | 27.89 | 76 | 60.61 | 569.94 |
| | C | 407 | 38.1 | 28.37 | 74 | 47.36 | 458.21 |

Hg: Height in meters;
Dbh: Diameter at breast height in cm;
hg/dbh: Slenderness coefficient or ratio.

***Statistical analysis***

Analysis of tree stress wave time and tree diameter at breast height was performed at both individual tree and sites level. The impact of the independent variables on the dependent variable MOEd was measured.

"Tree diameter at breast height - DBH" and "number of trees" were selected as independent variables. The definitions of both dependent and independent variables and how to measure them are summarized below:

Dependent variable:

MOEd = Modulus of elasticity, measured as eqn 2;

Independent variables (two groups in mixed model):

a = tree diameter at breast height (cm) – DBH,

b = number of trees $ha^{-1}$ (treatments),

Theoretically, the equation below is then obtained (eqn 3):

$$MOEd = f\,(a, b)$$

SPSS Statistical Software and Excel 2012 were used for the analysis. Analysis of variance (ANOVA) was conducted to determine the differences of MOEd in DBH and thinning regimes. Multiple comparisons by Tukey's test were then done to identify the significant differences among groups.

***Results and Discussion***

The wood density computed from basic density measured on the cylindrical specimens is reported in Table 2.

The regression model was calculated as follows (eqn 4):

$$MOEd= 12556.680 - 52.852a - 551.522b$$

a = tree diameter at breast height (cm) – DBH,

b = number of trees $ha^{-1}$,

*Table 2 – Wood density computed from basic density measured in four sites*

| Sites | T | A | B | C |
|---|---|---|---|---|
| Stem density (n. $ha^{-1}$) | 1315 | 803 | 605 | 407 |
| **Wood density $MC_{12\%}$** | | | | |
| Specimens per area (n.) | 118 | 115 | 111 | 106 |
| Average ($kg/m^3$) | 603 | 587 | 580 | 563 |
| St. dev. ($kg/m^3$) | 39.7 | 33.7 | 37.5 | 40.4 |
| *CoV (%)* | *6.58* | *5.74* | *6.47* | *7.18* |
| 5th perc. ($kg/m^3$) | 542 | 527 | 519 | 491 |
| 95th perc. ($kg/m^3$) | 664 | 634 | 635 | 617 |

Four DBH classes were considered: 30, 35, 40, and 45 cm in each site; these classes were considered representative for the purpose of estimating the quality of wood properties because they are considered a typical size for commercial trees. The values found in the diameter classes 30 cm showed a higher MOEd as compared to other sites. This result might justify how the treatments affect the quality of the wood. For trees of the same age, bigger trees resulting from higher growth rate would generally produce wood of lower density and lower stiffness (Zhang, 1995; Koubaa *et al.* 2000).

The data were divided into the four test treatments (sites). The Fakopp velocity was 4.36 km/s (±0.56 SD), 4.57 km/s (±0.29 SD) and 4.46 km/s (±0.31 SD), respectively in treatments T, A and B, respectively. At the same time, acoustic velocity was lower in treatment C (3.98 km/s and ±0.52 SD, Fig. 3). The stress wave time average of trees in treatment A was about 5% higher than in the control treatment (T); in plot C (heavy thinning), the value was lower at about 9%.

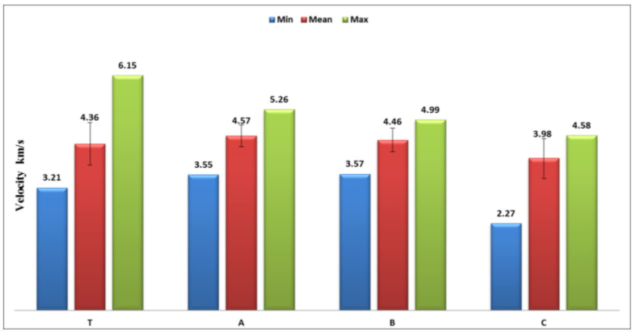


Figure 3 - Minimum, maximum and mean values of velocity (km/s) in the sites.

The average MOEd determined in standing trees was directly influenced by DBH (Tab. 4-5) and thinning regimes, and both parameters were judged to be good predictors. Among the different diameter classes, the highest values were registered in classes 30 and 35 cm; specifically, it was confirmed that light and moderate thinning produced significant benefits in terms of quality. The reduced density in stand C resulted in faster diameter at breast height growth, but less stiff mature wood. In fact, the MOEd values for treatment C were all lower than in the control plot. The stress wave time and MOEd are presented in table 3.

*Table 3 – Data registered from four sites.*

| Site | Stress wave time (µs) | | | | Speed (km/s) | | | | MOEd (MPa) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Min** | **Mean** | **Max** | **SD** | **Min** | **Mean** | **Max** | **SD** | **Min** | **Mean** | **Max** | **SD** |
| T | 162.4 | 233.5 | 303.8 | 31.8 | 3.21 | 4.36 | 6.15 | 0.56 | 5611.4 | 9982.98 | 19624.6 | 2580.0 |
| A | 190.1 | 219.3 | 281.4 | 15.3 | 3.55 | 4.57 | 5.26 | 0.29 | 6537. | 10901.48 | 14328.1 | 1401.6 |
| B | 200.0 | 225.3 | 279.4 | 16.8 | 3.57 | 4.46 | 4.99 | 0.31 | 6631.2 | 10352.71 | 12931.7 | 1454.6 |
| C | 218.1 | 256.6 | 439.8 | 45.6 | 2.27 | 3.98 | 4.58 | 0.52 | 2677.3 | 8364.57 | 10885.3 | 1989.1 |

Dynamic modulus of elasticity of wood in trees ranged from 6,537 to 14,328 MPa, with a mean of 10,901 MPa in A and 6,631 to 12,931 MPa, with a mean of 10,352 MPa in B. The characteristics for the regression models are presented in Table 4. According to the statistical analysis, the model presented for MOEd was valid; in addition, the Tukey tests verified the differences within treatments with values less than $p < 0.005$. From the comparison of the four treatments, the results demonstrated that the effect of silvicultural practices on properties of wood can be successfully identified by stress wave MOEd; indeed thinning operations caused a significant and valid variation in terms of MOEd measured in DBH tree class (Fig. 4). For example, Todaro and Macchioni (2011) registered a significant variation of wood properties caused by thinning operation in a Douglas-fir in Southern Italy.

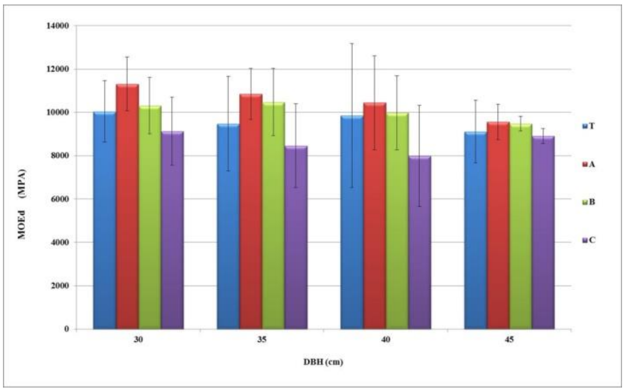


Figure 4 - MOEd assessed in standing trees in the diameter classes

Statistical analysis demonstrated significant MOEd between the stands with moderate thinning (A and B) and those with heavy thinning (C) (Tabb. 4-5). Tukey product correlation coefficients were computed between MOEd, thinning regimes and DBH.

*Table 4 – Analysis of variance table describing the interactive effect of treatments and diameter on the modulus of elasticity*

*Treatments*

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 153555296.89 | 3 | 51185098.965 | 15.460 | 0.000 |
| Within Groups | 635655126.90 | 192 | 3310703.786 | | |
| Total | 789210423.79 | 195 | | | |

*DBH*

| Model | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 282716298.739 | 35 | 8077608.535 | 2.552 | 0.000 |
| Within Groups | 506494125.058 | 160 | 3165588.282 | | |
| Total | 789210423.797 | 195 | | | |

*Table 5 – Modulus of elasticity (MOEd) regression model*

| Model | Unstandardized coefficients | | Standardized coefficients | t | Sig. | $R^2$ |
|---|---|---|---|---|---|---|
| | B | Standard deviation | β | | | |
| Constant | 12556.680 | 658.414 | - | 17.071 | 0.00 | 0.34 |
| DBH | -52.852 | 18.151 | -1.99 | -2.192 | 0.004 | |
| Treatments | -551.522 | 120.731 | -0.312 | -4.568 | 0.000 | |

Dependent variable: MOEd

The results suggest that thinning regimes cause rapid diameter growth and may be susceptible to a reduction in overall stiffness. The applicability of acoustic waves to assess the intrinsic wood properties of standing trees has been validated by many studies around the world (Nanami *et al.* 1992a; Nanami *et al*. 1992b; Nanami *et al*. 1993; Wang, 1999; Ikeda and Kino 2000; Ikeda and Arima, 2000; Huang, 2000; Wang *et al.* 2001b, Lindstrom *et al.* 2002). A similar result was found by Wang (2012) that a range of wood and fibre properties can be predicted through a simple acoustic measurement in standing trees. Many studies reported that, for softwood trees of the same age, stress wave velocity is higher for trees with slower growth rates or narrower rings. The species tested included Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), jack pine (*Pinus banksiana*), ponderosa pine (*Pinus ponderosa*), and radiata pine (*Pinus radiata*) (Wang *et al.* 2003). This same condition was present in these test areas. Indeed, faster growth in area C, caused by repeated intensive thinning, has reduced within stand competition and this may explain the relationship between the acoustic velocity and DBH in this stand. Zhang (1995) and Todaro and Macchioni, (2011) observed that within a stand the bigger trees resulting from higher growth rate would generally produce wood of lower stiffness. Chauhan and Walker (2006) showed that in fast growing trees the increased diameter with its larger second moment of inertia means there is less need for high material stiffness while for trees of the same age, slow growing trees tend to have high stiffness to sustain them under various stresses like wind, crown weight, etc.

Younger wood is lower in specific gravity and stiffness, while fast-growing wood has a larger diameter core of juvenile wood (Clark and Daniels, 2002). This result demonstrates how wood quality and intrinsic wood properties are generally affected by silvicultural practices, especially by stand density (Fioravanti, 1999; Macdonald and Hubert, 2002; Todaro 2002; Eriksson *et al*. 2006).

The lower velocity with increased DBH appeared to be associated with a higher growth rate in trees, which adversely affects specific gravity as well as the strength and stiffness of the wood. The higher variability exhibited within trees of the same diameter classes in different sites may reflect the natural variation between individual trees as well as the thinning effect (Wang and Ross, 2008).

Wang (1999) examined the effect of thinning treatments on both acoustic and static bending properties of young-growth phase western hemlock and Sitka spruce trees obtained from seven sites in southeast Alaska. He found that trees with higher acoustic velocity and stiffness were mostly found in unthinned control stands and stands that received light and medium thinning, whereas the lowest values were found in heavily thinned stand. The technology may also be used to determine how environmental conditions and silvicultural treatments affect wood and fibre properties so that the most effective treatment can be selected for the desired fibre quality in future plantations (Wang, 2012). Since the DBH of trees is a readily available parameter, appropriate multivariate regression models with velocity and DBH as variables can be established to estimate wood quality.

***Conclusions***

These studies have shown that acoustics can be used to describe wood features that affect the visual appearance and drying distortion of solid wood products, e.g. knot structure, wood rot, fibre dimension and microfibril angle. Accordingly, acoustics has been used as a practical, low-cost method to assess the wood quality of standing trees (Lindstrom *et al.* 2009).

A strong positive association was observed between MOEd, measured on standing trees using the Fakopp instrument, thinning treatments and DBH. The MOEd is affected by initial stand density conditions, and change, minor or major, is produced by intensity of thinning. These results showed that tree diameter has a significant influence on acoustic wave measurements and a valid relationship exists between DBH and MOEd.

Wood properties remain a strategic research topic for improving wood quality in order to achieve correct treatments with high wood stiffness. Today, the precision of acoustic technology has improved to the point that tree quality and intrinsic wood properties can be predicted and correlated to the performance and economic values of the final products. With continuous advances and refinements, this technology could assist in managing wood quality, assessing forest value, and improving the timber quality of future plantations (Wang *et al.* 2007b).

This information could be relevant for tree breeding, pre-harvest assessment, and decision support at time of thinning. The effects of thinning and other silvicultural practices on wood properties can be identified with the stress wave technique used in this study. These results are encouraging and indicate that the non-destructive stress wave technique may be used to track wood property changes in trees and determine how forests could be managed to meet desired wood and fibre qualities (Wang *et al.* 2001a). The data collected for this study have illustrated the potential of the stress wave technique for determination of the influence of thinning treatment performed on Calabrian pine, taking into consideration the vast areas of cultivation of this species in the region.

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### *3.2 Activity 2 - Assessment wood quality in broadleaved (chestnut)*

***Introduction***

Wood is a biological end product generated during cambial growth over successive years. During the growth process, the cambium cells convert most of photosynthesized products and nutriments into various biopolymers for use in the formation of woody tissues (annual ring and cork formation) (Barnett and Jeronimidis 2003). The wood can thus be considered as a record of responses of trees exposed to different growth conditions but also to changing environments. The properties of an annual ring describe the morphological structure of the species and quantify the trees response to variations of their environment. In the particular case of plantations, the species are usually selected for their fast growing but the wood quantity produced does not necessarily involve quality. During this phases we can to have different defects and can be classified such as: defects induced by different irregularities from natural growth patterns (grain deviation, knots, pitch pockets, decay, etc.); and, abnormalities induced by biological attacks of fungi, insects, etc.

Acoustic tomography is an emerging NDT technology for tree decay detection in both urban community and production forest. Many field studies have been conducted to assess the applicability and reliability of the technique in such applications. Although investigations on urban trees showed great success using acoustic tomography to detect moderate to severe internal decay within the trunk, detection of early stage of decay using such technology still constitutes a challenge.

Internal decay is a major structural defect on trees of many species. The economic loss caused by internal decay is most significant for the hardwood trees that are used to produce appearance-grade veneer and other high value engineered wood products. Because of the exceptionally high prices paid for high quality hardwood trees, undetected decay can cause a substantial monetary loss to timber buyers and wood manufacturers (Wiedenbeck *et al.* 2004).

Early detection of internal decay in hardwoods could provide a significant benefit to the industry in terms of making accurate quality assessments and volume estimates and use of the resource. It can also help foresters in prescribing silvicultural treatments for improved management decision-making and thus help maintain a healthy forest (Wang *et al.* 2009). Acoustic tomography is an emerging NDT technology for tree decay detection in both urban community and production forest. It allows the users to visualize the velocity distribution of the acoustic waves as the waves propagate through the cross section of a tree trunk. Because acoustic velocity is directly related to density and dynamic modulus of elasticity of wood, acoustic velocity mapping of a cross section could be used as a diagnostic image to detect internal decay in trees (Bucur 2003).

The application of this technology was initially demonstrated on wooden poles by Tomikawa *et al.* (1990) for inspecting the internal condition of the poles. Later on, many researchers have investigated the applicability of the technology to detect internal decay in live trees (Comino *et al.* 2000; Gilbert and Smiley 2004; Wang *et al.* 2004, 2007, 2009; Allison *et al.* 2007; Deflorio 2008; Lin *et al.* 2008). Stress wave velocity has been traditionally regarded as an indicator of the presence and extent of internal wood decay (Tomikawa *et al.* 1986; Auty and Achim 2008; Roohnia *et al.* 2011). Generally, stress waves travel more slowly in decayed or deteriorated wood than in sound wood, as decayed wood could cause a prolonged wave transmission time in measurements (Wang 2013). When a tree suffers from decay or other internal damages, stress wave propagation velocity changes according to the change of its physical conditions. Therefore, when conducting the acoustic measurement, the internal condition of a tree can therefore be detected by analyzing the stress wave data.

So far, laboratory investigation and field application of acoustic tomography have been largely focused on urban trees with the principal goal being to determine the stability of the trees to minimize the risk of tree failure.

The various stages that are usually taken into consideration during ultrasonic inspection of the trees are: detection, localization, characterization and decision to act on it, if the defect is important enough. The ultrasonic techniques currently used are: scattering based techniques that use the travel time, and others wave parameters, and ultrasonic tomographic imaging techniques which seek to provide a high resolution picture of the defect.

In this activity of PhD, the main objective was to assess wood quality of standing trees with ultrasonic velocity methods and to analyzed the potential of this technology for assessing the quality of high-value hardwood trees in production forests of chestnut with different silvicolture methods (high forest and coppice).

***Materials and methods***

***Study sites and tree samples***

The study was conducted in September 2016 in the Massif Serre Vibonesi, Calabria region in the municipality of Cardinale, an area located in the historical part of the region that is characterized by forestry of chestnut. The forest here is located at 622243.74 E – 4277942.05N (WGS_84 – Fuso 33). Elevation is approximately 650/700 m above sea level, with a northern aspect. Average annual rainfall in this area amounts to 900 mm, with the lowest monthly average precipitation occurring in July (20 mm) and the highest in December (150 mm). Mean annual temperature is 19°C, with the lowest values in January. The soils in this area developed from igneous and metamorphic rocks and are classified as Umbrisols, with an udic soil regime moisture. The forest here is dominated by Chestnut (Castanea Sativa L.) trees and it covers 44 ha with a slope of 0%–40%. The study area consisted of two sites (A and B), each under different treatments: high (A – 800 plants per hectare) and coppice forest (B - 1800 plants per hectare). The density of both forests was generally uniform with small gaps only in area with more shallow soil depth. The main characteristics of the study sites are reported in Table 1.

*Table 1 - Characteristics of the two study sites*

| Site | A | B |
|---|---|---|
| Stand Type | Natural forest | Natural Forest |
| Total Area | 18 | 26 |
| Silviculture | High forest | Coppice |
| Density (trees /ha) | 800 | 1800 |
| Site volume ($m^3$/ha) | 870 | 480 |
| Average DBH of tress analyzed (cm) | 42 | 37 |
| Average Height of tress analyzed (m) | 22 | 18 |

***Instruments***

Ultrasonic tomography is a technique used to produce an image of the internal structure of a solid object by recording differences in the speed of sound wave transmission. NDT is needed as an integral part of manufacturing for the optimization of volume and quality of output from each tree. The ultrasonic Tomography consists of a set of sensors (typically 8 to 16) that are connected to the trunk by pins (roofing nails) 0.8 to 2 mm in diameter. Sound waves are produced by tapping each sensor with a small hammer. The system measures the transmission time from each impact with the hammer to each sensor.

The tomography main unit itself or the PC calculates the sonic tomogram when all readings have been taken. The tomogram shows the relative and apparent ability of the wood to transmit acoustic waves. Wood quality with NDT is calculated using the acoustic velocity estimated by the FAKOPP Ultrasonic Tomography™ (Fakopp Enterprise, Agfalva, Hungary). The tomography main unit itself or the PC calculates the sonic tomogram when all readings have been taken. The tomogram shows the relative and apparent ability of the wood to transmit acoustic waves. Different colors display the various properties of the wood: areas of good wood, where the fastest velocities can be found, are represented in (dark) green. The meaning of yellow varies according to the defect. It often describes the distance between healthy and damaged wood. Red and blues represent damaged areas. Using these data, a two-dimensional image, or tomogram, of the tree cross-section is generated. Tomography measurements were taken on 3 cross-sections from 60 trees (30 in high forestry and 30 in coppice forestry) at three sampling levels (50, 100 and 150 cm above the ground. Twelve sensor pins were equally spaced around the trunk and driven into the sapwood in a horizontal plane according to the manufacturer's instructions. A sensor was magnetically attached to each pin and tapped three times with a steel hammer. A tomogram was created for each cross-section. The software (ArboSonic 3D) of the used equipment automatically calculates the straight - line distance between automatically calculates the straight-line distance between the sensors acting as transmitter and receivers and, based on the sound propagation time from the transmitter to the receiver, it calculates the speed and draws a straight line whose color corresponds to a speed category. Based on the recorded speeds and the traced straight lines (Divos *et al*. 2005), the software constructs a map of speeds which represents the tomographic image of the analyzed section (Fig. 1).

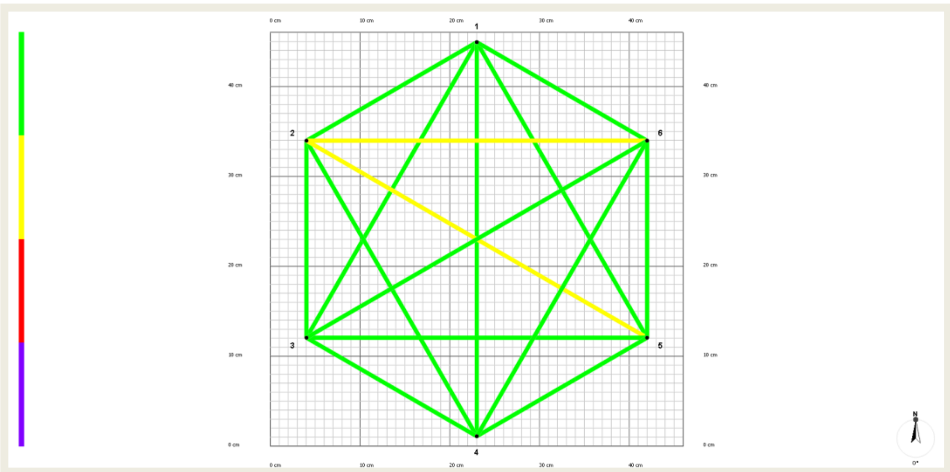

Figure 1 - Propagation of sound speed in the cross section

The tomogram shows the relative and apparent ability of the wood to transmit acoustic waves. Different colors display the various properties of the wood: Areas of good wood, where the fastest velocities can be found, are represented in (dark) green. The meaning of yellow varies according to the defect. It often describes the distance between healthy and damaged wood. Red and blues represent damaged areas. In Figure 2 is reported an example of tomograms.

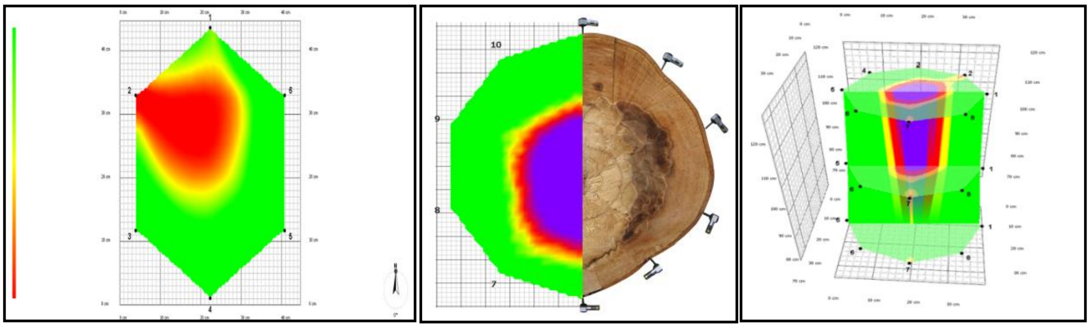

Figure 2 - Tomograms in single cross section and in the three cross section

***Statistical Analysis***

Two-way ANOVA (calculated using SPSS version 20.1) was used to assess the effects of silviculture method, cross-sections, and their interaction in standing trees. Tukey's test ($p<0.05$) was used to determine significant differences in Silviculture and cross-sections among the different treatments.

***Results and discussion***

Ultrasonic Tomography are instruments that detect decay and cavities in standing trees non-invasively. It measure the velocity of sound waves in wood and depends on the modulus of elasticity and the density of the wood itself. Most damage and disease causes fractures, cavities, or rot and reduces the wood's elasticity and density.

Determining the value of wave propagation velocity at every point in the cross section has been the key in assessing the internal condition of the tree. The propagation velocity of a stress wave has been treated as a variable distributed in the region, and the features of internal condition are reflected by the values of the variable.

In the tomographic images constructed for the test samples, four colors schemes (dark green, yellow, blue, and red) were considered to represent the internal conditions of the cross section tested. The color scale is expanded between the 100% and lowest velocity.  In principle, a stress wave tomogram shows the distribution of stress wave velocity in the cross section of a tree. The color presentation of the velocity zones demonstrates the differences in the ability of the wood to transmit stress waves. The ability of the wood to transmit stress wave signals within a cross-section strongly correlates with its modulus of elasticity and density.

For the analyzed chestnut trees, the diameters at breast height ranged from 32 at 56 cm, so the number of sensors used was variable related to the tree diameter. Thus, by taking into account the literature recommendations, Rinn (2014) and Wunder (2014), according to which the number of sensor must be large to capture the complexity of the analyzed section, in this study were used 8 sensors.

By visual examination, no full decay was evident in all trees examined. Only by ultrasonic tomography, the wood quality evaluated in 180 cross-sections (90 in high forest and 90 in coppice forest) showed some different sizes of decay (72 and 21 in coppice and high forest, respectively) (figure 3) while 87 cross-sections high forest displayed no decay evident (figure 4). This result might justify how the treatments affect the quality of the wood on standing trees.

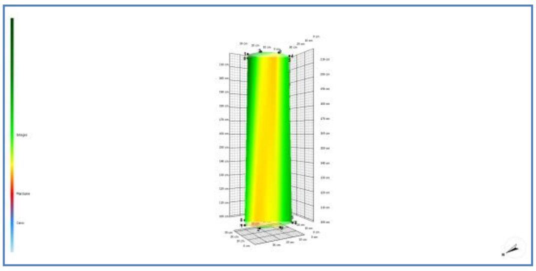

Figure 3 - Decay in cross-section

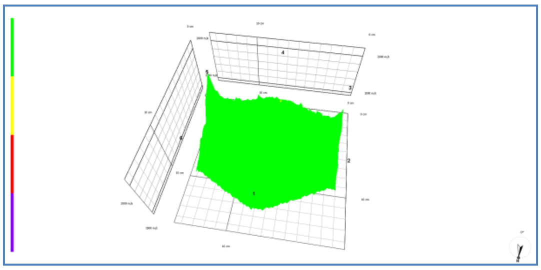

Figure 4 - Decay not evident

From results obtain by wave propagation speeds, it is possible considered that high forest and coppice showed significant differences. In site A (high forest) the values of speed was 30% highest and the percentage of decay was 70% lower respect to coppice (site B). In what concerns the wave propagation speeds, it was found that in high forest they had minimum values ranging from 1,881 m/s to 2,496 m/s. The distribution of minimum values for wave propagation speeds, recorded on the three analyzed section (50, 100 and 150 cm) is shown in

Table 2, where it can be seen that the values are not influenced by the above-ground level of the analyzed sections, as there were situations in which the speed recorded at 50 cm above the ground was greater than those recorder at 100 or 150 cm (case of trees n 22). Only four trees showed lower values from 2,425 m/s to 2,496 m/s (Figure 5). The predominance of low values of the wave speed propagation through the wood was explained by the presence of serious internal defects such as decay.

*Table 2 - Propagation of sound speed in Site A*

| Cross Section | Trees with decay (m/s) | Trees without decay (m/s) |
|---|---|---|
| Section 50 cm | 2170 | 2496 |
| Section 100 cm | 2120 | 2456 |
| Section 150 cm | 1881 | 2425 |

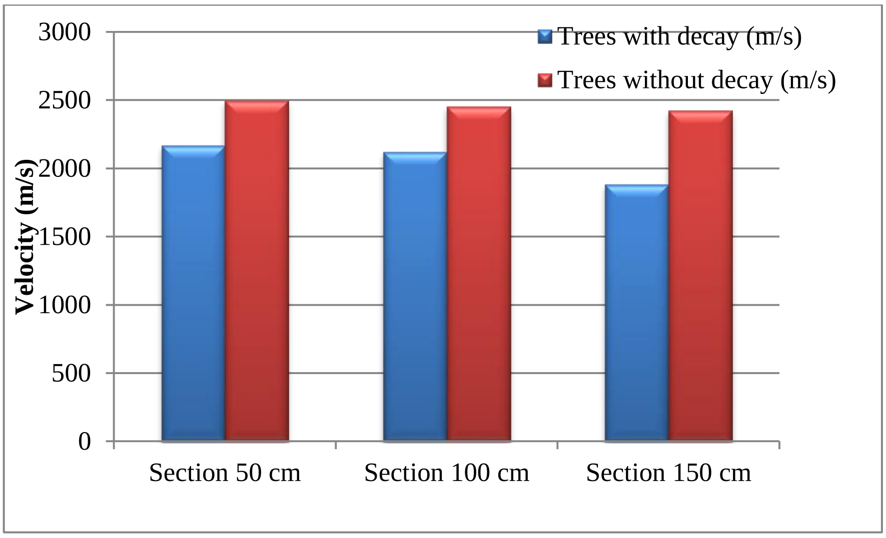


Figure 5 - Differences of sound Speed in the cross Section

In site B, instead, the wave speed propagation were found frequently lower respect high forest; 24 trees and 72 cross sections showed evident decay. In particular, there are not significant different of speed in the same site. It was found that in coppice they had minimum values ranging from 1,865 m/s to 2,378 m/s (Figure 6).

The distribution of minimum values for wave propagation speeds, recorded on the three analyzed section (50, 100 and 150 cm) is shown in Table 4.

*Table 4 - Propagation of sound speed in Site B*

| **Cross Section** | **Trees with decay (m/s)** | **Trees without decay (m/s)** |
|---|---|---|
| Section 50 cm | 2050 | 2256 |
| Section 100 cm | 1993 | 2378 |
| Section 150 cm | 1865 | 2301 |

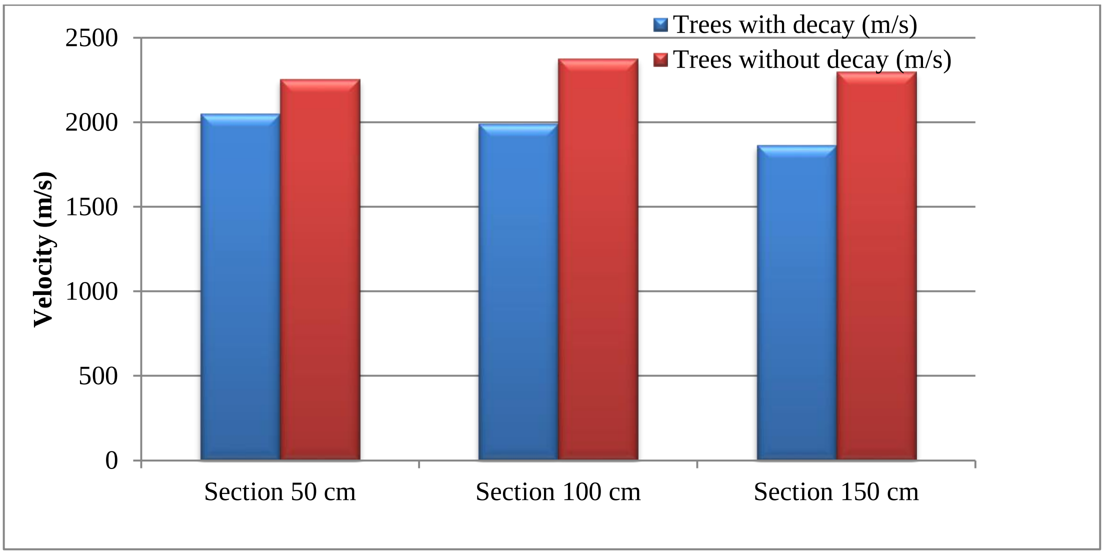


Figure 6 - Differences of sound Speed in the cross Section

Wood quality was influenced significantly by the method silviculture ($p<0.05$) but not by diameter and height. In particular, the percentage of decay was considerably lower in high forest than in the coppice. The interaction between the method silviculture and cross section was not significant ($p>0.05$), the same condition has been found comparing the tree cross section from two different sites (A and B) (Table 5).

*Table 5 - Statistical Analysis*

| **Source** | **Type III Sum of Squares** | **df** | **Mean Square** | **F** | **Sig.** |
|---|---|---|---|---|---|
| Corrected Model | 1.503 | 5 | 0.301 | 1.203 | 0.310 |
| Intercept | 42.930 | 1 | 42.930 | 171.81 | 0.000 |
| Method Silviculture | 0.767 | 1 | 0.767 | 3.068 | 0.082 |
| Cross - Sectiom | 0.669 | 2 | 0.335 | 1.340 | 0.265 |
| Interaction | 0.025 | 2 | 0.013 | 0.050 | 0.951 |
| Error | 43.475 | 174 | 0.250 | | |
| Total | 88.000 | 180 | | | |
| Corrected Total | 44.978 | 179 | | | |

The correlations suggest that the coppice regimes cause rapid diameter growth and may be susceptible to a reduction of wood quality. The applicability of acoustic waves to assess the intrinsic wood properties of standing trees has been validated by many studies around the world (Nanami *et al.* 1992a; Nanami *et al.* 1992b; Nanami *et al.* 1993; Ikeda and Kino 2000; Ikeda and Arima 2000; Huang 2000; Wang *et al.* 2001; Lindstrom et al. 2002; Proto *et al.* 2017). A similar result was found by Wang (2012) that a range of wood and fibre properties can be predicted through a simple acoustic measurement in standing trees. Many studies reported that, for softwood trees of the same age stress wave, velocity is higher for trees with slower growth rates or narrower rings.

Although acoustic tomography has been found useful in detecting internal decay of urban trees, the potential of this technology has not yet been fully explored for assessment of wood quality and this first survey could give useful informations. The results have illustrated the potential of the stress wave technique for determination of the influence of silvicultural method performed on chestnut, taking into consideration the vast areas of cultivation of this species in the region and the economic value of wood.

***Conclusion***

In this study the use of an interpolation technology was explored for reconstructing stress wave tomographic images and detecting internal decay in two different method silviculture of chestnut (Coppice and High Forest). The wood quality is affected by initial stand density conditions, and change, minor or major, is produced by method silviculture. These results showed that different method has a significant influence on acoustic wave measurements and a valid relationship exists between coppice and high forest. These results are encouraging and indicate that the tomography technique may be used to track wood property changes in trees and determine how forests could be managed to meet desired wood and fibre qualities (Wang *et al.* 2001). Based on the preliminary results obtained from this laboratory study, the following conclusions were drawn:

1. A stress wave tomogram can be reconstructed using an interpolation technology based on TOF data obtained from tree samples. The location and extent of internal decay in tested tree samples were well reflected in the tomograms. A good match was found between tomographic images and the true physical conditions of the samples.
2. Repeated measurements on same cross section of a tree sample resulted in consistent stress wave propagation data. Consequently, the tomograms obtained were generally consistent.
3. Deep crack inside the tree sample was not recognized accurately in the tomogram, highlighting the limitation of stress wave-based tomography technique in detecting internal defects of trees other than decay.
4. Stress wave velocity pattern with respect to wave propagation path in a tree's cross section was found to be a good indicator of internal condition of trees. The combination of stress wave tomography and velocity pattern may lead to a better diagnosis of internal condition of urban trees in future.

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### *3.3 Activity 3 - Mechanization Forestry – Skidder*

***Introduction***

More than a third of Italy is covered by arboreal and shrub vegetation, equivalent to 35% of the national surface (NFI, 2005). Out of all the regions of Italy, several regions in South Italy have the largest percentage of forest. In this area, delineated geographically as southern Italy, woodlands are very important, not only in terms of forest production, but also for the variety of typical landscapes that they form. Their economic potential is considerable due to the favourable seasonal conditions, which prolong the vegetative time, consequently increasing productivity levels (Proto *et al.* 2017a). In fact, forests in southern Italy present an average increment of 6–8 $m^3$ $ha^{-1}$ per year and these forests can provide a significant wood resource for the economy of the entire Mediterranean basin with over 1,517,000 ha of forest cover. Making up 32% of the total are beech (Fagus sylvatica L.), chestnut (Castanea sativa Mill.), Corsican pine (Pinus nigra Arnold subsp. Calabrica Delamare) and silver fir high forests (Abies alba Mill). With improved, more efficient mechanization of harvesting operations, the production of wood-based products could be an increasingly significant resource for the southern Italy economy. In fact, forests and wood represent a basis for economic, environmental and social stability in rural areas and wood harvesting has always represented one of the most important management interventions for the future of forests (Zambon *et al.* 2016; Tam *et al.* 2017). Additionally, several techniques have been developed during the last fifty years to increase operator productivity, work qualifications and occupational safety (Proto *et al.* 2017b; Klein *et al.* 2016). However, in these regions, the level of mechanization in harvesting is low: the most common harvesting method can be described as being at an early stage of mechanization (Zimbalatti and Proto, 2009) This level of mechanization in forest utilization is due to the site features of the forests, where almost half of the forest areas have slopes of over 40%, prevalence of state ownership with respect to private owners, abundance of coppice stands in comparison to high forests, preponderance of firewood and wooden pole production as opposed to roundwood, the small-scale characteristics of the forest ownership structure (approximately 75% of the forests are owned in parcels of less than 250 hectares) and the small size of many forest enterprises (NFI 2005, Zimbalatti and Proto, 2009). In the Calabrian region of southern Italy, the most widely used means of timber extraction is the farm tractor equipped with forestry winches (87%) (Zimbalatti and Proto, 2009); a similar trend is seen in other southern and central Italy regions (Marchi *et al.* 2014). The remnant 13% of wood is extracted by tractors with a trailer or bin, cable cranes, forwarders, chutes and animals (horses, mules and oxen) (Macrì *et al.* 2016). The use of forestry skidders is largely unknown. Several studies have evaluated the performance of innovative harvesting systems (cable cranes and forwarders) in southern Italy, highlighting profit margins sufficient to justify higher investment costs (Zimbalatti and Proto, 2009; Proto *et al.* 2017c). However, no previous study has analysed the productivity and costs of harvesting using skidders in heterogeneous forests, despite the fact that skidders have been diffused abundantly over the last several decades.

The general knowledge of ground-based harvesting and extraction technology is considerable (Heinimann, 2009; Gumus *et al*. 2016). Several studies have examined skidders in order to find out the influence of different factors on productivity and cost, or to compare different methods (winch versus grapple) in different countries and different terrain and stand conditions (Mousavi, 2012; Mousavi *et al.* 2017). Kluender *et al.* (1997) studied the productivity of rubber-tired cable and grapple skidders in southern pine stands in Arkansas: they found that grapple skidders were considerably faster and more productive than cable skidders. In the hilly and mountainous forests of Croatia, wheeled skidders equipped with winches are the most commonly used vehicle for timber skidding after preparatory and selective felling (Horvat, *et al.* 2007), while the use of adapted farming tractors and tractor assemblies has decreased (Stankić, *et al*. 2012). Mederski *et al.* (2012) compared the productivity of grapple skidders and rope skidders under the same stand conditions in North Poland. Recently, in southern Poland, Kulak *et al.* (2017) evaluated the efficiency of a variety of skidding operations performed in stands. In Romania, the most frequently used harvesting system uses skidders and skidding distance has been found to be one of the most relevant independent variables for explaining the time consumption (Borz, *et al.* 2013). In Austria, extraction is predominantly carried out using skidders while cable yarding is commonly used on more difficult and sensitive sites (Russell and Mortimer, 2005). Over the last decade, numerous studies on skidding were conducted in Iran (Mousavi, 2012). Najafi *et al.* (2007) carried out a time study to obtain a mathematical model and to calculate the production cost. Eghtesadi (1991) studied the influencing factors on skidding performed by the TAF skidder in relation to several variables (skidding distance, longitudinal slope, number of trees and volume per cycle). Wang *et al*. (2004) mentioned that the skidding cycle time was mainly affected by turn payload size and skidding distance on the Appalachian Mountains (West Virginia). In New Zealand, cable skidders (rather than grapple skidders) remain the preferred machine for extracting felled trees from the felling face to the landing, and were first introduced many decades ago (Hurst, 1986). In particular, the object of a research, conducted in New Zealand in 1987, was to compare the performances of a grapple and a cable skidder working under the same conditions (Moore, 1987). Based on literature data and on the experience of converting from manual to mechanised systems in other countries, this study focused on the potential benefits of introducing a more mechanised, purpose-built extraction system—specifically a John Deere 548H skidder. The objectives were (1) to calculate the production rates (m3·$h^{-1}$) and costs (€·$m^{-3}$) of skidding under South Italy conditions; and (2) to develop models of time consumption and productivity for skidding [Kluender *et al.* 1997; Najafi *et al* 2007; Mousavi 2012).

## Materials and Methods

### Study Site

The tests were carried out in the Serre Massif (VV) forest (Figure 1). The work phases were recorded separately at two different test worksites, indicated with the letters A and B. During skidding operations, the machine was constantly monitored, the various work phases were observed using a time and motion study, and the extraction distances were recorded for each cycle. The total number of trees transported was counted and each tree was measured using Huber's formula (Philip, 1994). The volume of each tree was calculated. The chestnut forest is located at an elevation of 1200 m above sea level. The study was conducted at a selective felling site, which had an area of 4.5 ha with N–E exposition. The forest land is classified as I class for roughness, while the slope is between III and IV class in accordance with the terrain classification of the UK Forestry Commission (1995). The stand density was 800 and 880 trees per hectare for site A and B, respectively. The total volume was 675 $m^3$ at site A and 585 $m^3$ at site B. The density of the forest in both sites is generally uniform; small gaps are present only in the areas with lower soil depth. The forest area has a good main road network (25 m $ha^{-1}$) and is flanked by a provincial road; the trails opened during felling were used as a secondary road network (Cavalli and Grigolato, 2010). Site characteristics are described in Table 1.

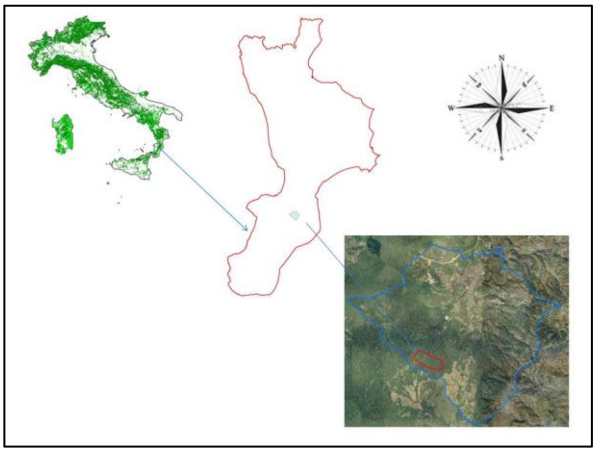

Figure 1- Location of case study

*Table 1- Test site characteristics*

| **Features** | **Site A** | **Site B** |
|---|---|---|
| Silvicultural system | High forest | High forest |
| Stand density | 800 trees/ha | 880 trees/ha |
| Basal area | 36.2 m2/ha | 34.9 m2/ha |
| Average DBH | 24 cm | 22.4 cm |
| Average height per tree | 21 m | 20 m |
| Average volume per tree | 0.52 m3 | 0.47 m3 |
| Average Slope | 27% | 27% |
| Range of Slopes | 23–37% | 19–32% |

**Machine Characteristics**

The skidder used was a John Deere 548H, equipped with both a cable winch and a grapple (Table 2). At site A, the skidding operation has been conducted using the cable winch because it was not possible to drive up to the felled timber. At site B, the grapple was used as the timber had been felled and pulled to the skid road. Elevation was measured using a handheld Global Positioning System (GPS), Magellan TritonTM 2000 while the gradient was assessed with a Suunto clinometer. Extraction distances were measured with a laser rangefinder. Dendrometric data were recorded in order to attain the total volume extracted/yielded in each area using a volume table (double entry) and a plot sample. The data collected during the phases of winching and skidding allowed the calculation of the hourly productivity of the machine.

*Table 2 - Specifications of the skidder*

| Parameters | Unit | Value |
|---|---|---|
| Make | ------- | John Deere |
| Model | ------- | 548H |
| Power | kW | 110 |
| Weight | tonnes | 12.16 |
| Height | mm | 3002 |
| Width | mm | 2640 |
| Length | mm | 6662 |
| Clearance | mm | 493 |
| Wheelbase | mm | 2920 |
| Grapple area | m2 | 0.74 |
| Diameter Winch Cable | mm | 15.8 |
| Drum capacity | m | 80 |
| Nominal Pulling Force of Winch | kN | 193 |

**Working Systems**

The time study data were collected during the autumn of 2016 and the spring of 2017. At both sites, the work system adopted was the Full Tree System (F.T.S.). At site A, the working group consisted of one skidder operator, two choker setters and one operator at the landing site. The operator drove the skidder from the roadside to the felling site, then released the cable for hooking (Figure 2). Loads were attached to the cable by the choker setters, winched to the skid trails, and extracted to the landing area by the skidder. In contrast, at site B, the crew consisted only of two workers: a skidder operator (same as the skidder operator working at site A), who used a skidding grapple to drag the trees to the landing area where the second operator awaited the load.

Figure 2- Extracting trees with a John Deere skidder at site A.

***Productivity and Costs***

The study used continuous elemental time study format to determine the total extraction cycle times (Harstela, 1995; Spinelli and Magagnotti, 2012). The extraction cycle was divided into several elements:

- Travel unloaded (similar for cable winch and grapple): begins when the skidder leaves the landing area and ends when the skidder stops in the stump area;
- Release and hooking (cable winch): begins when the worker has just grabbed the cable and sets the choker on the tree about 0.5–1.0 m away from the tree end, and ends when the skidder operator starts winching;
- Winching (cable winch): begins when the driver starts to winch and ends when the tree has arrived at the rear part of the skidder;
- Grabbing (grapple): begins when the grapple of the skidder opens and takes the trees and ends when the grapple is closed;

- ❖ Travel loaded (similar for cable winch and grapple): begins when the machine moves to the landing and ends when it reaches the landing;
- ❖ Unhooking (similar for cable winch and grapple): begins when the machine reaches the landing and ends when the load is unhooked;

The time required for the completion of each phase was measured using a digital chronometer (1 min = 100 units), Tag-HeuerMicrosplit™. Operational, technical and personal delay types were measured in skidding (Zimbalatti and Proto, 2009).

This study measured the impact of several independent variables: “Skidding distance”, “Winching distance”, “Number of trees” and “Load Volume” on the “total cycle time”, considered as a dependent variable.

In order to calculate the hourly cost of wood extraction, many parameters were considered (Olsen, 1983) and the Miyata (1980) approach was applied. The machine rate method described by Miyata includes fixed costs, variable costs, and labor costs. The fixed costs (depreciation, interest, insurance, and taxes) were estimated using straight line depreciation (Miyata,1980). The variable costs comprise fuel, lube and maintenance and repair, calculated as a percent of depreciation. Labor costs included hourly wages plus overheads and fringe costs.

The skidding cost was calculated based on observed productivity. In order to calculate the production cost of extracting 1 $m^3$ of wood, the cost analysis measured the following parameters: the number of workers, the hourly cost of an operator, the hourly cost of the machine, the volume of wood extracted and productive machine hours. Machine costs per hour are reported as Scheduled Machine Hours (SMHs) (Table 3). The purchase prices and operator wages required for the cost calculations were obtained from catalogues and accounting records. Labor cost was set to 21 € SMH−1 inclusive of indirect salary costs. Diesel fuel consumption was measured by evaluating the volume of fuel used to fill the fuel tank to the brim and recording the amount of fuel used during that day. A salvage value of 20% of the purchase price was assumed and the Value Added Tax (VAT) was excluded. Cost calculations were based on the assumption that companies worked throughout the entire year with the exception of the rainy season, when the harvest areas of southern Italy are not normally accessible. In general, this correlates to 130–150 working days in the year (21 working days per month), at an average of 7 scheduled working hours per day (assuming one to two hours spent having lunch, rest and other breaks); it yielded an annual working time of 910–1050 SMHs with a coefficient of utilization of 70% (Miyata, 1980; Nikooy *et al.* 2013). These parameters are slightly lower in comparison to recent economic studies carried out by Mousavi (2012), Spinelli and Maganotti, (2011), Nikooy *et al.* (2013), and have been chosen to represent the reality of small-scale nonindustrial private forestry, which may prevent the intense annual utilization of mechanical equipment.

*Table 3 - Assumed cost parameters for machine rate calculation*

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Purchase price (€) | 200,000 | Interest (€ year−1) | 8960 |
| Salvage value (€) | 40,000 | Taxes and insurance (€ year−1) | 10,240 |
| Estimated life (n year) | 10 | Total fixed cost (€ h−1) | 33.52 |
| Scheduled machine hour (SMH) (h) | 1050 | Total variable cost (€ h−1) | 25.62 |
| Productive machine hour (PMH) (%) | 70 | Total labour cost (€ h−1) | 21 |
| Fuel & Lubricant (€ h−1) | 14.95 | Repair & maintenance (€ h−1) | 10.67 |
| Annual depreciation (€ year−1) | 16,000 | Total hourly cost (€ h−1) | 80.14 |

### *Data Analyses*

The time study data consisted of 80 skidding cycles (40 at each site). Two different techniques were adopted to construct the models for time and productivity. A delay-free time model was formed separately for each time element and a model for total time was formed by combining the elements. SPSS software version 20.0 (IBM Corp., Amonk, NY, USA) was used for the statistical analysis of the compiled data. A regression model was thus developed. Initially, a 95% significance level was chosen to test the null and alternative hypotheses given above. An F-test was conducted to examine the goodness of fit of regression models and to test the cosignificance of the coefficients. Each coefficient of the work phase models was also tested separately using a t-test. If the test results indicated p-values lower than 0.05, the null hypothesis was rejected and the differences in the time were due to treatments as reported in similar studies on the performance of skidders [Mousavi, 2012; Mousavi *et al.* 2012; Wang *et al.* 2004). Regression analysis with variable transformation was used to model skidding: the total cycle time could be explained by the independent variables (number of trees, average volume, skidding distance, winching distance and number of trees). An additional variable was inserted to differentiate the two work sites: site A = 0 for the cable skidder and site B = 1 for the grapple skidder. Finally, the total time of a working cycle has been defined by summing the time for the individual cycle work phases.

## *Results and Discussion*

### *Elemental Time Study and Efficiency Analysis*

At site A, the average number of trees extracted per cycle was 7, the average skidding distance was 276 m, the average and maximum winching distances were respectively 34 and 65 m, and the average volume skidded per turn was 3.88 m3. At site B, the average number of trees per turn was 8, the average skidding distance was 266 m, and the volume per turn was 4.01 m3. Travel loaded and travel unloaded were the two main time elements, and winching only occurred at site A. On average, the extraction cycle time at site A with the winch was 9.35 min (±1.34 standard deviation (SD)), while at site B the grapple extraction cycle time was 8.75 min (±0.99 SD), with the breakdown of the individual elements shown in Table 4. One confounding effect was the unloaded and loaded travel time. By adding the distance for the travel unloaded and loaded, and dividing it by the distance travelled within that element, it was possible to establish average travels speed. The average speed for travel unloaded was 8.58 km/h at site A and 4.91 km/h at site B. For travel loaded, the average speed was 6.02 km/h at site A and 4.33 km/h at site B. The grapple skidder working at site B traversed a much rougher trail and took considerably longer to travel an equivalent distance in comparison to site A. This off-set the time saving from not having to set chokers and pre-extract the trees to the skidder at site A.

*Table 4 - Descriptive statistics of the mean value and standard deviation (SD) at sites A and B.*

| Work Phase | Measurements Unit | Site A Mean | Site A (SD) | Site B Mean | Site B (SD) |
|---|---|---|---|---|---|
| Travel unloaded | Minutes | 1.93 | 0.39 | 3.25 | 0.35 |
| Hooking/Grabbing | Minutes | 1.88 | 0.36 | 0.78 | 0.25 |
| Winching | Minutes | 2.00 | 0.43 | ------- | ------ |
| Travel loaded | Minutes | 2.75 | 0.56 | 3.68 | 0.53 |
| Unhooking | Minutes | 0.59 | 0.07 | 0.01 | 0.00 |
| Delay time | Minutes | 0.20 | 0.03 | 0.24 | 0.01 |
| Total time | Minutes | 9.35 | 1.34 | 8.75 | 0.99 |

***Time Consumption and Productivity Models***

Table 5 shows the time consumption model of skidding in all work phases, overall time consumption, and the statistical characteristics of both the regression models and the productivity model. The F-values and *p*-values show that the presented models are statistically significant. The average skidding productivity at site A was 30.4 $m^3$ per Productive machine hour (PMH) and 24.8 $m^3$ per SMH. At site B, the grapple skidder had an average hourly productivity of 35.1 $m^3$ per effective hour and 28.1 $m^3$ per gross effective hour. There was no significant difference (*p*-values: 0.94) in the productivity of skidding of the two methods of extraction (cable winch versus grapple) because of the confounding road effect. Winching time at site A was directly related to winching distance. At both sites, productivity has an inverse relationship with skidding distance and a direct relationship with the volume skidded; therefore, the highest productivity was found when the skidding distance is short and load volume is high. The number of valid observations collected during the tests was large enough to develop a reliable model for predicting cycle time. Two different models for predicting total times were evaluated using linear regression and selecting the independent variables with a step-by-step regression. According to the statistical analysis, the models presented for the work sites are valid ($p < 0.05$). The cycle time equations, calculated for the skidding operations in the two different systems (Cable winch versus Grapple), were correlated with several parameters (Skidding distance (Sd); Winching distance (Wd) and Volume (V), see Tables 6 and 7). Winching distance, skidding distance and volume ($p < 0.005$) had a significant effect on total cycle time at both sites. Time consumption of unhooking did not show dependency on any of the independent variables. The number of trees ($p > 0.05$) had a reduced and a nonsignificant effect in the model of the total cycle time at both sites. In the productivity models, all variables showed a significant effect. Therefore, two models were developed and the resulting R2adjusted was used as a measure of the predictive capacity of the equations. The multiple correlation coefficients ($R^2$) of the two models of total time (Equations (1) and (2)) are 91% and 88% of the total variability for Winch and Grapple, respectively. The productivity model (Equation (3)), which can be used to predict output as a function of the same variables, is highly significant and explains almost 77% of the overall variability. There are significant differences between the two sites ($p < 0.05$).

Table 5- Statistical characteristics of regression analysis-based models

| System | Model | Unstandardised Coefficients | | Standardised Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| Winch | (Constant) | −4.384 | 1.844 | ------ | −2.378 | 0.023 |
| | Winching distance | 0.039 | 0.015 | 0.335 | 2.627 | 0.013 |
| | Skidding Distance | 0.037 | 0.008 | 0.570 | 4.857 | 0.000 |
| | Volume | 0.494 | 0.154 | 0.188 | 3.202 | 0.003 |
| Grapple | (Constant) | 2.505 | 0.387 | ------ | 6.4171 | 0.000 |
| | Skidding Distance | 0.017 | 0.002 | 0.765 | 10.885 | 0.000 |
| | Volume | 0.402 | 0.113 | 0.250 | 3.554 | 0.001 |

Table 6. Cycle time and productivity equations for sites A (cable skidder) and B (grapple skidder)

| Site | Model | Equation | | F | P | $R^2$ adjusted |
|---|---|---|---|---|---|---|
| A | Tot time | Equation (1) | $Tt = -4.384 + 0.039 \times Wd\ (m) + 0.037 \times Sd\ (m) + 0.494 \times V\ (m3)$ | 133.3 | 0.00 | 0.91 |
| B | Tot time | Equation (2) | $Tt = 2.505 + 0.017 \times Sd\ (m) + 0.402 \times V\ (m3)$ | 151.3 | 0.00 | 0.88 |
| | Productivity | Equation (3) | $P = 23.95 - 0.072 \times Sd\ (m) + 4.833 \times V\ (m3) + 1.833 \times St$ | 91.6 | 0.00 | 0.77 |

Wd = Winching distance, Sd = Skidding Distance, V = Volume, St = Skidding type (0 = cable skidder; 1 = grapple skidder)

*Table 7 - Results of the analysis of variance on the productivity*

| **Factor** | **Model** | **Sum of Squares** | **Df** | **Mean Square** | **F** | **Sig.** |
|---|---|---|---|---|---|---|
| Productivity | Regression | 1188.896 | 3 | 396.299 | 91.653 | 0.000 |
| | Residual | 328.616 | 76 | 4.324 | | |
| | Total | 1517.512 | 79 | | | |

Dependent Variable: Productivity

***Production Cost***

The hourly cost of the skidder was € 80.14 including the sum of machine cost and labour cost; the difference between the minimum and maximum cost of skidding was not considerable. The calculated extraction costs were €5.80 $m–^{3}$ at site A and €3.60 $m^{-3}$ at site B. In particular, there was lower measured productivity at site A due to the amount of time taken to complete a cycle and, consequently, higher unit costs in comparison to site B. Operational delay and technical delay accounted for almost 92% of the delay time and the percentage of personal delay was low. The total delay time was only 15% of the skidding time, and was low in comparison with other skid cycle elements. Delay times increase the operating cost by 18% at both sites and production costs increase when both the skidding distance and the load volume increases. Increasing each variable on this machine causes an increase in cost; skidding cost per cubic meter decreases only when the utilization increases.

A few studies on skidding with traditional methods, such as using a farm tractor equipped with a skidding grapple or cable winch, have been carried out in central and southern Italy (Spinelli and Magagnotti, 2012; Nikooy *et al.* 2013; Spinelli and Baldini,1992; Hiesl and Benjamin, 2013). However, to date, no detailed time study has been performed on wood extraction using a purpose-built skidder. This study provides the cycle time and productivity of skidding, and also introduces partial and overall time consumption models.

Travel unloaded in terrain with a slope greater than 30% limits the skidder speed in downhill skidding because the skidder must perform the return leg of the trip uphill—increasing the time consumption (8.58 km/h at site A and 4.91 km/h at site B). At both sites, modeling the travel unloaded time showed that the time was highly dependent on the skidding distance, consistent with Wang *et al.* (2004). The amount of time spent travelling unloaded was the second largest element of the skidding cycle at both sites (21% at site A, 41% at site B).

Mousavi *et al.* (2012) found that the winching phase can be modelled solely based on the winching distance; however, the condition of the cable, winch drum, understory trees and worker conditions may influence the time consumption of releasing. Underbrush may have an impact when the cable is pulled and the chokers are set. More time is required to prepare a load for skidding under heavy brush conditions (Mousavi, 2012).

When the number of trees in each cycle increases, the time consumption of hooking also increases. Attaching and releasing the chokers manually at site A took twice as long as grabbing and releasing the trees with the grapple at site B.

The winching phase at site A accounted for 21% of the total cycle time. The regression analysis conducted on winching cycle time has revealed that the winching distance as well as the number of winched trees significantly affected the time consumption.

Travel loaded is the most time-consuming element of skidding at both sites: 30% of the total cycle time at site A and 46% at site B. Similar to travel unloaded, travel loaded is strongly related to skidding distances and is also influenced by the number of trees. These findings are consistent with the results of studies by Wang *et al.* 2004 and Mousavi 2012.

Nevertheless, Wang *et al.* (2004) found that unhooking time depends on butt diameter, average merchantable length, and number of logs per cycle. The comparison of the total operating cycle for winch skidding and grapple skidding revealed no significant differences between the two methods when operating on reasonably level terrain under the described conditions, although there were some differences in the specific phase components. For the total operating cycle under both methods, over 50 percent of the variation in cycle time was accounted for by the travel unload and travel load times. The model indicates that the most important factor affecting skidding productivity is skidding distance, and that comes only after other more important elements, such as load volume, winching distance and the number of trees (Hiesl *et al.* 2013). There is little doubt that skidding distance significantly affected skid cycle time and productivity (Kluender *et al.* 1997; Spinelli *et al.* 2012; Liu and Corcoran, 1993; Lotfalian *et al.* 2011). Productivity was high compared to the literature data on skidding with traditional methods. For example, Spinelli and Magagnotti (2012) calculated a range from 1.5 to 7.9 $m^3$ $PMH^{-1}$ using four wheel-drive farm tractors, with a nominal power ranging from 48 to 116 kW; in high forest, Calafatello *et al.* (2005) measured a lower value of productivity of 6 $m^3$/PMH using a farm tractor equipped with a winch. The productivity of skidding in this study was similar and sometimes higher in comparison to the other studies conducted with other skidders. For example, in a similar study, Behjou *et al.* (2008) showed that the production rate of a Timberjack 450C wheeled skidder was 22.93 $m^3$ $PMH^{-1}$ in the Caspian forest over a distance of 300 m and Lotfalian (2011) calculated (for the same wheeled skidder) a net and gross production rate of 20.2 PMH and 16.6 $m^3$ SMH, respectively, at a skidding distance of 980 m. Kulak *et al.* (2017) monitored a similar John Deere grapple skidder, reporting efficiency of 14 $m^3$ $h^{-1}$ PMH at a distance of 250 m. Borz *et al.* (2013) measured the productivity of a TAF 657 wheeled winch skidder in the Romanian Carpathians, at a skidding distance of 1000 m. They found a net and gross production rate of 7.7 PMH and 3.75 SMH $m^3$ $h^{-1}$, respectively. In Northern Iran, Mousavi *et al.* (2012) calculated a productivity of 7.1 $m^3$ PMH using a HSM-904 skidder. The unit cost of skidding was €4.50

$m^{-3}$ at site A and €3.90 $m^{-3}$ at site B, which is similar to other studies. Horvat *et al.* (2007) reported that, for a skidding distance of 300 m using an Ecotrac 120 V skidder in the Croatian mountains, the costs amount to €4.88 $m^{-3}$ for a hilly working site. Lotfalian *et al.* (2011) reported that the unit cost in the Caspian region, considering the gross and net production rate, was €4.7 $m^{-3}$ and €5.7 $m^{-3}$, respectively.

**Conclusions**

A work and time study of full tree skidding was performed using a John Deere 548H at two sites of chestnut high forest in southern Italy. The relationship between the time consumption and independent variables was introduced as a model for two methods of skidding (cable winch versus grapple). Two regression equations were developed for the total cycle time, and the results indicated that the total time was related to the number of logs per turn, distance, and load volume. The comparison of the two extraction methods in this study clearly shows that productivity depends primarily on skidding distance. Skidder efficiency in a full-tree system is strongly correlated to both the load volume and the average extraction distance, and is expected to increase with increasing volume, but decrease with increasing average extraction distances. The results obtained confirm high productivity through using a grapple, as previously reported in literature [Kluender *et al.* 1997; Hurst, 1986; Moore, 1987; Spinelli *et al.* 2014). The presence of this innovative, articulated machine purpose-built for skidding logs has attracted particular interest in the forestry industry. Wood extraction has always been challenging, especially in mountainous environments, as in southern Italy, where the slope causes processing limitations (Proto *et al.* 2017d). The levels of productivity measured in this research far exceed the average productivity of a typical traditional skidding process and, taking into account the vast incidence of forests cover in southern Italy, the data presented appears to be very significant. In fact, the model developed by this paper may be useful in production organization when dealing with similar work conditions. The numerous observations recorded in this study confirm that this type of machine is a good investment, allowing high levels of productivity. The results of this study can be used to set the piece rate, in the rationalization of work, in work scheduling, and in cost estimation. Based on this study, it can be concluded that the investigated skidder is a highly productive machine that requires professional planning and supervision of work to obtain an improvement in productivity. In Italy, a specific license of competence for the skidder driver is not mandatory. This situation can penalise the performance of the skidder during the first periods of utilization despite similar studies (Haynes and Visser, 2001; Hoffmann, *et al.* 2016) that have demonstrated that the costs of a training course can be recovered within a short period. Assuming an average annual utilization of 910 h $year^{-1}$ and an average hourly productivity of 10 $m^3$ $h^{-1}$ (which is lower than the values observed in this study), the skidder would harvest 9100 $m^3$ $year^{-1}$ with a net profit for the owners of almost €8–10 per $m^3$ on the basis of the current conditions of timber markets. Therefore, the volume of trees needed to be cut in order to compensate the initial capital investment of purchasing this skidder is assessed to be around 25,000 $m^3$ in a period of less than three years.

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### *3.4 Activity 4 - Mechanization Forestry - Forwarder*

***Introduction***

In many parts of the world, small-scale harvesting machines have been used in forest operations on various terrain conditions where size was not restricted (Akay, 2005). In Southern Italy this is happening very slowly, due small dimensions of the forestry enterprises and of the laws current. In particularly, in Calabria region in the high forestry the clearcut is prohibited, while in the coppice the max areas for cutting are 10 ha. Forests in southern Italy are important in terms of forest production, having the largest percentage forest cover of all regions of the country (Proto *et al.* 2017). The 1.5 million ha forest area in southern Italy consist mainly of mature beech, chestnut (coppice), Corsican pine, and silver fir forests (INFI, 2005). These forests can provide a significant resource for the economy of the entire Mediterranean basin, an objective that could be attained with better and more efficient mechanization of forest operations (Istat, 2013). However, the current level of mechanization is low (Zimbalatti and Proto, 2009), while the dynamic international wood market has led to more efficient timber extraction technologies that reduce time and labour required for production (Cavalli *et al.* 2014; Moneti *et al.* 2015).

The most common work method in southern Italy, referred to as traditional, can be considered as an early stage of mechanization. It is based mainly on agricultural tractors, sometimes equipped with specific forest-related accessories (e.g. winches, hydraulic cranes, log grapples, etc.). The use of animals for gathering and yarding is also widespread. This level of mechanization for forest resource extraction has to date been adequate due to the characteristics of the forest properties and the small dimensions of many forest enterprises (Proto and Zimbalatti, 2015), in fact, most of the wood is felled and processed with chainsaws and extracted with forestry-fitted farm tractors (Ferrari *et al.* 2014) and so the use of forwarder in Mediterranean conifer Forest remains limited.

Respect to FTS (Fully Tree System) and TLS (Tree Length System) systems most commonly used in Central and Northern Europe, in South Italy the CTL is more diffuse, due a low level of mechanization and a limited knowledge of modern machinery, as well at methods silvicultures based on sustainable management. The system Cut-To-Length (CTL) that consists of felling, delimbing and bucking trees into logs of specified lengths at the stump. Logs are then transported to a landing or roadside by a forwarder. Forwarding was the prevailing extraction technique and most tractors were fitted with forestry trailers or short wood bins (Spinelli *et al.* 2010a). This system offers several advantages, notably the smaller size of landing area that is required and minimal damage to the logs during handling and transport. Furthermore this systems typically require less labour, less access road construction, and fewer landing areas than other ground-based systems such as whole tree harvesting (Bettinger and Kellogg, 1993), and also lead to more efficient wood recovery (McDonald and Seixas, 1997). In the light of increased global competition that is imposing a growing strain on all commercial activities, including wood harvesting, forest operations must increase their productivity while decreasing production costs (Hoesch, 2003). Increasing efficiency in the forestry-wood chain is one of the main policies to support forestry entrepreneurship (Niskanen *et al.* 2007).

Forwarders are self-propelled vehicles intended for the transport of trees and their parts loaded in the vehicle bunk area (ISO, 2009). The development of the first forwarder started in Sweden around 1950s. Nowadays forwarders are not conceptually different from those of half a century ago, but they have made serious progress in terms of environmental soundness, ergonomics and steering automation (Pandur *et al.* 2009).

As reported in other studies (Tiernan *et al.* 2004; Ghaffarian *et al.* 2007; Spinelli and Magagnotti 2010b), the forwarder efficiency is affected by numerous factors. The most important factors influencing the efficiency of timber forwarding is the travel distance (Sever, 1988). With the increase of the travel distance the impact of the load volume on the vehicle productivity is also increased (Raymond, 1989). Furthermore, it was found that it is the forwarded log concentration that is influential on the forwarding time consumption (Manner *et al.* 2013).

Productivity is also affected by the average assortment volume (i.e. number of pieces in the load) and quantity of timber on a felling site, which is more pronounced in thinning operations (Tufts and Brinker, 1993; Tufts, 1997). The largest time component of the forwarder cycle is related to the so called terminal times; namely loading and unloading of timber (Minette *et al.* 2004). Terrain slope higher than 30% considerably decreases the productivity of forwarders because vehicle mobility becomes limited (Zimbalatti and Proto, 2010). It is considered possible to use forwarders on steep terrain up to 60% with a winch; the so-called cable forwarders (Kuhmaier and Stampfer, 2010). This cable assist system has significantly increase the ability to operate on steep slopes and avoid soil damaging slip (Visser and Stampfer, 2015). However, there is insufficient knowledge to define the real positive or negative aspects of ground-based harvesting cable assist system (Mologni *et al.* 2016). The use of semi-tracks in conditions of limited soil bearing strength increases fuel consumption but provides increased vehicle mobility (Wasterlund *et al.* 2011). Forwarder efficiency also depends on its carrying capacity, as forwarders of higher carrying capacity normally achieve lower costs and higher productivity per product unit (Jirouek *et al.* 2007). Forwarder come in a range of sizes, whereby larger machines (10+ tonnes) are typically used in clear-felling operations, while those for thinning operations have payload capability less than 8 tonnes (Forest Service, 2000). In a study carried out in central Finland for different cutting sites, harvesting density on strip roads, the average extraction distance, forwarder load capacity, timber assortment and bunching of assortments on the strip road had an effect on the extraction system (Nurminen *et al.* 2006).

This preliminary study on forwarder operations in Mediterranean conifer forests aimed at improving the technical knowledge concerning the use of this machinery in Southern Italy and how advisable its extension to other areas would be. Thus, the objective of this study was to provide sound data for permitting the formulation of models of the cycle time for forwarding in a small scale forestry. The specific objectives were: (1) to calculate production rates ($m^3 \cdot h^{-1}$) and costs ($€ \cdot m^{-3}$) of forwarding in southern Italy a small scale, (2) to develop models of cycle time and productivity for forwarding, and (3) to determine the most influential factors respective to each work phase.

***Material and Methods***

***Study Sites***

The two case studies was representative of selective cuts in coniferous stands in Southern Italy and mostly in some other Mediterranean areas. The forwarders studied operated at two different sites, on private industry land in Calabria Region (Figure 1). The first (A) was selective felling in an 18 ha *Calabrian Pine* forest with S-O exposure at an elevation of 1,280m above sea level. Site B was a 16 ha stand of silver fir (*Abies Alba*) at 1,100m elevation in S-E exposition. Both forests were classified as moderately rough (I-II class), while the slopes are between 20 and 60% (class II and III) (UK Forestry Commission 1995). The area had a good main road network and was flanked by the provincial road; the trails opened during felling were used as the secondary road network.

Figure 1- Location of case study of productivity of forwarders in small scale forests of Southern Italy

The density of both forests is generally uniform with small gaps present only in the areas with lower soil depth. The characteristics of the study sites are reported in table 1. The trees was felling motor - manual using a chainsaw of medium dimension.

*Table 1 - Characteristics of the two study sites in small scale Southern Italian forests where the forwarders operated.*

| **Site** | **A** | **B** |
|---|---|---|
| Place | Taverna | Brognaturo |
| Province | Catanzaro | Vibo Valentia |
| Elevation (m) | 1280 | 1100 |
| Species | Calabrian Pine | Silver fir |
| Stand Type | Plantation | Natural forest |
| Operation Type | Selective cut and thinning | Selective cut |
| Total area (ha) | 18 | 16 |
| Density (trees /ha) | 950 | 570 |
| Site volume ($m^3$/ha) | 650 | 980 |
| Removal (trees/ha) | 238 | 86 |
| Removal volume ($m^3$/ha) | 130 | 196 |
| Average DBH (cm) | 30 | 45 |
| Average Height (m) | 20 | 27 |
| Average Volume tree ($m^3$) | 0.67 | 1.72 |
| Average tree volume (felled) ($m^3$) | 0.55 | 2.28 |
| Average Slope (%) | 26 | 29 |
| Roughness | Moderately rough | Moderately rough |

In both sites the work system was cut–to–length. All logs (of various sizes) were extracted from the harvest area to the landing on the main road using a ground extraction system with a farm tractor and winch. In this areas, the total number of logs were counted and transported to calculate the volume of each load in order to obtain a good estimate of the total volume carried. In this case, the volume of each log was calculated based on Smalian's formula by multiplying the average cross-sectional area of the stem by the stem length (Macrì *et al.* 2016). A selective cut was adopted and removed 20% of the volume per hectare at both sites. The level of elevation was measured using a handheld GPS while the gradient was assessed with the maps of the slope in ArcMap GIS (Version 10.1). The distance of each single travel was measured with a "black-box" GPS/GSM Global Positioning System/Global System for Mobile Communications unit for continuous real-time collection of the main work data, including position, status (e.g. engine off, engine on, traveling), and speed. It use the system Can-Bus, and collect the most important data such as fuel consumption and level, brakes, etc. The GPS/GSM collected position data at 30-second intervals and had a buffer memory to store data when GSM coverage was unavailable. Stored data were sent to the server as soon as the unit could connect again to the GSM network. Each daily record also include: date, work hours, number of trips and travel distance. Different applications highlighted the useful to use GPS to determine the real extraction distance (Veal *et al.* 2001; Horcher and Visser, 2011; Gallo *et al.* 2013; Strandgard and Mitchell, 2015; Spinelli *et al.* 2015a; Grigolato *et al.* 2016). The calculated extraction distance gets closer to the real distance as GPS points identify the real trail of the machine. In the case of this study has been preferred to use an interval of 30 s to reduce the GPS error. The black-box system used for the study downloaded all data at the end of each day into one spreadsheet per machine. All position data carried a time stamp, which was used to estimate speed. Data loggers were connected to the engine contact, and hence they recorded the time that the engine was on. As a consequence, each produced a daily estimate of work hours, which was downloaded together with the position points and speed graphs (Fig. 2). The units used for the study were a commercial tracker used for truck fleet management (www.visirun.com).

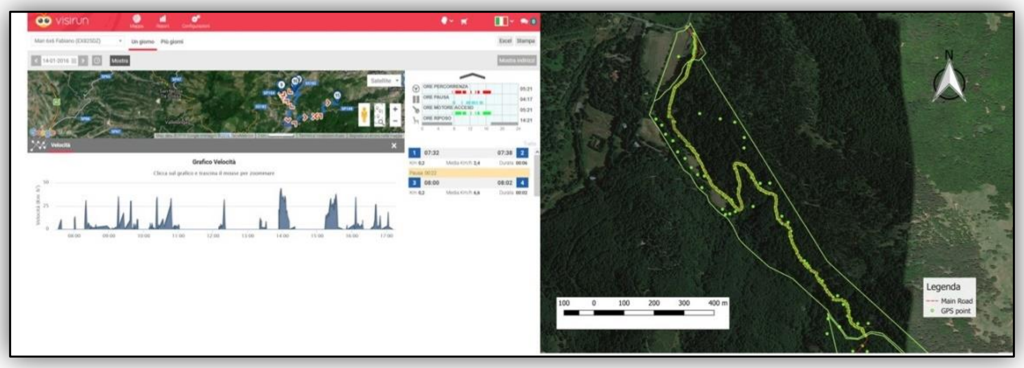


Figure 2 - Example of machine track and speed graph monitored at Site A

***Machines Used***

The two forwarders available for the study were a John Deere 1110D and John Deere 1010D (Figure 2). They are medium-size forwarders, but suitable as they have the power for regeneration harvesting and the agility for thinnings (Figure 2 and Table 2). The working group consisted one forwarder operator, one farm tractor driver, and one chokers setter in the bunching phases. In particular, the operator drove the farm tractor from roadside to felling site, then he released the cable for hooking.

*Figure 2 - John Deere 1010 unloading in the Calabrian pine stand at Site A*

*Table 2 - Specifications of the John Deere forwarders used during the case study in small scale Southern Italian forests.*

| | | **Model 1110D** | **Model 1010D** |
|---|---|---|---|
| **Features** | **Measurement Unit** | **Value** | |
| Power | kW | 121 | 86 |
| Transmission | - | IDM | IDM |
| Cylinders | N | 6 | 4 |
| Numeber of wheel | N | 8 | 6 |
| Wheel drive | N | 8 | 6 |
| Max speed of progress | km $h^{-1}$ | 24.5 | 22.0 |
| Total weight empty | Tonnes | 14.6 | 12 |
| Payload | Tonnes | 17.3 | 12.5 |

***Productivity***

According to Harstela (1993), productivity is the ratio between output (volume of wood) and input (time). In this study, time was measured using the repetition-timing method to determine the total yarding cycle times (Spinelli and Magagnotti, 2012; Nikooy *et al.* 2013). Each work cycle was divided into work elements and classified as productive time or delay time, following the terminology suggested by the IUFRO Working Group (Björheden *et al.* 1995) and timed using a digital chronometer (i.e. 1 min = 100 unit), Tag-HeuerMicrosplit™. In addition to the productive cycle time, delay time was also measured. Each forwarding cycle was stop watched individually, separating productive time from delay time (Bjorheden *et al.* 1995). The time study data were collected during autumn of 2016. Table 3 reported the elements identified and timed to determine the total cycle time (Tiernan *et al.* 2004; Sanchez *et al.* 2016).

*Table 3 - Forwarding elements*

| ***Forwarding elements*** | ***Description*** |
|---|---|
| *Travel empty* | Begins when work starts or after unloading of logs at landing, the forwarder has to return to the work zone unloaded. |
| *Loading* | Begins once the forwarder is at the side of the logs to be loaded, displacement stops and crane arm begins to move or seat begins to turn in order to begin loading. It includes the time spent after the forwarder finishes loading the logs from one pile and moves to the next pile, until the forwarder is fully loaded. |
| *Travel loaded* | Once the box of the forwarder is full, it begins to move with the load to the landing. |
| *Unloading* | At landing, the forwarder uses the crane to unload the logs from its bunk. This activity includes small displacements required at landing in order to complete the unloading. |
| *Delay time and others* | Operational delay, Mechanical delays, and personal delay were recorded. |

***Statistical Models***

The time study data consisted of 100 forwarder cycles (i.e. 50 for each site). Two different techniques were adopted to construct a model for time and productivity. A delay-free time model was formed separately for each time element and the model for total time formed by combining the elements. Regression analysis with variable transformation was used for modelling forwarding in which the time could be explained with the independent variables (i.e. number of logs, average volume, total volume payloads, slope, distance of loading and forwarding distance. An additional variable was inserted to differentiate the two work sites, Site A = 0 and Site B = 1. An F-test was conducted to examine the goodness of fit of regression models and to test the co-significance of the coefficients. Each coefficient of the work phase models was also tested separately in the t-test. If the test results indicated p-values larger than 0.05 the null hypotheses was rejected and the differences in the time were assumed to be from random variation.

***Cost***

The machines costs were calculated as described by Miyata (1980) for the forest machines. In order to calculate the production cost of 1 $m^3$ of timber extracted, the cost analysis measured the following parameters: the number of operators, the hourly cost of an operator, the hourly cost of machine, the volume of timber and productive machine hours excluding all delay times (PMH). Machine costs per hour are reported as both Productive Machine Hours excluding delays (PMH) and Scheduled Machine Hours (SMH). The production costs were calculated based on fixed cost (investment, depreciation and interest) and variable cost (repair and maintenance, petrol oil and lubricants, and wages of labourers). System cost is the sum of machine cost and labour cost. The purchase prices and operator wages required by the cost calculations were obtained from catalogues and accounting records. Cost calculations were based on the assumption that companies worked the whole year except the rainy season when the harvest areas in Southern Italy are not normally accessible. In general this correlates to 170 working days in the year, at an average of 7 scheduled working hours per day (equals 1190 hr / year). A salvage value of 20% of the purchase price is assumed at the economic life of 15 years. These parameters has been considered lower respect recent economic studies carried in Northern Europe (Spinelli *et al.* 2011; Spinelli *et al.* 2015b) because in southern Italy the use of this type of machine remains limited, dues attributed to orographical difficulties, characteristics of the forests and the small scale of many enterprises. For both machines the Value Added Tax (VAT) was excluded.

***Results and discussion***

Table 4 shows the descriptive statistics of work element times for both systems, as well as the percentage of time spent in each work element time (productive time excluded the delay time - PMH), in relation to total time. For about 95% of cycle times the forwarders were involved in the main work elements, specifically moving empty, loading, moving loaded and unloading. The average cycle time was 38.7 minutes at A, and 39.5 at Site B.

The total volumes extracted were 2,340 $m^3$ at Site A and 3,136 $m^3$ at B (i.e. 130 $m^3$ $ha^{-1}$ for Site A and 196 $m^3$ $ha^{-1}$ for Site B). Table 5 presents the summary statistics of the independent variables (e.g. forwarding distance, distance of load, slope, number of logs and average volume) for both work sites. The most time was spent loading the logs. The average delay time was 0.28 min/cycle in Site A, and 0.53 in Site B.

*Table 4 - Time per element for the John Deere 1100D and 1010D working at Site A and B, respectively.*

| Work phase | Unit measurements | Site A | | | | | | Site B | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Min | Medium | Max | Dev St | % | N | Min | Medium | Max | Dev St | % |
| Travel Empty | Minutes | 50 | 2.35 | 5.28 | 9.02 | 1.76 | 13.6 | 50 | 2.29 | 5.51 | 14.3 | 2.35 | 13.9 |
| Loading | Minutes | 50 | 11 | 13.84 | 16.8 | 0.97 | 35.7 | 50 | 11 | 13.69 | 15.7 | 1.1 | 34.6 |
| Travel loaded | Minutes | 50 | 3.8 | 5.67 | 9.25 | 1.51 | 14.6 | 50 | 3.8 | 5.81 | 12.4 | 1.78 | 14.7 |
| Unloading | Minutes | 50 | 8.94 | 12.2 | 14.8 | 1.17 | 31.5 | 50 | 8.94 | 12.44 | 15.7 | 1.27 | 31.5 |
| Delay Time | Minutes | 50 | 0 | 1.73 | 3.25 | 0.67 | 4.5 | 50 | 1 | 2.06 | 4.2 | 0.77 | 5.2 |
| Total Time | Minutes | - | - | - | - | - | 100 | - | - | - | - | - | 100 |

*Table 5 - Summary statistics of parameters*

| Variables | Work Site | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Site A | | | | | Site B | | | | |
| | **N** | **Min** | **Mean** | **Max** | **Dev. St** | **N** | **Min** | **Mean** | **Max** | **Dev. St** |
| Forwarding distance (m) | 50 | 100 | 306 | 1,300 | 306.1 | 50 | 180 | 597 | 1,350 | 3.26 |
| Distance of load (m) | 50 | 80 | 127 | 145 | 12.9 | 50 | 90 | 136 | 180 | 17.05 |
| Slope (%) | 50 | 10 | 29 | 50 | 11.4 | 50 | 12 | 31 | 55 | 9.65 |
| Numer of logs (n°) | 50 | 29 | 37 | 42 | 3.1 | 50 | 10 | 22 | 30 | 3.89 |
| Average volume ($m^3$) | 50 | 0.27 | 0.32 | 0.38 | 0.02 | 50 | 0.31 | 0.44 | 0.52 | 0.05 |
| Total volume payloads ($m^3$) | 50 | 8.37 | 11.8 | 13.3 | 1.15 | 50 | 3.84 | 9.97 | 15.6 | 2.59 |

The average productivity of forwarding in Site A was 18.4 $m^3$/SMH and 19.3 $m^3$/PMH, respectively. In contrast, at Site B, the average hourly productivity was 14.4 $m^3$/SMH and 15.7 $m^3$/PMH.

Different models to predict main work times (moving empty and loading, loading and unloading) were evaluated using stepwise regression and selecting the independent variables by step-by-step regression. The number of valid observations (Cycle) collected during the tests was large enough to develop a reliable model for predicting cycle time (Proto *et al.* 2016a).According to the statistical analysis, the models presented for travel empty, loading, travel loaded, unloading, overall time and productivity are valid (p<0.005) (Table 6).

*Travel empty*

Time for travel unloaded depended on forwarding distance and slope. Average Travel unloaded speed was 6.05 $km \cdot h^{-1}$ in Site A and 6.21 in B.

$T_{TU}$=1.39+0.005*Dist + 0.032*S $R^2$= 0.95

where $T_{TU}$ is time for travel unloaded (min); Dist = forwarding distance (m); S = is longitudinal slope.

*Loading*

Time for loading depended on distance of load, number of log, and average volume in each cycle:

$T_{LO}$= 7.29+0.020*$D_L$ + 0.065*NL + 4.9*Av $R^2$= 0.59

where $T_{LO}$ is time for loading (min); $D_L$ = distance of load (m); NL =  is the number of logs and Av is average volume of logs ($m^3$).

*Travel loaded*

Time for travel unloaded depended on the forwarding distance, and log slope. Average speed of the skidder in travel loaded was 5.60 $km \cdot h^{-1}$ in Site A and 5.75 in B.

$T_{TL}$=2.59 + 0.005 * Dist + 0.016 * S $R^2$= 0.97

where $T_{TL}$ is time for travel loaded (min); Dist = forwarding distance (m); S = is longitudinal slope.

*Unloading*

Time for unloading depends on number of logs, and average volume in each cycle. Unloading times were significantly different between the sites. Time for unloading was conducted as a function:

$T_{UL}$= 3.24 + 0.160 * NL + 9.72 * Av + 1.36 * Site $R^2$= 0.69

where $T_{UL}$ is time for unloading (min); NL = number of logs, Av = average volume and Site = 0 when A and = 1 when Site B.

*Total time (Overall)*

The total time model of a delay free work cycle was defined by adding up the time consumption for each work phase. The variables included in the model were forwarding distance, slope, distance of load, number of logs and average volume.

$T_{TOT} =$ 12.9 + 0.008 * Dist + 0.123 * S + 0.035 * $D_L$ + 0.174 * NL + 21.3*Av $R^2$= 0.95

Total effective time was converted into delay free productivity (P) and gross effective productivity:

**P** ($m^3$ per effective hour) **= (Total Volume for cycle * 60 / Total Time) / total time**

The variable included in the model of productivity were distance, distance, distance of load, slope number of logs and average volume.

P= -6.38-0.004 * Dist - 0.017 * $D_L$ - 0.053 * S+ 0.51 * NL + 35.8*Av $R^2$= 0.95

*Table 6 - Statistical characteristics of regression analysis based models*

| **Model** | **Dependent Variable** | **R²** | **N** | **F-Test** | | **Term** | **Constant coefficient** | **Std. error** | **T-Test** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **F Value** | ***p*** | | | | **T Value** | ***p*** |
| Travel Empty | $T_1$ | 0.95 | 100 | 365.109 | 0.000 | Constant coefficient | 1.390 | 0.236 | 5.901 | 0.000 |
| | | | | | | Xd | 0.005 | 0.000 | 11.220 | 0.000 |
| | | | | | | Xs | 0.032 | 0.014 | 2.304 | 0.023 |
| Loading | $T_2$ | 0.59 | 100 | 17.140 | 0.000 | Constant coefficient | 7.292 | 0.926 | 7.785 | 0.000 |
| | | | | | | Xdl | 0.020 | 0.007 | 2.887 | 0.005 |
| | | | | | | Xnl | 0.065 | 0.015 | 4.336 | 0.000 |
| | | | | | | Xav | 4.995 | 1.945 | 2.569 | 0.012 |
| Travel | $T_3$ | 0.97 | 100 | 797.928 | 0.000 | Constant | 2.590 | 0.131 | 19.814 | 0.000 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| unloaded | | | | | | coefficient | | | | |
| | | | | | | Xd | 0.005 | 0.000 | 17.836 | 0.000 |
| | | | | | | Xs | 0.016 | 0.008 | 2.025 | 0.046 |
| Unloading | $T_4$ | 0.69 | 100 | 28.57 | 0.000 | Constant coefficient | 3.240 | 0.996 | 3.254 | 0.002 |
| | | | | | | Xnt | 0.160 | 0.031 | 5.255 | 0.000 |
| | | | | | | Xav | 9.725 | 2.672 | 3.640 | 0.000 |
| | | | | | | Xd_d | 1.360 | 0.692 | 1.964 | 0.005 |
| Total Time | $T_t$ | 0.95 | 100 | 170.752 | 0.000 | Constant coefficient | 12.995 | 2.223 | 5.846 | 0.000 |
| | | | | | | Xd | 0.008 | 0.001 | 6.908 | 0.000 |
| | | | | | | Xs | 0.123 | 0.000 | 3.623 | 0.000 |
| | | | | | | Xdl | 0.035 | 0.034 | 2.194 | 0.031 |
| | | | | | | Xnl | 0.174 | 0.032 | 5.403 | 0.000 |
| | | | | | | Xav | 21.31 | 4.022 | 5.299 | 0.000 |
| Productivity | P | 0.95 | 100 | 181.588 | 0.000 | Constant coefficient | -6.385 | 1.233 | -5.180 | 0.000 |
| | | | | | | Xd | -0.004 | 0.001 | -5.776 | 0.000 |
| | | | | | | Xdl | -0.017 | 0.009 | -1.921 | 0.058 |
| | | | | | | Xs | -0.053 | 0.019 | -2.799 | 0.006 |
| | | | | | | Xnl | 0.519 | 0.018 | 28.998 | 0.000 |
| | | | | | | Xav | 35.896 | 2.230 | 16.096 | 0.000 |

Fixed and hourly operating costs of the forwarder are reported in Table 6. At Site A the extraction costs were calculated at € 3.60 $m^3$ and € 4.90 $m^3$ at B. These costs refer to work time per SMH (i.e. Productive + Unproductive time). Considering only the forwarder productive time (i.e. €/PMH), the extraction costs were € 3.40 $m^3$ in A and € 4.50 $m^3$ in B.

Delay times increase the operating cost by 5-7 % in both sites and production cost increased when both forwarding distance increased and load volume decreased. The increase of each variable on this machine with exception to number of logs and average volume, causes an increase in cost. Only with increasing the annual utilization PMH (days/years) does forwarding cost per cubic meter decrease.

*Table 6 - Calculation of hourly costs for the two John Deere forwarders used in the case study for forwarding in small scale forest of Southern Italy.*

| Parameter | Value | |
|---|---|---|
| | **1110D** | **1010D** |
| Purchase price (€) | 220,000 | 190,000 |
| Salvage value (€) | 44,000 | 38,000 |
| Economic Life (y) | 15 | 15 |
| Scheduled operating time (h) | 1,190 | 1,190 |
| Annual depreciation (€) | 9,778 | 8,444 |
| Interest cost (€) | 9,582 | 8,276 |
| Taxes and insurance (€) | 10,951 | 9,525 |
| Total fixed cost (€ h-1) | 27.2 | 23.5 |
| Total variable cost (€ h-1) | 43.3 | 42.3 |
| Total labour cost (€ h-1) | 20.0 | 20.0 |
| **Total cost (€ $h^{-1}$)** | **70.5** | **65.8** |

Forwarding time includes travel empty, loading, travel loaded, and unloading. Time consumption for transportation only work elements depend on the extraction distance and driving speed, which in turn are mainly determined by geophysical factors.

The distance of each single cycle, measured with a “black-box” GPS/GSM unit for continuous real-time, has simplified one the problems arising of the definition and determination of the mean distance of timber forwarding. Some authors consider that the distance of timber forwarding is the distance between the roadside landing and the point in the felling site when the bunk area is half loaded with timber (Kuitto *et al.* 1994; Nurminen *et al.* 2006). Accordingly, the mean distance of timber forwarding would be equal to the sum of travel distance of unloaded vehicle and half the travel in timber loading i.e. the travel between the loading points (Suvinen, 2006; Vakeva *et al.* 2001; Cordeo *et al.* 2006) used GPS technology to monitor cut-to-length (CTL) system in Chile. In this method, by capturing the position of the machine, it was possible to generate surface progress grids, which when combined with inventory grids, resulted in yield information by surface and time.

Modeling of travel unloaded showed that it was highly dependent on the forwarding distance and slope. Travel unloaded time increases with increasing distance and slope and accounted for approximately 14 % of the total cycle time including delays, at both sites. Time for loading is directly related to the number of logs, distance of load and average volume and accounted for approximately 35 % of the total cycle time including delays, at both sites.

Travel loaded, similar to travel unloaded, is strongly related to forwarding distance and slope. The two main effects of the factors total log concentration (distance of load) and the number of assortments in a load significantly affected the total time consumption. The number of logs and the volume per load do not influence the travel loaded time. The time for unloading is strongly related to the number of logs and average volume and accounted for approximately 14 % of the total gross effective time in both sites. For unloading there was a significant difference between Site A and Site B mainly due to average volume difference.

The most important factor influencing the efficiency of timber forwarding is the extraction distance (Sever 1988). With the increase of extraction distance, the impact of the load volume on the vehicle productivity is also increased (Raymond, 1989). Productivity is also affected by the average assortment volume (i.e. number of pieces in the load) and quantity of timber on a road forestry, which is less favourable in thinning operations (Tufts 1997; Tufts and Brinker, 1993). As rule, forwarding productivity is calculated from productivity standards based on the mean volume (payload) and forwarding distance.

Both sites compare similarly with results from a study of short-wood forwarding carried out in Northern Spain; that resulted in a productivity of 6 to 15 t/SMH (Spinelli *et al.* 2003). Other productivity studies resulted in the range of 8 to over 20 t/SMH, depending on the model and working conditions (Horvat *et al.* 1990; Saunders, 1996; Gullberg, 1997).

Comparative research of tractor based skidding with winch (the main system used in Calabria) and forwarding machines carried out in stands of small coniferous trees showed that, in terms of costs the figures are in favour of forwarding, as forwarder productivity can be twice that of a skidder (Li *et al.* 2006). Under difficult working conditions, such as in the study area (steep terrain, limited infrastructure, long forwarding distance), these results could be of great practical help in terms of improving logging planning, and consequently for reducing extraction cost in most timber harvesting operations in the Southern Mediterranean area of Italy, in particular in the selective cut. In additon, several aspect should be evaluted as the impact of timber harvesting on some parts of the forest ecosystem, in particular when are used machinery heavy (skidder and forwarder). Indeed, recent studies have shown the impact of harvesting may have impacts on the soil characteristics for several years (Proto *et al.* 2016b; Cambi *et al.* 2016). Generally, harvesting effects include changes in vegetation, nutrient availability, soil microclimate and structure and litter quantity and quality (Keenan and Kimmins, 1993; Jurgensen *et al.* 1997).

***Conclusions***

This research covered the analysis of the factors impacting forwarding as the primary extraction method in the forests of the Southern Italy. It is characteristic of timber harvesting systems in the area in which felling is performed motor-manually and trees processed by chainsaws, and extraction of timber to roadside landings is only rarely fully mechanized.

No detailed time study of forwarding has been conducted in Southern Italy to date. This study provides cycle time and productivity of forwarding in Calabria, and also introduces partial and overall time models. Forwarding productivity and costs are typically calculated from productivity standards based on the average volume, forwarding distance, distance of load, slope and number of logs. The operation of forwarders in Calabria, unlike the Scandinavian CTL systems, makes no use of felling and processing machines.

This study showed that the increase of forwarding distances diminishes the forwarder's productivity, as the share of the time spent moving increases. Likewise, with the increase of forwarding distance, the load volume becomes more significant. Variables such as forwarding distance, distance of load, slope, average volume and number of logs, were entered into the general model for predicting forwarding time as significant variables; which can be applied in planning future logging operations.

These results will be of practical help in terms of improving logging planning, and consequently for performing and achieving cost competitiveness of the wood supply chain in Calabria. Since specific terrain conditions of forest harvesting operations have such a significant effect on this type of machine, these equations should be extended to include various other extraction alternatives, such as skidders.

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### *3.5 Activity 5 - Mechanization Forestry - Comparison of forwarder*

***Introduction***

One of the common ground-based harvesting systems used in pine plantations is cut-to-length (CTL). The CTL system consists of felling, delimbing and bucking trees into logs of specified lengths at the stump. Logs are then transported to a roadside or landing area by a forwarder (Spinelli et al. 2004). This system offers several advantages compared to the other ground-based systems: notably less road construction, lower levels of soil disturbance, smaller landing size through reduced processing requirements, minimal damage to the logs during handling and extraction and fewer workers (Bettinger and Kellogg, 1993). The fully-mechanized CTL timber harvesting system has become widely used in many industrialized European countries where the conditions and the stands are favorable such as in Sweden (ca. 98%), Ireland (ca. 95%) and Finland (ca. 91%), as compared to motor-manual harvesting (Karjalainen *et al.* 2001).

In Italy forests account for about 10.9 million hectares, corresponding to 37% of the land area and are mainly located in hill and mountain ranges (Zimbalatti and Proto, 2009a). Italian forestry is characterized by steep terrain, ownership fragmentation and the application of close-to-nature management criteria such as continuous-cover forestry (Mason *et al.* 1999). Forests in southern Italy are important, having the largest percentage forest cover of all regions of the country, even though the highest concentration of productive woodlands occurs in the northern regions of Italy. These southern forests can provide a significant resource for the economy of the entire Mediterranean basin; an objective that could be attained with better and more efficient mechanization of timber harvesting systems (Istat, 2013). The most common harvesting system in southern Italy, referred to as ‘traditional’, can be considered as an early stage of mechanization. Traditional methods are based mainly on agricultural tractors, sometimes equipped with specific forest-related accessories such as winches, hydraulic cranes and log grapples. This level of mechanization has to date been adequate due to the characteristics of the forest ownership and the small dimensions of many forest enterprises (Zimbalatti and Proto, 2009b; Proto and Zimbalatti, 2016a). However, there is growing interest in Southern Italy towards fully mechanized CTL systems due to their lower unit harvesting costs and higher productivity compared to traditional methods. In order to successfully transition from traditional to fully mechanized CTL systems in Southern Italy, an improved understanding of factors affecting the productivity and costs is necessary.

Productivity of a CTL system depends on the forest stand, site and operational factors such as: ground conditions, slope, operator's motivation and skill, branch size, operational layout, tree size, tree form, log assortments processed, numbers of un merchantable and merchantable trees per unit area, hauling distance, undergrowth density and machine design (Spinelli *et al.* 2002; Stampfer, 1999). Timber extraction (e.g. forwarding in CTL systems) from stump to landing is one of the most time-consuming and expensive parts of harvesting systems (Mousavi 2009). There have been a number of previous studies on various aspects of forwarders (e.g. Brunberg, 2004, Nurminen *et al.* 2006; Spinelli *et al.* 2003), but few have been conducted in Southern Italian forest types like pine plantations. Furthermore, researchers have used differing definitions of cycle elements, investigated different factors affecting productivity and used different methods to measure variables; forwarding distance in particular. Therefore, there is a need for a production study to benchmark current forwarding operations in Southern Italy and compare with other nations using a common study methodology.

One nation that shares similarity with pine plantation harvesting methods is New Zealand. Although full-tree length extraction by grapple skidders to large landings is by far the most common ground-based extraction system (Visser, 2015), CTL systems are also common.

The aim of this study was to better understand factors that affect productivity of forwarders in pine plantations by comparing larger scale New Zealand operations with the newly introduced southern Italian system. Specific study objectives were to:

1. Analyze operational time consumption for estimating the productivity of two different models of forwarders (John Deere 1910E and 1110E).
2. Estimate productivity in relation to common factors in harvesting operations.
3. Determine the operation cost for the two forwarders studied.

***Materials and methods***

***Site description***

The forwarder productivity study was recorded in three different locations, indicated with letters A, B and C respectively. The plantation at site A was a stand of *Calabrian Pine*, at an altitude of 1,200 m above sea level (Table 1). The study was conducted in a selective felling site that was 22 ha in size, with south-east exposition. The forest area was classified as class I for roughness, while the slope was between class III and IV, in accordance with terrain classification of UK Forestry Commission (1995). The density of the forest was generally uniform; small gaps were present only in the areas with lower soil depth. The area had a good main road network and was flanked by the provincial road; the trails opened during felling were used as the secondary road network (Cavalli and Grigolato, 2010). The clearcut operations in the New Zealand radiata pine forests were both in the South Island; B was located on the West Coast and C in Canterbury at an altitude of 280 m and 230 m above sea level and 25 and 27 ha in size, respectively. The West Coast forest area was split into a grid pattern by well-constructed roads that were suitable for log trucks. In between this grid pattern was general clear-cut operations where an excavator with bucket attachment would cut tracks through the clear-cut for the forwarder to extract the timber. These tracks became very muddy and the forwarder often had to travel over wet guts and ditches. This slowed the machine down considerably as the machine was not using chains or band tracks; as the machine would rarely venture off these tracks. Conversely the Canterbury site was dry. The terrain class at both sites would be rated as 1 (UK Forestry Commission 1995).

*Table 1 - Characteristics of the three forwarder work sites.*

| Site | A | B | C |
|---|---|---|---|
| Country | Italy | New Zealand | New Zealand |
| Place | San Giovanni in Fiore | Paparoa Forest | Balmoral Forest |
| Province | Cosenza | West Coast | Canterbury |
| Elevation (m) | 1150 | 280 | 230 |
| Species | Calabrian Pine | Pinus radiata | Pinus radiata |
| Stand Type | Plantation | Plantation | Plantation |
| Operation Type | Selective cut | Clearcut | Clearcut |
| Total area (ha) | 22 | 25 | 27 |
| Density (trees /ha) | 870 | 148 | 700 |
| Site volume ($m^3$/ha) | 630 | 300 | 405 |
| Removal (trees/ha) | 158 | all | all |
| Removal volume ($m^3$/ha) | 126 | all | all |
| Average tree volume ($m^3$) | 1.20 | 1.90 | 0.57 |
| Average DBH (cm) | 38 | 52 | 31 |
| Average Height (m) | 26 | 38 | 29 |
| Average Slope (%) | 25 | 5 | 5 |
| Roughness | Medium | Medium (muddy/wet) | Low (clear, dry ground) |

### *Machines used*

Forwarders can be classified by tare weight, load capacity or gross mass (vehicle + load), (Porsinsky, 1997). However, they are more commonly rated according to their loading capacity (payload), from light (<10 t), medium (10 t – 14 t) to heavy forwarders with a load capacity over 14 t (Brunberg 2004). At site A the forwarder studied was a medium-sized John Deere 1110E with 136 kW engine power (Table 2). At work sites B and C, two large (21.8

tonnes) John Deere 1910E eight-wheeled forwarders with 186 kW engine power and 20 tonnes payload capacity were used (Figure 1).

*Table 2 - Technical characteristics of the forwarders studied*

| | | **Model 1110E** | **Model 1910E** |
|---|---|---|---|
| **Features** | **Measurement Unit** | **Value** | |
| Power | kW | 136 | 186 |
| Transmission | - | IDM | IDM |
| Cylinders | N | 6 | 6 |
| Numeber of wheel | N | 8 | 8 |
| Wheel drive | N | 8 | 8 |
| Max speed of progress | km $h^{-1}$ | 24.5 | 21.3 |
| Total weight empty | Tonnes | 17.3 | 21.8 |
| Max load capacity | Tonnes | 13.2 | 20.2 |
| **Tyre dimension** | | | |
| Std tire size rear | - | 26.5-20 | 26.5-20 |
| Std tire size front | | 34-14 | 36-16 / 26.5-20 |
| **Boom** | Model | CF5 | CF8 |
| Gross lifting torque | kNm | 102 | 151 |
| Maximum reach lengths | meters | 8.5 | 8.5 |

*Figure 1 - John Deere 1910E loaded in the radiata pine stand at Site C*

***Work Study***

Each work cycle was divided into work elements and classified as productive time or delay time, following the terminology suggested by the IUFRO Working Group (Bjorheden *et al.*1995). They were timed using a digital chronometer (i.e. 1 min = 100 units). The time study data was collected at site A during autumn of 2016, at B during the summer 2016 and at C in autumn 2017. Extraction of timber by forwarders has the characteristics of cyclic work. Each cycle (turn) consists of four main cycle elements namely, unloaded traveling, timber loading, loaded traveling and unloading of timber (Bergstrand, 1985; Väkevä *et al.* 2001; Nurminen *et al.* 2006). The definitions used in this study are consistent with those used by Tiernan *et al.* (2004); Cavalli *et al.* (2009); and Sanchez et *et al.* 2016):

***Travel empty:*** Begins when work starts or after unloading of logs at landing, the forwarder has to return to the work zone unloaded;

***Loading***: Begins once the forwarder is at the side of the logs to be loaded, displacement stops and crane arm begins to move or seat begins to turn in order to begin loading. It includes the time spent after the forwarder finishes loading the logs from one pile and moves to the next pile, until the forwarder is fully loaded;

***Travel loaded:*** Once the bunk of the forwarder is full, it begins to move with the load to the landing;

***Unloading:*** At landing, the forwarder uses the crane to unload the logs from its bunk. This activity includes small displacements required at landing in order to complete the unloading;

***Complementary work times:*** Action involving the crane and/or the machine, other than loading, unloading and displacement such as: handling logs (at landing, stand or in the forwarder bunk), planning or accessing forest road;

Delays in harvesting operations are characterized as periodic (Spinelli and Visser, 2008). They include operational, mechanical or personal delays. They were recorded during the study and a utilization rate calculated for the study period, but the study focus is on the productive elements. The study period is not long enough to provide a meaningful long term utilization estimate.

For each cycle, the total number of logs in the bunk were counted, identified and recorded as a function of the dimension (large saw timber and small assortments – pulpwood) to calculate the volume of each load. At site A it was possible to measure each log prior to loading. At Site B a sample of loads were measured, the remainder estimated based on accurate log counts in the bunk to avoid unnecessary impact on productivity. At site C more than 50 logs were measured in the stock-piles to provide an average log volume for the main assortments. In each case the volume of each log was calculated using Huber's formula by multiplying the average cross-sectional area of the stem by length (Philip, 1994; Macrì *et al.* 2016). Extraction distances were measured with a laser rangefinder and the gradient was assessed with a Suunto clinometer.

***Statistical Analysis***

Delay-free time models were formed using the data of all three case studies for both individual elements as well as the complete cycle time. Regression analysis with variable transformation was used for modelling forwarding in which the time could be explained with the independent variables (i.e. number of logs, total volume payloads, slope, distance of loading and forwarding distance). Two block factors were introduced to identify site differences; WC (West Coast) for B site and CA (Canterbury) for site C.

An F-test was conducted to examine the goodness of fit of regression models and to test the co-significance of the coefficients. Each coefficient of the work phase models was also tested separately with a t-test. If the test results indicated *p*-values larger than 0.05 the null hypotheses was rejected and the differences in cycle times were assumed to be from random variation.

***Cost***

The machine's costs were calculated as described by Miyata (1980). The production costs were calculated based on fixed cost (investment, depreciation and interest) and variable cost (repair and maintenance, petrol oil and lubricants, and wages). Total hourly machine cost is the sum of fixed and variable cost. The purchase prices and operator wages required for the cost calculations were obtained from catalogues and accounting records (Forme, 2015). A salvage value of 20% of the purchase price was assumed with an economic life of 8 years for all forwarders. Cost calculations were based on the assumption that companies worked the whole year except the rainy season when the harvest areas in Southern Italy are not normally accessible. Spinelli et al. (2011) considered a total 180 working days in the year, at an average of 8 scheduled working hours per day (equals 1440 hr $year^{-1}$), and was adopted in this study.

***Results and Discussion***

The time studies covered in total 73.4 hrs; of which 29.2 hr were recorded at site A, 28.5 hr at site B, and 15.7 at site C. Within this time, the forwarders completed 159 forwarding cycles (50 for site A, 69 for B and 40 for C, respectively) and extracted 6,884 logs with a total volume of about 2,078 $m^3$. Basic study data regarding total travel distance for the cycles, the number of logs and the total payload (volume) is presented in Table 3. Only short delays were measured during all three different studies, giving 97, 93 and 93% utilization rates, for sites A, B and C, respectively. While such high levels of utilization indicate very reliable machines and efficient systems, long term utilization rates are likely to be much lower (Spinelli and Visser ,2008).

*Table 3 - A summary of the variable recorded at the three different forwarder study sites*

| Variables | Work Sites | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Site A | | | Site B | | | Site C | | |
| | **Min** | **Average** | **Max** | **Min** | **Average** | **Max** | **Min** | **Average** | **Max** |
| Total travel distance (m) | 290 | 729 | 1560 | 100 | 650 | 1400 | 240 | 665 | 1640 |
| Loading distance (m) | 25 | 54 | 90 | 10 | 10 | 10 | 30 | 83 | 270 |
| Numer of logs (n°) | 20 | 20 | 39 | 25 | 35 | 43 | 52 | 77 | 119 |
| Average log volume ($m^3$) | 0.27 | 0.36 | 0.53 | 0.35 | 0.42 | 0.54 | 0.15 | 0.25 | 0.47 |
| Total payload volume ($m^3$) | 8.3 | 10.1 | 10.8 | 11.4 | 14.3 | 17.6 | 8.4 | 14.8 | 18 |

The mean time consumption per cycle was 33.2 minutes at site A, 24.2 at B and 22.8 at C, respectively (Table 4). At Site A, the higher average cycle time was in part due to the longer average distance, but also the relatively poor road network. Furthermore, the larger scale clear-cut at site B and C facilitated the pre-bunching of logs by the harvester, which concentrated them in a smaller area.

*Table 4 - Descriptive statistics of forwarder work element times, in minutes and percentage of total delay-free cycle time*

| **Work Sites** | **Work phase** | **Average (min)** | **Min (min)** | **Max (min)** | **%** |
|---|---|---|---|---|---|
| A | Travel Empty | **3.3** | 1.15 | 6.4 | 9.8 |
| | Loading | **13.3** | 7 | 22 | 40.1 |
| | Travel Loaded | **5.8** | 2.45 | 15.2 | 17.5 |
| | Unloading | **10.8** | 5 | 14,3 | 32.6 |
| | Total Cycle Time | **33.2** | 22 | 51.5 | 100 |
| B | Travel Empty | **4.9** | 1.07 | 9.95 | 20.4 |
| | Loading | **8.6** | 2.67 | 13.9 | 35.6 |
| | Travel loaded | **5.0** | 1.06 | 10.5 | 20.7 |
| | Unloading | **5.6** | 2.89 | 8.06 | 23.3 |

| | | | | | |
|---|---|---|---|---|---|
| | Total Cycle Time | **24.2** | 17.0 | 62 | 100 |
| C | Travel Empty | **3.0** | 1.1 | 6.45 | 13 |
| | Loading | **10.2** | 5.04 | 28.3 | 44.9 |
| | Travel loaded | **3.4** | 1.15 | 7.2 | 14.7 |
| | Unloading | **6.3** | 3.22 | 11.4 | 27.5 |
| | Total Cycle Time | **22.8** | 29.3 | 58.2 | 100 |

Figure 2 shows the ratio of the time elements for the total work time at each site. Site A differed significantly for the loading and unloading elements to both site B and C. Loading at site A took over 40% of the total time. Loading time was lowest at Site B as the logs were pre-bunched (shovelled) to the extraction corridor.

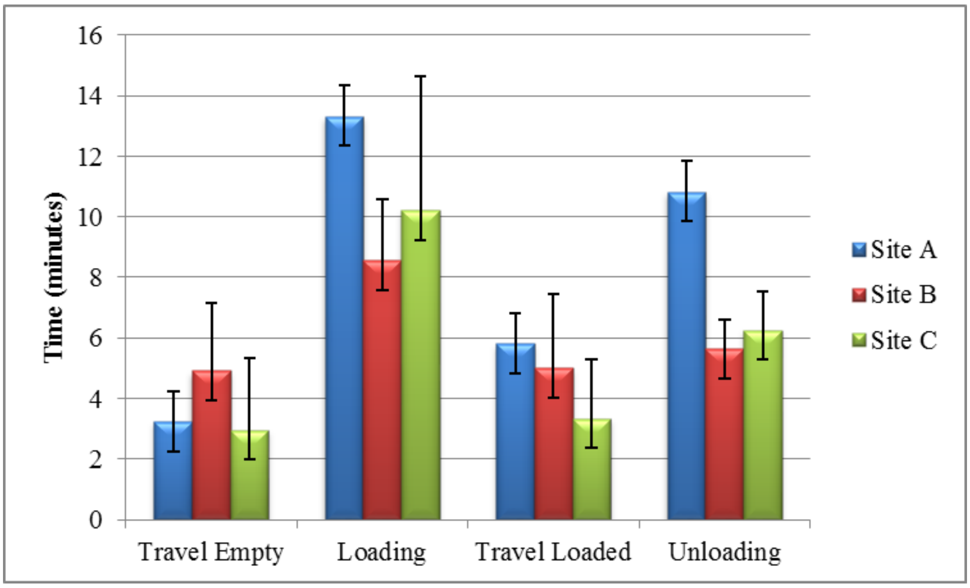


Figure 2 - Share of operations under analysis within work time

By adding the distance for the travel empty and loaded, and dividing it by the distance travelled within that element, it is possible to establish average travels speed. The average speed for travel empty was 6.68 km/h at site A, 3.77 km/h at B and 6.90 km/h at C, respectively. For travel loaded the average speed was 3.75 km/h at site A, 3.68 km/h at B and 6.17 km/h at C, respectively. For the relatively flat sites B and C this shows that unloaded and loaded speeds are very similar and indicate modern forwarders have enough power and that speed is limited by terrain roughness. This is indicated by the average speed at the rough and muddy site B being much slower than site C. Site A shows the effect of slope on speed, whereby unloaded downhill was almost twice as fast as loaded uphill. Different models to predict work element times were evaluated using linear regression and selecting the independent variables by stepwise regression. The number of valid observations collected during the tests was large enough to develop a reliable model for predicting cycle time (Proto *et al.* 2016b). While regression equations for each individual site yield models that explain more of the variation, the data from all three locations were combined to provide more robust models. A travel time equation was developed (Eq 1), whereby travel time includes both unloaded and loaded travel. This is because a forwarder might travel a shorter distance and load over an extended distance, and then travel back from the furthest point. However, the forwarder might also travel out to the furthest point and load on the way back, or as common at site C complete a circuit to avoid having to turn or reverse. The distance (Dist) in the equation is the total distance travelled. The equation shows the effect of poor ground conditions at the West Coast (WC – site B) slowed the machine significantly; whereby the travel time at the Canterbury (CA – site C) was similar to that in Calabria.

Eq.1 Travel (min) = 3.64 + 0.007*Dist + 2.89*WC - 2.24*CA

($F=86.9$; $p < 0.01$; $R^2 = 0.79$)

Equation 2 shows the regression model for loading time. While the model is significant for the data from the three sites, one surprising component is the negative effect of load size (Vol). It would suggest that the larger machines loading at site B and C were faster than the smaller machine at site A. However, the other factor is that the logs were more spread out at site A; the bunched logs at site B reduced the average cycle time by almost 3 minutes.

Eq 2. Loading (min) = 18.02 - 0.457*Vol - 2.90*WC - 0.98*CA

(F=28.3; $p < 0.01$; $R^2 = 0.59$)

Equation 3 for unloading shows a very similar effect as equation 2 for loading. It does show that the larger machines at both Site B and C unloading onto a large landing were much faster than unloading the smaller forwarder in the more constrained site in Calabria (Site A).

Eq 3. Unloading (min) = 13.43 - 0.25*Vol - 4.17*WC - 3.39*CA

(F=102.8; $p < 0.01$; $R^2 = 0.81$)

While the regression models for the individual time components are significant and informative in helping explain the results for this study, they should be used with caution to predict time elements at other sites as they are confounded by site and machine factors between the three sites.

Equation 4 provides a regression model for the total cycle time and combines the characteristic of the individual elements in equations 1 through to 3. Overall it shows that the larger scale clearcut operations in New Zealand (site B and C) are faster that the smaller scale operation in Calabria, despite having to load approximately 50% more volume.

Eq 4. Total Cycle Time (min) = 36.09 + 0.012*Dist - 1.10*Vol - 2.75*WC - 4.23*CA

(F=66.6; $p < 0.01$; $R^2 = 0.79$)

The average productivity of forwarding at Site A was 18.9 $m^3$/PMH, at Site B 37.1 $m^3$/PMH, while at C 42.7 $m^3$/PMH. Figure 3 shows the relationship and variability between average forwarding distance and productivity. While the cycle time models already show a difference, when factoring in the larger payloads, productivity at site B and C are considerably higher.

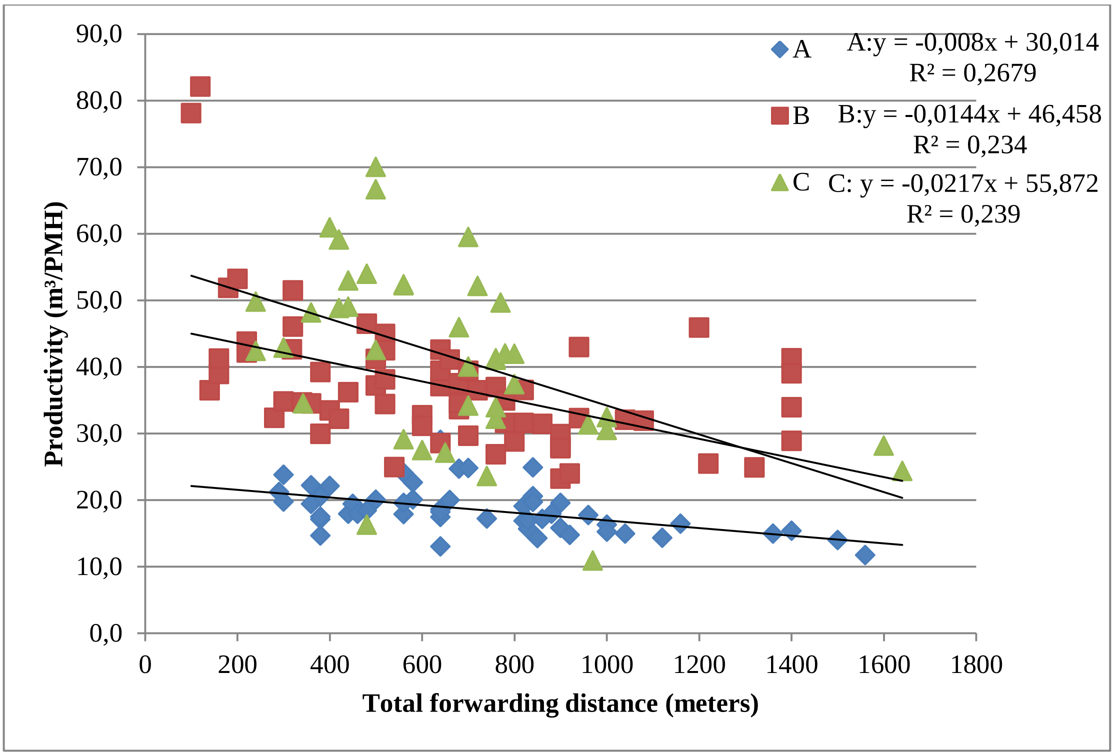


Figure 3 - Relationship between average distance and productivity for forwarding at the three study sites.

Equation 5 shows the productivity model for delay-free productive machine hours (PMH). For this model all parameters are logical with a reduction in productivity with distance (Dist), and increase with payload volume (Vol), a decrease with poor track conditions at site B (WC), and the highest productivity on the good dry flat terrain at site C (CA).

$$\text{Eq 5. Prod } (m^3 / PMH) = -11.2 - 0.015*Dist + 3.95*Vol + 0.47*WC + 3.71*CA$$

$$(F=74.36;\ p<<0.1;\ R^2=0.82)$$

The Calabrian productivity range is consistent with results from a study of forwarding carried out in Northern Spain that resulted in a productivity of 6 to 15 t/SMH (Spinelli et al. 2003). Other productivity studies resulted in the range of 8 to over 20 t/SMH, depending on the model and working conditions (Gullberg, 1997; Saunders, 1996; Horvat *et al.* 1990). The results are also consistent with Sever (1988), Valenta and Neruda (2004), and (Raymond 1989) who all showed that the most important factor influencing forwarding productivity was the extraction distance and load volume. The effect of site has also been identified by Tufts (1997) and Tufts and Brinker (1993) that showed productivity was also affected by the average assortment volume (i.e. number of pieces in the load) and quantity and concentration of timber on a felling site.

Interestingly, slope was not found to be a significant predictor of a forwarder's productivity; but this may have been due to the fact that the forwarders were equipped with tracks to accommodate for wet soil conditions (Williams and Ackerman 2016). In other studies (e.g. Bergstrand, 1985; Kellogg and Bettinger, 1994; Nurminen *et al.* 2006) the forwarding productivity depended on the number of loaded assortments, and the productivity also varied between different assortments. Within this study there was no significant difference identified between log assortments. Fixed and hourly operating costs for productive machine time of the forwarder are reported in Table 5. At Site A the extraction costs were calculated to be € 4.55/$m^3$, at site B € 2.85/ $m^3$ and at site C € 2.50/$m^3$. The calculated costs were consistent with Jirousek *et al.* (2007) who showed forwarder extraction cost depends on the type of the vehicle used (i.e. its nominal carrying capacity) and that forwarders of higher carrying capacity achieve lower costs per product unit and higher productivity.

*Table 5 - Calculation of hourly costs for the two John Deere forwarders used in the case study for forwarding in Southern Italy and New Zealand*

| Parameter | Value | |
|---|---|---|
| | **1110E** | **1910E** |
| Purchase price (€) | 265,000 | 432,000 |
| Salvage value (€) | 86,400 | 86,000 |
| Economic Life (y) | 8 | 8 |
| Scheduled operating time (h) | 1,440 | 1,440 |
| Annual depreciation (€) | 26,500 | 43,200 |
| Interest cost (€) | 12,058 | 19,656 |
| Taxes and insurance (€) | 13,780 | 22,464 |

| | | |
|---|---|---|
| Total fixed cost (€ $h^{-1}$) | 36.35 | 59.25 |
| Total variable cost (€ $h^{-1}$) | 50.7 | 47.5 |
| Total labour cost (€ $h^{-1}$) | 20 | 13 |
| **Total cost (€ $h^{-1}$)** | **87.1** | **106.7** |

***Conclusions***

Time consumption, productivity and costs of forwarding were calculated for two different models of forwarder, a John Deere 1110E and a John Deere 1910E based on data collected at three different sites. Forwarder productivity in cut-to-length forest harvesting systems is strongly positively correlated with the volume of payload and negatively with the average extraction distance. Even when considering the higher operating cost of the larger machines, the much higher productivity rates at the plantation clearcut New Zealand sites resulted in significantly lower unit extraction cost.

The data provided shows a clear opportunity for southern Italian sites adopting higher levels of mechanization, even if conditions such as steeper terrain, limited infrastructure, or longer forwarding distance will negatively impact productivity. The data provided should help facilitate improved logging planning, and consequently achieving cost competitiveness of the system for harvesting Calabrian pine.

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*3.6 Paper 1 - Mechanization Forestry - An Investigation in Roundwood Extraction of Fagus sylvatica and Calabrian Pine by Greifenberg TG700*

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# An Investigation in Roundwood Extraction of *Fagus sylvatica* and *Calabrian Pine* by Greifenberg TG700

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**Abstract**

Cable yarding is especially popular in the European mountains, where slope and roughness parameters are limits for ground-based harvesting technology. This system, most commonly steep slope harvesting techniques worldwide, is poorly diffused in Southern Italy. The study was conducted in two forests in the Apennine mountain range. The time and motion study was conducted using the repetition timing method to determine the total yarding cycle time. We measured the impact of the following independent variables on the “total cycle time” (total time) and on the “productivity”. The productivity study carried out showed that the work capacity of cable crane tested was satisfactory. Using the Greifenberg TG700, the extraction costs were calculated as 17.70 € per m$^3$ at site A and 17.44 € at site B, where these costs refer to the working time (productive + unproductive time).

**Keywords:** Productivity, Extraction, Cost, Time consumption, Cable crane

## 1. Introduction

In the last ten years, several types of cable crane are marketed with different characteristics in terms of size, power, extraction system, gravity system, and loading capacity. All-terrain mobile tower cable cranes are promising innovations, which can operate under conditions with different soils. New forms of equipment are released periodically to respond to the increasing needs of producers regarding productivity, operator safety, and product quality. Cable cranes with universal carriages, in fact, are not limited to a narrow working area and they can be very efficient in locations where other forms of wood extraction are not possible or permissible due to various natural or ecological limitations. The aim of this study was to investigate the productivity of mobile cable crane, Greifenberg TG700, in two different sites characteristic of Southern Italy. The time and motion study was conducted using the repetition timing method to determine the total yarding cycle time.

## 2. Materials and Methods

Greifenberg TG 700 cable crane was monitored and all the data was collected in the two test sites. Similar to other studies conducted to determine the performance and cost of cable yarding technology, we analyzed time consumption data using the general concepts employed in observational modeling studies [8, 9, 13, 17]. The study was conducted in two forests in the Apennine mountain range, in Southern Italy. The forests considered are a beech (*Fagus sylvatica*) in site A (stand Pollino) and pine (*Calabrian Pine*) in site B (stand Sila), high forest, at an altitude of 1,450 m a.l.s for site A, and 1,250 in site B (Fig.1). The study was conducted in selective felling site, on area of 14 ha with N-E exposition in A, and 20 ha with N-O exposition in B. The forests land are classified as I class for roughness, while the slope is between II class and III (20/60%). The stand density was 850 trees for hectare in site A and 900 for site B. The total volume was 630 m$^3$/ha in site A and 720 m$^3$ in B. The timbers extracted was trees with an average height of 19 meters and an average diameter of 30 cm in site A and an average diameter of 32 cm in site B with height of 24 meters. The volume of average tree was 0.80 m$^3$ in site A and 0.70 in site B (table 1).The density of the forests is generally uniform in both sites; small gaps are present only in the areas with lower soil depth. The areas not have a main road network; the trails opened during felling were used as the secondary road network. In both sites the work system adopted was the Full Tree System (F.T.S.). The logs were then transported to the landing where they were bucked and loaded into a truck. The volume of each tree was calculated using Smalian's formula by multiplying the average cross-sectional area of the stem by the stem length [10]. Selective cut was adopted and was removed 25% per hectare in both sites. A team of four workmen operated in the timber yards in sites A and B. The working group consisted one haulage engineman, two workers for yarder and one worker for timber unloading in landing site. Selective cut was adopted and was removed 25% per hectare in both sites. The operating area of the cable crane was about 2.40 ha at site A and 2.80 ha at site B.

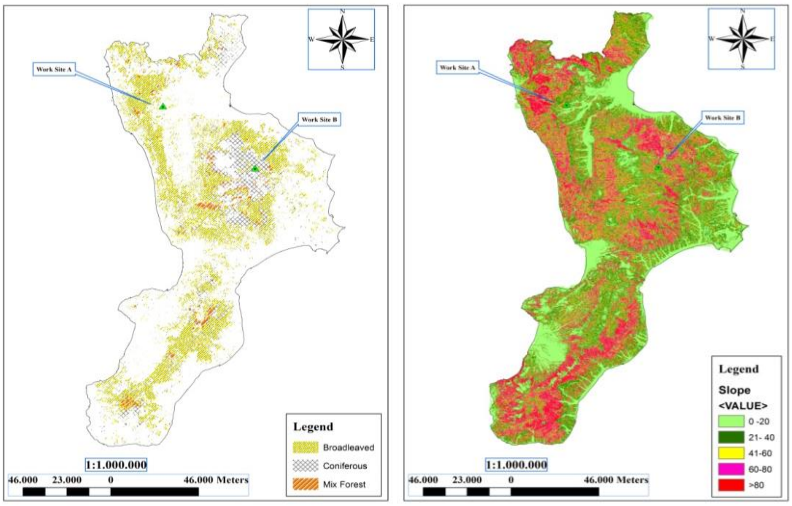


**Fig. 1.** Geographic location the research areas and maps of the slope

**Table 1**. Test sites characteristics

| **Work Site** | **A** | **B** |
|---|---|---|
| Placename | Mormanno | San Giovanni in Fiore |
| Province | Cosenza | Cosenza |
| Elevation m (asl) | 1,450 | 1,250 |
| Species | Beech | Calabrian Pine |
| Stand Type | Hig forest | Higt forest |
| Operation | Selective cut | Selective cut |
| Density (tress /ha) | 850 | 900 |
| Volume site (m³/ha) | 630 | 720 |
| Removal trees (ha) | 213 | 225 |
| Removal m³/ha | 157 | 180 |
| Average tree m³ | 0.8 | 0.7 |
| Average DBH (cm) | 30 | 32 |
| Average Slope gradient (%) | 51 | 33 |
| Extraction (direction) | Uphill | Uphill |

### 2.1 Tower Yarder

The investigated mobile cable crane is a Greifenberg TG700 which is a mobile cable crane designed for extracting wood uphill. The system comprises two principal lines: skyline and mainline. The basic characteristics of the cable crane are as follows:

- cable crane mass is 6000 kg (with winch, ropes and engine);
- diesel engine power is 84 kW;
- 4 Guylines of 40 meter length and 12 mm of diameter;
- skyline drum capacity of 700 meters;
- carriage type Crg 25 is automatic.

### 2.3 Time consumption and productivity study

Similar to other studies conducted to determine the performance and cost of cable yarding technology, we analyzed time consumption data using the general concepts employed in observational modeling studies [3, 5, 12, 13, 15, 17]. The time and motion study was conducted using the repetition timing method to determine the total yarding cycle time, i.e., the amount of time required for the carriage to travel from the landing until the unhooking of the payload. These activities were investigated in terms of the cycle times by using stopwatches for each individual cycle, where we separated the productive time from the delay time, as well as identifying the variables that were most likely to affect the time consumption [2]. Seven yarding elements were identified and timed to determine the total cycle time [6]:

***Outhaul Empty:*** Begins when the operator is ready to move the carriage from the landing out to choke setter and ends when the choke setter touches the choke.

***Hook descent*:** Begins when the operator locks the carriage and begins to release the hook, and it ends when the operator starts to connect with the load.

***Lateral Out:*** Begins at the end of outhaul empty and ends when the choke setter is ready to hook a turn. (Choke setter's forward motion has stopped and is ready to begin setting the chokers).

***Hookup:*** Begins at the end of lateral out and ends when the choke setter has completed hooking the chokers and signals to begin yarding.

***Lateral in:*** Begins at the end of hookup and ends when the turn is pulled up to the carriage and the carriage begins to move up the corridor.

***In haul:*** Begins at the end of lateral in and ends when the turn has reached the position on the deck where it can be directly unhooked at the landing.

***Unhook:*** Begins at the end of in haul when the carriage passes over the trip block and ends when the chokers have returned to the carriage.

In practice, 140 cycle times were recorded in total to determine the average performance at each site (A and B). The time data were recorded by two researchers, i.e., one stationed with the timber at the bunching location and the other stationed next to the cable system. Wireless communication was maintained between these researchers. During the trials, the Greifenberg TG 700 was operated by the remote control, both from the landing and the stand (when setting the chokers). The in and out haul functions of the drums were synchronized by computer, so the operators only used simple orders to control the yarder [8]. The machine costs were calculated as described by Miyata (1980) [11] for forest machine and by using the COST model proposed by Ackerman *et al.* (2014) [1]. In order to calculate the production cost for 1 $m^3$ of wood, the cost analysis employed the following parameters: the number of operators, the hourly cost of an operator, the hourly cost of machines, the volume of wood extracted, and productive machine hours excluding all delay times.

**Data analysis**

We measured the impact of the following independent variables on the "total cycle time" (total time) and on the "productivity". We used the total cycle time as a dependent variable whereas "Lateral distance, Skyline slope distance, volume and Slope" were selected as independent variables. For the model productivity "*Lateral Distances, Skyline slope distances and number trees for turn*" were selected as independent variables. The definitions of independent variables as well as their measurements are summarized as follows:

***Lateral distance:*** The lateral yarding distance in feet was measured either by pacing the distance or by ocular estimation of the distance to the nearest 10 m.

***Skyline Slope Distance:*** On each corridor, the ground slope distance in feet was measured and marked at regular intervals to aid in recording slope distance that the carriage traveled during the study period.

***Volume*****:** Each piece was measured in the corridor and marked with an identification number and recorder by turn number. The large – and small – and diameters and length were scaled.

***Slope:*** was classified in terms of gradient and topographic form of the slope with GPS and maps of slope of the region Calabria.

***Number of trees for turn:*** The number of stems per cycle were recorded.

All of previous independent variables are considered to be scale variable (Eq. 1). Theoretically, the following mathematical equation is obtained.

**Total cycle time = f (*Lateral distance, Skyline slope distance, Volume and Slope*)** Eq. 1

SPSS and Excel 2012 were used for the analysis. A regression model was developed for the statistical analysis. Initially, a 95% significance level was set to test the null and alternative hypotheses given above.

## 3. Results and discussion

The table 2 shows the average time of the cycle in two sites. Generally the time of a cycle of timber haulage in site A was 8.55 minutes, while in site B was 11.26 minutes.

**Table 2.** Time consumption (min+SD) per working component

| Phases | Site A | | | | Site B | | | |
|---|---|---|---|---|---|---|---|---|
| | **Min** | **Mean** | **Max** | **Dev St** | **Min** | **Mean** | **Max** | **Dev St** |
| Outhaul Empty | 1.01 | 2.41 | 4.21 | 0.91 | 1.5 | 2.7 | 5.25 | 0.87 |
| Hook descent | 0.11 | 0.19 | 0.31 | 0.04 | 0.15 | 0.39 | 1.1 | 0.23 |
| Lateral Out + Hook Up + Lateral In | 1.23 | 2.31 | 4.5 | 0.78 | 2.25 | 3.51 | 5.15 | 0.6 |
| In Haul | 2.01 | 3.25 | 5.59 | 0.95 | 2.2 | 3.59 | 6.25 | 0.8 |
| Unhook | 0.1 | 0.18 | 0.9 | 0.13 | 0.2 | 0.51 | 1.28 | 0.25 |
| Delay time | 0.1 | 0.2 | 0.9 | 0.16 | 0.25 | 0.53 | 1.2 | 0.25 |
| Cycle time | 5.62 | 8.55 | 12 | 1.63 | 7.7 | 11.2 | 17.28 | 1.94 |

The average timber haulage times were 8.55 min at site A and 11.26 min at site B. Regression analysis was performed on the Grefeinberg TG 700 time study data to develop a delay free cycle time equation for the machine under the stand conditions stated in the study. The variables included for both sites skyline slope distance, lateral distance, slope and volume per turn cubic. The cycle – time equation for the site A took the form:
*Cycle Time (minutes)* = 3.075 + 0.049 * Lateral distance + 0.005 * Skyline slope distance + 0.067 * Volume + 0.051 * Slope **$R^2$**= 0.71
In site B the cycle – time equation took the form:
*Cycle Time (minutes)* = 2.516 + 0.047 * Lateral distance + 0.013 * Skyline slope distance + 0.401 * Volume + 0.125 * Slope **$R^2$**= 0.73
Lateral distance, Skyline slope distance and slope ($p < 0.0005$) showed a significant contribute, Volume ($p > 0.05$) shower a reduced and a non-significant contribute in both sites.
The total volumes were 2,198 $m^3$ at site A and 3,600 $m^3$ at B, i.e., 157 $m^3$ $ha^{-1}$ for site A and 180 $m^3$ $ha^{-1}$ for site B. On average, a worker produced 7.24 $m^3$ $d^{-1}$ at site A and 7.35 $m^3$ $d^{-1}$ at site B. The low difference between the two sites (A and B) was directly dependent on the extraction distance, slope and the volume of each load. In particular, the length of the logs influenced the time required for extraction and bunching at both sites. In fact, the number of logs in each load (two or three in the most of the cases) and the speed of the transport were restrained in order to reduce residual stand damage. The average delay time was 0.28 min/cycle in site A, and 0.52 in site B. The lost time occurred during the loading and unloading of the carriage. The mounting and dismounting of this cable crane was easy, fast and the productivity was low influenced (Table 3). Thus, the yarding of semi-suspended trees is only compatible with uphill extraction. Given the lengths of the trees extracted, it might be helpful to employ a carriage that extracts long loads in a fully horizontal direction or to increase the distance of the skyline cable above the ground. Two independent operating hoisting winches mounted on the carriage could allow the horizontal transport of long and high loads even with a small distance between the skyline cable and ground. This could increase the speed of extraction and thus the productivity of the yard.

**Table 3.** The average daily operative results of the work site

| | Unit | Greifenberg TG 700 | |
|---|---|---|---|
| | | Site A | Site B |
| Wood Harvest Systems | | Full Tree System | |
| Number of valid observations | n. | 70 | 70 |
| **Yard cycles** | | | |
| • Average volume per cycle | $m^3$ | 1.38 | 1.59 |
| • Yarding cycle per day | n. | 42 | 37 |
| • Yarding cycle per hour | n. | 6-7 | 5-6 |
| • Average time for one cycle | min. | 8.55 | 11.26 |
| • Standard deviation (σ) | ± | 1.63 | 1.94 |
| **Productivity** | | | |
| • Daily SMH | $m^3\ d^{-1}$ | 57.96 | 58.83 |
| • Daily PMH | $m^3\ d^{-1}$ | 77.28 | 67.68 |
| • Hourly SMH | $m^3\ h^{-1}$ | 7.24 | 7.35 |
| • Hourly PMH | $m^3\ h^{-1}$ | 9.66 | 8.46 |
| **Manpower** | | | |
| • Operators | n. | 4 | 4 |
| • Work capacity | $m^3\ h^{-1}$-man | 1.81 | 1.83 |
| • Unit Time | $h\ m^{-3}$ | 0.14 | 0.12 |
| • Productivity | h-man $m^{-3}$ | 0.55 | 0.54 |

The fixed and hourly operating costs for the cable crane are shown in Table 4. Using the Greifenberg TG700, the extraction costs were calculated as 17.70 € per $m^3$ at site A and 17.44 € at site B, where these costs refer to the working time (productive + unproductive time).

**Table 4.** Calculation of hourly costs of cable crane

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Purchase price (€) | 150,000 | Interest cost (€) | 6,720 |
| Salvage value (€) | 30,000 | Taxes and insurance (€) | 3,840 |
| Economic Life (y) | 10 | Total fixed cost (€ $h^{-1}$) | 20.14 |
| Yearly utilization (n) | 140 | Total variable cost (€ $h^{-1}$) | 48.05 |
| Scheduled operating time (h) | 1120 | Total labour cost (€ $h^{-1}$) | 20.00 |
| Annual depreciation (€) | 12,000 | Total cost (€ $h^{-1}$) | 68.20 |

Thus, when the cable crane was productive, the extraction costs were 13.27 € per $m^3$ at site A and € 14.20 at site B. The delay times increased the operating cost by 4.43 € (25%) at site A and 3.24 € (19%) at site B. Therefore, it is necessary to reduce the unproductive time in order to increase the site productivity, thereby reducing the extraction costs. In order to lower the fixed and operating costs of the cable cranes, it is necessary to increase the number of annual working days. The test of the cable crane obtained satisfactory results but a number of organizational features could be improved in order to fully exploit its potential. The cost per cubic meter and efficiency are influenced greatly by the productivity.

## 4. Conclusions

The objective of this study was to analyze the productivity of Greifenberg TG 700 sites in two different using a time motion methodology. No significant differences in productivity and costs were found between site A and site B. In this study, productivity (SMH) was found as 7.24 $m^3h^{-1}$ for transporting distance (for average 155 m) in site A, and 7.35 $m^3h^{-1}$ (for average distance 176 m) in B, causes number of tress per turn. The acquired data and the resulting analysis focused on the bunching operation since it is one of the most critical working elements of logging. Even though the productivity of the tested crane was lower than other cable cranes used outside Italy, the data obtained throughout this study was higher than 0.5 $m^3$ $m^{-1}$, the necessary minimum for economic logging with traditional cableway and 0.2 $m^3$ $m^{-1}$, the necessary minimum for economic logging with cable cranes in Italy. Unproductive time should be reduced by employing workers specialized in cable system operations; and maintenance and repair of carriages, chokers, and cables must be done at the start of the activity. Finally, the high purchase price of this type of machine may be discounted against its minimal negative impact on the environment and the fact that it may be the only viable and sustainable extraction method for the management of sensitive sites [6, 14, 16]. Interaction between silviculture and logging operations remain particularly important on steep terrain. For cable systems, communication between the forest manager (who marks the trees to be removed) and the logging company (who calculates the location of the lines) is essential [8, 9]. Further research into cable extraction systems could employ a global navigation satellite system installed in the carriage to support automatic or semi-automatic operational monitoring, as well as improving the quantity of data acquired to reduce the workload of the surveyor [4, 5].

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*3.7 Paper 2 - Measuring the mobility parameters of tree-length forwarding systems using GPS technology in the Southern Italy forestry*

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# Measuring the mobility parameters of tree-length forwarding systems using GPS technology in the Southern Italy forestry

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**Abstract.** The introduction of modern forwarders to Apennines forest operations must account for the traditional forwarding units used by local logging contractors. They generally use the same machine for extraction and intermediate off-road transportation on mountain trails, inaccessible to heavy road vehicles. Conventional forwarders are not designed for fast transportation on trail and cannot replace conventional. This research set up a long-term follow-up study to determine the use pattern of three conventional tractor-trailer units (Forwarder, forestry trailer and articulated truck). The goal of this study was to gauge the potential of these machines. In particular, the study determined for both machine types: monthly usage, incidence of travelling time over total time, distance covered and travel speed. The null hypothesis was that use pattern, average travel distance and speed distribution did not differ between traditional tractor and trailer units and high-speed forwarders. For this purpose, Global Positioning System/Global System for Mobile Communications data loggers were installed for continuous real-time collection of the main work data, including position, status, speed and fuel consumption. The study showed that new forwarders could actually travel at a speed higher than 24 km $h^{-1}$, and they performed both extraction and intermediate transportation. They were capable of independent relocation, which made them suitable for small-scale forestry. Both machine types were used intensively, but the annual usage of forwarders was almost twice as large as that of tractor-trailer units. Furthermore, forwarders had a 27% higher hourly productivity and a 50% higher fuel consumption per hour, compared with tractor-trailer units.

**Key words:** GPS – Track logger, data logger, extraction, precision forestry.

## INTRODUCTION

Forests in southern Italy are an important area in terms of forest production, having the largest forest cover of all regions of the country even though the highest concentration of woodlands occurs in the northern regions of Italy. Forests cover 1,517,836 ha (NFI 2005) in southern Italy and consist mainly of mature beech, chestnut, Corsican pine, and silver fir forests (more than 300,000 ha combined). These forests account for a wooded area percentage of 31.8%. Therefore, use of these forests could certainly provide a more significant resource for the economy of the entire Mediterranean basin, an objective that could be attained with better and more efficient mechanization of forest operations, which should play a growing role (Istat, 2013). Unfortunately, the current level of mechanization is fairly low (Zimbalatti & Proto, 2009). The current increasing dynamism of the wood market has led to the development and improvement of technologies able to extract logs more efficiently by reducing consistently the time and labour required for production (Cavalli et al., 2014; Moneti et al., 2015). Indeed, the most common work method in southern Italy, referred to as traditional, can be considered as an early stage of mechanization. It is based mainly on agricultural tractors, sometimes equipped with specific forest-related machines (winches, hydraulic cranes, log grapples, etc.); use of animals for gathering and yarding is also widespread. This level of mechanization of forest resource extraction is due to the features of the forest sites, the characteristics of the forest properties, and the small dimensions of many forest enterprises (Proto et al., 2014).

Time motion study by GPS is a key factor for the road network planning (Cavalli & Grigolato, 2010). Similar methods have recently been used in forest engineering studies dealing with wood transportation (Holzleitner et al., 2011a), forwarding units (Veal et al. 2001), mobility parameters (Suvinen & Saarilahti, 2006) and autonomous path tracking (Ringdahl et al. 2011; Spinelli et al., 2015; Russo et al., 2016). Respect to the previous studies, however, the forest features, harvesting and skidding methods are completely different in South Italy, the sites of the present research. In Calabria, where the test were conducted, the expanse of forest is 40.6% respect on average data national of 34.7%. Every year, the average increase in wood volume in this region (equal to 6–8 $m^3$ $ha^{-1}$) exceeds and sometimes doubles the estimated increase in other forests in Italy (Proto & Zimbalatti 2015,), roughness, slope, and silvicultural system affect the mobility parameters of tree-length forwarding systems. In this respect, the present research aims to develop technical and economical knowledge regarding the different use of three machinery used in Calabria (South Italy) by using GPS/GSM technology.

## MATERIALS AND METHODS

Three representative machines were selected for the study: an articulated Man Truck, model TGX 6×6 (471 kW), a forwarder, model John Deere 110 D (125 kW), and a forestry tractor-trailer (70 kW) (Table 1). All machines were road-legal and could travel at a theoretical maximum speed of 40 km $h^{-1}$. The machines were owned by separate small-scale logging contractors, which is typical of the region.

**Table 1.** Description of machines

| Machine | Articulated Truck | Forwarder | Forestry Tractor-railer |
|---|---|---|---|
| Type | MAN | John Deere | Lamborghini |
| Model | TGX 6x6 | 110 D | 1,060 |
| Trasmission | Hydrostat | Hydrostat | Mechanic |
| Axles total | 3 | 4 | 4 |
| Power (kW) | 353 | 125 | 77 |
| Weight (kg) | 33,000 | 14,600 | 8,050 |
| Width (mm) | 2,490 | 2,650 | 2,350 |
| Length (mm) | 5,200 | 5,000 | 2,350 |
| Gps Study - Months | 7 | 7 | 7 |

All these machines worked in the same valley in southern Italy and were operated by the same owner-operator. For the purpose of the study, the university researchers installed on all machines a commercial black-box GPS/GSM unit for continuous real-time collection of the main work data, including position, status (engine off, engine on, traveling), and speed (Fig. 1).

The tests were carried out at three forest sites, indicated below by the letters A, B, and C and all located in the Serre massif (VV). Table 2 gives the features and vegetation characteristics of the three test sites from surveys carried out beforehand.

**Figure 1.** Installing the GPS/GSM black-box unit.

**Table 2.** Characteristics of the two test sites

| Features | Measurement Units | Site A (Articulated truck) | Site B (Forwarder) | Site C (Forestry tractor-trailer) |
|---|---|---|---|---|
| Altitude | a.s.l. | 950 | 800 | 850 |
| Prevalent species | - | Chestnut | Corsican pine | Mediterranean pine |
| Government | - | Coppice | High forest | High forest |
| Treatment | - | Clearcuts with reservations | Thinning | Thinning |
| Stand density | n. p. $ha^{-1}$ | 2,400 | 900 | 1,200 |
| Average volume per tree | $m^3$ | 0.20 | 0.65 | 0.40 |
| Total volume | $m^3$ $ha^{-1}$ | 480 | 585 | 480 |
| Average slope | % | 31 | 22.5 | 27 |
| Max gradient | | 50 | 38 | 43 |
| Min slope | | 12 | 7 | 11 |
| Roughness | - | Very rough | Moderately rough | Moderately rough |

The GPS/GSM black box collected position data at 30-second intervals and had a buffer memory to store data when GSM coverage was unavailable. Stored data were sent to the server as soon as the unit could connect again to the GSM network. The units used for the study were a commercial tracker used for truck fleet management and available at a very attractive monthly fee (www.visirun.com).

The black-box system used for the study downloaded all data at the end of each day into one spreadsheet per machine. All position data carried a time stamp, which was used to estimate speed. Data loggers were connected to the engine contact, and hence they recorded the time that the engine was on. As a consequence, each produced a daily estimate of work hours, which was downloaded together with the position points and speed graphs (Fig. 2). Data processing was rationalized by developing a new automated procedure to merge all daily spreadsheets into a single master data base per machine to convert it into a data base management system. This made it possible to select and edit all the events. Data were recorded at two records per minute more or less, which was the standard data collection rate at a 30-second pulse interval. Query views were finally converted into a spreadsheet (MS Excel) to produce suitable pivot tables. The data were then processed using the SPSS software.

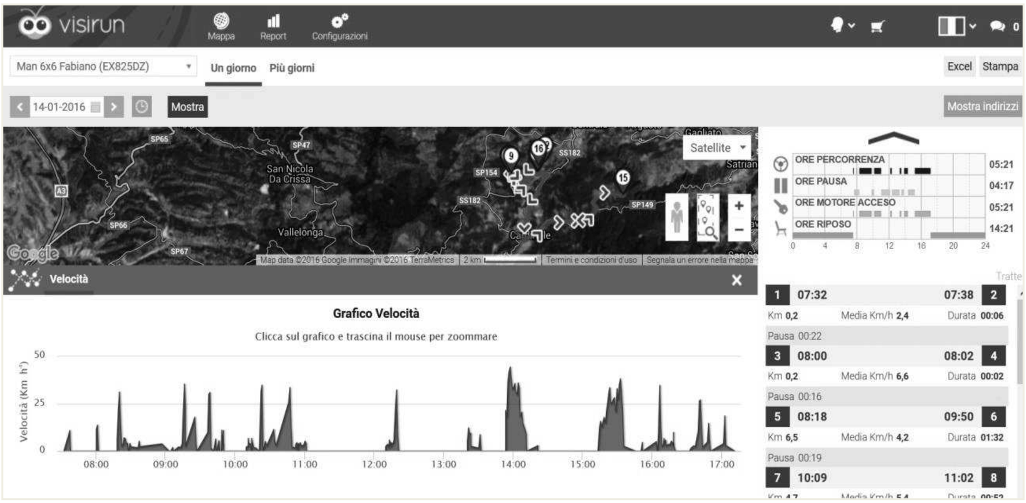


**Figure 2.** Example of machine track and speed graph for one work day.

The data considered in this preliminary study covered 7 months during the same period, from May 2015 to December 2015 inclusive. The following data were used in the analysis: duration of the working day, in hours (roughly the same as worksite time); time when the engine was running, in hours; time that the machine was moving, in hours; and total distance traveled, in km. Before analysis, the daily figures were consolidated into sums representing five working days to reduce the confounding effect of daily variability. A similar consolidation was carried out to describe the volume of wood extracted in each trip to determine the mean hourly productivity of the different machines. The total number of logs was counted and their transportation recorded to calculate the volume of each load and hence to obtain a good estimate of the total volume carried. Overall data for the periods of work and the skidding-cycle volumes on the test days were also collected.

The logs obtained during the study at the three test sites were calculated by measuring the total length and the diameter at half height (Proto & Zimbalatti, 2015; Proto et al., 2016a). At the first site (A), the full-tree harvesting method was used; the trees were delimbed, topped, and bucked on site. At the second and third sites (B and C), the tree-length method was used. Trees were felled, then delimbed and topped at the stump. The volume of logs was calculated using the Huber formula (1):

$$V = D^2 \cdot \pi/4 \cdot L, \qquad (1)$$

where: V = total tree volume ($m^3$); D = mid-height diameter (m); L = length (m).

The distribution of consolidated travel distance data was normalized through a logarithmic transformation. Current speed data were recorded every 30 seconds, and each record was allocated to one of the following speed classes: 0 to 2, > 2 to 5, > 5 to 10, > 10 to 20, and > 20 km $h^{-1}$. The incidence of each speed class over the total travel time was cumulated as a sum over five working days to dampen the effect of extreme daily values.

## RESULTS AND DISCUSSION

Over the seven-month period, the forwarder worked 158 days, the articulated truck 85, and the forestry tractor-trailer 75 days. The average workday lasted 8.20 hours in the forwarder, 9.40 in the articulated truck, and 8.00 with the forestry tractor-trailer. The longest workday lasted 13.4 hours with the articulated truck, 10.2 with the forwarder, and 9.25 with the forestry tractor-trailer. The total worksite time accumulated during the study period by the forwarder was 3,807 hours, 2,263 by the articulated truck, and 1865 by the forestry tractor-trailer. Engine time was 1,383 hours for the forwarder, 561 for the articulated truck, and 600 for the forestry tractor-trailer. Utilization time was about 40% for the articulated truck, subdivided into 21% for loading and unloading and 19% for time spent traveling empty and facing delays. The forwarder was used 56% of the time, with 20% of this time spent in loading and unloading. The forestry tractor-trailer was used 52% of the time, with 40% of this time used for loading and unloading. In this last machine, the greatest amount of time was spent to load and unload the wood. This high time consumption is caused by the type of mechanical grapple used, which is less powerful than the other grapples on the forwarder and the articulated truck.

Table 3 shows the average monthly data over the cumulated 7-month study period. The forwarder worked more hours per week and had a higher utilization rate than the articulated truck or the forestry tractor-trailer. However, it covered a shorter distance. The articulated truck covered a total distance of 5,063 km at an average speed of 25.5 km $h^{-1}$, the forwarder 532 km at an average speed of 2.6 km $h^{-1}$, and the forestry tractor-trailer 412 km at an average speed of 1.4 km $h^{-1}$.

**Table 3.** Worksite time, engine time, utilization rate, and travel distance (average month)

| | | Articulated truck | | Forwarder | | Forestry tractor - trailer | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD |
| Worksite time | h | 80.1 | 72.1 | 197.6 | 38.3 | 85.7 | 29.1 |
| Engine on | h | 81.6 | 68.1 | 218.6 | 43.1 | 128.6 | 37.6 |
| Moving | h | 26.7 | 25.3 | 176.4 | 34.1 | 51 | 20.9 |
| Utilization | % | 40 | 23.9 | 75 | 14.3 | 55 | 12.1 |
| Distance | km | 723 | 710.2 | 76 | 8.9 | 58.9 | 3.9 |

Analysis of variance showed that all these differences were statistically significant except for travel distance (Table 4). Although a significant factor, machine type seldom accounted for more than 20% of the variability in the data pool, which was consistent with the predominant effect of site variability in natural forests. The cumulative distance covered in 7months did not differ significantly among the three sites, but the hours worked during the same time did, and therefore the articulated truck covered a significantly longer distance per unit time (Table. 4).

**Table 4.** ANOVA for worksite time, engine time, utilization rate, and travel distance

| | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|
| Between groups | 61,442.571 | 2 | 30,721.286 | 12.263 | 0.000 |
| Within groups | 45,092.000 | 18 | 2,505.111 | | |
| Total | 106,534.571 | 20 | | | |
| **Engine time** | | | | | |
| | Sum of squares | df | Mean square | F | Sig. |
| Between groups | 67,848.667 | 2 | 33,924.333 | 12.769 | 0.0004 |
| Within groups | 47,823.143 | 18 | 2,656.841 | | |
| Total | 115,671.810 | 20 | | | |
| **Move time** | | | | | |
| | Sum of squares | df | Mean square | F | Sig. |
| Between groups | 90,385.143 | 2 | 45,192.571 | 60.575 | 0.0000 |
| Within groups | 13,429.143 | 18 | 746.063 | | |
| Total | 103,814.286 | 20 | | | |
| **Distance** | | | | | |
| | Sum of squares | df | Mean square | F | Sig. |
| Between groups | 2,008,388.667 | 2 | 1,004,194.333 | 5.972 | 0.0103 |
| Within groups | 3,026,826.286 | 18 | 168,157.016 | | |
| Total | 5,035,214.952 | 20 | | | |
| **Utilization** | | | | | |
| | Sum of squares | df | Mean square | F | Sig. |
| Between groups | 6,517.460 | 2 | 3,258.730 | 10.516 | 0.0009 |
| Within groups | 5,577.778 | 18 | 309.877 | | |
| Total | 12,095.238 | 20 | | | |

These results were compatible with the distribution of moving time within predefined speed classes, as shown in Fig. 3. Almost 70% of forestry tractor-trailer moving time fell within the slowest speed class, compared to 40% for the forwarder and 5% for the articulated truck. In contrast, the percentage of moving time within the higher speed classes (2–10 km $h^{-1}$) was twice as high for the articulated truck as for the forwarder. The percentage of moving time in which the articulated truck traveled at a speed higher than 20 km $h^{-1}$ was 66% of the total time monitored. Technically, both the articulated truck and the forwarder were capable of traveling at speeds higher than 20 km $h^{-1}$. The database even contained rare recorded speeds greater than 30–40 km $h^{-1}$, but these could have been the result of position errors. Table 5 shows the number of hours spent moving at a given speed for the whole seven-month study period. This was obtained by multiplying total moving time by the percent incidence of each speed class. During the whole study period, the articulated truck spent much more time moving at speeds greater than 20 km $h^{-1}$. In contrast, the forestry tractor and the forwarder moved at speeds less than 20 km $h^{-1}$. This may indicate that the articulated truck reached its highest speed only when traveling unloaded during relocations, whereas the forwarder and tractor were used for road transportation over short distances.

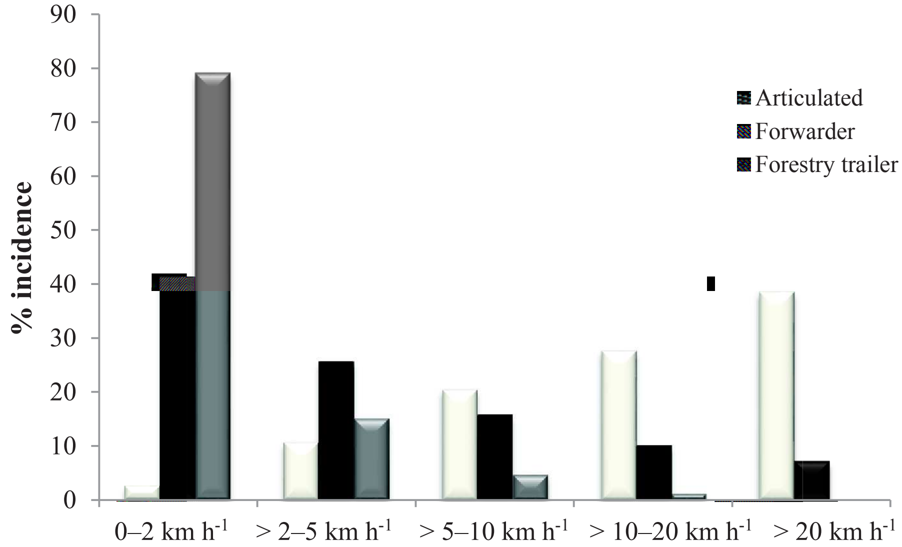


**Figure 3.** Breakdown of moving time within speed classes.

**Table 5.** Hours traveled within each speed class during the 7-month study period

| Speed Class | Articulated truck | Forwarder | Forestry trailer |
|---|---|---|---|
| 0–2 km $h^{-1}$ | 15 | 570 | 474 |
| > 2–5 km $h^{-1}$ | 60 | 355 | 91 |
| > 5–10 km $h^{-1}$ | 115 | 218 | 28 |
| > 10–20 km $h^{-1}$ | 155 | 140 | 7 |
| > 20 km $h^{-1}$ | 216 | 100 | - |
| Total hours | 561 | 1,383 | 600 |

The study showed that the three machines were used differently, which disproves the null hypothesis that the usage pattern did not change with machine type. The main difference in usage pattern was that the tractor was occasionally used for road transport, whereas the forwarder and the articulated truck were not. On the other hand, the forwarder and the forestry tractor-trailer both seemed equally capable of intermediate transport on lower-class roads, because the hours worked at speeds between 12 and 20 km $h^{-1}$ were about the same for all machines. Indeed, the articulated truck spent much more time moving over intermediate and long distances. Annual usage was substantially higher for the forwarder and the articulated truck than for the forestry tractor-trailer, probably due to the combination of their better work capability and the need to depreciate their larger associated capital investment (Spinelli & Magagnotti, 2010). This study also highlights the substantial difference between worksite time and engine time, or hour-meter time. Differences between worksite time records and hour-meter records have already been noticed in a previous study by Spinelli & Magagnotti (2011). This is obviously related to the effect of machine utilization, which this study approximates by the ratio of engine time to worksite time (Björheden et al., 1995). The machine utilization figures obtained in this study are slightly larger than those reported by Brinker et al. (2002), and more recently by Holzleitner et al. (2011b). This may result from including non-work time within engine time, which is bound to increase utilization. For this reason, further studies are planned to compare GPS and manual records.

These studies will also aim to determine productivity, which could not be estimated from the GPS records. These machines were capable of independent relocation, which made them suitable for small-scale forestry. All machine types were used intensively, but the annual usage of the forwarder and the articulated machine was almost twice as large as that of the tractor-trailer unit. Furthermore, the forwarders had 27% higher hourly productivity and 50% higher fuel consumption per hour than the tractor-trailer units.

## CONCLUSIONS

The usefulness of articulated truck, forwarder, forestry trailer for extracting and transporting logs has attracted particular interest in the Calabrian forest industry. The transportation of timber has always been challenging, especially in mountainous environments where slopes cause processing limitations. This research has revealed that these machine types were used intensively, but that the annual usage of the forestry tractor-trailer was about half that of the other machines. The numerous observations recorded in this study confirm that the use of these different machines is influenced by the work site (Proto et al., 2016b). The forwarder is essential for efficiency in timber handling, thinning, and regeneration harvesting; the articulated truck for transport over intermediate and long distances; and the forestry tractor-trailer for extraction in gently sloping areas and transport over short distances. In terms of future road building, the position of these roads should minimize the extent of forwarding that may be economical. The models developed here provide a basis for site-specific costing of transportation operations and potentially a convenient and transparent means of negotiating contract timber extraction. Further research on extraction and transport system comparison could be based on the use of GNSS installed on carriage for supporting automatic or semi-automatic operational monitoring and for improving the quantity of acquired data reducing the engagement of the surveyor (Gallo et al., 2013).

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### *3.8 Activity 6 - Assessment the yield of lumber in sawmill*

### *Introduction*

#### *Wood Processing*

The sawmill can be defined as a 'wood processing industry equipped with various wood processing machines' (Kukogho *et al.* 2011). Sawmills are key contributors to the wood industry as they represent a significant share of the market. Maximizing the profits obtained by conversion of softwood and hardwood logs into lumber is a primary concern of forest products companies.

Sawmilling, which is usually considered as a simple manufacturing process, (i.e. cutting down a tree, sawing, and generating lumber), is a highly technical and sophisticated wood industry that must be constantly monitored so that businesses can effectively respond to change. The major factors that influences sawmilling operations include the securing of log supplies, the properly designed and engineered production facilities, the environmental, regulatory and power supply issues, the constant training for professionals in management, operations, maintenance, sales, marketing and logistics, and the analysis of raw material resources and product lines for maintaining a long term profitability.

The increase of the logs cost and their limited availability are forcing the wood processors to become more efficient in their operations (Occena *et al.* 2001). In particular, the wood sawmills are facing many challenges, including the decline of the log size and quality, the limitation of the resource availability, the reduction of the profit margin between log cost and lumber prices, and the competition pressures (Milauskas *et al.* 2005). These challenges determined more efficient log taper and processing methods that can increase the value or volume of lumber produced from logs. Further, many large-scale sawmills have adopted the latest sawing and optimization technologies to increase the value and yield of lumber.

Finally, maximizing the volume recovery of lumber from logs is one of the most common ways of improving the conversion efficiency and competitiveness in lumber production (Occena *et al.* 2001).

***Sawmill Process***

Sawing method is the sequence of cuts used to break down a log into lumber for obtained a product type (Ese-Etame 2009). Sawmills are facilities that process logs into lumber. While modern mills are mostly automated, the fundamental sawmill process has changed little over the past several hundred years. Although they may not occur in the identical order, the Lumber mill operations are typically grouped into the steps as following: (Figure 1).

1. Trees are felled and trunks are bucked into manageable lengths at the harvest site.
2. A logging truck, train, or log drive transports the logs to the sawmill facility.
3. Logs are scaled before entering the mill, transport or just outside the facility. This involves the measurements, the inspection of defects and the identification of the tree species for the purpose of tracking the volume of salable wood.
4. A system of conveyors, cranes and other material handling equipment moves the log into the mill. A debarker then strips the bark. The logs may then be decked or sorted by parameters such as species, size, or intended end use.
5. A band saw cuts small sections from the edges of the log's profile.
6. A head saw (also known as a gang saw) breaks the log into cants and flitches. Cants are unfinished logs that require further processing, while flitches are unfinished planks.
7. Cants are then broken down into multiple flitches using a resaw, a type of large band saw.
8. An edger trims irregular edges to produce squared lumber. The flitch ends are trimmed to standard lumber lengths.

9. A kiln or air-drying process removes naturally occurring moisture from the planks. A planer smooths the lumber surface to a uniform width and thickness. The lumber is successively inspected, tagged, and shipped to the market.

Within the timber industry, new production technologies and machinery are constantly being developed that mean less man-handling of timber and more accuracy, efficiency and versatility across.

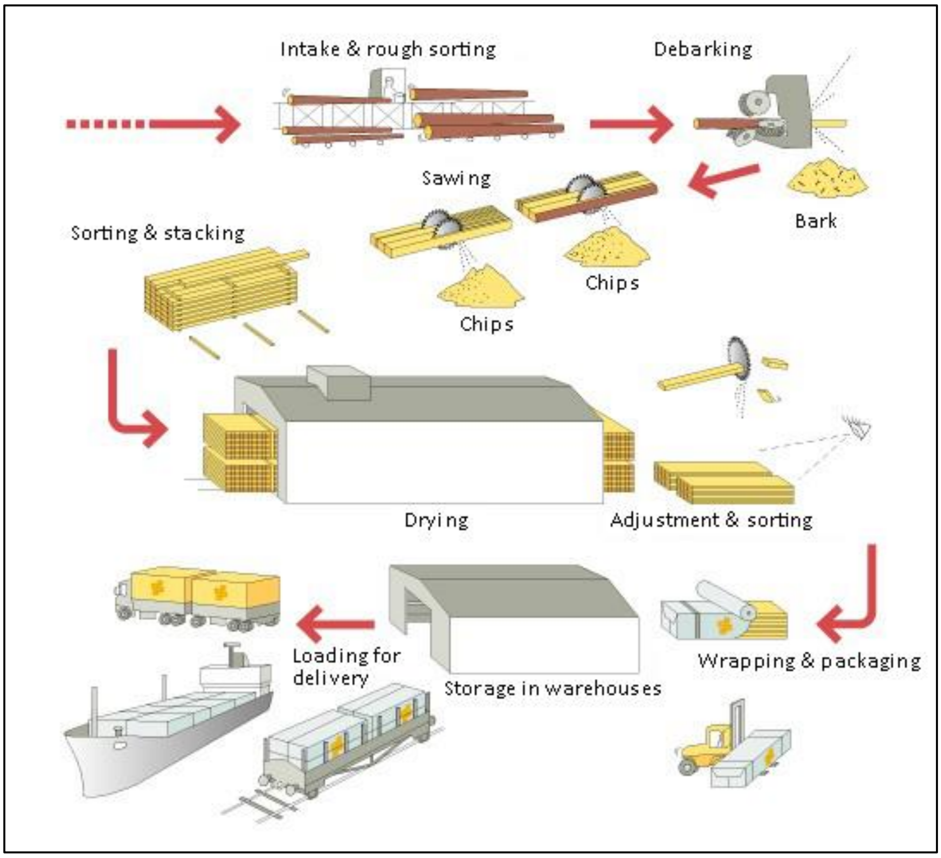


Figure 1 - Typical Wood Supply Chain in Saws

***Lumber Yield***

In a manufacturing plant, the lumber yield was defined as ‘‘the ratio of the amount of primary product output to the amount of raw material input, expressed as a percentage’’ (Pepke and Kroon 1981; Mitchell *et al.* 2005). This means that, to calculate lumber yield, estimations of two variables are needed: raw material input and primary product output from a mill. The raw material input is the log volume at the mill gates, which can be estimated using various methods (Wenger 1984; Avery and Burkhart 1994; Briggs 1994; Li *et al.* 2015). The primary product output is the production of lumber yield from the given log volume.

Yield, or the other term used in the literature, lumber recovery rate/factor, is a way to describe how efficiently a sawmill works. The yield analysis in terms of volume of sawn timber produced per actual log volume is a simple way to consider this (Bowyer *et al.* 2003). About 30-405 of the processed lumber is of export high quality. The commercial feasibility of sawmilling mainly depends on the expected production yield. At the same time, the choice of sawing method is one of primary factors affecting yield. Volume yield in sawmilling is determined by a interaction of several variables, such as kerf width, allowable widths, thickness and length, edging routines, and trimming routines, sawing method and so on. Among them, sawing method is an important determinant of volume yield in the sawmill. Sawing method is used to break down the log into lumber. In order to improve the volume yield, the researchers tried some different sawing methods. In particular, Hallock *et al.* (1987) compared the volume yield of eight different sawing methods: the live sawing method gave markedly lower yields than the cant sawing methods which, conversely, gave the highest yield but depending on the diameter of the log, log length, and taper. Similar, results were obtained by Gronlund (1989) which carried out a similar investigation adapted to European conditions, regarding allowable thickness, width, and length of the sawn timber, and timber dimension.

***Material and Methods***

***Work Sites***

This study was conducted in the firm ‘Fabiano Legnami SRL’, a midsize sawmill, with a production between 1000 and 1500 $m^3$/month of lumber, located in the municipality of Chiaravalle (CZ), in the geographic coordinates 626390.05 E and 4283250.5 N. Elevation is approximately 700 m above sea level, with a northern aspect. All logs used by the company have been purchased by suppliers who apply forest management plans and are located at a distance of approximately 50-200 kilometers from Chiaravalle.

The selection of timber species for the study was based on commercially available timber forest species. In particular, three different species (*Abies alba, Pinus Nigra and Chestnut*) were selected.

The roundwood for the yield assessment in sawmill was evaluated in three different forests: spruce (*Abies Alba*) (altitude of 1,100 m a.l.s), pine (*Calabrian Pine*) and chestnut (*Castanea sativa*) defined as site A, site B (altitude of 1.250 m a.s.l.) and site C (altitude of 900 m a.s.l.), respectively. The selective felling sites of stand Pollino, stand Sila and stand Serre, were 35 ha with N-E exposition, 46 ha with N-O exposition and 22 ha with N-O exposition, respectively. The sites characteristics are shown in Table 1. Each log in forestry area was identified with a code reported on a red plastic card with written "UNIRC" and a progressive number also (Figure 2).

Figure 2 - Identification of logs in forestry

*Table 1- Characteristics of the three work sites.*

| Site | A | B | C |
|---|---|---|---|
| Place | Brognaturo | San Giovanni in Fiore | Cardinale |
| Province | Catanzaro | Cosenza | Catanzaro |
| Elevation (m) | 1150 | 1250 | 900 |
| Species | Silver Fir | Calabrian Pine | Chestnut |
| Stand Type | Natural forest | Plantation | Natural forest |
| Operation Type | Selective cut | Thinning and selective cut | Selective cut |
| Total area (ha) | 35 | 46 | 22 |
| Density (trees /ha) | 600 | 850 | 650 |
| Site volume ($m^3$/ha) | 940 | 670 | 800 |
| Removal (trees/ha) | 200 | 215 | 270 |
| Removal volume ($m^3$/ha) | 150 | 165 | 150 |

***Data Analysis***

The features timber species selected and their densities at 12-15% (max) moisture content are shown in Table 2. The roundwood selection was based on the availability of the species at the forest area and characteristics of the Calabria.

*Table 2 - Features of the roundwood in Sawmill*

| Work Samples | A | B | C |
|---|---|---|---|
| Number of logs (n) | 192 | 201 | 92 |
| Length (m) | 4.10 | 4.10 | 8.10 |
| Diameter min (cm) | 22 | 24 | 24 |
| Diameter max (cm) | 68 | 65 | 67 |
| Average Diameter (cm) | 42 | 40 | 43 |
| Total Volume ($m^3$) | 106 | 113 | 107.5 |

In total 485 logs were selected in the sawmill deposit, belonging to nine different diametric classes. Each log was numbered to facilitate identification during the sawing process and diametric class was attributed in 5 cm among the logs. Before each cycle of sawing, the blade of headsaw was sharpened (Figure 3).

Figure 3 - Blade Sharpening Phase

The formula of Smalian was used to obtain logs volume, such that by the mean diameter calculated from base and top of logs and with their lengths, it is possible to determine the volume of each one of them:

$$V = \frac{\pi}{40000} * \left[\frac{D1 + D2}{2}\right]^2 * L$$

Were:

V: Volume of Log ($m^3$);

D1: Diameter of the larger end or extremity 1 (cm);

D2: Diameter of the smaller end or extremity 2 (cm);

L: Length of log;

After sawing, planks of each log were measured (length, width and breadth) and the volume (V) was determined using the formula below:

$$V = W \times L \times T$$

Where: V = Volume of lumber recovered, W = Width of the lumber, T = Thickness of the Lumber, L = Length of the lumber.

The lumber recovery (LR) percentage for each log was determined as:

$$(LR)\% = \frac{\text{Volume of timber recovered}(m^3) * 100}{\text{Volume of log } (m^3)}$$

Two sawing patterns were used: single production of boards or mixed production of boards for Silver Fir and Calabrian Pine and Sawn timber (centre pieces) for the chestnut. The boards were cut with the maximum allowed width. The first cut was made with the head ridge saw on a direction parallel to the log axis, i.e. live sawing. The second cut edged the boards and lumber in order to avoid any wane, being responsible for the correct board width and lumber thickness. The third cut (chestnut process) squared the end of the sawn pieces at the final length.

In this study, yield was calculated as the relation between the lumbers volume and logs volume in three different species. The objective of the third study was to analyze the parameters in the wood processing to the sawmill. In particular has been evaluated the yield of lumber in each species and to determine the better classes in diameter in the wood processing.

***Silver fir process***

The , *Silver Fir* was used for wood laminate and different cuttings were adopted:

- Debarking of the logs;
- Determination of thickeness with Headsaw;
- Determination of lenght with Circular saw;
- Determination of widht with Multi blade cutting.

The final length obtained by circular saw, was 4 mt. Different logs varied in diameter from 23 cm to 68 cm and the lumber yield has been studied for nine different classes for diameter. The final productions of the sawmill for silver fir was wood laminate of 4.7*13 cm (figure 4, 5 and 6).

Figure 4 - Logs before the saw

Figure 5 - Example of multi blade cutting

Figure 6 - Final lumber product for wood laminate

### *Calabrian pine process*

The Fabiano sawmill, *Calabrian Pine* was used for green regularized timber and different cutting were adopted:

- Debarking of the logs;
- Determination of thickness with Headsaw;
- Determination of length with Circular sawn;
- Determination of width with Multiblade cutting.

The final length obtained by circular saw, was 4 mt (Figure 7). Different logs varied in diameter from 23 cm to 68 cm and the lumber yield has been studied for nine different classes for diameter The final productions of the sawmill for silver fir was wood laminate of 7.5*15 cm (Figure 8).

Figure 7 - Logs of Calabrian Pine on the saw

Figure 8 - Multi blade cutting

***Chestnut's process***

Each log, 8.10 mt of length, was cut by a headsaw (Figure 9) for removal of the lateral board in each four sides (Figure 10). The final length was 8 mt and determined by a chainsaw. Different logs varied in diameter from 24 cm to 67 cm and the lumber yield has been studied for nine different classes for diameter. The final productions of the sawmill for chestnut were sawn logs of different dimension: 15*15 cm, 20 *20 cm, 25*25 cm, 30*30 cm and 40*40 cm.

Figure 9 - Analysis of cutting type with software

Figure 10 - Determination of thickness with Headsaw

***Statistical Analysis***

One way analysis of variance and the Tukey range test at 95% of probability were conducted to compare the means of the lumber yield among the different diametric classes. Further, the Pearson correlation between timber diameter and lumber yield was also tested.

***Results and Discussion***

The results were different for the tree different processes; the sawmill worked in different period the tree species. In total for all species were monitored a total of 326.5 $m^3$, while the final lumber was of 187.7 $m^3$.

During the processing of Silver Fire, 192 logs were monitored with a total volume of 105.9 $m^3$. The slabs produced 39.23 $m^3$. The nine diameter classes showed different yield. In particular, the lower value was registered in the VIII and IX class (60 and 65 cm ø), instead the higher value of yield was identify in the 45 and 50 cm diameter class for the production of wood laminate.

Table 3 showed the value of yield in each class diameter. The final dimension obtained was 4.7*13 cm. In total were obtained 2,731 prepared timber. The length final was of 4 mt. and the percentage of yield lumber was 61 %.

*Table 3 - Main results in the processing of the chestnut*

| **Classes Of diameter (cm)** | **Number of Logs** | **Average Volume of logs (m³)** | **Dimension of Final logs (cm)** | **Number of assortments obtained from each log** |
|---|---|---|---|---|
| 25 | 32 | 0.20 | 4.7*13 | 5 |
| 30 | 23 | 0.29 | 4.7*13 | 7 |
| 35 | 25 | 0.39 | 4.7*13 | 10 |
| 40 | 34 | 0.51 | 4.7*13 | 14 |
| 45 | 28 | 0.65 | 4.7*13 | 18 |
| 50 | 23 | 0.80 | 4.7*13 | 22 |
| 55 | 18 | 0.97 | 4.7*13 | 24 |
| 60 | 5 | 1.16 | 4.7*13 | 26 |
| 65 | 4 | 1.36 | 4.7*13 | 28 |

For the Calabria Pine, 201 logs were monitored with a total volume of 133 $m^3$. The slabs produced were 48.37 $m^3$. The nine diameter classes showed different yield. In particular the lower value was registered in the II and III class (25 - 30 cm ø), instead the higher value of yield was identify in the 40-45 and 50 cm diameter class for the production of regularized green timber with dimension of 7.5 * 15 cm. Table 4 reported the value of yield in each class diameter. The percentage of lumber yield was 57.2 %.

*Table 4 - Main results in the processing of the Calabria pine*

| **Classes Of diameter (cm)** | **Number of Logs** | **Average Volume of logs (m³)** | **Dimension of Final logs (cm)** | **Number of assortments obtained from each log** |
|---|---|---|---|---|
| 25 | 15 | 0.40 | 7.5*15 | 2 |
| 30 | 14 | 0.57 | 7.5*15 | 3 |
| 35 | 10 | 0.78 | 7.5*15 | 5 |
| 40 | 15 | 1.02 | 7.5*15 | 7 |
| 45 | 10 | 1.29 | 7.5*15 | 9 |
| 50 | 10 | 1.59 | 7.5*15 | 11 |
| 55 | 5 | 1.92 | 7.5*15 | 12 |
| 60 | 7 | 2.29 | 7.5*15 | 14 |
| 65 | 6 | 2.69 | 7.5*15 | 16 |

During the processing of chestnut, 92 logs were monitored with a total volume of 107.5 $m^3$. The slabs produced 51.08 $m^3$ (Figure 11). The nine diameter classes showed different yield. In particular, the lower value was registered in the III class (35 cm ø), instead the higher value of yield was identify in the 50 cm class for the production of saw timber (35 cm for side).

Figure 11 - Slabs produced

In the following table 5, the value of yield in each class diameter has reported. The maximum dimension obtained was 40 x 40 cm while the smaller product was 15 x 15 cm. The percentage of yield lumber was 52.3 %.

*Table 5 - Main results in the processing of the chestnut*

| **Classes of diameter (cm)** | **Number of Logs** | **Average Volume of logs ($m^3$)** | **Dimension of Final logs (cm)** | **Number of assortments obtained from each log** |
|---|---|---|---|---|
| 25 | 15 | 0.40 | 15*15 | 1 |
| 30 | 14 | 0.57 | 20*20 | 1 |
| 35 | 10 | 0.78 | 20*20 | 1 |
| 40 | 15 | 1.02 | 25*25 | 1 |
| 45 | 10 | 1.29 | 30*30 | 1 |
| 50 | 10 | 1.59 | 35*35 | 1 |
| 55 | 5 | 1.92 | 35*35 | 1 |
| 60 | 7 | 2.29 | 40*40 | 1 |
| 65 | 6 | 2.69 | 40*40 | 1 |

The tables 6 show yield results as lumber of the species tested in its respective diametric classes. It is verified that the lowest yield was given by diametric class I and the highest was by diametric class V and it is notable a significant difference between diametric classes VI and VII.

*Table 6 - Yield in diameter classes for all species*

| Species | Yield Lumber | Diametric classes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | I | II | III | IV | V | VI | VII | VIII | IX |
| **Silver Fir** | % | 60.7[a] | 59.1 [a] | 62[b] | 66.4 [a] | 67.5 [ab] | 66.8 [ab] | 60.2 [a] | 54.8[a] | 50.3 [a] |
| **Calabrian Pine** | % | 44.7 [a] | 46.7 [a] | 57.0[b] | 61.1 [ab] | 62.1 [ab] | 61.5 [ab] | 55.4[b] | 54.3 [a] | 52.9 [a] |
| **Chestnut** | % | 45.3 [a] | 55.9 [b] | 41.1 [a] | 49.1 [a] | 55.9 [b] | 61.6[ab] | 51 [a] | 55.9 [b] | 47.6 [a] |

* Means followed by the same letter along the rows have no statistical significant difference at 95% level of probability.

Among Silver fir and Calabria Pine there were no significant ($P>0.05$) differences on the lumber percentage. The data reported in table 6 shows that there were significant ($P<0.05$) differences between the sawing methods on lumber volume, with different sawing methods for dissimilar types of assortments.

The Pearson's correlation between variables diameter (cm) and yield (%) of both Silver Fir and Calabrian Pine highlighted a positive correlation with a value of 0.048 ($p<0.05$). For chestnut the yield was high in VIII and IX classes, due at final dimension of roundwood and the correlation between diameter and yield was negative ($p> 0.05$).

The results found show high yields for all species and are similar with the data showed by Biasi (2005). In fact, he obtained average yield of 59.83% in sawing process of three tropical species with diametric classes between 31 and 70 cm. Furthermore, Oliveira et al. (2003) found average yield of 49.28% in fifteen different native species, studying three sawmills in the municipality of Jaru, RO. Finally, Santos (1986) found a yield of 52.80% in sawmills of the Amazonas State for similar assortments.

In the processing of chestnut, a high yield has been found and also in this case we are in according to Rocha (2002), where the sawing process yield varies between 45 and 55% in hardwood species. The present study adopted for different forestry species from Calabrian Region, has revealed that log taper, the sawing method, and their interaction significantly affected the lumber volume. The significant interaction between sawing method and log taper confirms that different processing methods can produce different average lumber with different degrees of sawing process yield. There was a strong negative significant relationship between final lumber and logs processed. Lumber percentage increase with the diameter, until at intermediate classes (40-55 cm of diameter) for all species. In all processing the IV-V and VI diametric classes presented the best average yield compared to the rest (55 - 65%). Logs of this class presented few or almost no defects. The I and II diameter classes showed less yield (-5/6 %). Vianna Neto (1984), studying sawing techniques for eucalyptus in small diameter logs, concluded that yield increased according to increase in diameter of the worked timbers, and that quality of the raw matter may influence up to 70% the results when looking for optimal yield.

The last two examined classes (VIII and IX), gave smaller yield than other classes, due to the fact that logs of this diameter presented defects like cracks and internal hollows, appeared during the sawing process, resulting in a small yield reduction. For this reason, it is appropriate to estimate wood quality in forestry using “Non Destructive Technologies”.

Estimation of lumber yield has historically been one of the most important issues for mill managers and wood segregation decision makers from an optimal resources utilization perspective. It is also crucial in a value-based forest management paradigm due to the significant contribution of lumber in the Calabria forest sector in particularly in the plantation forestry. Therefore, accurate, consistent and reliable methods to estimate the lumber yield for a given sawmill are required to satisfy not only the regional forest management planning but also the practical sawmill operations and fair trade of wood for both buyers and sellers. However, confusion in forestry practice could arise due to the various methods of lumber yield estimation and the different expressions of lumber yield in addition to different measuring unit systems. This lack of consistency often presents challenges to forest managers and practitioners as to which method is most appropriate for their purposes. The results of our comparative study can assist in the selection of suitable method (s) by providing managers and practitioners with essential information for the determination of the final assortments. In fact, the shape of the roundwood, both in the longitudinal direction and in the transverse direction, have been determinative for high yields of sawing. The most important form defects occurred on the first section of the tree. This data showed a good model for the wood raw material predicting quality distribution of the sawn products resulting from the volume of trees. However, it is possible to deduce from results obtained that, in general, sawing yields increase as diameter increases, particularly for diameters up to about 50 cm. For higher diameters the yield rate ceases to grow; indicating that an increase in yields does not occur when the diameter increases. In fact, the top diameter tips are the basic ones where there is the influence of those factors already evoked, such as the shape of the stem (tapering and irregular shape) and especially the ligniferous decay attacks. The results have shown that, as the height of the position of the log in the tree increases, the yields decrease moderately. The phenomenon is explained by the decrease in the diameter of the logs and by observing the distribution profile of the defects on the tree.

This study showed that the factors influencing the production yield are various and random between the sawing of logs with human operational decisions, errors along the sawing line and in measuring that affect the sawing yields. These facts are not always taken into account in the sawing analysis where the calculation procedures are exactly the same for all the logs.

### *Conclusion*

This first study has showed that the sawing yields depend on the characteristics of the material being machined; in particular, one of the most significant parameters is the average diameter of the roundwood.

The study of wood yield has suggested an efficient use of the raw material available not only makes economic benefits possible but can also add a dimension of environmental thinking and sustainability. A large number of factors affected the volume of lumber obtained from any given log by the sawing process. These factors has been of two different types. The first are those commonly recognized as kerf width, rough lumber target size, smallest lumber allowed, and slabbing and edging practices. The second were the differences in the log break-down patterns. The effects of the first factors were logical and predictable and are relatively easily understood. The second interact less predictably with log form and size. These are not easily understood and their effect on the volume of lumber obtained is not apparent from casual consideration.

The efficiency of the sawing process has always been a key issue for the optimization of the whole wood conversion chain where the primary and secondary conversion industries provide the link between customer needs and forest production.

Furthermore, in an industrial environment the factors influencing the production yield are various and random between the sawing of two logs with human operational decisions, errors along the sawing line and in measuring that affect the sawing yields.

Our results indicated that estimated lumber yield can be significantly different respect to sawmill methods and the optimization of sawmill can provide the best estimate of lumber yield for a given sawmill as long as the mill conditions and lumber dimensions from market demand are specified. The significant interaction between sawing method and final lumber confirms that different processing methods can produce different average lumber recovery with different degrees of logs. In resume, though further studies will be necessary to further validation, the wood yield was able to reproduce the sawing of different logs. The tree/log yield could be useful tools to develop various sawing studies for this species, to evaluate the impact of raw material and process characteristics on the production performance, and to support the development of tools for industrial application.

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### *4. Conclusion and future perspectives*

This PhD thesis developed different approaches to evaluate the wood supply chain in Calabrian Region. In particular, primary object of this study was to determine the several parameters that influenced the wood quality and wood production in forestry sectors in Calabria. Actually, this sector suffers the economic crisis in all segments of wood supply chain. Silvicultural management and low commercial value of the wood products causes abandonment of correct practices to obtain wood quality and final wood good products. For this reason, a three-step experimental procedure was set up by performing in sequence the following independent tests: (i) Acoustic evaluation of wood quality using non-destructive technologies; (ii) Monitoring and to determine of the productivity and cost in the innovative work sites using Skidders, Forwarders and Cable Crane; (iii) Determination of the parameters in the wood processing to the sawmill. In the first procedure, the results showed that acoustic methods can be used to describe wood features that affect the visual appearance and drying distortion of solid wood products, e.g. knot structure, wood rot, fibre dimension and microfibril angle. This result represents an important focal point because the study of wood properties remain a strategic research topic for improving wood quality in order to achieve correct treatments with high wood stiffness. This information could be relevant for tree breeding, pre-harvest assessment, and decision support at time of thinning. The effects of thinning and other silvicultural practices on wood properties can be identified with the stress wave technique used in this study. These results are encouraging and indicate that the non-destructive stress wave technique may be used to track wood property changes in trees and determine how forests could be managed to meet desired wood and fibre qualities. In addition, the use of sonic and ultrasonic instruments could be used for determination of the influence of thinning treatment performed on Calabrian pine, taking into consideration the vast areas of cultivation of this species in the region. After the assessment the wood quality in standing trees, the second step of my PhD thesis was to evaluate the efficiency of the innovative machines (Skidder, Forwarder and cable crane) in Calabria forestry to continue the wood supply chain. The importance of this study was motivated to establish if these machines could be recommended for efficient harvesting in the forest conditions in Southern Italy. In fact, the first results showed the necessity to have a good interaction between silviculture and harvesting operations, particularly important on steep terrain. For different systems analyzed, communication between the forest manager (who marks the trees to be removed) and the extraction company could be essential. A time and motion study and economic analysis showed that the productivity of these machine for wood extraction, tested in several calabrian forestry, were satisfactory although there are a number of organizational aspects that could be improved in order to fully exploit their potential. The numerous observations recorded in this study confirm that this type of machines could be a good investment, allowing high levels of productivity. The results can be used immediately to set piece rate, rationalization of work and cost estimation. These informations will give a practical help in terms of improving logging planning, and consequently for performing and achieving cost competitiveness of the wood supply chain in Calabria. Since specific terrain conditions of forest harvesting operations have such a significant effect on this type of machines, these parameters should be extended to include various other extraction alternatives. The last phase of wood supply chain monitored during this thesis has evaluated the efficiency of the sawing process as a key issue for the optimization of all segments of the chain. Therefore, the results of this study can assist in the selection of suitable method by providing managers and practitioners with essential information for the determination of the final assortments. In fact, the shape of the roundwood, both in the longitudinal direction and in the transverse direction, could been determinative for high yields of sawing. This study showed that the factors influencing the production yield are various and random between the sawing of logs with human operational decisions, errors along the sawing line and in measuring that affect the sawing yields. These facts are not always taken into account in the sawing analysis where the calculation procedures are exactly the same for all the logs. The significant interaction between wood quality, sawing method and final wood products confirms that different processing methods can produce different average lumber recovery with different degrees of logs.

The outcomes of this PhD thesis can be useful for forestry operators, farmers associations and stakeholders involved in forestry management as well as for technicians and decision makers to support the development of a specific subsidy framework and choice of logging operations or different wood chips utilization pathways with the lowest environmental impact. Though related to forestry operations carried out in Southern Italy, the achieved results can be up-scaled to other geographic forestry areas (e.g., Central and Eastern European Countries; Mediterranean Basin) with similar characteristics in terms of productivity, slopes and road network.

The future investigations will focused on the use of different methods to determine the environmental management using the application of LCA in forestry and in all sectors of wood supply chain. In fact, in forestry, environmental impact studies usually exclude the wood process (sawmill and furniture) impact, which is correlated, to silviculture management, mechanization and wood quality.

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50th Anniversary of the International Symposium on Forestry Mechanization, Brasov, Romania, 25th-29th September 2017 - https://formec.ro/

MECHTECH 2016 Conference, Alghero, Italy, 29th May-1st June 2016 - Mechanization and new technologies for the control and sustainability of agricultural and forestry systems.

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