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Firewood cable extraction in the southern Mediterranean area of Italy

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This research assesses the efficiency and the costs of different cable cranes used in harvesting, in the forests of the southern Mediterranean area of Italy. During the study process a total of 100 cycle times were recorded in order to obtain the average performance. The cable cranes were tested in six different sites. Machine costs make up an essential part of timber harvesting costs; it is necessary to analyze these costs in order to decide which methods or machine types to use. Costs have been calculated using a standard hourly method. The present investigation showed that the three cable cranes extracted inferior volumes of timber compared to their load potential; in fact, the average extracted volume was inferior compared to the load capacity of the carriage. Nevertheless, from the comparison between cost per m^3 and the market price of firewood, sufficient margins of value for the producer emerged. The level of productivity analyzed on these different sites showed that unproductive time influenced the extraction costs of wood. In fact, when the three cable cranes were productive the extraction cost of 1 m^3 of firewood varied from €20.89 to €27.84.

Keywords: cable extraction; time study; costs; forest operation; productivity; firewood

Introduction

Wood extraction on steep slopes and other rough terrain has typically been associated with cable logging systems. Cable yarding proves to be an efficient and effective harvesting system for the extraction of timber on steep terrain, and their use in the mountainous regions of Europe is becoming more widespread (Stampfer et al. 2006). In Italy, Switzerland, and Austria, 10% to 20% of harvested wood is extracted by cableway (Grulois 2007). Productivity analysis of cable extraction is a key factor for road network planning (Cavalli and Grigolato 2010; Ghaffariyan et al. 2010). In contrast, the use of this kind of machinery in southern Italy remains limited, particularly in forests that produce firewood where cable cranes are virtually not used at all. Ninety-five per cent of timber production in southern Italy (2.3 million m^3 $year^{-1}$; 25% of the total in Italy) comes from terrain classified as very steep slope (Tiernan et al. 2004), limiting the use of machines for ground-based extraction. Cable extraction is a desirable alternative to either a skidder or forwarder on a sensitive site (Visser and Stampfer 1998). Therefore, wood production on such terrain demands a well thought-out capital investment. Consequently, there are two main reasons to increase the coverage of cableways. First, the substantial timber production associated with orographical difficulties and, second, the growing need to safeguard the environment.

In Calabria (Southern Italy) the expanse of forest is 40.6% compared to average national coverage of 34.7%. 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 (Cavalli et al. 2008). As a result, Calabria supplies numerous wood industry sectors in Southern Italy. The annual amount of harvested timber in 2011 was 668,912 m^3 (ISTAT 2012), about 8.5% of the national total and 37% of the total amount of timber harvested in Southern Italy. Over the last 14 years, an increase in the amount of harvested timber has been documented. According to the National Statistical Database (ISTAT 2011), firewood harvesting has increased more than roundwood harvesting (Cavalli et al. 2008). The current increasing dynamism of the firewood market has led to the development and improvement of technologies able to extract and process hardwood logs more efficiently by reducing consistently the time and labor required for firewood production (Cavalli et al. 2014). Despite being such an apparent woodland resource, the most common working method in Calabria is still a traditional one, with many yards in the early stages of mechanization. Such a low level of mechanization can be attributed to location, characteristics of the property, the small scale of many enterprises, limited knowledge of modern machinery, and the scarcity of relevant studies on the use of modern machinery (Zimbalatti and Proto 2009).

The harvesting method in Southern Italy forestry is cut-to-length (Zimbalatti and Proto 2008; Proto et al. 2014). The trees are cut, felled, delimbed, topped, and bucked to various ranges by chainsaw directly in the area of the stump. The cut branches and tops are then left to stand. The extraction of wood from stump to land is mostly carried out manually on steep forest land, by means of gravity, rolling, throwing, and sliding the timber along the ground. On flat ground, primarily animals, then agricultural tractors, (equipped with specific forestry machinery such as winches and hydraulic cranes) are used

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to move the timber. Forest tractors or skidders are used on the slope stands and skidding.

This experimental research, carried out in Calabria, was centered around a time motion study and cost analysis to assess the use of cable cranes with a mobile power supply. The research aims to develop technical and economic knowledge regarding the use of this machinery in Southern Italy, and highlight its effectiveness in similar areas.

Materials and methods

The research was carried out in three different areas using three dissimilar models of single-span cable cranes (Figure 1). The cable cranes were installed in two different points in the felling areas and were designated the letters A and B. Consequently, all the data was collected in the six test sites by obtaining the necessary parameters from the forest in question. Altitude was measured using a portable global positioning system (GPS), Magellan Triton^{TM} 2000, and the slopes were assessed with SUUNTO clinometers, PM-5/360 PC. The average deflection measurement was carried out using a stadia, Kolida TC2. Dendrometric data were recorded in order to attain the total volume yarded/yielded in each area using a volume table (double entry) and a plot sample.

Study area

In the first study area at Sila Masif (Table 1), a Koller K300 cable crane was utilized. These two holm oak (*Quercus ilex* L.) woods were managed and treated differently. The timber extracted was almost exclusively holm oak trees with an average diameter at breast height (dbh) of 18−20 cm. The operating area of the cable crane was c. 2.24 ha in site 1A and 1.23 ha in site 1B, with the level difference between the two extremities of the line being 51 m in site 1A and 42 m in site 1B. In the second study area, located in the Aspromonte Massif (Table 1), a Greifenberg VSG 2000 cable crane was used in two turkey oak woods (*Quercus cerris* L.), following a coppice system. This area was characterized by a dominant, steep, rough terrain. The dbh of harvested timber was 19−21 cm on each site. The Greifenberg VSG 2000 cable crane was used in c. 4.05 ha in site 2A and 1.38 ha in site 2B, and the level difference between the two extremities of the line was 75 m in site 2A and 63 m in site 2B. In the third area, located in the Serre Vibonesi Massif (Table 1), a Greifenberg TG 700 cable crane was used in a beech wood (*Fagus sylvatica* L.), following a reserve-cutting coppice system. The average dbh varied between 20 cm and 23 cm in each site. The two test sites covered an area of 1.92 ha for site 3A and 2.75 ha for site 3B. The level difference between the two extremities of the line was 76 m in site 3A and 85 m in 3B.

Working systems

The fully suspended timber was transported to the three research areas along with the three cable systems used for the uphill yard. In the first area, the cut-to-length method

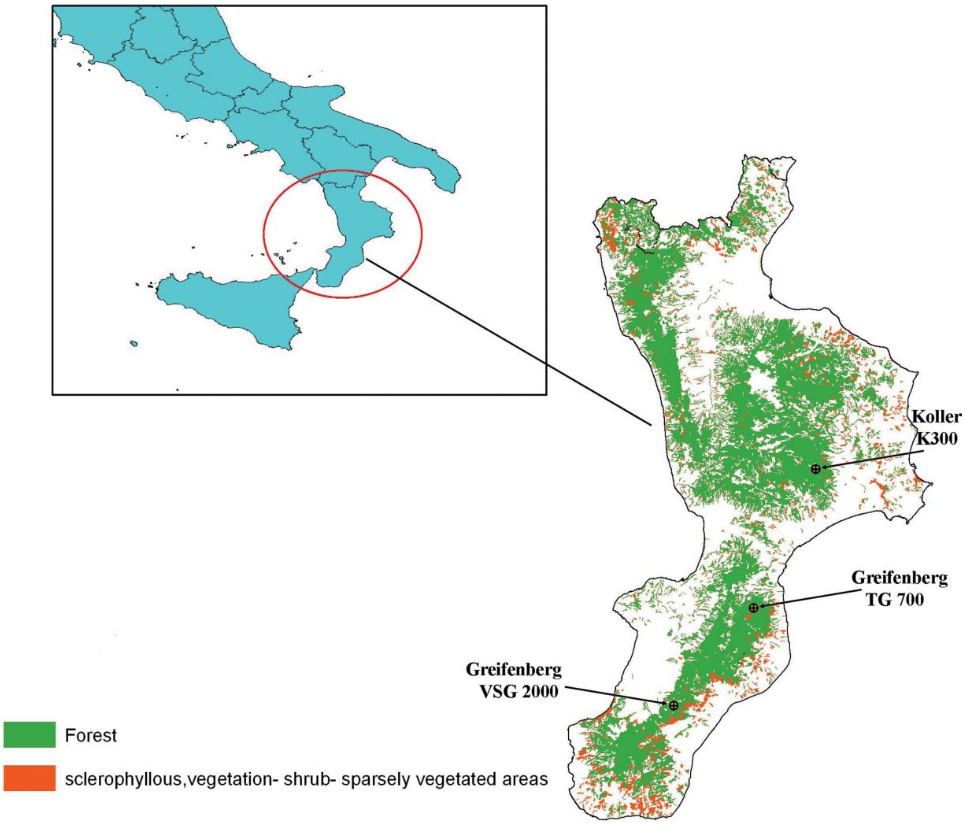

Figure 1. Geographic location of forest distribution and research areas.

Table 1. Test sites characteristics.

	Work sites					
	1A	1B	2A	2B	3A	3B
Area	Sila Masif	Sila Masif	Aspromonte Masif	Aspromonte Masif	Serre V. Masif	Serre V. Masif
Altitude (m a.s.l.)	1135	1138	1050	1104	890	920
Forest						
• Species	Holm oak	Holm oak	Turkey oak	Turkey oak	Beech	Beech
• Silvicultural system	Coppice	High forest	Coppice	Coppice	Coppice	Coppice
• Density (trees ha^{-1})	785	815	750	820	790	760
• Volume site (m^3 ha^{-1})	128	145	137	149	250	220
Average slope (%)	64	59	75	78	68	75
Lateral pull (m)	40	35	45	30	55	53
Yarding direction	Uphill	Uphill	Uphill	Uphill	Uphill	Uphill
Roughness	Average	High	High	High	Average	High
Length of line (m)	315	200	530	260	250	280
Average sag (m)	3.45	2.80	3.08	2.90	3.10	3.20

was applied; the trees were bucked in the forest, in approximately 1 m long logs. The volume of the single short log was estimated employing Huber's formula (Philip 1994). A team of four workers (a haulage operator, two labourers for yarding, and a labourer for unloading timber) operated at sites 1A and 1B.

In the second area, the full tree harvesting method was adopted; the trees were delimbed, topped, and bucked on site. In this case, the volume of each tree was calculated using Smalian's formula by multiplying the average cross-sectional area of the stem by stem length (Philip 1994). In the third area, the tree-length method was adopted. Trees were felled then delimbed and topped at the stump. The logs were then transported to the area where they were bucked and loaded onto a truck. Smalian's formula was also used here to calculate log volume per cycle. The volume of one cycle measured 0.51 m^3 in site 3A and 0.63 m^3 in site 3B. The total volume was 210 m^3 in site 3A and 320 m^3 in 3B, equivalent to 109 m^3 ha^{-1} for site 3A and 116 m^3 ha^{-1} for 3B. In both of these sites (VSG 2000 and TG 700) there were three workers (a haulage operator, an employee for yarding, and a worker for unloading timber).

The line length and total volume of transported material determined in each site were used to calculate the efficiency of the three cable cranes (Fabiano and Marchi 2001). The result obtained was the volume of transported wood from the area and the field length of cable crane line (m^3 m^{-1}) from each site. On each site, the cable cranes were only installed and dismantled once. The time required for mounting and dismantling the cable cranes on each site, together with the total number of trips made to each site, was then established. This calculation was subsequently applied to the 100 trips carried out and to the total wood extracted.

Productivity and costs

According to Harstela (1993), productivity is the ratio between output (volume of wood) and input (time consumption or fund). In this study, time consumption was conducted using the repetition-timing method to determine the total yarding cycle times. This is the amount of time that it takes the carriage to travel from the area to the payload unhooking. In addition to the total haulage cycle time, delay time was also considered. The time required for the completion of each stage was measured by a digital chronometer (1 min = 100 unit), Tag-Heuer Microsplit™. The data obtained from this research on the six different harvesting areas was recorded on computer and, consequently, tables were prepared according to the various work phases. Data obtained from statistical analysis was later compared and examined. Five yarding elements were identified and timed in order to determine the total cycle time:

- *Carriage descent:* this phase begins when the operator is ready to move the carriage from the choke setter. The phase ends when the choke setter keeps the hook.
- *Hook descent:* this phase begins at the end of outhaul empty and ends when the choke setter is ready to hook a turn.
- *Bunching:* this phase begins at the end of lateral out and ends when the operator is ready to move the carriage to the destination.
- *Extraction:* this phase begins when the operator moves the carriage and ends when the carriage has reached the ramp.
- *Carriage unloading*: this phase begins at the end of extraction and ends when the hook is unlocked and the log is left on the ground.

The International Union of Forest Research Organizations (IUFRO) methodology (WP 3.04.02 - 1995) was employed. This internationally recognized workplace standard illustrates that time is the portion of total time that a production system employs in a specific work task. In order to calculate the hourly cost of wood extraction many parameters were considered (Olsen and Kellogg 1983). Machine costs are an essential part of timber harvesting costs and necessary in order to decide on different methods or machine types (Rieger 2001). Costs were determined according to the cost analysis method used by Miyata. Logging costs are calculated to determine the right level of mechanization, and to compare different logging methods. Harvesting cost was calculated based on observed productivity. The study has considered the harvesting cost as the sum of machines, labor, and material costs (Acar and Yoshimura 1997). Costs were calculated by means of standard hourly cost methods, which include ownership costs and operating costs (Miyata 1980; Ackerman et al. 2014). In order to calculate the production cost of 1 m^3 of firewood, the cost analysis measured the following parameters: the number of operators; the hourly cost of an operator; the hourly cost of machines; the volume of firewood extracted; and productive machine hours excluding all delay times (PMH). The total hourly cost for the three different cable cranes calculated the running of the machine with an operator (Miyata 1980). Machine costs per hour are reported as both PMH and scheduled machine hours (SMH). The purchase prices and operator wages required for the cost calculation were, however, obtained from catalogues and accounting records.

Results

The time data were recorded by two individuals: one stationed at the bunching location and the second stationed next to the cable system. Communication between them was maintained by wireless. During the study process a total of 100 cycle times were recorded in order to obtain the average performance. The mean time values obtained from time studies are given in Table 2.

Time studies

The average timber haulage time for the Koller K300 was 9.42 min in site 1A and 6.28 min in 1B. The volume of one cycle was 0.82 m^3 in site 1A and 0.67 m^3 in site 1B. The total volume of transported material was 280 m^3 in site 1A and 145 m^3 in site 1B. Therefore, 125 m^3 ha^{-1} for site 1A and 118 m^3 ha^{-1} for site 1B. Daily productivity, based on a 8 h working day in work sites 1A and 1B, was estimated at 23 m^3 day^{-1} in 1A and 27.4 m^3 day^{-1} in 1B. On average, a worker produced 5.74 m^3 day^{-1} on site 1A and 6.87 m^3 day^{-1} on site 1B, whereas the time necessary for the extraction of 1 m^3 of timber was equal to 0.35 h on site 1A and 0.29 h on site 1B (Table 3). Table 1 shows that extraction (48% in site 1A and 45.2% in site 1B) and carriage descent (23% in site 1A and 17% in site 1B) were the two work phases that took up the majority of time in the total yarding cycle time. In particular, the little difference between the two extremities of the line influenced the time of carriage descent for both sites.

In the second area, workers extracted c. 2.50 m^3 from site 2A and almost 2.81 m^3 from 2B per hour. The average load was four/five trees. The volume of an average piece of timber was calculated at 0.14 m^3 in site 2A and 0.15 m^3 in 2B. The total volume of the transported material was 430 m^3 in site 2A and 160 m^3 in site 2B, equivalent to 106 m^3 ha^{-1} for site 2A and 116 m^3 ha^{-1} for site 2B. Table 1 shows that the work phases which took up most of the total yarding cycle time were bunching (41.5% in site A and 47.8% in site B) and extraction (34% for both sites). In sites 2A and 2B, production time totalled 75% of all work time and the time to extract 1 m^3 of timber was 0.40 h in site 2A and 0.35 h in site 2B (Table 3).

In the third study area, the work phases which took up most of the total yarding cycle time were bunching (55% for both sites) and extraction (18% for both sites) (Table 2). The volume of one cycle was 0.51 m^3 in site 3A and 0.63 m^3 in site 3B. The total volume was 210 m^3 in site 3A and 320 m^3 in site 3B, equivalent to 109 m^3 ha^{-1} for site 3A and 116 m^3 ha^{-1} for site 3B. The recorded productivity in a day of extracted timber per worker was c. 7.31 m^3 for site 3A and 8.19 m^3 for site 3B. The average time required to extract 1 m^3 of timber was equal to 0.36 h in site 3A and 0.33 h in site 3B; in an hour, a worker extracted 0.91 m^3 in site 3A and 1.02 m^3 in site 3B (Table 3). Productive time was 70% for both sites.

The evaluation of efficiency in organizational and economic terms revealed that, for the Koller K300 machine, the volume harvested per field length of cable line was 0.89 m^3 m^{-1} for site 1A and 0.73 m^3 m^{-1} for site 1B. For the Greifenberg VSG 2000 machine the volume harvested

Table 2. Time consumptions (min ± SD) of work phases.

	Koller K 300		Greifenberg VSG 2000		Greifenberg TG 700	
Phase	1A	1B	2A	2B	3A	3B
Carriage descent	2.19 ± 0.82	1.08 ± 0.27	2.85 ± 1.25	1.11 ± 0.48	1.02 ± 0.52	1.31 ± 0.42
Hook descent	0.58 ± 0.19	0.48 ± 0.31	0.51 ± 0.42	0.45 ± 0.35	0.37 ± 0.14	0.41 ± 0.17
Bunching	1.54 ± 1.03	1.39 ± 0.43	6.73 ± 1.52	5.32 ± 1.26	4.01 ± 0.95	4.42 ± 1.07
Extraction	4.52 ± 0.97	2.84 ± 0.66	5.54 ± 1.08	3.73 ± 0.57	1.35 ± 0.71	1.48 ± 0.43
Carriage unloading	0.59 ± 0.41	0.49 ± 0.22	0.58 ± 0.53	0.51 ± 0.37	0.38 ± 0.25	0.43 ± 0.31
Total (min)	9.42 ± 1.63	6.28 ± 1.15	16.21 ± 2.12	11.12 ± 1.44	7.13 ± 0.85	8.05 ± 1.03
Total (h)	0.15 ± 0.04	0.10 ± 0.02	0.27 ± 0.05	0.18 ± 0.03	0.11 ± 0.02	0.13 ± 0.03

Table 3. Average daily operative results of the work sites.

		Koller K 300		Greifenberg VSG 2000		Greifenberg TG 700	
Specifications of different attribute	Unit	1A	1B	2A	2B	3A	3B
Wood harvest system		Short wood system		Full tree system		Tree length system	
Number of valid observations	n.	100	100	100	100	100	100
Total duration of observations without mounting and dismantling times	h	28.57	19.53	36.40	26.69	18.61	20.52
	min.	1714	1172	2184	1601	1117	1231
Yard cycles							
• Average volume per cycle	m^3	0.82	0.67	0.91	0.75	0.51	0.63
• Yarding cycle per day	n.	28	41	22	30	43	39
• Yarding cycle per hour	n.	7	10	3	5	6	6
• Average time for one cycle	min.	9.42	6.28	16.21	11.12	7.13	8.05
• Standard deviation (σ)	±	1.63	1.15	2.12	1.44	0.85	1.03
• Coeff. of variation	%	17.3	18.3	13.1	12.9	11.9	12.8
Productivity							
• Daily	$m^3\ day^{-1}$	22.96	27.47	20.02	22.50	21.93	24.57
• Hourly	$m^3\ h^{-1}$	2.87	3.43	2.50	2.81	2.74	3.07
Manpower							
• Operators	n.	4	4	3	3	3	3
• Work capacity	$m^3\ h^{-1}$	0.71	0.86	0.83	0.94	0.91	1.02
• Unit time	$h\ m^{-3}$	0.35	0.29	0.40	0.35	0.36	0.33
• **Productivity**	$h\ m^{-3}$	1.39	1.16	1.20	1.07	1.09	0.98
Incidence of mounting and dismantling times in 100 trips observed	h	0.85	0.79	2.03	3.52	1.58	1.39
Total duration of observations including incidence of mounting and dismantling times	h	29.42	20.32	38.43	30.21	20.19	21.91
Mounting and dismantling times	h	2.90	1.70	9.60	7.50	6.49	7.08
Productivity							
• Volume per 100 cycles	m^3	82	67	91	75	51	63
• Daily	$m^3\ day^{-1}$	22.30	26.38	18.94	19.86	20.21	23.0
• Hourly	$m^3\ h^{-1}$	2.79	3.30	2.37	2.48	2.53	2.87
• Unit time	$h\ m^{-3}$	0.36	0.30	0.42	0.40	0.40	0.35

per field length of cable line was 0.81 $m^3\ m^{-1}$ for site 2A and 0.62 $m^3\ m^{-1}$ for site 2B, while the volume harvested per field length of cable line for the Greifenberg TG 700 machine was 0.84 $m^3\ m^{-1}$ for site 3A and 1.14 $m^3\ m^{-1}$ for site 3B. Table 3 shows that mounting and dismantling times affected productivity. The reduction in productivity established by these phases was 4% in Koller sites and c. 6%−10% for both the Greifenberg machines tested. In particular, in site 2B−VSG 2000, mounting and dismantling times were greater (c. 12%) because, compared to the other test sites, this site extracted less firewood.

Cost analysis

Fixed and hourly operating costs of the tree cable cranes are presented in Table 4 and Figure 2. Where the Koller K 300 was used, the extraction costs of firewood were calculated at €35.08 m^{-3} in site 1A and €29.32 m^{-3} in site 1B (Table 5). These costs refer to work time (productive + unproductive time): when the cable crane was productive, the extraction costs were €22.54 m^{-3} in site 1A and €20.89 m^{-3} in site 1B. Delay times increase the operating cost by €13 (36%) in site 1A and €8 (29%) in site 1B (Figure 3).

The Greifenberg VSG 2000 extraction costs were €35.07 m^{-3} in site 2A and €31.20 m^{-3} in site 2B. When the cable crane was productive, the extraction costs were estimated at €26.30 m^{-3} in site 2A and €23.01 m^{-3} in site 2B. Delay times notably increase the extraction costs (€9 in 2A and €8 in 2B). These low costs were caused by high productivity and low unproductive time on sites 2A and 2B.

In the third cable system, the extraction costs of firewood were calculated at €39.77 m^{-3} in site 3A and €35.49 m^{-3} in site 3B (Table 5). The Greifenberg TG700 was the cable crane with the highest management costs at €69.01 per h, 41% respect Koller and 31% respect VSG2000 (Figure 2 and Table 4), but the high productivity examined in this study consents a low extraction cost, similar to the other cable cranes. Without the time delays, these costs are further reduced to €27.84 m^{-3} in site 3A and €25.73 m^{-3} in site 3B.

Table 4. Calculation of hourly costs of cable cranes.

Costs	Symbol	Unit	Formula	K 300	VSG 2000	TG 700
Purchase price	P	€		55,000	70,000	150,000
Salvage value	S	€	20% P	10,000	12,000	29,000
Estimated life	N	Year	-	10	10	10
Power	Pt	kW	-	45	69	84
Daily utilization	DSH	h	-	8	8	8
Yearly utilization	DY	Days		135	135	135
Scheduled operating time	SH	h	DSH*DY	1080	1080	1080
Average fixed investment	Al	€ $year^{-1}$	(P-S)*(n+1)/2n+S	34750	43.900	95.550
Maintenance rate	RMr	%	%Depr	75	75	75
Interest rate	R	%	-	4	4	4
Taxes and insurance rate	ITGr	%	-	12	12	12
Fuel consumption rate	Fc	L h^{-1}	-	7	10	13
Oil consumption rate	Lc	L h^{-1}	-	0.22	0.34	0.4
Fuel cost	Fp	€ L^{-1}	-	1.0 5	1.05	1.0 5
Oil cost	Lp	€ L^{-1}	-	4	4	4
Operator labor cost	WB	€ h^{-1}	-	20	20	20
Fixed costs						
Annual depreciation	Depr	€ $year^{-1}$	(P-S)/n	4500	5800	12100
Interest cost	In	€ $year^{-1}$	Al*R	1390	1756	3822
Taxes and insurance	ITG	€ $year^{-1}$	Al*ITGr	4170	5268	11466
Fixed cost SMH	OC	€ h^{-1}	Depr+In+ITG/SH	9.31	11.87	25.36
Operating costs						
Maintenance and repair cost	RM	€ h^{-1}	(Depr*RMr)/SH	3.13	4.03	8.40
Fuel consumption cost	FC	€ h^{-1}	Fc*Fp	7.35	10.5	13.65
Oil and lubricants cost	LC	€ h^{-1}	Lc*Lp	0.88	1.36	1.6
Operator labor cost	Pc	€ h^{-1}	= WB	20	20	20
Operating cost SMH	OpC	€ h^{-1}	RM + FC+LC+Pc	31.36	35.89	43.65
Total cost SMH		**€ h^{-1}**	**OC + OpC**	**40.67**	**47.76**	**69.01**

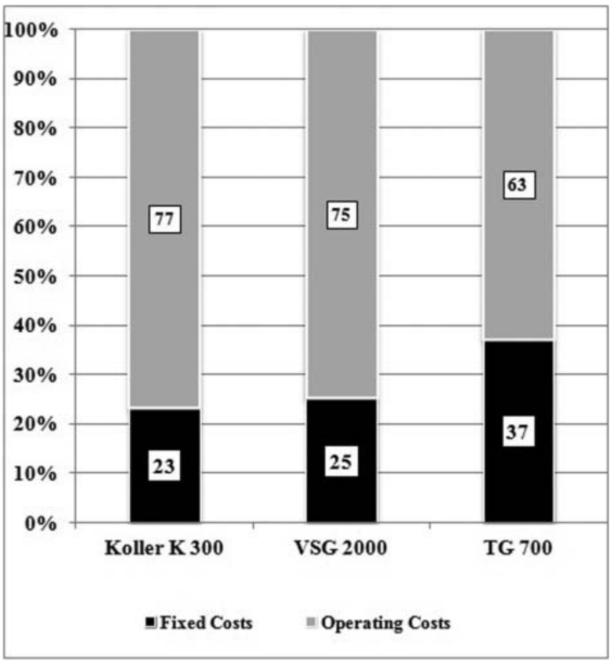

Figure 2. Fixed and operating costs of the tree cable cranes.

Discussion

Data obtained from the time studies showed that employing two operators on the Koller K300 sites speeded up the bunching phase and favored productivity. In fact, time consumption was low compared to the VSG 2000 and the TG 700, the equality of transported volumes, despite a greater load. The employment of only one worker during the bunching phase in the VSG 2000 and the TG 700 appears insufficient. The number of workers for these

Table 5. Productivity and costs.

		Productivity		Extraction costs	
	Site	SMH $m^3\,h^{-1}$	PMH $m^3\,h^{-1}$	SMH € m^{-3}	PMH € m^{-3}
Koller K 300	1A	2.87	4.47	35.08	22.54
	1B	3.43	4.82	29.32	20.89
Greifenberg VSG 2000	2A	2.50	3.34	35.07	26.30
	2B	2.81	3.81	31.20	23.01
Greifenberg TG 700	3A	2.74	3.92	39.77	27.84
	3B	3.07	4.24	35.49	25.73

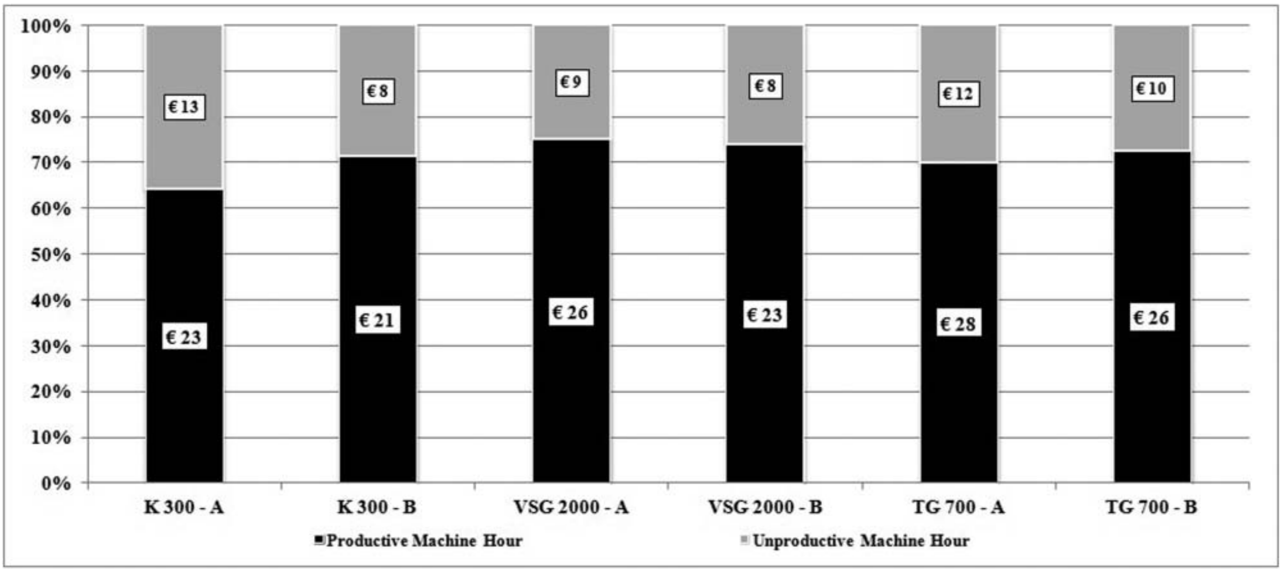

Figure 3. Hourly costs of the tree cable cranes to extract 1 m^3.

operations should therefore be increased in order to achieve greater cable crane productivity.

Another factor that restricted bunching time in the Koller K300 site was the harvesting method (Short Wood System (SWS)). The maximum lateral yard distance, 45 m for VSG 2000 and 53 m for TG 700, did not facilitate the bunching operations of trees with the FTS (Full Tree System) and TLS (Tree Length System) adopted in VSG 2000 and TG 700. Aside from the addition of another working unit in the bunching phase, it is therefore necessary to widely evaluate the best operation systems.

The present investigation showed that the three cable cranes extracted inferior volumes of timber compared to their load potential; in fact, the average extracted volume was inferior compared to the load capacity of the carriage. In particular, the TG 700 extracted volume was 0.7 tons, on average, compared to the 2 ton load ability of the carriage. The limited average extracted volume recorded in this study may depend more on the characteristics of the silvicultural treatment than on machine capacity. Others studies conducted in Turkey using the same hauling distances (250 m in site 1A) and a Koller K300, showed greater productivity levels at 5.67 m^{-3} h^{-1} (Sentürk et al. 2007) and 6.41 m^{-3} h^{-1} (Tunay and Melemez 2001). In the French Alps, Chagnon and Pischedda (2005) have reported greater productivity and costs of 40 m^{-3} day^{-1} and €41.7 m^{-3}. In Italy, a similar study conducted by Spinelli et al. (2010), using the same light tower yarders for hauling firewood in Central Italy, found similar productivities, including delays, set-up, and dismantling.

The study also highlights the need to optimize operations. Over 30% of the total workplace time is made up of unproductive time that could subsequently be reduced with improved planning and maintenance. Production costs differed from site to site mainly because of the site characteristics, cable system configurations, and staff-related factors. The cost analysis indicated that the total cost of operating the three cable systems generally decreased with PMH.

The fixed and hourly operating costs between the Koller K300 and Greifenberg VSG 2000 were similar. For both the cable cranes, the fixed costs represented 23% (Koller) and 25% (VSG 2000) of the total hourly cost (SMH) while the Greifenberg TG 700 fixed costs were equal to 37%.

The level of productivity analyzed on these different sites showed that unproductive time influenced the extraction costs of wood. In fact, when the three cable cranes were productive the extraction cost of 1 m^3 of firewood varied from €20.89 to €27.84, with a difference of €7 between sites. If the entire working day is considered (unproductive times + productive times), the extraction costs ranged from €29.32 m^{-3} to €39.77 m^{-3}, a difference of more than €10 m^{-3} between sites. It is therefore necessary to reduce unproductive time in order to increase site productivity and, consequently, lower extraction costs. In order to lower the fixed and operating costs of the cable cranes, it is opportune to increase the number of annual working days.

Conclusions

Even though the productivity of the tested cranes 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 (Fabiano and Marchi 2001).

Therefore, the three cable cranes tested in Calabria ought to provide satisfactory results even though a number of organizational aspects could be improved in order to fully exploit their potential. 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. The cost per m^3 and respective efficiency are greatly influenced by the dimension of the wood, as it is known that harvesting small-sized timber with cable systems can be less economic (Efthymiou 2001).

Nevertheless, the results obtained in this cost analysis are satisfactory enough; in fact, from the comparison between cost per m^3 and the market price of firewood (€60–65 m^{-3}), sufficient margins of value for the producer emerged.

If a cable crane system is to be employed in a forest, there should be an adequate quantity of wood in the area. In an area where timber hauls are to be carried out, forest cable systems should be brought into the area and installed after production operations have been completed. Consequently, haulage operations should then be carried out (Senturk et al. 2007). Further research on cable extraction system comparison could be based on the use of GNSS (Global Navigation Satellite System) 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).

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 (Tiernan et al. 2004).

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.

Disclosure statement

No potential conflict of interest was reported by the authors.

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