Annals of Silvicultural Research
45(1), 2020: 44-52
https://journals-crea.4science.it/index.php/asr

Research paper

Collection: "4th Italian National Congress of Silviculture"
Torino, 5-9 November 2018

Whole tree system evaluation of thinning a pine plantation in southern Italy

Andrea R. Proto[1*], Vincenzo Bernardini[2], Maria F. Cataldo[1], Giuseppe Zimbalatti[1]

Received: 8/02/2019 *Accepted: 22/05/2019* *Published: 21/07/2020*

ABSTRACT In Italy, some silvicultural treatment as thinning could be carried out in an economic way adopting systems based on small-scale mechanization. This paper examines the productivity standards of wood biomass in coniferous plantation thinning in Southern Italy under the conditions of small-scale forestry. The objectives of the study were to evaluate the incidence of different silvicultural treatments on productivity and harvesting costs and create productivity models for typical harvesting system used for wood thinned from Calabrian pine. Three different sites were monitored on the Sila Massif forest, and the experimental plan included three area tests, subjected in the last thirty years to intermediate cuttings with different thinning grade: light thinning (A thesis), moderate thinning (B thesis), heavy thinning (C thesis). The authors developed a productivity model for motor-manual felling and skidding timber with wheeled farm tractors, equipped with winch using a time motion study. Whole tree extraction system in coniferous plantation applied with typical felling system traditional has guaranteed productivity standards at a reasonable cost reducing high operational cost per unit harvested. The results, therefore, underlined that it economic possible to wood biomass harvest relatively small-diameter from thinning stands favoring moderate and heavy thinning.

KEYWORDS: small-scale forestry, time studies, productivity, thinning, costs, mechanization.

Introduction

Calabria is a region in Southern Italy particularly rich in forests that are also often highly productive; indeed, every year, in Calabrian forests, the average increase in wood volume, which is equal to 6-8 m^3 ha^{-1}, exceeds and sometimes doubles the increase estimated in the other forests of Southern Italy (Ciancio, 1998). Making up 32% of the total are beech (*Fagus sylvatica* L.), chestnut (*Castanea sativa* Mill.), Calabrian pine (*Pinus nigra* Arnold subsp. *Calabrica* Delamare) and silver fir high forests (*Abies alba* Mill.). In particular, the current distribution of Calabrian pine in the Aspromonte mountain and, mainly, in the Sila plateau, covering about 114,000 ha, indicates what remains of the largest coating forest of southern Italy, the so-called *Silva brutia* (Avolio and Ciancio 1985, Bonavita et al. 2015) and more than 50% are pure stands of both natural regeneration and planted origin. The latter originated from extensive reforestation projects carried out between 1950 and 1970 following specific State laws (Iovino and Menguzzato 2002a and 2002b). In fact, Calabrian pine is endemic to southern Italy with a natural range extending from Calabria to Sicily (Nicolaci et al. 2014) and characterizes the forest landscape of Calabrian Region with an important role in the local forest economy. The structure of Calabrian pine stands on the Sila Plateau is the result of the management history, which depends on land ownership, as well as the economic and social changes that have taken place in the area (Ciancio et al. 2006). In public properties (townships and State forests), management of Calabrian pine has usually been based on various types of clear felling (strip or patch), whereas on private properties, pine stands have generally been managed according to traditional and locally developed forms of selection cutting, which have contributed to the maintenance of pure pine stands with complex structures (Ciancio et al. 2006). This type of management has preserved the typical forest landscape by maintaining a continuous forest cover. Among the various forest management practices, the thinning is widely conducted to produce more valuable and large-diameter timber. It reduces competition among the remaining trees, reduces the risk of fire (Corona et al. 2015), and helps to maintain a healthy forest (Kerr and Hauf 2011). Considering the role of Calabrian pine as colonizing in Calabria Region, from the last century the thinning treatment played a key role to produce more valuable and large-diameter timber for the proper management of softwood stands (Breda et al. 1995, Nishizono et al. 2008, Marchi et al. 2014). Thinning should be early and frequent, especially in artificial plantations, to be fully effective (Peltola et al. 2002, Rytter and Werner 2007) and prevent the occurrence of degradation, fire susceptibility and instability of stands (Savelli et al. 2010, Picchio et al. 2011) but it is time-consuming and expensive. Usually, thinnings generate poor financial returns due to the handling of small trees, which have relatively low financial value but have a relatively high operational cost per unit harvested (Kärhä et al. 2004, Spinelli and Magagnotti 2010). For this reason, in Calabrian pine stands the thinning procedure is not always adopted and the necessary treatments have not been applied regularly in Calabrian region as in Italy (Cantiani and

1 Department of AGRARIA, Mediterranean University of Reggio Calabria - Italy
2 CREA - Research Centre for Forestry and Wood
*Corresponding author: andrea.proto@unirc.it

http://dx.doi.org/10.12899/asr-1845

Chiavetta 2015) because seen as a costly silvicultural treatment. This explains the worrying tendency to avoid thinning, especially in artificial coniferous forests, and the consequent rise of degradation and instability problems in many forests (Bergström et al. 2007). The aim of this study was to determine the cost efficiency of typical harvesting system used for wood thinned from Calabrian pine forests used as biomass fuel for power plants installed in the region. The study was conducted in three Calabrian pine stands thinned with different intensity to evaluate the incidence of silvicultural treatments on productivity rates and wood harvesting costs.

Material and Method

Study sites and Working system

The studies were carried out in a Calabrian pine plantation, established in the sixties for protection purpose. The forestation was realized by planting on soils, mostly with 80-100 cm wide terraces and drawn according to the level curves. On the terraces, spaced between them of 3-4 m, were placed the seedlings in 40x40x40 cm pits with an interdistance of about 1 m, for an initial density of planting that ranged between 2,500 and 3,500 plants per hectare. The planting growth was particularly fast, and at 15-20 years of age the stand of 180-200 m^3 per hectare were found (Avolio and Ciancio 1979). Thinning treatments were planned in the following decades and the study areas were subject to several researches. Avolio et al. studied the effect of different thinning intensities on growth and yield (1997 and 2012) while Baldini and Spinelli (1995) reported the efficiency and productivity in first thinning. Specifically, the aim of this study has been to evaluate on the same plantation the incidence of thinning intensities on productivity rate during the last and third thinning. Three different plots were monitored sites at Varco S. Mauro, on the Sila Massif forest, in Calabria region of south Italy. The experimental plan included three randomized blocks consisting of three areas, subjected in the last thirty years to intermediate cuttings with different thinning grade: light thinning (A thesis), moderate thinning (B thesis), heavy thinning (C thesis) (Fig. 1). Each site is classified as I class for roughness, while the slope is between I and II class (UK Forestry Commission 1995); 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 stand density was 1,033, 875 and 704 trees per hectare for site A, B and C. The total volume per hectare was 665 m^3 at site A, 629 m^3 at site B and 572 m^3 at site C. The main characteristics of the three sites are reported in Table 1. The forest area has a good main road network (31 m ha^{-1}) and the trails opened during felling were used as a secondary road network. The Whole-tree harvesting method was adopted for each sites (A, B and C). This method is the most common harvesting method in Italy because include the possibility of removing the woody residues from the site. Whole-tree harvesting can be defined as the removal of most branches and needles from a harvesting site in addition to the stem wood that is removed in conventional harvesting (Nisbet et al. 1997, Proto et al. 2017a). In fact, when using wood for energy production, the final product is biomass ready to be transformed into energy, regardless of the part of the tree from which it originated.

Table 1 - Test sites characteristics.

	Total Trees					Removal Trees				
Thesis	N ha^{-1}	G ha^{-1} m^2	V ha^{-1} m^3	DBH cm	Hg m	N ha^{-1}	G ha^{-1} m^2	V ha-$^{-1}$ m^3	DBH cm	Hg m
A	1033	71.89	664.446	29.8	22.59	233	12.74	116.106	26.3	22.06
B	875	69.62	628.501	31.7	22.86	275	19.28	159.323	30.0	22.63
C	704	61.98	572.519	33.4	23.77	304	24.17	218.394	31.6	22.86

n: Stand density; G: basal area; V: stand volume; DBH: diameter at breast height.

Figure 1 - Study area: site A (left) and site C (right).

Therefore, extraction of not only stemwood but also branches, tops, needles and bark contributes to the total amount of forest biomass harvested (Sängstuvall 2010). A single team of workers was used for each of three sites to reduce the variability due to human factors. In fact, it is common knowledge in the literature in the field that, under the same work conditions, different work teams achieve a different productivity (Campu and Ciubotaru 2017). Also, it is well known that the operator has a large influence on productivity in most types of forest works (Gullberg 1955). The team consisted of one chainsaw (Stihl MS 390, 3.4 kW) operator, one farm tractor driver (Landini Landpower 145 TDI, 104 kW) equipped with forest cable winch (Bernard, BK700R, 70 kN, 100 m capability), and one chokers setter in the bunching phases. The workers evaluated had more than five years of experience. Both sites were thinned selectively, in order to create enough space around good quality crop trees, while removing the trees that were defective in some way, or direct competitors (Spinelli et al. 2014) releasing final crops consisting respectively of 800 (site A), 600 (site B) and 400 (site C) trees per hectare. Extraction distances and between felled trees were measured with a laser rangefinder. In each site, the operators felled the marked trees and extracted the undelimbed whole-tree sections to the roadside. The trees, after the felling, were split in two parts to facilitate the skidding operations.

Time motion study

In this study, time consumption was conducted. The time required for the completion of each phase was measured using a digital chronometer. Operational, technical and personal delay types were collected during the field study. A number of 180 work cycles (60 at each site) were measured for tree felling. In particular non-work time consisted mostly of delays whereas the supportive time consisted of chainsaw refueling, chain sharpening and chainsaw repairing. Skidding operations were studied monitoring 120 cycles (40 at each site). The study determined productive time including breaks less than 15 minutes in duration (PMH15). Data analysis was done according to the recommendations of IUFRO (Björheden et al. 1995) and the *Good Practice Guidelines For Biomass Production Studies* (Acuna et al. 2012). Similar to other studies, to determine the field performance, this study analyzed the time consumption data using concepts generally used in observational studies (Wang et al. 2004, Behjou et al. 2009, Balimunsi et al. 2012, Borz and Ciobanu, 2013, Jourgholami et al. 2013, Proto et al. 2017a), as shown in Table 2.

Table 2 - Description of work elements and independent variables.

Work and time elements	Definition	Independent variables
Felling		
Walk to tree - Wtt	Begins when the worker starts toward the tree to be cut and ends when he reaches to the tree.	Distance between trees - Dt Diameter at breast height - DBH
Cut - Ct	Begins when the worker starts to make a wedge-shaped notch in the base of the tree to ensure that it accurately faces the felling direction and ends when the worker starts backcut.	
Fell - Ft	Begins when the worker starts cutting the opposite side of the direction of fall and ends when the tree hits the ground.	
Cross-cutting - CRc	Begins when the worker moves to the felled tree and ends when the feller finishes the last of the cross-cutting and starts toward the next tree to be felled.	
Refuel and sharpening	-	
Extraction cycle with cable winch		
Travel unloaded – T U	Begins when the farm tractor leaves the landing area and ends when the farm tractor stops in the stump area.	Winching distance - Wd Skidding Distance – Sd Number of logs – Nl
Hooking - H	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 farm tractor operator starts winching.	Volume - V
Winching - W	Begins when the driver starts to winch and ends when the tree has arrived at the rear part of the farm tractor.	
Travel loaded – T L	Begins when the farm tractor moves to the landing and ends when it reaches the landing.	
Unhooking - Un	Begins when the farm tractor reaches the landing and ends when the load is unhooked.	
Delays – D T	Personal delay, Technical delay, and Operational delay.	

Data Analyses and Cost Analysis

Time consumption estimation models were developed by the means of stepwise backward regression technique. Thus, in both cases were developed maximal models including all predictor variables collected in the field (Borz and Ciobanu 2013, Macrì et al. 2016, Proto et al. 2018). SPSS software version 20.0 (IBM Corp., Amonk, NY, USA) was used for the statistical analysis of the compiled data. Similar to other studies, to determine the performance, a regression model was thus developed. Harvesting costs were considered and the Miyata approach (1980) was applied including fixed costs, variable costs, and labor costs. The scheduled machine hour (SMH) was assumed considering a ten-year economic life for the tractor and only one year for the chainsaw. The purchase prices and operator wages required for the cost calculation were, however, obtained from catalogues and accounting records. Cost calculations were based on the assumptions similar adopted in recent economic studies (Spinelli and Magagnotti 2012, Proto et al. 2018).

Results

The main statistical indicators of work time variation according to phases in tree felling and of operational variables measured in the three sites are presented in Tables 3 and 4. In site A were removed 233 trees, 275 and 304 felled respectively in site B and C amounting to a total volume of 493.8 m^3. The total work time monitored during 180 work cycles necessary for felling trees in the three felling areas was of 1,579.70 minutes (463.30 minutes in A, 535.37 in B and 581.03 in C). Hourly productivity of manual chainsaw felling and cross-cutting was 4.85 $m^3\ h^{-1}$ (9.3 tree h^{-1}) in A, 5.71 $m^3\ h^{-1}$ (8.3 tree h^{-1}) and 5.85 $m^3\ h^{-1}$ (7.8 tree h^{-1}) in C. The data showed that the productivity is strongly influenced by diameter. In order to emphasize productivity dependence on DBH, the average work time corresponding to a complete cycle according to diameter classes and including delays was taken into consideration. Differences in work time cycle between the three sites occur mainly due to the time element W_{tt}, the moving time to and from the different trees marked to be cut. In fact, in site C the low density and the long distances between the trees have influenced (+11%) respect other two sites. As confirmed recent studies, walk to tree is directly related to initial stand density and harvesting intensity. Most time consuming work operation in applying the C_t and F_t phases, then follows cross-cutting with 27-32% respect the total cycle. The cross-cutting phase took more time in site B and C (11-13%) respect in site A. Personal, organizational and technical delays was similar for each site (4-5%) while supportive time (*refuel and sharpening*) varied from 4.7% (site C) to 6.5% (site A). The skidding cycle time varied hardly between the three sites; the cycle time averaged about 12.00 minutes for an average skidding distance of 223 m. Instead, statistically significant differences were evident in most of the examined work elements during the skidding phase. Hourly productivity of skidding was 3.04 $m^3\ h^{-1}$ (0.197 h m^{-3}) in A, 3.89 $m^3\ h^{-1}$ (0.154 h m^{-3}) and 4.11 $m^3\ h^{-1}$ (0.146 h m^{-3}) in C. According to the average values, the longest time among the work phases of skidding by farm tractor with winch was travel loaded (43-46%), with the breakdown of the individual elements shown in figure 2. Considerable differences were found with thinning treatments, starting from the load volume and the distances (bunching and skidding) which contribute to the total skidding cycle time. The farm tractor working at site A traversed a higher stand density and took considerably longer to travel similar distance in comparison to sites B and C. The average number of logs per turn was equivalent for each site but the different DBH influenced the average volume per load (0.56, 0.73 and 0.78). During extraction, justified delays consisted of around 5-6% of the studied work time in both treatments. Production rates also differed among the three sites. Mean productivity for A was found to be 26 % lower than that of the site C; in fact, the total distance for each cycle was higher (+ 10%) and the average volume per travel was lower (- 28%). The correlation analysis between the studied variables confirmed the degree of association of the variables of the work cycle. The independent variables were selected for the step-by-step regression analysis. The number of valid observations collected during the tests was large enough to develop a reliable model for predicting the productivity. Two different models for predicting the productivity were evaluated using linear regression and selecting the independent variables with a step-by-step regression (Tab. 5). According to the statistical analysis, the models presented for the worksites are valid ($p < 0.05$). There was no significant difference in skidding productivity respect the number of logs extracted (p-value: 0.15), but bunching distance, skidding distance and volume extracted for cycle influence significantly. The models of felling productivity equation indicate the diameter, distance between trees to cut and total cycle time the most important factors affecting felling productivity. The models of skidding productivity equation indicate bunching distance, extraction distance and volume extracted for cycle the most important factors affecting skidding productivity. The system productivity and cost were examined based on the manual harvesting system that consisted of one chainsaw, one farm tractor with winch, one chainsaw operator, one driver and two assistants. The system costs included felling (cross-cutting comprised), and skidding costs.

Table 3 - Descriptive statistics at site A, B and C for felling phase.

Parameter	Unit	Site A		Site B		Site C	
		Mean	SD	Mean	SD	Mean	SD
Walk to tree - Wtt	min	0.91	0.34	0.89	0.34	1.03	0.39
Cut - Ct	min	2.49	2.60	3.30	3.42	3.48	3.60
Fell - Ft	min	1.29	0.12	1.54	0.16	1.70	0.17
Cross-cutting - CRc	min	2.04	0.22	2.18	0.23	2.48	0.27
Refuel and sharpening – R & S	min	0.50	0.13	0.53	0.15	0.45	0.15
Delay T	min	0.45	0.15	0.52	0.14	0.40	0.09
Distance	m	42.98	14.78	40.83	14.04	45.87	15.77
Diameter	cm	26.25	1.39	30.03	1.44	31.60	1.44
Productivity	$m^3 h^{-1}$	4.85	1.28	5.71	1.61	5.85	1.62

Table 4 - Descriptive statistics at site A, B and C for skidding phase.

Parameter	Unit	Site A		Site B		Site C	
		Mean	SD	Mean	SD	Mean	SD
Total cycle time	min	11.01	0.91	11.30	0.68	11.42	0.84
Time travel unloaded – T U	min	1.65	0.47	1.48	0.41	1.33	0.37
Hooking - H	min	1.44	0.39	1.53	0.41	1.61	0.48
Winching - W	min	1.93	0.27	2.06	0.35	2.15	0.39
Time travel loaded – T L	min	4.68	0.47	5.14	0.55	5.20	0.59
Unhooking - Un	min	0.93	0.16	1.08	0.22	1.11	0.29
Delay Time – D T	min	0.38	0.21	0.50	0.19	0.53	0.26
Bunching distance	m	37.57	10.31	33.25	9.12	30.93	40.10
Skidding distance	m	223.16	22.61	203.87	20.66	201.12	20.38
Number of logs	-	4.63	0.49	4.55	0.50	4.58	0.50
Volume	m^3	0.56	0.06	0.73	0.08	0.78	0.09
Productivity	$m^3 h^{-1}$	3.04	0.42	3.89	0.54	4.11	0.52

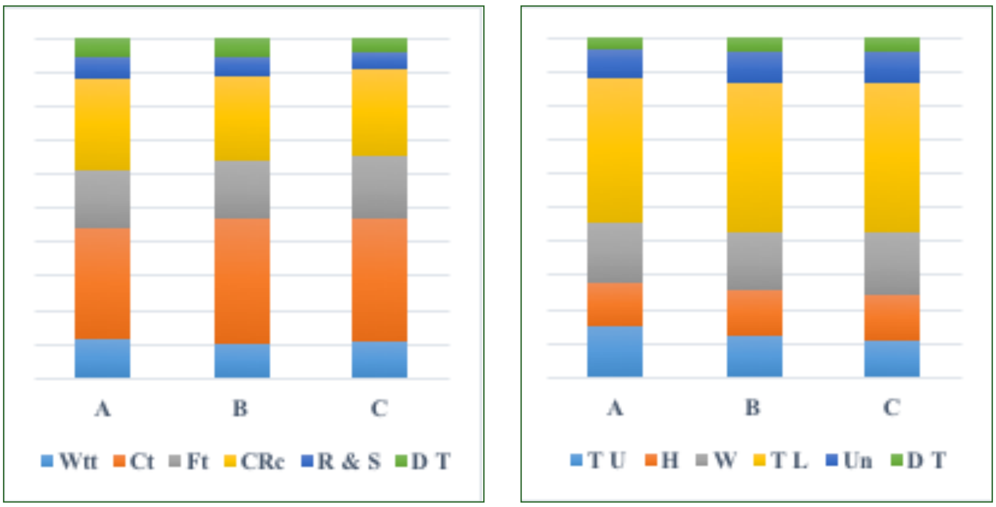

Figure 2 - Time distribution for felling operation (left) and skidding phase (right).

Table 5 - Productivity equation models for cutting and winching phases.

Model		Equation	F	P	$R^2_{adjusted}$
Productivity	Felling	P = 7.286 + 0.5 * Diam - 0.452 * TCT - 0.004 * Dist + 0.856 * SS	856.97	0.000	0.950
	Skidding	P = 1.932 - 0.003 * BDist - 0.008 * SDist + 5.339 * V - 0.162 * SS	342.371	0.000	0.920

P = Productivity; Diam = Diameter; TCT = Total Cycle Time; Dist = Distance; SS = Study Site (0 =A, 1 = B, 2 = C); BDist = Bunching Distance; SDist = Skidding Distance.

Estimates of hourly costs of chainsaw felling and farm tractor equipped with a winch were computed using the machine rate method (Miyata 1980). A total of 1,680 hours per year went scheduled for the operations (210 days per year for 8 scheduled working hours per day) and labor was € 15.00 per scheduled machine hour. Total hourly cost for manual chainsaw felling was estimated to be € 19.14. Combination of the hourly cost with an average productivity between 4.85 and 5.85 m^3h^{-1} provided an estimated average unit cost less than 4.00 € m^3 for manual chainsaw felling in all sites. Total hourly cost of farm tractor with winch, included two operators, was 53.18 € h^{-1} and the extraction costs were calculated varied from 17.5 € m^3 in site A, 13.7 € m^3 and 12.9 € m^3 for site B and C, respectively. The level of productivity analyzed on these different sites showed that different thinning intensity influenced the extraction costs. The wood biomass harvesting system amounted between 18 € t^{-1} (site C) and 24 € t^{-1} (site A) with a coefficient of conversion for Calabrian pine wood of 1 m^3 equal to 900 kg.

Discussion

The study had the objective to evaluate the influence of thinning treatments on whole-tree system in coniferous plantation. Tree felling using chainsaws followed by farm tractor is a practise conducted in many countries (Borz and Ciobanu 2013). In Italy, for example, this harvesting system is mostly applied in very dense stands where thinning operations are done and the development of assessing time consumption and productivity for similar work conditions was the aim of this study. Several studies showed the fact that in felling operations time consumption is mainly influenced by tree breast height diameter (dbh) (Sobhani 1984, Kluender and Stokes1996, Lortz et al. 1997, Ciubotaru and Maria 2012, Campu and Ciubotaru 2017). Samset (1990), Ghaffarian (2007) and Uotila et al.(2014) proved linear correlation between felling time on tree breast height diameter but the different and variegated tasks and operation with the chainsaw do not permit to assessment a unique time prediction model. For example in this study cross-cutting was included in the felling operation respect other researchers (Lortz et al. 1997, Wang et al. 2004) considered only delimbing phase. Similar to other studies (Kluender and Stokes 1996, Wang et al. 2004), this study confirmed that the distance between trees influence time consumption in tree felling operations. The economical and productivity analysis have demonstrated that the motor-manual felling with chainsaws with the use a farm tractor is especially when dealing with biomass production during thinning treatments where the ground-based heavy forest machinery cannot be used and different method cannot be adopted. In fact, power chainsaw is still an important equipment in tree felling (Jourgholami et al. 2013) and is still used even in Nordic countries, where it is favored by small-scale operators for wood energy demand (Laitila et al. 2007). In Romanian resinous forests, Câmpu and Ciubotaru (2017) monitored time consumption and productivity in manual tree felling with a chainsaw finding the limiting factors of this activity.

The observed productivity differences during the skidding phases can be attributed to the volume per turn and the distances. In fact, several authors reported that in thinning treatments the time consumption for moving has been proved to decrease when the number of removed stems increases (Kuitto et al. 1994, Sirén 1998) or the stem size decreases (Ryynänen and Rönkkö 2001). Nurminen (2006) described that the time travel (unload and load) was largely dependent on driving speed, driving distance, but also timber volume per load. The results can compare favorably with those showed in other studies about farm tractor extraction under similar conditions (Zecic et al. 2005). Spinelli and Magagnotti (2012) calculated for thinning a value of productivity of 4.7 m^3 PMH^{-1} using a farm tractor (116 kW) and Menemencioglu and Acar (2004) found a value to be 6.35 m^3 PMh^{-1}. Acar (1997) reported an average productivity of 4.18 m^3 PMh^{-1} in a skidding distance of 100 m, while Gilanipoor et al. (2012) found that average productivity rate of 2.50 m^3 PMh^{-1}. Efthymiou and Karambatzakis (1992) reported a gross skidding production rate of 3.57 m^3 using a Unimog tractor. Similar to other studies, the cost analysis demonstrated that the cost of wood biomass harvesting from thinnings is higher than that from final cuttings (Kalio and Leinonen 2005). The gap is caused by the cost of cutting and piling of small-sized trees from precommercial fellings, whereas in the other phases of the procurement chain, cost differences are modest (Mizaraite et al. 2007). Considered the harvesting costs, the current dynamics of biomass prices in Southern Italy markets could favor thinning treatments in coniferous plantations of Calabria region considering simultaneously an opportunity to improve forest stand stability and timber wood quality (Proto et al. 2017b).

Conclusions

The present study examined all work phases from tree felling to the extraction of wood biomass to the landing under small-scale forestry conditions managed with different thinning treatments. Whole-tree system in coniferous plantation applied with typical harvesting system traditional has guaranteed productivity standards at a reasonable cost reducing high operational cost per unit harvested. In addition, given the high proportion of manual tasks, there is a need to evaluate the ergonomic conditions of the work because investing in occupational safety and health could provide improved productivity and working conditions (Proto and Zimbalatti 2010, 2015) and in particular during the use of chainsaw (Calcante et al. 2018) and farm tractor (Pessina and Facchinetti 2017). From the experience gained at the study area, a significant optimization potential can be identified, that could substantially improve the operational efficiency and reduce the production cost (Koutsianitis and Tsioras 2017). For example, alternative skidding equipment could be applied replacing the winch with a grapple considered the good accessibility of the stands. Another important improving could be the use of double-drum winch to reduce the number of skidding cycles. The study results, therefore, underlined that it economic possible to wood biomass harvest relatively small-diameter from thinning stands favoring moderate and heavy thinning and evaluated the role of biomass supply chain, the use of forest and wood-processing residues can appear as a circular economy approach in the bio-energy sector (González-García and Bacenetti 2019). In fact, considering the role and the important distribution of Calabrian pine and evaluated the valid growth response of this species, the effect of higher thinning intensity will influence productivity standards for wood biomass harvesting.

Acknowledgements

This study is funded by the National Operational Programme for Research and Competitiveness (PON R&C) 2014-2020, XXXIII Cycle - “Investments in Human Capital” - Action I.1 - Innovative doctorates with industrial characterization and “ALForLab” Project (PON03PE_00024_1) co-funded by the National Operational Programme for Research and Competitiveness (PON R&C) 2007–2013, through the European Regional Development Fund (ERDF) and national resource (Revolving Fund-Cohesion Action Plan (CAP) MIUR).

References

Acar H. 1997 - *Investigation of extraction with forest tractors on mountainous areas.* Turkish Journal of Agriculture and Forestry 21 (3): 299-306.

Acuna M., Bigot M., Guerra S., Hartsough B., Kanzian C., Kärhä K., Lindroos O., Magagnotti N., et al. 2012 - *Good practice guidelines for biomass production studies.* In: Magagnotti N., Spinelli R. (eds.), CNR IVALSA, Sesto Fiorentino.

Avolio S., Bernardini V. 1997 – *Prove di diradamento (1° e 2° taglio) con scelta degli alberi d’avvenire per pinete artificiali di pino laricio di Calabria.* Annali Istituto Sperimentale per la Selvicoltura 28: 9-37.

Avolio S., Bernardini V., Clerici E., Tomaiuolo M. 2012 - *Management Guidelines for Calabrian Pine Reforestations Carried Out in Southern Italy in the 1950s-70s.* Journal of Life Sciences Vol. 6 (9): 1050-1056. ISSN: 1934-7391.

Avolio S., Ciancio O. 1979 – *Prove di diradamento e tavola di cubatura per pinete artificiali di pino laricio.* Annali Istituto Sperimentale per la Selvicoltura 10: 25-78.

Avolio S., Ciancio O. 1985 - *The Sila giants.* Annali Istituto Sperimentale per la Selvicoltura 16: 373–421. ISBN: 0390-0010.

Baldini S., Spinelli R. 1995 – *Primi diradamenti nelle piantagioni di pino laricio della Presila cosentina: risultati di 4 cantieri sperimentali.* Annali Istituto Sperimentale per la Selvicoltura 24: 91-104.

Balimunsi H., Grigolato S., Picchio R., Nyombi K., Cavalli R. 2012 - *Productivity and energy balance of forest plantation harvesting in Uganda.* Forestry Studies in China 14: 276–282.

Behjou F.K., Majnounian B., Dvorak J., Namiranian M., Saeed A., Feghhi J. 2009 - *Productivity and cost of manual felling with chainsaw in Caspian forests.* Journal of Forest Science 55 (2): 96-100.

Bergström D., Bergsten U., Nordfjell T., Lundmark T. 2007 - *Simulation of Geometric Thinning Systems and Their Time Requirements for Young Forests.* Silva Fennica 41 (1): 137-147.

Björheden R., Apel K., Shiba H., Thompson M.A. 1995 - *IUFRO Forest work study nomenclature.* Swedish University of Agricultural Science, Department of Operational Efficiency, Grapenberg. 16 p.

Bonavita S., Vendramin G.G., Bernardini V., Avolio S. Regina T.M.R. 2015 - *The first SSR-based assessment of genetic variation and structure among Pinus laricio Poiret populations within their native area.* Plant Biosystems 150 (6): 1271-1281. DOI: 10.1080/11263504.2015.1027316

Borz S.A., Ciobanu V. 2013 - *Efficiency of motor-manual felling and horse logging in small-scale firewood production.* African Journal of Agricultural Research 8 (24): 3126-3135. DOI: 10.5897/AJAR2013.7306

Breda N., Granier A., Aussenac G. 1995 - *Effects of thinning on soil and tree water relations, transpiration and growth in an oak forest (*Quercus petraea *(Matt.) Liebl.).* Tree Physiology 15: 295-306.

Calcante A., Facchinetti D., Pessina D. 2018 - *Analysis of hazardous emissions of hand-operated forestry machines fuelled with standard mix or alkylate gasoline.* Croatian Journal of Forest Engineering 39 (1): 109-116.

Câmpu V.R., Ciubotaru A. 2017 - *Time consumption and* *productivity in manual tree felling with a chainsaw – a case study of resinous stands from mountainous areas.* Silva Fennica 51 (2) 1657: 19 p. https://doi.org/10.14214/sf.1657

Cantiani P., Chiavetta U. 2015 - *Estimating the mechanical stability of* Pinus nigra *Arn. using an alternative approach across several plantations in central Italy.* iForest 8: 846-852.

Ciancio O. 1998 - *Limiti e possibilità della selvicoltura e della pianificazione forestale in Calabria.* In: Proceedings of "Giornata preparatoria al secondo congresso nazionale di selvicoltura", Crotone, Italy, 14 March: 199-210.

Ciancio O., Iovino F., Menguzzato A., Nicolaci A., Nocentini S. 2006 - *Structure and growth of a small group selection forest of Calabrian pine in Southern Italy: a hypothesis for continuous cover forestry based on traditional silviculture.* Forest Ecology and Management 224: 229-234. DOI: 10.1016/j.foreco.2005.12.057

Ciubotaru A., Maria G.D. 2012 - *Research regarding structure of working time in spruce felling with mechanical chainsaw Husqvarna 365*. Bulletin of the Transilvania University of Brașov, series II: forestry. Wood industry. Agricultural Food Engineering 5 (54): 43-48.

Corona P., Ascoli D., Barbati A., Bovio G., Colangelo G., Elia M., Garfì V., Iovino, F., Lafortezza R., Leone V., et al. 2015 - *Integrated forest management to prevent wildfires under Mediterranean environments.* Annals of Silvicultural Research 39: 1-22.

Efthymiou P.N., Karambatzakis T. 1992 - *Evaluation of the wood harvesting and trade system by the forest workers' cooperatives with the Presidential Decree 126/86*. In: Proceedings of the 5th Conference of the Hellenic Forestry Society. Hellenic Forestry Society, Thessaloniki: 321-328.

Ghaffarian M.R., Shobani H. 2007 - *Cost production study of motor-manually felling and processing of logs*. Forest Science 3: 69-76.

Gilanipoor N., Najafi A., Heshmat Alvaezin S.M. 2012 - *Productivity and cost of farm tractor skidding.* Journal of Forest Science 58 (1): 21-26.

González-García S., Bacenetti J. 2019 - *Exploring the production of bio-energy from wood biomass. Italian case study*. Science Total Environment 647: 158-168. doi: 10.1016/j.scitotenv.2018.07.295.

Gullberg T. 1995 - *Evaluating operator-machine interactions in comparative time studies.* Journal of Forest Engineering 7 (1): 51–61. https://doi.org/10.1080/08435243.1995.10702678.

Iovino F., Menguzzato G. 2002a - *Rimboschimenti in Calabria: storia e significato [Reforestation in Calabria: the history and meaning]*. In: Proceedings of the "12° Seminario IAED on Rimboschimenti e piantagioni nelle trasformazioni del paesaggio" (Corona P. Marchetti M. eds). Ed. Papageno, Palermo, Italy.

Iovino F., Menguzzato G. 2002b - *Disboscamento e ripristino del manto boschivo nell'Appennino calabrese [Deforestation and retrieval of forest cover in the Calabrian Apennines]*. In: "Disboscamento montano e politiche territoriali. Alpi e Appennini dal Settecento al Duemila". Lazzarini A., Angeli Storia F.:494-509.

Jourgholami M., Majnounian B., Zargham N. 2013 - *Performance, capability and costs of motor- manual tree felling in Hyrcanian hardwood forest.* Croatian Journal of Forest Engineering 34 (2): 283-293.

Kalio M., Leinonen A. 2005 - *Production technology of forest chips in Finland. VTT processes.* Project report PRO2/P2032/05. 103 p.

Kärhä K., Rökkö E., Gumse S.I. 2004 - *Productivity and cutting costs of thinning harvesters.* International Journal of Forest Engineering 15 (2): 43-56.

Kerr G., Hauf J. 2011 - *Thinning Practice. A Silvicultural Guide.* Version 1.0. January 2011. Forestry Commission.

Kluender R.A., Stokes B.J. 1996 - *Felling and skidding productivity and harvesting cost in southern pine forests.* In: Proceedings of Certification-Environmental implications for forestry operations, September 9–11: 35-39.

Koutsianitis D., Tsioras P.A. 2017 - *Time Consumption and Production Costs of Two Small-Scale Wood Harvesting Systems in Northern Greece.* Small-scale Forestry 16: 19 p. DOI: 10.1007/s11842-016-9340-3

Kuitto P.J., Keskinen S., Lindroos J., Oijala T., Rajamäki J., Räsänen T., Terävä J. 1994 - *Puutavaran koneellinen hakkuu ja metsäkuljetus.* Summary: Mechanized cutting and forest haulage. Metsäteho Report 410. 38 p.

Laitila J., Asikainen A., Nuutinen Y. 2007 - *Forwarding of whole trees after manual and mechanized felling bunching in pre-commercial thinnings.* Journal of Forest Engineering 18 (2): 29-39.

Lortz D., Kluender R., McCoy W., Stokes B., Klepac J. 1997 - *Manual felling time and productivity in southern pine forests.* Forest Product Journal 47 (10): 59-63.

Macrì G., Russo D., Zimbalatti G., Proto A.R. 2016 - *Measuring the mobility parameters of tree-length forwarding systems using GPS technology in the Southern Italy forestry.* Agronomy Research 14 (3): 836-845.

Marchi E., Picchio R., Spinelli R., Verani S., Venanzi R., Certini G. 2014 - *Environmental impact assessment of different logging methods in pine forests thinning.* Ecological Engineering 70: 429-36. DOI:10.1016/j.ecoleng.2014.06.019

Menemencioglu K., Acar H. 2004 - *Ormancilikta bolmeden cikarma calismalarinda transport planlamasi ve etkileri.* GU Orman Fakültesi Dergisi 4 (2): 143-163.

Miyata E.S. 1980 - *Determining Fixed and Operating Costs of Logging Equipment.* Forest Service, North Central Forest Experiment Station: St Paul, MN, USA. 55 p.

Mizaraite M., Mizaras S., Sadauskiene L. 2007 - *Wood fuel supply, costs and home consumption in Lithuania.* Biomass Bioenergy 31: 739-746.

Nicolaci A., Travaglini D., Menguzzato G., Nocentini S., Veltri A., Iovino F. 2014 - *Ecological and anthropogenic drivers of Calabrian pine (*Pinus nigra *J.F. Arn. ssp.* laricio *(Poiret) Maire) distribution in the Sila mountain range.* iForest 8 (4): 497.

Nisbet T., Dutch J., Moffat A. 1997 - *Whole -Tree Harvesting: a guide to good practice.* Forestry Commission Research Agency, Edinburgh. 19 p. ISBN 0-85538-360-7

Nishizono T., Tanaka K., Hosoda K., Awaya Y., Oishi Y. 2008 - *Effects of thinning and site productivity on culmination of stand growth: results from long-term monitoring experiments in Japanese cedar (*Cryptomeria japonica *D. Don) forests in northeastern Japan*. Journal of Forest Research 13: 264-274.

Nurminen T., Korpunen H., Uusitalo J. 2006 - *Time consumption analysis of the mechanized cut-to-length harvesting system.*

Peltola H., Miina J., Rouvinen I., Kellomäki S. 2002 - *Effect of early thinning on the diameter growth distribution along the stem of Scots pine.* Silva Fennica 36: 813-825.

Pessina D., Facchinetti D. 2017 - *A survey on fatal accidents for overturning of agricultural tractors in Italy*. Chemical Engineering Transactions 58: 79-84.

Picchio R., Neri F., Maesano M., Savelli S., Sirna A., Blasi S., Baldini S., Marchi E. 2011 - *Growth effects of thinning damage in a Corsican pine (*Pinus laricio *Poiret) stand in central Italy*. Forest Ecology and Management 262: 237-243.

Proto A.R., Bacenetti J., Macrì G., Zimbalatti G. 2017a - *Roundwood and bioenergy production from forestry: Environmental impact assessment considering different logging systems.* Journal of Cleaner Production 165: 1485–1498. https://doi.org/10.1016/j.jclepro.2017.07.227.

Proto A.R., Macrì G., Bernardini V., Russo D., Zimbalatti G. 2017b - *Acoustic evaluation of wood quality with a non-destructive method in standing trees: A first survey in Italy.* iForest: Biogeosciences and Forestry 10 (4): 700-706.

Proto A.R., Macrì G., Visser R., Russo D., Zimbalatti G. 2018 - *Comparison of timber extraction productivity between winch and grapple skidding: A Case study in Southern Italian Forests*. Forests 9 (2). 61 p.

Proto A.R., Zimbalatti G. 2010 - *Risk assessment of repetitive movements in the citrus fruit industry*. Journal of Agricultural Safety and Health 16 (4): 219-228. doi.org/10.13031/2013.34834

Proto A.R., Zimbalatti G. 2015 - *Risk assessment of repetitive movements in olive growing: analysis of annual exposure level assessment models with the OCRA CHECKLIST*. Journal of Agriultural Safety and Health 21 (4): 241-253. doi.org/10.13031/jash.21.10884

Rytter L., Werner M. 2007 - *Influence of early thinning in broadleaved stands on development of remaining stems.* Scandinavian Journal of Forest Research 22: 198-210.

Ryynänen S., Rönkkö E. 2001 - *Harvennusharvest- ereiden tuottavuus ja kustannukset.* Summary: Productivity and expenses associated with thinning harvesters. TTS-Institute's Publications 381. 67 p. (In Finnish, English summary).

Samset I. 1990 - *Some observations on time and performance studies in forestry.* Meddelelser fra Norsk institutt for skogforskning 43 (5): 1-80.

Sängstuvall L. 2010 - *Estimates of the productivity of logging operations with a focus on forest fuel extraction.* Arbetsrapport 297, Sveriges lantbruks universitet, Institutionen for resurshusha şllning. 41 p.

Savelli S., Cavalli R., Baldini S., Picchio R. 2010 - *Small scale mechanization of thinning in artificial coniferous plantation.* Croatian Journal of Forest Engineering 31: 11-21.

Sirén M. 1998 - *Hakkuukonetyö, sen korjuujälki ja puustovaurioiden ennustaminen.* Summary: One- grip harvester operation, its silvicultural result and possibilities to predict tree damage. Doctoral thesis. Finnish Forest Research Institute, Research Papers 694. 179 p.

Sobhani H. 1984 - *A method data collection for the evaluation of forest harvesting systems.* PhD Thesis, Virginia Tech University. 150 p.

Spinelli R., Magagnotti N. 2010 - *Comparison of two harvesting systems for the production of forest biomass from the thinning of* Picea abies *plantations.* Scandinavian Journal of Forest Research 25: 69-77.

Spinelli R., Magagnotti N. 2012 - *Wood extraction with farm tractor and sulky: estimating productivity; cost and energy consumption.* Small-Scale Forestry 11: 73-85. DOI 10.1007/s11842-011-9169-8.

Spinelli R., Magagnotti N., Di Fulvio F., Bergström D., Danelon M., Alberti G. 2014 - *Comparison of cost efficiency of mechanized fuel wood thinning systems for hardwood plantations on farmland.* Croatian Journal of Forest Engineering 35 (2): 111-123.

UK Forestry Commission 1995 - *Terrain classification.* Tech Note 16 (95): 5.

Uotila K., Saksa T., Rantala J., Kiljunen N. 2014 - *Labour consumption models applied to motor- manual pre-commercial thinning in Finland.* Silva Fennica 48 (2) 982. https://doi. org/10.14214/sf.982.

Wang J., Charlie L., Mcneel J., Baumgras J. 2004 - *Productivity and cost of manual felling and cable skidding in central Appalachian hardwood forests*. Forest Products Journal 53: 47-53.

Zecic Z., Krpan A., Vukuşic S. 2005 - *Productivity of Holder 870 tractor with double drum winch Igland 4002 in thinning beech stands.* Croatian Journal of Forest Engineering 26: 49-56.