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ORIGINAL PAPER

Techniques and productivity of coppice harvesting operations in Europe: a meta-analysis of available data

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Abstract
• ***Key message*** **Coppice harvesting technology is evolving toward increased mechanization and larger more efficient equipment. Nevertheless, cheap and versatile general-purpose machines (excavators and farm tractors) still represent the backbone of coppice mechanization, which is consistent with the rural character of coppice economy.**
• ***Context*** Operating within the scope of COST Action FP1301 "Eurocoppice", the authors conducted a survey of coppice harvesting studies produced in Europe from 1970 to present. The survey focused on traditional coppice stands and excluded industrial short-rotation coppice, established with willow, poplar, eucalyptus, or other fast-growing species.
• ***Aims*** The goals of this study were to calculate productivity benchmarks for coppice harvesting operations and to gauge the progress achieved over the past 40-plus years.
• ***Methods*** Data from existing studies (published and unpublished) were collected through a harmonized questionnaire and gathered into a single master database. Statistical analysis was used to estimate productivity models and determine possible differences between methods, work conditions, and time periods.
• ***Results*** Six productivity models were estimated for the main harvesting steps and technologies. Productivity varied with a number of factors and notably with removal (m^3 ha^{-1}). The analysis disclosed a clear trend toward increased mechanization and higher productivity.
• ***Conclusion*** Coppice harvesting is being mechanized, but the mechanization deployed in coppice stands is adapted to the specific conditions offered by these stands. Light, cheap, and versatile machines are generally preferred to heavy industrial equipment.

Keywords Felling · Extraction · Logging · Hardwood mechanization · Clear cut · Selection

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Contribution of the co-authors All the authors worked at collecting the data and refining the data, writing the paper and discussing its results. Dr. Spinelli and Prof. Tolosana also worked at the statistical analysis of the data. The research project was coordinated by Dr. Spinelli

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1 Introduction

Long and intense settlement history makes human activity a characterizing factor of European forestry (Szabò 2009). In

Europe, old growth is relegated to a few remote areas, which have remained inaccessible (Splechtna et al. 2005). Most European forests are under active management or have been under active management until recent years (Kirby and Watkins 1998). Near rural settlements, coppice stands are often abundant because they are well suited to provide for the immediate material needs of a dense rural population (Wolfslehner et al. 2009). For centuries, these forests have provided local communities with firewood, posts, tool handles, and fencing materials (Buckley 1992). Coppice stands are economically efficient, due to the short waiting time (15–30 year rotations) and simplified management (clear-cut at the end of rotation and regeneration by resprouting). Coppice management was popular all over Europe in the recent past, and today it is still widespread in the Mediterranean and Balkan regions (Jansen and Kuiper 2004), and in general, wherever industrialization was not introduced so early as to shape all the landscape, including forestry (Spinelli et al. 2014). In Europe, coppice is especially common in France (6.3 million ha), Italy (3.3 million ha), Bulgaria (1.8 million ha), Greece (1.7 million ha), and Serbia and Montenegro (1.4 million ha). Bosnia-Herzegovina, Croatia, Macedonia, and Hungary represent between 0.5 and 1 million hectares of coppice each. Coppice accounts for much smaller areas in the other European countries, but it is present in all of them, at least to some extent (Nicolescu et al. 2014).

However, the European coppice economy is suffering due to the competition from oil and plastic (Hédl et al. 2010), and especially from the reduced availability of rural labor, willing to accept heavy and low-paying jobs. Under these conditions, frequent harvesting has turned from an advantage into a drawback, and delayed cutting of aged coppice has become increasingly common.

Fortunately, there is still a strong interest in restoring and maintaining traditional coppice stands, which may play a crucial role in supporting rural development, while providing a wealth of new products and services, especially soil protection, biodiversity, energy biomass, and carbon sequestration (Vacik et al. 2009).

For this reason, it is important to improve the efficiency of coppice harvesting operations, facilitating the transition of coppice management from a part-time rural activity to a modern industrial business. Mechanization may seem the obvious solution, but the simple extension of modern technology to coppice management is no guarantee of immediate success. Coppice stands present some features that may not suit conventional forest technology. Steep terrain and small stem size represent severe constraints, which are encountered in most coppice stands (Magagnotti et al. 2012). What is more, coppice presents the peculiar characteristic of sprouting multiple stems from the same stump. That is especially challenging when trying to introduce mechanized felling to coppice harvesting operations, because stem crowding hinders felling head movements and can be handled by very compact units only (Spinelli et al. 2010). A further constraint of coppice harvesting operations is the absolute need to prevent stump damage, in order to guarantee prompt regeneration. All cuts must be clean and as near to the ground as possible. For the same reason, extraction machines must not climb on stumps, and the use of tracks and tire chains is often discouraged in coppice operations.

Increasing the efficiency of coppice harvesting requires a good understanding of current operations, regardless of technology level. In fact, a wide-ranging survey may help to pinpoint problem areas and possible solutions. Much research has already been conducted about coppice harvesting, but the majority of these studies have not achieved international visibility, partly due to their local character and partly to the limited interest into coppice-related subjects.

Therefore, the goals of this study were (1) to gather previous coppice harvesting studies into a large harmonized database, (2) to determine the regional importance of the subject, (3) to produce benchmark productivity figures and functions, and (4) to gauge the change in technology and performance over time.

2 Materials and methods

The study was performed within the scope of COST Action FP1301, which endeavored to show the state-of-the-art of coppice research in Europe. The authors took up the task of covering coppice harvesting research and enrolled the support of national delegates appointed to represent 30 countries. The authors first developed a harmonized query format, and then asked national delegates to provide a list of scientific publications produced within their respective countries on the topic of coppice harvesting from 1970 to present. Accepted source material included national and international journal articles, project reports (published and internal), and theses. When a paper was in a national language that none of the authors could understand, then the national delegates were asked to fill out themselves the query forms, in order to minimize translation errors. The basic query format requested inputs about (1) country of origin and reference title; (2) site and stand characteristics; (3) work technique, equipment, crew size, net productivity, and delay incidence—separately for each work phase, i.e. felling, processing, and extraction.

Overall, 102 forms were collected. Data from each individual form were consolidated into one large master database, containing separate worksheets for each work phase. This yielded a total of 377 data points, variously distributed among countries and work phases (Table 1). Data were analyzed statistically using the Statview software (SAS Institute Inc 1999). As a first step, descriptive statistics were drawn, separately for each work phase. Then, the significance of the differences

Table 1 Data points by country of origin and work phase

Country	Work phase			
	Felling	Processing	Harvesting	Extraction
France	3	3	52	3
Germany	0	0	1	0
Italy	49	43	35	115
Poland	0	0	4	0
Serbia	4	0	0	2
Slovenia	2	0	0	2
Spain	4	6	12	22
UK	3	3	4	5
Total	65	55	108	149

between mean values for different options was tested with non-parametric techniques, in order to overcome any violations of the statistical assumptions. The significance of any differences between distributions was checked using a classic χ^2 test. Linear and non-linear regression analysis of the data allowed testing of the relationship between productivity and the main site, stand, and technical work conditions, for each work phase. Regressions were assumed as the productivity benchmark of each specific work system and technology, as deployed in coppice harvesting. The regression coefficient R^2 was taken as an indicator of how strong the effect of the main site and technical parameters on productivity was. The mean absolute error (MAE) was used to compare alternative regression models, in order to select the most reliable ones (Chai and Draxler 2014).

For the sake of simplification, the analysis was divided into three parts: the first part dealing with the database in general; the second part dealing with "felling," "processing," and combined "felling-processing" (henceforth called "harvesting"); and the third part dealing with extraction. Grouped work steps (i.e., felling, processing, and harvesting) presented important similarities and generally reacted to the same independent variables, which explained aggregation. On the other hand, the two groups of felling and extraction included inherently different activities that reacted to different independent variables, which justified separate analysis.

3 Results

3.1 Characteristics of the database

The search was conducted within the scope of COST Action FP1301 and covered 14 countries, where part of the forest resource is traditionally managed as coppice. The search focused on traditional coppice and excluded new high-density short-rotation coppice plantations grown for energy, generally established with willows, poplars, and robinia. These stands are established on ex-arable land at densities exceeding 6000 stools ha^{-1}, (ca. three times higher than traditional coppice), and they are clear-cut at 2- to 5-year intervals (ca. five to ten times shorter than for traditional coppice). For this reason, short-rotation coppice is generally considered an agricultural crop rather than a forest crop. The study also excluded industrial eucalypt plantations, even if they are often managed as coppice (McEwan et al. 2016). Eucalypt plantations are very different from traditional coppice stands in terms of management, economics, ecology, and cultural value (Siry et al. 2005). Stands included in the database consisted of beech, chestnut, oaks, and other indigenous species. The database occasionally included naturalized exotics (typically robinia), if these were grown according to traditional practice.

Viable coppice studies were sourced from eight countries only. In the other countries, no studies were found that dealt directly with the harvesting of traditional coppice forests. The largest majority of the studies were found in France and Italy, together accounting for 84 % of the studies (Fig. 1) and 80 % of the single data points (Table 1). In fact, more than one data point was obtained from a study if the study covered different work phases or different technological options.

Of the 102 studies used to build the database, only 20 % had been published in English. In fact, over 50 % of the studies collected in this survey consisted of unpublished internal reports, which were not available to the larger scientific community. The remaining 30 % of the studies had been published in national languages different from English and were difficult to access for most researchers.

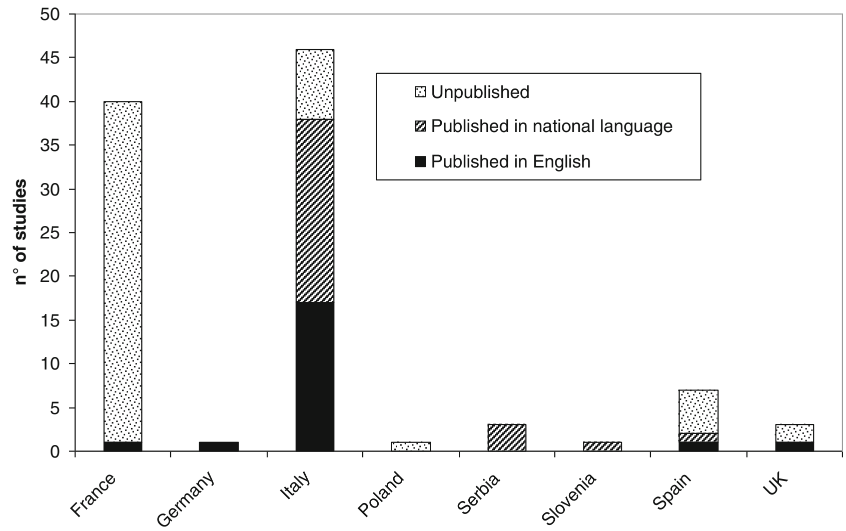
3.2 Felling, processing, and "harvesting"

First of all, it is useful to define the work phases considered here. Felling consists of cutting the tree at the base and laying it down without any further processing. In contrast, processing is defined as removing the limbs from pre felled stems and crosscutting the stems into commercial lengths. Finally, harvesting is the uninterrupted sequence of felling and processing. Felling, processing, and harvesting can be performed manually with a chainsaw or mechanically with a feller, a processor, or a harvester.

Studies about mechanized operations were more recent than those conducted on manual operations, but the difference was statistically significant for harvesting only (Table 2).

Concerning work conditions, mechanized felling and mechanized harvesting were tested on flatter terrain than were their manual counterparts, while no terrain differences were found between manual and mechanized processing. Mechanized operations did not target larger removals or specific treatments (i.e., clear cut or conversion to high forest) compared with manual operations, except for mechanized

Fig. 1 Number of studies by country of origin and document type



processing that was deployed preferentially on clear cuts, with large removals. Mechanized processing and mechanized harvesting were systematically deployed on larger trees than were manual processing and manual harvesting, whereas no tree size differences were found for felling. In fact, data were suggestive of mechanized felling being associated with smaller tree size compared with manual felling, although this difference lacked statistical significance ($P = 0.166$). Mechanized processing and mechanized harvesting studies were most often associated with chestnut coppice, whereas their manual counterparts related preferentially to oaks. Oaks were also the most frequent species considered in mechanized felling studies, whereas manual felling studies showed a more even spread. This likely depended on the fact that mechanized

Table 2 Main results of the analysis of felling, processing, and harvesting data

Work phase	Felling		Processing		Harvesting	
Technology level Date study (year)	Manual 2003a	Mech. 2008a	Manual 2005a	Mech. 2008a	Manual 1998a	Mech. 2008b
Site characteristics						
Slope gradient (%)	36a	10b	31a	33a	21a	9b
Clear cut (*n*)	21a	6a	4a	16b	46a	22a
Conversion (*n*)	23a	11a	16a	6b	25a	12a
Total removal (m3 ha^{-1})	116a	118a	88a	162 b	149a	172a
Tree size (m^3)	0.19a	0.121a	0.134a	0.164b	0.116a	0.148b
Tree species						
Chestnut (%)	30	18	24	55	30	48
Beech (%)	26	0	24	18	8	0
Oaks (%)	30	53	52	9	61	44
Other (%)	14	29	0	18	1	8
Distribution (χ^2)	8.374	($P = 0.039$)	14.334	($P = 0.002$)	9.326	($P = 0.025$)
Operation						
Crew (n°)	1.6a	1b	1.8 a	1b	1.6a	1b
Utilization (%)	66a	80b	68 a	77b	64a	76b
Productivity (m^3 h^{-1} $worker^{-1}$)	3.3a	6.9b	1.0 a	7.0b	1.3a	6.5b
n sorts (*n*)	–	–	1.7 a	2.4a	1.3a	2.5b
Min log length (m)	–	–	1.5 a	2.4b	2.1a	2.3a
Max log length (m)	–	–	2.7 a	4.3b	2.9a	3.7b

Different letters for the technology levels (i.e., manual vs. mechanized) of the same work phase indicate a statistically significant difference for $\alpha < 0.05$; the significance of the differences found in the species distribution is indicated in the χ^2 row; utilization = productive work time/worksite time technology deployed in oak stands was generally designed for the production of whole-tree chips, and therefore it did not integrate any delimbing and crosscutting (i.e., processing) capabilities.

Compared with manual operations, mechanized operations were characterized by a smaller crew size, a higher utilization, and a much higher worker productivity (two to seven times). Mechanized processing and mechanized harvesting tended to produce more log specifications than did their manual counterparts, although this difference was significant for harvesting only. However, maximum log length was significantly higher for mechanized operations, compared with manual ones (Table 2).

Regression analysis showed that worker productivity was strongly affected by technology level and by stem size or total removal (Table 3). Stem size had a marked effect on productivity in single-stem operations, namely, processing and harvesting. In contrast, felling productivity reacted better to total removal than to stem size (Fig. 2).

3.3 Extraction

"Extraction" is defined as the moving of cut trees or processed logs from the stump site to a roadside landing or a landing pad, accessible to transport vehicles.

The database contained 142 valid data points, which were attributed to one of the following extraction systems: animal extraction, sliding in chutes, shoveling (i.e., moving to the landing with an excavator), skidding (dragging on the ground behind a tractor), forwarding (carrying on a loading deck), and cable yarding. However, animal extraction, sliding in chutes, and shoveling were represented by relatively few data points, and inference for these specific extraction methods could not be as solid as for the other methods. In that regard, it is important to consider that animal extraction was performed exclusively with mules and horses, which hauled short logs on packsaddles in seven cases out of eight (the remaining one consisting of horse skidding). On the same note, skidding and forwarding were performed with forestry-fitted farm tractors in 85 and 60 % of the cases, respectively. Concerning the direction of extraction, sliding occurred exclusively (and obviously) downhill; animal logging, skidding, and forwarding occurred preferably downhill, but occasionally also uphill; yarding occurred uphill in three cases out of four.

Studies about animal logging, sliding in chutes, and skidding were generally older than studies about shoveling, forwarding, and yarding, indicating a shift of interest toward more modern systems, which may or may not depend on the growing popularity of these more mechanized systems among logging contractors engaged with coppice operations (Table 4).

Concerning work conditions, mechanized ground-based systems (i.e., skidding and forwarding) were generally associated with lower slope gradients than were cable-systems and non-mechanized ground-based systems (i.e., animals and sliding). In contrast, the analysis did not disclose any significant relationships between extraction system and silvicultural practice (i.e., clear cut or conversion to high forest), removal, or

Table 3 Regression equations for felling, processing, and harvesting productivity

Felling				
$m^3\ h^{-1}\ worker^{-1}$ = a*Removal + b*Removal*Mech				
R^2 adjusted = 0.764, n = 60				
	Coefficient	SE	F-value	*P* value
a	0.029	0.003	8.790	<0.0001
b	0.027	0.006	4.477	<0.0001
Processing				
$m^3\ h^{-1}\ worker^{-1}$ = a*Stem size + b*Stem size*Mech				
R^2 adjusted = 0.844, n = 38				
	Coefficient	SE	F-value	*P* value
a	11.243	5.304	2.120	0.0410
b	32.283	6.121	5.274	<0.0001
Harvesting				
$m^3\ h^{-1}\ worker^{-1}$ = a + b*Stem size + c*Mech + d*Stem size*Mech				
R^2 adjusted = 0.773, n = 107				
	Coefficient	SE	F-value	*P* value
a	0.645	0.238	2.704	0.0080
b	5.430	1.259	4.311	<0.0001
c	2.504	0.52	4.817	<0.0001
d	16.948	2.842	5.964	<0.0001

Mech = 0 if operation is manual, Mech = 1 if operation is mechanized

SE standard error, *Removal* total removal in $m^3\ ha^{-1}$, *Stem size* mean stem volume in m^3

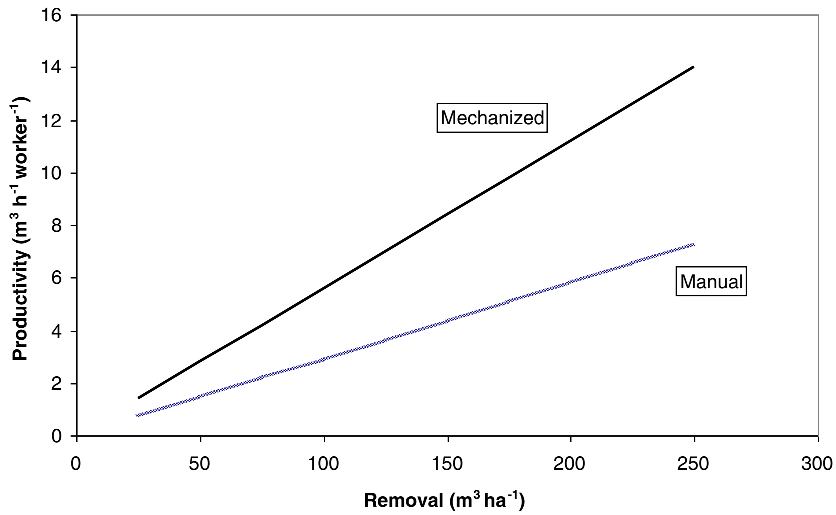


Fig. 2 Felling productivity as a function of removal and technology level

stem size. On the other hand, the classic χ^2 showed that yarding was more frequent in beech stands, while skidding and forwarding were more frequent in oak stands (Table 2).

Except for shoveling, crew size was always relatively large, which was consistent with substantial labor input, as required for the manual loading of mules, forwarding boxes, and trailers or for the manual choking of skidder and yarder loads. Labor inputs were significantly larger for log sliding, which is an almost entirely manual practice. This could also explain the significantly lower utilization recorded for this method, which is physically demanding. Different extraction distance and mean load size were also associated with different systems, as befitted their specific technical characteristics. In particular, forwarding was associated with the largest loads and the

Table 4 Main results of the analysis of "extraction" data

System *n* Date (year)	Animal 8 1996a	Chutes 5 1996a	Shovel 3 2006	Skidding 52 2000a	Forwarding 41 2005b	Yarding 33 2006b
Site characteristics						
Slope gradient (%)	48a	49a	35	30b	22b	57a
Clear cut (*n*)	7	2	3	31	16	15
Conversion (*n*)	1	3	0	22	25	17
Total removal (m^3 ha^{-1})	121a	119a	213	108a	92a	118a
Tree size (m^3)	0.102a	0.126a	0.417	0.109a	0.158a	0.161a
Tree species						
Chestnut (%)	25	20	67	23	17	12
Beech (%)	0	40	0	13	5	48
Oaks (%)	75	40	0	47	78	36
Other (%)	0	0	33	17	0	3
Distribution (χ^2)	388.814 (P = <0.0001)					
Operation						
Crew (*n*)	1.9a	3.2b	1.0	1.9a	1.5a	2.6b
Utilization (%)	91a	65b	80	78a	83a	77a
Distance (m)	396ac	96b	158	294a	750c	236a
Load per turn (m^3)	1.112a	0.014a	0.299	0.843a	5.219b	0.502a
Productivity (m^3 h^{-1})	1.8a	2.4a	8.7	2.9a	6.0b	3.1a

Different letters along the same rows indicate a statistically significant difference between extraction systems for $\alpha < 0.05$. Shovel extraction figures bear no letters because they were excluded from the analyses due to the insufficient number of data points. The significance of the differences found in the species distribution is indicated in the χ^2 row. Utilization = productive work time/worksite time. Distance is the maximum extraction distance reported in the study (i.e., system reach). Load size in animal extraction refers to the total load hauled by the whole animal team, not by the single animal. Productivity figures refer to the whole extraction team and not to the single worker longest extraction distances, whereas sliding accounted for the smallest loads and the shortest distances. Productivity was significantly higher for shoveling and forwarding, compared with the other systems (Table 4).

Animal extraction, sliding, and shoveling did not offer enough data points for attempting individual regression analyses, whereas skidding, forwarding, and yarding did. The general model formulation was logical, since productivity increased with load size and decreased with distance, and the two independent variables tended to balance each other (Table 5). Removal had a significant effect on skidding and yarding, but not on forwarding. Other independent variables were also tested, but the data pool was not large enough for detecting any significant effects.

The use of these models is shown in Fig. 3, where forwarding productivity was modeled as a function of extraction distance and load size. In this specific example, the three load sizes represented three different forwarding equipment: a farm tractor with front and rear boxes (2 m^3), especially popular with Mediterranean contractors; a farm tractor with a dedicated forestry trailer (6 m^3); and a proper light- to medium-sized forwarder (10 m^3).

Finally, the data for skidding, forwarding, and yarding were categorized in two groups, depending on whether they came from studies dated between 2006 and 2015 or from earlier studies (cf. Cacot et al. 2015a). The purpose of the exercise was to determine if any significant progress had occurred in coppice extraction performance. Data analysis confirmed that this was the case. The mean productivity reported in studies performed after 2005 was substantially higher than the mean productivity derived from earlier studies for all the three extraction systems, and the differences were statistically significant for skidding and forwarding (Table 6). However, productivity gains were obtained in different ways for the different systems. Increases in skidding productivity were associated with larger removals, hinting at a new deployment strategy rather than a technology change. In contrast, increases in forwarding and yarding productivity were associated with larger payloads and longer distances, which indicate the introduction of larger specialist machines.

Table 5 Regression equations for skidding, forwarding, and yarding

Skidding				
$m^3\ h^{-1}$ = a*Load^b*Dist^c + d*Removal				
R^2 adj = 0.839, n = 48				
	Coeff	SE	F-value	P value
a	51.305	8.226	6.237	<0.0001
b	1.142	0.112	4.362	<0.0001
c	−0.574	0.118	−2.201	0.0023
d	0.009	0.002	3.83	<0.0001
Forwarding				
$m^3\ h^{-1}$ = a*Load^b*Dist^c				
R^2 adj = 0.894, n = 31				
	Coeff	SE	F-value	P value
a	55.369	1406.24	262.432	<0.0001
b	0.750	0.152	4.934	<0.0001
c	−0.568	0.127	−4.476	<0.0001
Yarding				
$m^3\ h^{-1}$ = a*Load^b*Dist^c + d*Removal				
R^2 adj = 0.914, n = 30				
	Coeff	SE	F-value	P value
a	16.351	3.557	4.597	<0.0001
b	0.699	0.127	5.298	<0.0001
c	−0.304	0.205	−2.115	0.0031
d	0.011	0.003	3.341	0.0024

SE Standard error, *Removal* total removal in $m^3\ ha^{-1}$, *Load* mean load per turn in m^3, *Dist* maximum extraction distance, in m

4 Discussion

4.1 General

This study is a first attempt at conducting a large review and a meta-analysis of existing coppice harvesting studies, which would have been impossible without the large network of scientists supported by the European Union through COST Action 1301. Such a network has allowed access to the 80 % of the studies that are not published in English. In fact, many of those studies have not been published at all and exist only as internal reports, personally contributed to this project by researchers participating in the network. For this reason, the scientific quality of many studies included in the analysis had not been verified by international peer review. However, these studies were still considered to contain reliable information because they were all produced by reputable research institutes. The prevalence of French and Italian studies simply reflects the importance of coppice forest in these countries: coppice forests cover over 6 million ha in France and over 3 million ha in Italy, representing a crucial forest management approach.

The large amount of data points assembled in the master data base provides a solid platform, from which meaningful information can be extracted. Of course, the studies constituting this database are extremely variable in their scope, goals, and methodologies. Even if methodological harmonization was achieved (Koŝir et al. 2015), these studies would still reflect the different species and different silvicultural practices typical of each country, providing an unbalanced dataset as a result of unbalanced country contributions. For this reason, our analyses can clearly detect the main trends but cannot go deeply into the specific details. In general, meta-analyses trade accuracy for robustness, which is their main asset (Borenstein et al. 2009).

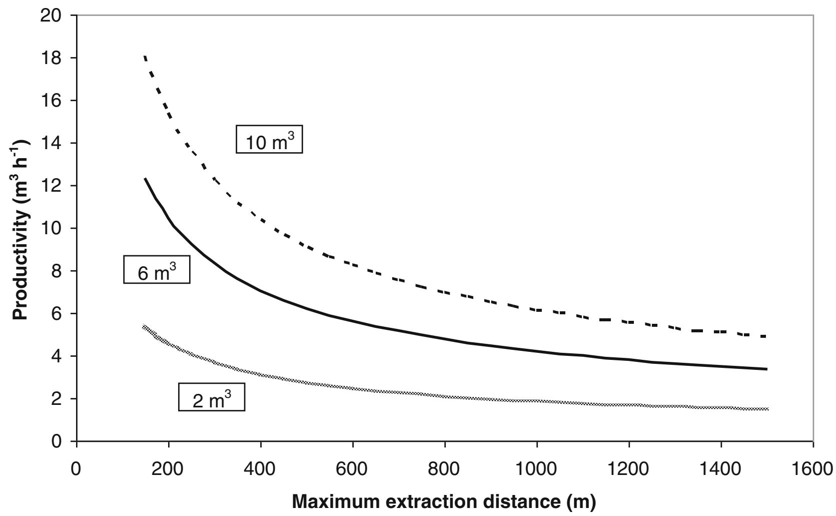


Fig. 3 Forwarding productivity as a function of maximum extraction distance and load size

In that regard, it is important to stress that the data points used for the analysis are not the equivalent of single studies, and that a single study often produces more data points. This is especially relevant when calculating frequencies and time trends. Traditional, somewhat "archaic" technologies might be found in recent papers just because they represent the control in a comparison study, and therefore, the association of recent dates to these data points does not necessarily reflect revived interest in older methods (although it does not exclude it, either).

Table 6 Results for skidding, forwarding, and yarding by study date

Study date	Up to 2005	After 2005	*P* value
Skidding			
Data points (*n*)	28	24	
Productivity (m^3 h^{-1})	1.973	3.962	<0.0001
Utilization (%)	81	76	0.1119
Distance (m)	355	226	0.1193
Load per turn (m^3)	0.806	0.891	0.3532
Total removal (m^3 ha^{-1})	84	135	0.0021
Slope gradient (%)	25	35	0.0277
Forwarding			
Data points (*n*)	14	27	
Productivity (m^3 h^{-1})	3.112	7.535	0.0003
Utilization (%)	81	85	0.3033
Distance (m)	871	699	0.2111
Load per turn (m$^{3)}$	2.916	6.413	0.0005
Total removal (m^3 ha^{-1})	107	85	0.0989
Slope gradient (%)	22	22	0.4657
Yarding			
Data points (*n*)	10	23	
Productivity (m^3 h^{-1})	2.636	3.366	0.3675
Utilization (%)	81	74	0.2082
Distance (m)	141	278	0.0107
Load per turn (m^3)	0.314	0.584	0.0061
Total removal (m^3 ha^{-1})	100	127	0.1627
Slope gradient (%)	59	56	0.7183

P values for the comparison between the two date groups conducted with the Mann-Whitney non-parametric test; utilization = productive work time/worksite time; productivity figures refer to the whole extraction team and not to the single worker

Similarly, concentrations of studies about one specific technology may approximate—but not necessarily describe—how popular this technology is in actual practice. In fact, research often addresses emerging technologies, not mainstream ones. Therefore, any inference produced by this study about technological preference in current practice is highly conjectural. In that regard, it is important to bear in mind that most of the data points come from France, Italy, and Spain: therefore, any technology trends shown by this study may be valid for south-western Europe but are not necessarily true for other parts of the European Union.

In general, the productivity benchmarks reported here for coppice operations are much lower than the productivity benchmarks indicated in other previous studies about operations in high forests (cf. Eriksson and Lindroos 2014, Spinelli et al. 2015). There is a two-way causal relationship between the low productivity achieved in coppice operations and the low level of mechanization deployed there. On one hand, the low level of mechanization is one of the reasons for the limited productivity achieved in coppice operations. On the other hand, coppice stands present objective constraints (small tree size, irregular tree distribution, poor tree form, etc.) that may prevent the productivity achieved in high forests from being reached, for any given level of mechanization. This discourages the introduction of more efficient and expensive machines, and the current general trend toward larger, more sophisticated and more expensive machines is not going to make things easier (Nordfjell et al. 2010). There is a need for lighter, simpler, and cheaper versions of the same modern machines

>used in high forests, but most machine manufacturers prefer targeting the most profitable operations, where the big money is. The development of a modern mechanization for coppice harvesting is still a niche market that is bound to attract smaller players, but its future expected growth may make it an increasingly interesting niche (Ferrari et al. 2012).

4.2 Felling, processing, and harvesting

With regard to felling, processing, and harvesting, the study highlights several strong trends. Mechanization boosts operator productivity, increases utilization, and reduces crew size, all of which represent vital solutions to the shortage of manual labor (Cacot et al. 2015b, Spinelli and Magagnotti 2011). Equally obvious is the indication that direct access of felling and harvesting machines to the forest is favored by flat terrain, with a mean slope gradient not higher than 10 % (of course, this may include short drops and inclines with a much higher gradient). All of this is already known. However, this study also contributes new and important knowledge. First of all, it offers the evidence that mechanized felling, processing, and harvesting are viable options for coppice stands. This is quite important, considering that the viability of mechanized felling, processing, and harvesting in coppice stands is still the object of much debate (Ramantswana et al. 2012). The study also shows that different work procedures are sensitive to different factors. Regardless of technology level, processing and harvesting are most affected by stem size, because they are single-stem operations. In contrast, the effect of stem size on felling is secondary, because of the possibility of cutting more stems at a time to compensate for small stem size (Erber et al. 2016). This occurs with manual felling as well as with mechanized felling, which is generally based on multiple-stem technology and may be partly facilitated by natural clumping, as stems growing close together are easier to grab in one single motion. The successful introduction of mechanized felling is largely dependent on the growing demand for biomass, which justifies whole-tree chipping (Mitchell and Gallagher 2007).

Mechanized processing and harvesting also tend to produce more and longer assortments than do manual processing and harvesting. The main technical reason is that short logs (1 m) are difficult to handle with any machine, whereas long logs are too heavy for manual handling. The economic consequence is that introducing mechanization may favor an increased diversification of coppice products, possibly to the benefit of larger and more valuable structural products.

In any case, assortment type and specifications depend on tree species. This study shows a clear association between certain species and the technology level applied to felling, processing, and harvesting. However, such choice is not necessarily motivated by inherent technical requirements, but it often depends on contingent economic factors. The prevalence of chestnut in mechanized processing and harvesting studies may partly depend on inherent technical factors (i.e., the generally good form of chestnut sprouts), but it is also explained by the fact that chestnut coppice is often concentrated in specific regions, where wide availability of this raw material has fostered a whole industrial sector with the means and the perspectives for introducing mechanization (Pettenella 2001). In contrast, oak coppice is often scattered in rural areas with little industrial development, which may explain the delayed reaction to new technology opportunities (Fraser 1982).

4.3 Extraction

While felling, processing, and harvesting are either performed with a chainsaw or with a boom-mounted hydraulic attachment, extraction is performed with a large variety of techniques, each deployed according to different technology levels. The study shows the enduring prevalence of three systems: skidding, forwarding, and yarding. Over time, skidding seems to be losing favor, whereas forwarding and yarding are gaining popularity. This is further demonstrated by the different levels of technical progress within the systems themselves. All systems became more productive with time, but productivity increases seem to be associated with technology advances in the cases of forwarding and yarding, not skidding.

Forwarding seems particularly promising, because it requires the lowest labor input and it achieves the highest productivity, despite deployment on significantly longer extraction distances. In that regard, it is important to recall that the distance considered in the study is the maximum extraction distance, not the mean distance as used in many other similar studies. The decision to use maximum distance instead of mean distance was dictated by the fact that most papers in the database did report the maximum extraction distance, while only some of them also offered information about the mean extraction distance. Clarity about this point is especially relevant to using the models shown in Table 5 and graphed in Fig. 3. If all trips were conducted exactly from the distance reported on the X-axis of Fig. 3 (that is, if that distance was the mean distance and not the maximum one), then actual productivity would be much lower than predicted. In fact, the productivity indicated on the Y-axis of Fig. 3 represents the mean productivity for an extraction operation conducted over a whole range of distances up to the maximum distance indicated on the X-axis; therefore, the corresponding mean extraction distance is much shorter.

Forwarding is also much less dependent on removal intensity, which makes it the choice extraction system for conversion cuts (i.e., thinning). Unfortunately, conversion to high forest is often applied to steep sites that are inaccessible to ground-based equipment (Ciancio et al. 2006). In that case, it may be worth considering conversion along corridors (Tulbure and Duduman 2012), which may offer better conditions for cost-effective cable yarding.

Finally, the close association between terrain characteristics and extraction system demonstrates that system selection is dictated by access conditions. This may also explain the association between extraction system and tree species, because tree species often reflects terrain conditions. Yarding occurs more often with beech, because beech forests occupy higher and steeper sites than do other forest types. Similarly, mechanized ground-based extraction is more often associated with oak stands, which generally grow on rolling hills, accessible to tractors.

5 Conclusions

The study offers valuable benchmark figures about coppice harvesting performance. These may help direct decision-makers when trying to modernize coppice management and increase its competitive capacity, which is crucial to the survival of coppicing as an economical practice. The productivity models presented in this study indicate the crucial role of removal intensity on harvesting performance and should be considered carefully when deciding about the future of coppice management. While these models do not discriminate against conversion per se, they warn against excessively light removals, which may occur in the repeated thinning operations often applied to achieve conversion to high forest. The study also demonstrates that coppice harvesting technology has been evolving, like for all other forestry sectors. Coppice can be felled and processed mechanically, and the trend toward increasingly larger machines is clearly visible in coppice operations, as it is in high forests and plantation operations (Nordfjell et al. 2010). However, while trends are the same, the type of mechanization deployed in coppice operation is quite specific and it is generally lighter and less specialized than that used in high forests. Relatively cheap and versatile general-purpose machines (excavators, farm tractors, and light forwarders) still represent the backbone of coppice mechanization, which is consistent with the rural and small-scale character of the coppice economy.

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Appendix

List of studies used for the meta-analysis

Compiler	Reference	Country	Year	Published	English
Emmanuel Cacot	Project n°SD03, date : 1996, location :Caumon	France	1996	0	0
Emmanuel Cacot	Project n°SD03, date : 1997, location :Chalvignac	France	1996	0	0
Emmanuel Cacot	Project n°SD03, date : 1996, location :Saint Alvère (24)	France	1996	0	0
Raffaele Spinelli	Grulois S., Cassotti P., Julien C., Perinot C. (1996) Productivity of harvesting operations in coppice forests in the Mediterranean region:situation in France. Annali Istituto Sperimentale di Selvicoltura 27: 183-190	France	1996	1	1
Emmanuel Cacot	Project n°SD03, date : 1998, location : La Gane (19)	France	1997	0	0
Emmanuel Cacot	Project n°SD03, date : 1997, location : Les Piles (24)	France	1997	0	0
Emmanuel Cacot	Project n°SD03, date : 1997, location : Le Rouget (15)	France	1997	0	0
Emmanuel Cacot	Project n°SD03, date : 1997	France	1997	0	0
Emmanuel Cacot	Project n°SD03, date : 1997, location : Palat	France	1998	0	0
Emmanuel Cacot	Project n°SD03, date : 1998, location : La Pouge (19)	France	1998	0	0
Emmanuel Cacot	Project n°SD03, date : 1998, location : Puy d'Arnac (19)	France	1998	0	0
Emmanuel Cacot	Project n°SD03, date : 1998, location : Saligoux (15)	France	1998	0	0
Emmanuel Cacot	Project n°SD03, date : 1998, location : Saint Crépin (24)	France	1998	0	0
Emmanuel Cacot	Project n°SD04, date : 01-05/02/1999, location : Noërs (54)	France	1999	0	0
Emmanuel Cacot	Project n°SD06, date : 25/01/2000, location : Rougnac I (16)	France	2000	0	0
Emmanuel Cacot	Project n°SY54, date : 05/12/2000, location : Ambazac I (87)	France	2000	0	0
Emmanuel Cacot	Project n°SD07, date : 01/04/2002, location : Gages (12)	France	2002	0	0
Emmanuel Cacot	Project n°ZY51, date : 06/05/2004, location : Rougnac IV (16)	France	2004	0	0
Emmanuel Cacot	Project n°SD09, date : 28-29/09/2004, location : FD de Secondigny (79)	France	2004	0	0
Emmanuel Cacot	Project n°VZ64, date : 25-26/11/2004, location : Le Creux (3)	France	2004	0	0
Emmanuel Cacot	Project n°ZD06, date : 09/03/2006, location : Bois des Echelles I (87)	France	2006	0	0
Emmanuel Cacot	Project n°ZD06, date : 05/04/2006, location : Bois des Echelles II (87)	France	2006	0	0
Emmanuel Cacot	Project n°ZD06, date : 12/04/2006, location : Bois des Echelles III (87)	France	2006	0	0
		France	2006	0	0

Emmanuel Cacot	Project n°SD11, date : 01/06/2006, location : Lacabarède (81)				
Emmanuel Cacot	Project n°SD11, date : 01/07/2006, location : Caraman (31)	France	2006	0	0
Emmanuel Cacot	Project n°SD11, date : 01/09/2006, location : Labastide-Rouairoux (81)	France	2006	0	0
Emmanuel Cacot	Project n°SD11, date : 16-17/11/06, location : Dompierre-sur-Nièvre (58)	France	2006	0	0
Emmanuel Cacot	Project n°SD10, date : 16/10-15/11/06, location : Sussac (87)	France	2006	0	0
Emmanuel Cacot	Project n°SD10, date : 16/11-20/12/06, location : Cognac-la-Forêt (87)	France	2006	0	0
Emmanuel Cacot	Project n°SD12, date : 04-05/12/07, location : Savignac-de-Miremont (24)	France	2007	0	0
Emmanuel Cacot	Project n°SD12, date : 18/12/2007, location : St Outrille (18)	France	2007	0	0
Emmanuel Cacot	Project n°SD12, date : 22/01/2008, location : FD de Bommiers III (36)	France	2008	0	0
Emmanuel Cacot	Project n°B00160, date : 20-21/10/2008, location : FD de la Mothe-clédou II (16)	France	2008	0	0
Emmanuel Cacot	Project n°B00609, date : 25/07/2011, location : Combiers (16)	France	2011	0	0
Emmanuel Cacot	Project n°B00609, date : 05/04/2011, location : Rougnac (16)	France	2011	0	0
Emmanuel Cacot	Project n°B00609, date : 21/02/2011, location : Chapelle Péchaud (24)	France	2011	0	0
Emmanuel Cacot	Project n°B00609, date : 19/01/2015, location : Villandraut (33)	France	2011	0	0
Emmanuel Cacot	Project n°B00609, date : 21/01/2015, location : Noaillan Route du Reche (33)	France	2015	0	0
Emmanuel Cacot	Project n°B00609, date : 04/02/2015, location : Vaurez (24)	France	2015	0	0
Emmanuel Cacot	Project n°SD03, date : 1996, location : Le Bugue (24)	France	2015	0	0
Zbigniew Karasze-wski	Suchomel C., Becker G., Pyttel P. (2011). Fully Mechanized Harvesting in Aged Oak Coppice Stands. Forest Products Journal 61 (4): 290-296	Germany	2011	1	1
Raffaele Spinelli	Baldini S. (1973) Relazione sulla utilizzazione sperimentale di bosco ceduo nella FD di Cecina. Cellulosa e Carta 6: 37-51.	Italy	1973	1	0
	Piegai F., Uzielli L., Hippoliti G. (1980)				
Raffaele Spinelli	Diradamento geometrico a strisce in un ceduo di cerro: prove comparative fra sei sietmi di lavoro con vari mezzi di esbosco. Cellulosa e carta 31: 3-23	Italy	1980	1	0
Raffaele Spinelli	Currò P., Verani S. (1984) Tempi di lavoro e rendimenti di esbosco in un ceduo di cerro con Timberjack 225. CSAF Quaderni di Ricerca n°4. 6 p.	Italy	1984	1	0
Raffaele Spinelli	Currò P., Verani S. (1986) Prove di Concentramento del legname in ceduo di cerro con due tipi di gru a cavo. CSAF Quaderni di Ricerca n° 10. 11 p.	Italy	1986	1	0
Raffaele Spinelli	Baldini S., Garavaglia S. (1987). The farm tractor for hauling operations. Proceedings of the FAO/ECE/ILO seminar on small-scale logging operations and machines.Garpenberg 15-18 June, 1987. 8 p.	Italy	1987	0	1
Raffaele Spinelli	Baldini S. (1987) Prove di utilizzazioni meccanizzate nelle conversioni. In: AA.VV: (1987) La conversione dei boschi cedui in alto fusto: stato attuale delle ricerche. UNIF, Viterbo. 84 p.	Italy	1987	1	0
Raffaele Spinelli	Baldini S., Spinelli R. (1988) Macchine e sistemi di lavoro tradizionali nella utilizzazione dei castagneti trattati a ceduo matricinato. Monti e Boschi 39: 11-18	Italy	1988	1	0
Raffaele Spinelli	Baldini S., Spinelli R. (1989) Utilizzazione di un bosco ceduo matricinato con esbosco effettuato da animali. Monti e Boschi 2/89: 39-43	Italy	1989	1	0
Raffaele Spinelli	AA.VV. (1990) Orientamenti operativi per la valorizzazione dei cedui marginali. Ministero dell'Agricoltura e Foreste. Roma. 285 p.	Italy	1990	1	0
Raffaele Spinelli	Spinelli R., Baldini S. (1992) Utilizzazione di un ceduo quercino in stazione pianeggiante. Cellulosa e Carta 43: 33-41	Italy	1992	1	0

Raffaele Spinelli	Baldini S. (1992) Prove di idoneità all'impiego forestale del trattore Goldoni Forestal. CNR Internal Report. 114 p.	Italy	1992	0	0
Raffaele Spinelli	Baldini S., Spinelli R. (1994) Prove di utilizzazione dei cedui di faggio sull'Appennino Tosco-Emiliano. CNR Internal Report. 18 p. Baldini S., Brunetti M., Spinelli R. (1995) Innovative harvesting techniques in the Italian	Italy	1994	0	0
Raffaele Spinelli	Quercus cerris coppice stands. Project AIR 2 CT94-0905 MEDCOP. Consolidated Progress Report 1st year. EC DGXII Brussels, Belgium.	Italy	1995	0	1
Raffaele Spinelli	Cantiani P., Spinelli R. (1996) Conversion to high forest of Turkey oak coppices: technical and economical assessment of the first conversion stage. Annali Istituto Sperimentale Selvicoltura - Arezzo 27: 191-199	Italy	1996	1	1
Raffaele Spinelli	Spinelli R., Caliari M., Baldini S., Fabbri P.G. (1996) Harvesting holm-oak coppice conversions in Southern Italy: results from the six comparative trials held in Staiti (RC). Project AIR 2 CT94-0905 MEDCOP. Consolidated Progress Report 2nd year. EC DGXII Brussels, Belgium.	Italy	1996	0	1
Raffaele Spinelli	Spinelli R., Ricci F., Spinelli R. (1998) Prove in campo con una macchina abbattitrice: il feller-buncher Elmek EnHar. Sherwood - Foreste e Alberi Oggi 38: 41-45	Italy	1998	1	0
Raffaele Spinelli	Spinelli R., Ricci F., Spinelli R. (1998) Esbosco a strascico con mini-trattore articolato. Legno Cellulosa e Carta 4: 26-31	Italy	1998	1	0
Raffaele Spinelli	Spinelli R., Spinelli R. (2000). L'allestimento meccanizzato del ceduo di castagno. Monti e Boschi 51 (1): 36-42	Italy	2000	1	0
Raffaele Spinelli	Verani S., Sperandio G. (2003) Tre mezzi per l'esbosco di legna da ardere. Sherwood - Foreste e Alberi Oggi 92: 13-19	Italy	2003	1	0
Raffaele Spinelli	Spinelli R., Nati C., Magagnotti N. (2005) Biomassa dalla manutenzione delle bande boscate polivalenti. Terra e Vita 12: 82-88.	Italy	2005	1	0
Raffaele Spinelli	Fabiano F. (2006) Movimentazione manuale della legna da ardere - Entità, rischi e sicurezza nell'esbosco "a soma" con trattore. Sherwood - Foreste e Alberi Oggi 120: 33-37	Italy	2006	1	0
Raffaele Spinelli	Spinelli R., Nati C., Magagnotti N., Verani S. (2006) Raccolta integrata di legna da ardere e cippato dalla gestione dei cedui quercini degradati in Molise. CNR Internal Report. 12p	Italy	2006	0	0
Raffaele Spinelli	AA.VV. (2006) Guidelines for the development of a forest chips supply chain. GAL Prealpi e Dolomiti, Sedico, BL - Italy.	Italy	2006	1	1
Raffaele Spinelli	Bresciani A., Fratini R., Lorenzoni M., Piegai F. (2007) Tempi e costi nelle utilizzazioni boschive. Sherwood - Foreste e Alberi Oggi 130: 5-11	Italy	2007	1	0
Raffaele Spinelli	Piegai F. (2005) Tagli di utilizzazione e di avviamento nei cedui quercini. Sherwood -Foreste e Alberi Oggi 117: 5-8	Italy	2007	1	0
Raffaele Spinelli	Spinelli R., Cuchet E., Roux P. (2007) Biomass & Bioenergy 31: 205-210	Italy	2007	1	1
Raffaele Spinelli	Spinelli R., Magagnotti N. (2007) Protezione idraulica, ambiente e biomassa: un approccio integrato alla manutenzione degli alvei fluviali. Alberi e territorio	Italy	2007	1	0
Raffaele Spinelli	Spinelli R., Magagnotti N. (2007) Biomassa dai boschi di neoformazione: casi di studio in Friuli-Venezia Giulia. Sherwood - Foreste e Alberi Oggi 135: 45-49.	Italy	2007	1	0
Raffaele Spinelli	Moscatelli M, Pettenella D, Spinelli R, (2007). Produttività e costi della lavorazione meccanizzata dei cedui di castagno in ambiente appenninico. Forest@ 4 (1): 51-62	Italy	2007	1	0
		Italy	2008	1	0

Raffaele Spinelli	Verani S., Nati C., Spinelli R., Nocentini L. (2008) Meccanizzazione avanzata in bosco ceduo. Sherwood - Foreste e Albaeri Oggi 144: 41-46				
Raffaele Spinelli	Neri F. (2008) Utilizzazione della vegetazione ripariale. Sherwood - Foreste e Alberi Oggi 143: 45-49	Italy	2008	1	0
Raffaele Spinelli	Spinelli R., Magagnotti N., Nati C. (2009) Options for the mechanized processing of hardwood trees in Mediterranean forests. International Journal of Forest Engineering 20: 39-44.	Italy	2009	1	1
Raffaele Spinelli	Picchio R., Maesano M., Savelli S., Marchi E. (2009) Productivity and energy balance in conversion of a Quercus cerris L. coppice stand into high forest in Central Italy. Croatian Journal of Forest Engineering 30: 15-26	Italy	2009	1	1
Raffaele Spinelli	Zimbalatti G., Proto A. (2009) Cable logging opportunities for firewood in Calabrian forests -Biosystems Engineering 102: 63-68	Italy	2009	1	1
Raffaele Spinelli	Spinelli R., Magagnotti N., Lombardini C. (2010) Performance, capability and costs of small-scale cable yarding technology. Small-scale Forestry 9: 123-135	Italy	2010	1	1
Raffaele Spinelli	Magagnotti N., Spinelli R. (2011) Integrating animal and mechanical operations in protected areas. Croatian Journal of Forest Engineering 32: 489-499	Italy	2011	1	1
Raffaele Spinelli	Spinelli R., Magagnotti N. (2011) Prove di esbosco nell'Appennino Tosco-Emiliano. CNR Internal Report. 12 p.	Italy	2011	0	0
Raffaele Spinelli	Magagnotti N., Pari L., Spinelli R. (2012) Re-engineering firewood extraction in traditional Mediterranean coppice stands. Ecological Engineering 38: 45-50	Italy	2012	1	1
Raffaele Spinelli	Suchomel C., Spinelli R., Magagnotti N. (2012) Productivity of processing hardwoods from coppice forests. Croatian Journal of Forest Engineering 33: 39-47	Italy	2012	1	1
Raffaele Spinelli	Spinelli R., Magagnotti N. (2012) Wood extraction with farm tractor and sulky: estimating productivity, cost and energy consumption. Small-scale Forestry 11: 73-85	Italy	2012	1	1
Raffaele Spinelli	AA.VV. (2012) Linee guida per la gestione della vegetazione di sponda dei corsi d'acqua secondo criteri di sostenibilità ecologica ed economica. Regione Toscana - Giunta Regionale. 106 p.	Italy	2012	1	0
Raffaele Spinelli	Magagnotti N., Spinelli R. (2012) Replacing steel cable with synthetic rope to reduce operator workload in log winching operations. Small-scale Forestry 11: 223-236	Italy	2012	1	1
Raffaele Spinelli	Spinelli R., Ebone A., Gianella M. (2014) Biomass production from traditional coppice management in northern Italy. Biomass and Bioenergy 62: 68-73.	Italy	2014	1	1
Raffaele Spinelli	Schweier J., Spinelli R., Magagnotti N., Becker G. (2015) Mechanized coppice harvesting with new small-scale feller-bunchers: results from harvesting trials with newly manufactured felling heads in Italy. Biomass & Bioenergy 72: 85-94	Italy	2015	1	1
Raffaele Spinelli	Spinelli R., Lombardini C., Magagnotti N., De Francesco F., Aminti G. (2015) Rapporto sui cantieri PIT - Provincia di Como. CNR Internal Report. 18 p.	Italy	2015	0	0
Raffaele Spinelli	Magagnotti N., Ottaviani-Aalmo G., Brown M., Spinelli R. (2015) A new device for reducing crew size and operator workload during log winching operations. Manuscript submitted to Biosystems Engineering	Italy	2015	1	1
Mariusz Bemben-ek	Mederski P. et al. (2013-2016) Research project No. EO-5011-179/12 supported by the General Directorate of State Forests in Warsaw	Poland	2014	0	0
Matevž Mihelič	Rakič, M.,1988, Problematika iskorištavanja šuma u Š.I.K.	Serbia	1988	1	0

	"Crvena zastava" Kruševac sa posebnim osvrtom za dvofazno privlačenje, University of Belgrade, Faculty of Forestry, Bachelor Thesis, 36 p.				
Matevž Mihelič	Bajič, V., Danilović, M., Mehanizirano privlačenje prorednog materiala izdanačkim sastojinama bukve, 2004. Šumarstvo (Jul-Sept, 2004), number 3, 139-148	Serbia	2004	1	0
Matevž Mihelič	Bajić, V.,Danilović, M., 2004, Optimizacija tehnologije prorednih seča i izdaničkim sestojinama bukve na području crnog vrha, Glasnik šumarskog fakulteta , vol 89, 41-51	Serbia	2004	1	0
Matevž Mihelič	Simončič P, Eler K, Kobal M, Triplat M, Sinjur I, Žlindra D, Mihelič, M., Robek, R., Piškur, M., Klun, J., Premrl, T., Krajnc, N. Možnosti in omejitve pridobivanja biomase iz gozdov : zaključno poročilo projekta (V2-1126).	Slovenia	2014	1	0
Eduardo Tolosana	Ljubljana: Gozdarski inštitut Slovenije; 2014. Ranz, P P. Modelos de rendimientos y costes de las claras sobre rebollares de Quercus pyrenaica Wild. Master Thesis directed by Tolosana, E (unpublished). 2001	Spain	2001	0	0
Eduardo Tolosana	Tolosana E, Ambrosio Y, Agudín S & Boticario P: Estudio de tiempos y rendimientos de la saca con cable aéreo en montes de Lleida y Barcelona. UPM & CPF de Catalunya (unpublished), 2002	Spain	2002	0	0
Eduardo Tolosana	Rodríguez J, Ruiz D, Piqué M, Tolosana E: Experiencia de desembosc amb cable aeri. Aprofitament d'alzina a la Selva. CPF de Catalunya. Unpublished report, 2004	Spain	2002	0	0
Eduardo Tolosana	Tolosana E, Laina R, Martínez-Ferrari : Informe sobre metodología y resultados de las experiencias de recolección de biomasa en rebollares de la provincia de León. Unpublished report, 2007.	Spain	2007	0	0
Eduardo Tolosana	Tolosana E y Martín M: Informe final "Estudio de rendimientos entre operaciones manuales y mecanizadas en la clara del rebollar de Q.Pyrenaica en santa Colomba de Somoza (León)". Unpublished. 2009	Spain	2009	0	0
Eduardo Tolosana	Tolosana E. Manual Técnico para el aprovechamiento y elaboración de biomasa forestal. Ed. mundiPrensa - FUCOVASA. Pag. 287-309. 2009	Spain	2009	1	0
Eduardo Tolosana	Canga E, Fanjul A, Sánchez-García S, Alonso-Graña M, Majada J, 2014: Replacement of steel cable with synthetic rope in mountain logging operations in Castanea sativa Mill. coppice stands. Forest Systems 23(3): 461-469.	Spain	2014	1	1
Eduardo Tolosana	Forestry Commission's Forest Research Technical Development Branch, 1996:"Harvesting and comminution of sweet chesnut coppice for use as fuel stock for electricity production". Technical Note 28/96, 8 pages	UK	1996	1	1
Eduardo Tolosana	Forestry Commission's Forest Research Technical Development , 2011: "Tractor Based Mechanised Harvesting in Sweet Chestnut Coppice". Project Report Reference FCPR040, 18 pages	UK	2011	0	1
Eduardo Tolosana	Forestry Commission's Forest Research Technical Development , 2012: "Comparison of Mechanised and Motor-manual Harvesting in Sweet Chestnut Coppice". Job Report Reference FCJR081, 23 pages	Uk	2012	0	1

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