Fully Mechanized Harvesting in Aged Oak Coppice Stands

Christian Suchomel
Gero Becker
Patrick Pyttel

Abstract

Coppice is a traditional forest management system used all over the world. It takes advantage of fast early growth and the vegetative reproduction of the respective trees. Coppice forests provide firewood and many other products and services, especially to rural communities. In Central Europe, regular periodic cutting and management of coppice forests was abandoned due to socioeconomic changes in recent decades, resulting in aged stands that have gradually lost their coppice characteristics. Today, coppice forests are recognized again not only for their growth potential but also for their benefits for biodiversity and nature conservation. Together with the rising demand for energy wood, this recognition could result in a renaissance of the traditional coppice management system. Several stands grow on relatively easily accessible terrain where fully mechanized systems (harvester, forwarder) could be used. However, there is no current information regarding the technical feasibility and productivity of modern harvester technology used in coppice forests.

In this study, an HSM 405H 6WD harvester with an CTL 40HW processor head was investigated with time studies to determine technical feasibility and time consumption of harvesting aged oak coppice. The results show high productivity for harvesting hardwood. The multiple stem structure that is typical for coppice forests does not result in technical problems or significantly higher time consumption for the harvester, even though it is slightly more time-consuming to grab and fell multi-stem trees than a single tree. Compared with a forest worker with a chainsaw, the harvester left significantly (5 cm) higher stools.

Coppice is a traditional forest management system established in many regions all over the world. Coppice forests were and still are typical for rural areas, and they commonly supply local communities mainly with firewood, but also with many other products and services. By taking advantage of the fast growth in the early years of various coppice tree species (mostly broad-leaved) it is possible to grow a substantial amount of biomass within a short period of time. Natural regeneration through sprouting reduces costs and risks of stand establishment in this management system.

Following economic development and industrialization, coppice forests were often no longer relevant and many were converted into high forests for the production of larger, more valuable trees. However, large areas are still managed as coppice forests in Europe; for example, France with 4.71 million hectares (50% of total forest area; Bundesministerium für Ernährung, Landwirtschaft und Forsten [BMELF] 1982); Italy, 3.27 million hectares (55%; Food and Agriculture Organization of the United Nations 2005, Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio 2005); Bulgaria, 1.78 million hectares (48%; State Forest Agency 2008); Serbia, 1.46 million hectares (65%; Bankovic et al. 2008); Macedonia, 565,000 hectares (60%; State Statistical Office of Macedonia 2004); Croatia, 534,000 hectares (22%; Croatian Forests Ltd. 2006); Belgium, 174,000 hectares (30%; BMELF 1982); and Austria, 94,000 hectares (2%; Hochbichler 2008).

Coppice forests also have a long tradition in Germany, primarily in oak- and hornbeam-dominated forests. According to the German forest inventory (Bundeswaldinventur[2] 2002), coppice forests occupy 75,316 hectares (1% of total forest area). However, in this inventory only coppice forests with a maximum age of less than 40 years are classified as coppice. Thus many overaged (40+ y) coppice stands are not classified as coppice in this inventory (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz 2000). Today, many coppice stands in Germany are

The authors are, respectively, Research Associate and PhD student, Inst. of Forest Utilization and Work Sci. (christian.suchomel@fobawi.uni-freiburg.de), Head of the Inst. of Forest Utilization and Work Sci. (fobawi@fobawi.uni-freiburg.de), and Research Associate and PhD student, Inst. of Silviculture (patrick.pyttel@fobawi.uni-freiburg.de), Univ. of Freiburg, Freiburg, Germany. This paper was received for publication in February 2011. Article no. 11-00018.
©Forest Products Society 2011.
Forest Prod. J. 61(4):290–296.

http://prime-pdf-watermark.prime-prod.pubfactory.com/ | 2024-12-26

overaged as a result of postponed harvesting due to economic changes during the last 60 to 80 years. The area of overaged coppice in Germany amounts to several hundred thousand hectares. For example, in Rhineland-Palatinate alone the area of forests from resprouting is reported to be 160,000 hectares, which is approximately 20 percent of the total forest area in the state (Helfrich 2009). Coppice forests represent an important landscape element (Suchomel and Konold 2008, Helfrich 2009), are important for biodiversity (Fuller 1992, Vacik et al. 2009), and have a high potential as a biomass resource. Products obtained from overaged oak coppice in Germany include small size sawlogs (mostly of inferior quality), poles, wood for panels and pallets, firewood, and woodchips. With the increasing demand for renewable energy and wood biomass the traditional ''firewood coppice forest'' could experience a renaissance as ''energy coppice forest.''

The special challenges in harvesting hardwood compared with softwood forests are that the tree shape is commonly not straight, but more sinuous. Branches are larger and have steep insertion angles. Further, coppice stands have additional challenges that make harvesting technically and economically difficult, including small stem diameters, multiple stem structures from resprouting, and an irregular shape of the butt end resulting from resprouting. New and/or adapted technologies in mechanization may potentially be able to improve the efficiency of harvesting operations.

Geographic information system–based analysis of existing coppice and aged coppice forests in Rhineland-Palatinate in Germany has revealed that approximately 30 percent of these forests grow on relatively easily accessible terrain where partly or fully mechanized systems (harvester, forwarder) could be used. The main objective of this study was to investigate a new single grip harvester head system, specially designed for hardwood, operated in a traditional but overaged oak coppice stand. Feasibility (advantages, difficulties) and work time consumption of this system were explored. A special focus of interest was to investigate differences in time consumption between harvesting single trees as compared with trees with a multiple stem structure.

Methodology

Study design

Many previous time studies for single grip harvesters identify tree volume and/or diameter at breast height (dbh) as the parameter with the biggest influence on work time and productivity (Heinimann 2001, Stampfer and Steinmüller 2004, Cremer 2008). Additionally for harvesting in coppice forests a variable for TREE CATEGORY was chosen. TREE CATEGORY pertains to single or multiple tree: ''multiple tree'' (Fig. 1) is defined as a tree sprouted from a single stool that has aboveground wood contact with another tree, whereas a ''single tree'' (Fig. 2) has no aboveground contact with neighboring trees.

Furthermore, number of logs, social class of tree crown, and number of separately cut branches were chosen as variables for this study. Consequently the following hypothesis was investigated:

$$\text{Harvester work time consumption per tree} = f[\text{stem volume, logs } (n), \text{ branches } (n), \text{class of crown (class 1 to 5), TREE CATEGORY}]$$

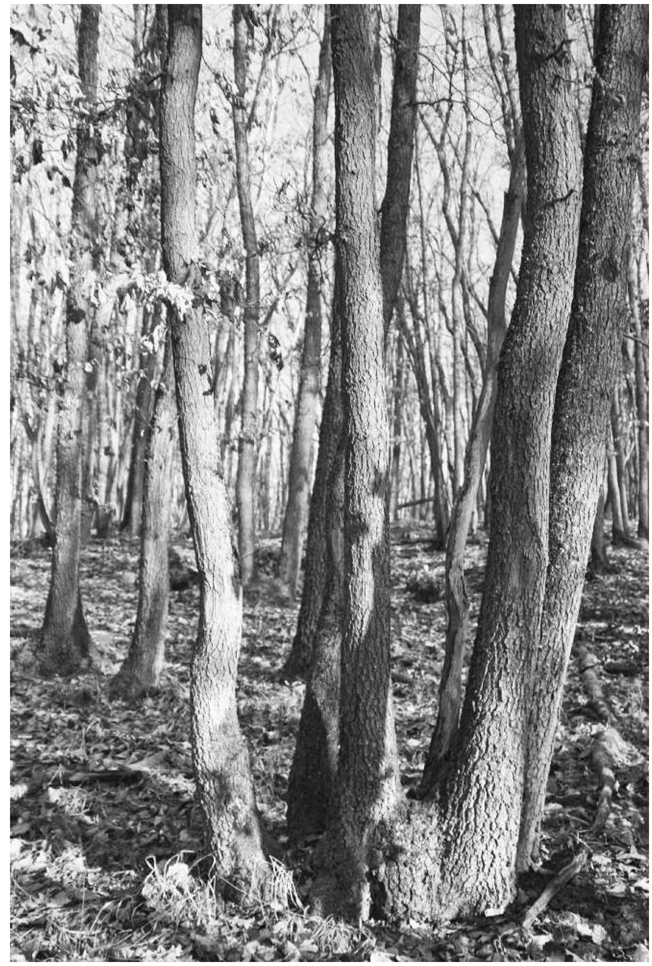

Figure 1.—Multiple stems from one stool with aboveground biomass in contact with neighbor stems.

Harvesting system

The investigated harvester was an HSM 405H 6WD (172-kW, 16-ton) harvester with a mounted CTL 40HW processor head that was specifically designed for beech thinnings through a cooperative research project between HSM, the University of Dresden, University of Sopron, University of Poznan, University of Latvia and Association forêt cellulose (ForstInno 2007). The processor head had a maximum cutting diameter of 430 mm, a weight of 740 kg, and a feed rate of 4.5 m/s. Stools with multiple stems were grabbed stem by stem. The machine did not have a multiple grip design and therefore grabbed and felled each tree separately. The harvester processed the trees into 4-m-long logs for firewood. Logs were stored at the skidding trail for the subsequent forwarder operation. Branches remained in the stand and were not used for wood energy. The harvester was controlled by a well-trained and skilled harvester operator with extensive work experience.

Study sites

The working task, typical for coppice management, was to clear-cut a part of the stand and to process all trees with a dbh above 10 cm. To increase accuracy, time studies were conducted in five different stands (Table 1).

http://prime-pdf-watermark.prime-prod.pubfactory.com/ | 2024-12-26

Figure 2.—Single stem without contact with neighbor trees.

Data collection

Detailed time-motion studies were carried out in order to measure machine working time and to identify the variables that are most likely to affect it. Cycle times were split into a number of time elements considered as typical for the working process (Table 2). Time elements were recorded with a Husky FS/2 handheld field computer running self-programmed time study software on a gwbasic basis with an accuracy of 1 second. In addition to the time of the cycle elements, the following tree variables were recorded during the harvesting process: number of logs per tree and number of branches per tree that required the machine to put the tree on the ground and grab it another time for debranching by the aggregate chainsaw because the branches were too big for regular knife debranching. Times were recorded and calculated in industrial seconds (100 s = 1 min).

Table 1.—Study sites.

Stand	Area (ha)	Slope (%)	Recorded trees with all tree information: Single tree	Multiple tree	Sum
1	0.2	30	105	57	162
2	0.2	25	76	121	197
3	0.3	25	73	175	248
4	0.2	30	53	107	160
5	0.2	25	63	43	106
Sum	1.1		370	503	873

Table 2.—Time elements of the harvester working cycle.

Working step	Description
Move	Machine starts moving; machine stops
Grab	Machine turns in direction of the tree; head arms close around the tree
Fell	Chainsaw starts; tree touches the ground
Process	Start debranching and crosscutting; complete debranching and perform the last crosscut, severing the tree top
Stack crown	Move the top to the top pile; top falls on the pile, head arms open
Product handling	Take assortments and move them to the appropriate pile; assortments dropped on the pile, head arms open
Other	Other working steps

In order to link cycle time to tree characteristics, the trees were marked with an individual tree number before the study commenced, and the following parameters were recorded: species, dbh, TREE CATEGORY (single tree or multiple tree), stool number to identify ‘‘partner trees’’ from one stool, and crown class according to Kraft (1884) representing five social classes (see Table 3). Individual stem volume was calculated with allometric equations derived from sample trees within the investigated stands. Productivity was related to the processed stem volume, excluding the volume of tops and branches.

All delays were recorded as operational, personal, or mechanical with information about the reason.

The total recorded time was 17.8 hours with 1,133 cycles, from which 873 cycles could be recorded and linked with complete tree information. In this study productivity was calculated as PMH_0 (productive machine hour without delays).

Additionally, the stool heights produced by the harvester and the stool heights of motor-manual felling (forest worker with a chainsaw) were measured. Using a randomized block design in the same stands, the height of the remaining stools after chainsaw felling and harvester felling were recorded on all study sites. On slopes, stool heights were measured on the uphill side.

Statistical analysis

A factorial layout was utilized to investigate the time consumption hypothesis for each working step and for a total cycle time. Statistical analysis was accomplished with statistical software package SPSS 19.0 for Windows using the following calculations and interpretations:

- Tests for linearity were done by graphic analysis and by testing 10 different adjustment models by significance value and value of R^2.
- Transfer values of nonlinear relationships to linear relationships (Ramsey and Schafer 1997).
- Calculation of significant effects of co-variables and factors and their statistical significance (analysis of variance).
- Analysis of regression (stepwise: backward elimination of variables).
- Interpretation of multicollinearity, which was detected by high variance inflation factor (VIF > 10), high correlation

http://prime-pdf-watermark.prime-prod.pubfactory.com/ | 2024-12-26

Table 3.—Variable definition for data sampling.

Variable type	Parameter and measurement	Definition
Dependent	Time consumption (s)	100/min
Factor	TREE CATEGORY (2 levels)	(0) single tree, (1) multiple stem from resprouting
Covariables	Stem volume (m^3 o.b.)	Stem volume (top diameter 7 cm over bark) per cycle
	Logs (*n*)	No. of logs per cycle
	Branches (*n*)	No. of separately cut branches with processor head chainsaw per cycle (machine had to put the tree on the ground, grab a branch, and cut the branch)
Ordinal covariable	Crown class (5 levels)	Social class (Kraft 1884): 1–5, where 1 is the highest social class and 5 the lowest

values between the co-variables, and graphic analysis of correlations.
- Test of regression model (residual analysis).

Outliers of more than three standard deviations (Olsen et al. 1998) were removed from the data set.

As a working hypothesis it was expected that the multiple stem structure, typical for many trees in coppice, may increase working time compared with single tree harvesting.

Results

Table 4 shows the results of the descriptive statistics for the variables. The harvester required an average of 0.85 minute per tree (PMH_0). The average proportion of the different working step times were move, 8.1 percent; grab, 20.5 percent; fell, 14.7 percent; process, 39.7 percent; stack, 12.4 percent; product handling, 2.7 percent; and other working steps, 1.9 percent.

Within a total recorded time of 17.8 hours, the productive machine working time was 16.6 hours, including delays shorter than 15 minutes (PMH_{15}). Overall, 1,133 cycles could be recorded within that period. Delay time of breaks shorter than 15 minutes had a proportion of 11.7 percent on PMH_{15}. From the total PMH_{15}, 2.7 percent were mechanical delays, 8.6 percent were operational delays, and 0.5 percent were personal delays. The main reasons for mechanical delays were loss of chain from the chainsaw (five times), changing a dull chain for a freshly sharpened one (two times), and fixing hydraulic hoses (two times). The reasons for delay times longer than 15 minutes were refuelling (one time), fixing hydraulic hoses (one time), and personal breaks.

Of the productive working time (PMH_0), 7.5 percent was for clear-cutting shrubs or trees with a diameter smaller than 10 cm and therefore without any possibility for utilization.

Regression models

The best fit for linear relationships between duration of the working steps and stem volume were established if an exponent for stem volume was used. Exponent *e* for stem_volume^e was chosen after Profile-Likelihood analysis. The value derives its maximum at an exponent of 0.75. Therefore, all of the following calculations are based on stem_volume$^{0.75}$.

The calculated models from the time consumption analysis are summarized in Table 5. The influencing parameters on every single working step can be seen in Table 6.

None of the recorded variables showed an effect on the working step ''move.''

The variables stem volume$^{0.75}$, crown class, branches, and logs had no significant influence on duration of working step ''grab.'' Only for the variable TREE CATEGORY could a significant effect be established. The time to grab a tree from a multiple stem structure was 1.186 seconds (between 0.6 and 1.5 s for the 0.95 prediction interval) higher than grabbing a single tree (*t* test with $P = 0.05$).

For the working step ''fell,'' significant effects could be established for stem_volume$^{0.75}$ and TREE CATEGORY.

The working step ''process'' was influenced by the variables stem_volume$^{0.75}$, crown class, number of logs, and the number of separately cut branches.

The variables stem_volume$^{0.75}$, crown class, number of separately cut branches, and number of logs had a significant effect on the duration of ''stack crown.'' The variable ''logs'' was removed from the model due to high correlation values between logs and stem_volume$^{0.75}$ and an only slightly higher value of adjusted R^2 (0.021 higher). Furthermore, the number of logs during the working process obviously had nothing to do with the time for stack crown.

For the regression models of ''product management'' and ''other'' times, none of the recorded variables showed an effect on the time consumption. The mean duration for product management was 2.25 seconds; the mean duration for other times was 1.73 seconds per tree.

Overall, the analysis of 873 recorded cycles with complete tree information allowed development of the total time consumption model. The variables with a significant effect on total cycle time were stem_volume$^{0.75}$, number of separately cut branches, and number of logs.

Even if there were several correlations between the variables stem volume, number of logs, crown class, and number of separately cut branches, a multicollinearity could

Table 4.—Descriptive statistics.

	Quantile 5	Mean	Quantile 95	SD	Min	Max	CI
Stem volume (m^3)	0.03	0.17	0.44	0.13	0.01	0.92	0.17–0.19
dbh (cm)[a]	9.76	17.89	27.18	5.41	7.0	36.4	17.5–18.2
Time/cycle (s)	41	85	159	39	20	275	82.9–88.1
Logs (*n*)	0.00	2.15	3.00	0.99	0	6	2.08–2.22
Branches (*n*)	0.00	0.14	1.00	0.43	0	3	0.11–0.17

[a] dbh = diameter at breast height.

http://prime-pdf-watermark.prime-prod.pubfactory.com/ | 2024-12-26

Table 5.—Results of regression analysis of the evaluated working steps.

Equation[a]	R^2	Adj. R^2	P value model
Move $(t) = 5.22$	—	—	—
Grab $(t) = 15.51 + 1.186 \times$ TREE CATEGORY	—	—	—
Fell $(t) = 6.804 + 16.437 \times \text{stem\_vol}^{0.75} + 1.174 \times$ TREE CATEGORY	0.193	0.192	<0.001
Process $(t) = -13.508 + 76.767 \times \text{stem\_vol}^{0.75} + 1.596 \times \text{crown} + 8.107 \times \text{logs} + 26.428 \times \text{branches}$	0.730	0.729	<0.001
Stack crown $(t) = 9.028 + 8.974 \times \text{stem\_vol}^{0.75} - 0.823 \times \text{crown} + 2.414 \times \text{branches}$	0.156	0.153	<0.001
Product management $(t) = 2.25$	—	—	—
Other $(t) = 1.73$	—	—	—
Total cycle time $(t) = 30.108 + 125.489 \times \text{vol}^{0.75} + 28.593 \times \text{branches} + 7.77 \times \text{logs}$	0.678	0.677	<0.001

[a] Where t = time in 100/min; TREE CATEGORY = single tree (0) or multiple tree (1); stem_vol = stem volume (m^3); branches = cut branches (n); crown = crown class (Kraft 1884); logs = number of logs (n).

Table 6.—Influences of variables on working step time consumption.[a]

	$\text{Stem\_vol}^{0.75}$	TREE CATEGORY	Crown class	Branches	Logs
Move					
Grab		*			
Fell	*	*			
Process	*		*	*	*
Stack crown	*		*	*	*
Product management					
Other					
Total cycle time	*			*	*

[a] * Significant at $P < 0.05$.

not be confirmed in any of the presented regression models. All VIF values were smaller than 10.

The equation for total cycle time shows a good fit with an adjusted R^2 of 0.659. The P value for significance of the model was $P < 0.001$.

Regardless, the very small amount of extra time required to grab and to fell a tree from a multiple stem structure showed no significant effect on the total time consumption per tree in this study.

Residual analysis shows a normal distribution of variance and no evidence contrary to statistical requirements for the regression models.

Following the model, Figure 3 shows the productivity curve for harvesting trees from aged coppice calculated by the equation

$$\text{prod} = 6,000 \times \text{vol}/t_{\text{total}}$$

where prod is the productivity (m^3/PMH_0), vol is the harvested stem volume (m^3), and t_{total} is the total effective time consumption per tree (seconds).

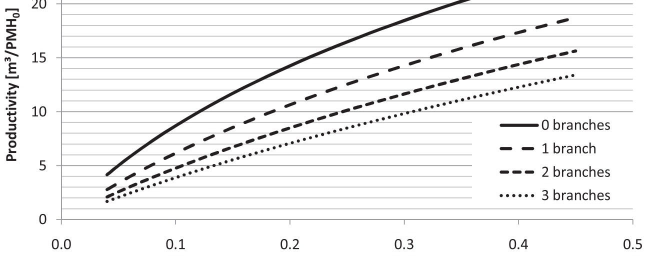

Figure 3.—Productivity model calculated with zero, one, two, and three branches and with the average of 2.14 logs per tree.

The overall productivity of the investigated machine was 9.5 m^3/PMH_0, which was calculated by total harvested volume by total effective working time (PMH_0) of trees with a diameter bigger than 10 cm. If small dimension trees and the shrubs were included in the calculations, the productivity decreased to 8.85 m^3/PMH_0.

Calculated costs of harvesting trees with an average of 0.17 m^3 are €16.38/m^3 (US\$23.45/m^3), including the operator (cost: €145/h = US\$207/h).

Felling height

The measurements of harvester stool heights ($n = 415$) showed that the average was 25.3 cm, which was 5 cm higher than the stool height ($n = 422$) of a forest worker using a chainsaw (20.3 cm) in comparable stands. The t test showed a significant difference at the 0.05 level.

Discussion

The study showed that a single grip hardwood harvester head can be successfully used to fell and process oak with a maximum diameter of 40 cm in overaged coppice stands, where the trees commonly have a sinuous shape and a multiple stem structure from resprouting. CTL technology offers a good alternative to motor-manual work in coppice stands with a gentle terrain. The statistical analysis showed that the total time consumption for harvesting a tree from a multiple stem group was not significantly higher than harvesting a single tree. The main reason was the high time consumption for move, process, stack crown, product management, and other times; however, the relatively small differences between single trees and trees from multiple stem structure for grab (+1.186 s) and fell (+1.117 s) had no significant effect on total cycle time consumption. The differences in times for grab and fell got lost in the total cycle time regression analysis because of the noise of the other working time steps. It is likely that in younger coppice stands with more trees per stool a statistical difference in total cycle time consumption would be found. More studies are required to reveal this information. The just slightly existing culmination of productivity values (Fig. 3) could be explained by the absence of numerous data for trees with a bigger diameter in the studied stands. Eventually the graph would likely take another shape if more trees with bigger dimensions could be included. Future research for this specific topic is needed.

Several tree variables were correlated with each other, particularly the variables $\text{stem\_volume}^{0.75}$, crown class,

http://prime-pdf-watermark.prime-prod.pubfactory.com/ | 2024-12-26

number of separately cut branches, and number of logs. However, in the statistical regression modeling they did not show multicollinearity effects.

The variable number of logs was counted during the harvesting process, while the stem volume was calculated by a volume equation with the measured dbh and not by the real harvested tree volume. This difference is certainly a failure source for interactions of time, volume, and number of logs.

Compared with previous studies on productivity in young hardwood high forests, the results of this study showed slightly higher productivity values at 9.5 m^3/PMH_0 (average stem volume = 0.17 m^3). The productivity value decreased to 8.85 m^3/PMH_0 when the time for harvesting shrubs and trees with dbh smaller than 10 cm was included in the calculations. For trees with a 0.20-m^3 stem volume, the productivity in this study was 14 m^3/PMH_0 (for 0 branches) and higher, compared with 12.5 m^3/PMH_0 reported by Cremer (2008) and 11 m^3/PMH_0 reported by Pausch and Ponitz (2002). The main advantage for the studied harvester was observed for bigger diameters. Compared with the hardwood studies by Cremer (2008) and Pausch and Ponitz (2002), diameters up to 35 cm can be processed more productively. Comparing results for coppice forests, in a French study, Bigot (2001) found productivities of 8.2 m^3/PMH_0 (mean stem volume, 0.109) and 5.1 m^3/PMH_0 (mean volume, 0.264 m^3) for chestnut. In Spanish and Portuguese clear-cuts of *Eucalyptus globulus,* a productivity of 12.5 m^3/PMH_0 was observed by Spinelli et al. (2002) for 4-m logs at an average tree volume of 0.25 m^3 and a light sweeped shape. The harvester in that study was an Akerman EC200 excavator with an AFM 60 harvester head (Spinelli et al. 2002). But, the productivity of our study is lower than the productivity of many harvesters in spruce stands (Heinimann 2001, Korten et al. 2003). In our study, the tree tops and branch mass was not used because of nutrient reasons. Future utilization of the concentrated material for wood chips should be taken into account.

The new hardwood processor head CTL 40HW illustrates that new technologies or adaptations of existing technology to the specific conditions of the harvested stand, including coppice, will likely increase productivity.

Performing small clear-cuts in this study allowed control of the incidence of moving time and increased the proportion of actual processing (delimbing-bucking) time. Furthermore, the machine operated in coppice clear-cuts (the most common silvicultural treatment in coppice stands) with the advantage of concentrated volume removal. The productivity in clear-cuts is higher than in thinnings or group selections because of higher volume per area and because machinery does not have to maneuver around residual trees (Kellogg et al. 1996, Hartley and Han 2007). Conversely, harvesting in coppice stands presents all the disadvantages related to small tree harvesting, i.e., small piece mass and low value assortments.

Additionally, stem quality and size of branches are significant factors affecting productivity (Spinelli and Spinelli 2000, Spinelli and Hartsough 2003, ForstInno 2007). These factors were not part of this study but should be included in future research.

Further differences in productivity could result from varying levels of skill and efficiency between different operators (Gellerstedt 2002, Purfürst 2009). Operator effect has previously been shown to affect machine productivity up to 40 percent (Ovaskainen et al. 2004). Therefore, the results of this study should be interpreted with caution, avoiding categorical conclusions.

The delay time was 11.7 percent of PMH_{15} which was relatively low. Delays are subject to special conditions in hardwood stands. A meta-analysis ($n = 34$) has shown that delays average 29 percent of total scheduled time, operations in mixed stands have more delays than plantation stands (50% vs. 21%), and felling and processing have more mechanical delays than just processing (Spinelli and Visser 2008).

A significantly higher stool after harvester felling compared with chainsaw felling was shown. Stocker (1999) found a strong correlation between cutting height and number of resprouts in *Melaleuca quinquenervia* forests. The resprouting effect of a 5-cm-higher stool in oak stands as well as the effect that older and higher sprouts have on stool stability will be evaluated in the following years.

Acknowledgments

We thank the Deutsche Bundesstiftung Umwelt (DBU), which financed this study within a project called ''Conservation through utilization: multifunctional development of coppice forests in Rhineland-Palatinate.'' Special thanks also go to the forest administration of Nastätten and Baumholder, to the forest operators for their help and support in the field, and to Mauricio Acuna.

Literature Cited

Bankovic, S., M. Medarevic, D. Pantic, and N. Petrovic. 2008. National forest inventory of the Republic of Serbia. Sumarstvo 3 (Forestry 3). Udruzenje sumarskih inzenjera I tehnicara Srbije [Association of Forest Engineers and Technicians of Serbia], Beograd [Belgrade].

Bigot, M. 2001. Using machines to harvest hardwoods in France. *In:* Appalachian Hardwoods: Managing Change, Proceedings of the 24th Meeting of the Council on Forest Engineering (COFE), July 15–19, 2001, Snowshoe, West Virginia; COFE, Corvallis, Oregon. 4 pp.

Bundesministerium für Ernährung, Landwirtschaft und Forsten (BMELF). 1982. Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland [Annual Statistical Report of Food, Agriculture and Forestry of Germany]. Deutscher Landwirtschaftsverlag, Münster-Hiltrup.

Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV). 2000. Aufnahmeanweisung für die Bundeswaldinventur II [Data Collection Guideline for the 2nd German Inventory]. 114 pp. http://www.bundeswaldinventur.de/media/archive/214.pdf. Accessed August 10, 2011.

Bundeswaldinventur[2] (BWI[2]). [German Inventory[2]]. 2002. http://www.bundeswaldinventur.de/enid/194118fa57c8b5f88975b6b6859ba6f5,4a5f0a6277695f70616765092d09746162656c6c652e706870093a095f7472636964092d09323536/6m.htmlsource=klassifizierungsmerkmale&theme=0&hr_database=&hrs_database=&K1=9999&K3=9999&K4=9999&K5=1000&abschicken=weiter+&merkmal_LangD_X=Betriebsart+%283%2B0%2B1%29&merkmal_LangD_Y=Land+%2816%2B2%2B1%29&Archiv_Datum=2004-05-13+08%3A28%3A45&x_coord=K2&y_coord=Gebiet&ZNr=10142-3100. Accessed June 2, 2010.

Croatian Forests Ltd. (CF). 2006. General Forest Management Plan for Croatia (2006–2015). CF, Zagreb.

Cremer, T. 2008. Bereitstellung von Holzhackschnitzeln durch die Forstwirtschaft: Produktivitätsmodelle als Entscheidungsgrundlage über Verfahren und Aushaltungsvarianten, entwickelt auf der Basis einer Metaanalyse [Supply of wood chips from forestry: Productivity models as a basis for supply chain management on basis of a meta analysis]. Dissertation. Albert-Ludwigs-Universität, Freiburg, Germany. 199 pp.

Food and Agriculture Organization of the United Nations (FAO). 2005. Global forest resource assessment. http://www.fao.org/forestry/static/

http://prime-pdf-watermark.prime-prod.pubfactory.com/ | 2024-12-26

data/fra2005/global_tables/FRA_2005_Global_Tables_EN.xls. Accessed November 1, 2010.

ForstInno. 2007. Development of ecologically compatible highly productive methods of timber harvesting for Central European forestry: Scientific part (report). ForstInno, Dresden and Neu-Kupfer, Germany. 23 pp.

Fuller, R. J. 1992. Effects of coppice management on woodland breeding birds. *In:* Ecology and Management of Coppice Woodlands. G. P. Buckley (Ed.). Chapman & Hall, London. pp. 169–192.

Gellerstedt, S. 2002. Operation of single-grip harvester: Motor-sensory and cognitive work. *Int. J. Forest Eng*. 13(2):35–47.

Hartley, D. S. and H.-S. Han. 2007. Effects of alternative silvicultural treatments on cable harvesting productivity and cost in western Washington. *West. J. Appl. Forestry* 22(3):204–212.

Heinimann, H. R. 2001. Productivity of a cut-to-length harvester family—An analysis based on operation data. *In:* Appalachian Hardwoods: Managing Change, Proceedings of the 24th Meeting of the Council on Forest Engineering (COFE), July 15–19, 2001, Snowshoe, West Virginia; COFE, Corvallis, Oregon. 5 pp.

Helfrich, T. 2009. Naturschutzfachliche und touristische Bedeutungen der Niederwälder in Rheinland-Pfalz [Nature conservation and touristic aspects of coppice forests in Rhineland-Palatinate]. *Tajökologiai Lapok* 7(2):443–455.

Hochbichler, E. 2008. Fallstudien zur Struktur, Produktion und Bewirtschaftung von Mittelwäldern im Osten Österreichs (Weinviertel) [Case Studies of Structure, Production and Management of Coppice with Standards in Eastern Austria]. Forstliche Schriftenreihe Universität für Bodenkultur 20, Vienna. 246 pp.

Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio (INFC). 2005. Ministere delle Politiche Agricole, Alimentari e Forestali. INFC, Trento. http://www.sian.it/inventarioforestale/jsp/home.jsp. Accessed November 1, 2010.

Kellogg, L. D., G. V. Milota, and M. Miller. 1996. A comparison of skyline harvesting costs for alternative commercial thinning prescriptions. *J. Forest Eng*. 7(3):7–23.

Korten, S., D. Matthies, C. Gennari, and M. Nagel. 2003. Leistung, Kosten, Pfleglichkeit des Valmet 911 X3M [Productivity, costs and damages of Valmet 911 X3M]. *Forst Technik* 15(9):4–7.

Kraft, G. 1884. Beiträge zur Lehre von Durchforstungen, Schlagstellungen und Lichtungshieben [Contributions to Thinnings, Order of Cutting and Light Felling]. Klindworth's, Hannover, Germany. 147 pp.

Olsen, E. D., M. M. Hossain, and M. E. Miller. 1998. Statistical comparision of methods used in harvesting work studies. Oregon State University Research Contribution 23. Oregon State University, Corvallis. 45 pp.

Ovaskainen, H., J. Uusitalo, and K. Väätainen. 2004. Characteristics and significance of a harvester operators' working technique in thinnings. *Int. J. Forest Eng*. 15(2):67–77.

Pausch, R. and K. Ponitz. 2002. Harvesterleistung und Hiebsbedingungen [Productivity and silvicultural situation]. *Forst Technik* 14(4):10–14.

Purfürst, T. 2009. Der Einfluss des Menschen auf den Harvester [The influence of the human being on the harvester]. Dissertation. Technische Universität Dresden, Germany. 307 pp.

Ramsey, F. L. and D. W. Schafer. 1997. The Statistical Sleuth. Duxbury Press, Pacific Grove, California. 742 pp.

Spinelli, R. and B. Hartsough. 2003. Thinning with the Valmet 500T steep-terrain harvester. *In:* Austro2003: High Tech Forest Operations for Mountainous Terrain, October 5–9, 2003, Schlaegl-Austria. 9 pp.

Spinelli, R., P. M. Owende, and S. M. Ward. 2002. Productivity and cost of CTL harvesting of *Eucalyptus globolus* stands using excavator-based harvesters. *Forest Prod. J*. 52(1):67–77.

Spinelli, R. and R. Spinelli. 2000. L'allestimento meccanizzato del ceduo di castagno [Mechanical cross-cutting in chestnut coppice]. *Monti Boschi* 51(1):36–42.

Spinelli, R. and R. Visser. 2008. Analyzing and estimating delays in harvester operations. *Int. J. Forest Eng*. 19(1):35–40.

Stampfer, K. and T. Steinmüller. 2004. Leistungsdaten Valmet 911.1 X3 M [Productivity values of Valmet 911.1 X3 M]. http://www.wabo.boku.ac.at/uploads/media/snake_fpp_endbericht.pdf. Accessed February 2, 2011.

State Forest Agency (SFA). 2008. Annual reports: 1995–2007. SFA, Sofia, Bulgaria.

State Statistical Office of Macedonia (SSORM). 2004. Statistical review: Agriculture, 5.4.03 504 Forestry, 1997–2004. SSORM, Skopje.

Stocker, R. 1999. Mechanical harvesting of *Melaleuca quinquenervia* in Lake Okeechobee, Florida. *Ecol. Eng*. 12(3/4):373–386.

Suchomel, C. and W. Konold. 2008. Niederwald als Energiequelle—Chancen und Grenzen aus Sicht des Naturschutzes [Coppice as source for energy—Chances and borders from a nature conservation view]. *Ber. Naturforsch. Ges. Freibg. Breisgau* 98(1):61–119.

Vacik, H., T. Zlatanov, P. Trajkov, and S. Dekanic. 2009. Role of coppice forests in maintaining forest biodiversity. *Silva Balcanica* 10(1):35–45.

http://prime-pdf-watermark.prime-prod.pubfactory.com/ | 2024-12-26