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The Impact of Season on Productivity and Time Consumption in Timber Harvesting from Young Alder Stands in Lowland Poland

Witold Grzywiński [1,*], Rafał Turowski [2], Bartłomiej Naskrent [1], Tomasz Jelonek [1] and Arkadiusz Tomczak [1]

[1] Faculty of Forestry and Wood Technology, Poznań University of Life Sciences, 60-637 Poznań, Poland; bartlomiej.naskrent@up.poczta.pl (B.N.); tomasz.jelonek@up.poznan.pl (T.J.); arkadiusz.tomczak@up.poznan.pl (A.T.)

[2] Płaska Forest District, 16-326 Płaska, Poland; rafal.turowski@bialystok.lasy.gov.pl

* Correspondence: witold.grzywinski@up.poznan.pl; Tel.: +48-61-848-75-88

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Abstract: The purpose of this study was to establish the impact of season on productivity, labour consumption, and working time structure during timber harvesting from young alder stands (*Alnus glutinosa* Gaertn.). An early thinning process was performed in summer and winter in pure alder stands (38 and 40 years old) in the Płaska Forest Division (NE Poland). The felling and processing operations were performed by experienced loggers using the cut-to-length (CTL) system, and forwarding with manual loading and unloading involved the use of a Zetor 7045 (65 HP) farming tractor and trailer. In both summer and winter, the loggers spent most of their labour time on felling trees (approx. 23%) and bucking (approx. 36%). Assistant loggers spent most of their time stacking logs (49.2% in summer and 58% in winter). The most time-consuming activities in forwarding were loading, unloading, and transportation. The average time consumption of tree felling and processing amounted to 0.36 ± 0.11 h/m^3; that of forwarding was lower, at 0.24 ± 0.07 h/m^3. No statistically significant differences in the labour consumption of tree felling were identified between winter and summer (p = 0.863). For forwarding, labour consumption was significantly higher in winter (0.28 h/m^3) than in summer (0.19 h/m^3, p = 0.001). Average productivity was 3.02 ± 1.09 m^3/h for tree felling and 4.76 ± 1.80 m^3/h for forwarding. The productivity of felling was similar in winter (2.83 m^3/h) and in summer (3.22 m^3/h). For forwarding, productivity was significantly higher in summer (5.70 m^3/h) than in winter (3.81 m^3/h, p < 0.01).

Keywords: *Alnus glutinosa*; commercial thinning; season of timber harvesting; productivity; time consumption; time study; working time structure

1. Introduction

Chainsaws are a commonly used tool in timber harvesting [1]. This is mainly due to the low cost of purchase, ease of maintenance, and ease of use [2]. Despite the gradually increasing proportion of fully mechanised harvesting, approximately 80% of Polish timber is still harvested with chainsaws [3]. However, the demand for timber continues to grow, driven by rapid economic development [4,5]. This requires innovative and more productive technology, ensuring rapid and safe harvesting of considerable volumes of material. The timber harvesting process is complex and involves multiple factors beyond human control. Pentti [6] and Silayo and Migunga [7] list the following among the factors having an impact on productivity and time consumption in the timber harvesting process: age, species composition, volume of trees and stands, site type, terrain characteristics, and weather conditions in the timber harvesting process. According to Hiesl and Benjamin [8], the configuration of the equipment and the operator's experience are also important factors.

Alder stands (the black alder *Alnus glutinosa* Gaertn. and the grey alder *A. incana* (L.) Moench) constitute approximately 5.9% of Poland's forests [9]. Alder timber has numerous uses and is relatively inexpensive. It is an excellent material for use in the furniture industry and in carpentry [10]. It is also valued and in high demand as a fuel wood [11], smoking wood [12,13], and wood used for the production of charcoal [14].

There is little information on productivity and labour consumption in the harvesting of timber from alder stands subject to thinning. The reason for this is the presence of alder stands in wetlands, which significantly hinders timber harvesting [15]. In many cases, the potential for using heavy multipurpose machinery is restricted by difficult terrain conditions. Bembenek et al. [16] reports that winters without snow and autumn rainfall can cause a shortening of the period in which it is possible to use forest machines, especially in stands with low load-bearing capacity. According to Grzywiński et al. [15], it is particularly important to select the right season, technology, and work organisation, which can significantly reduce environmental damage. The use of large and heavy machines, such as skidders and forwarders, may contribute to soil compaction [17], and later to erosion and ruts, especially visible on skidding trails [18]. Additionally, incorrectly planned skidding operations can increase costs and reduce the value of timber [19]. It may be expected that motor–manual technology will continue to be the dominant method of harvesting timber in alder stands.

Many researchers have conducted research on timber harvesting in intermediate coniferous stands [20–28]. These studies concern mainly the impact of the age of the stand on the productivity of logging. Alder stands were researched by Gałęzia [29], who studied the time required for work tasks, fuel consumption, and carbon dioxide emissions during timber harvesting from the Augustów Primeval Forest (NE Poland). The increasing use of forest harvesters for the harvesting of broadleaf species of wood has been a subject of interest for many researchers. Liepiņš et al. [30] compared the effectiveness of mechanised and motor–manual harvesting of grey alder (*Alnus incana* (L.) Moench). Karaszewski et al. [31] considered the potential for using harvesters in the logging of alder stands, but the main purpose of the research was to determine the level of damage and loss of wood. Because timber skidding on marshland is very difficult, Sosnowski and Kaczorowski [32] studied the usefulness of cable logging in timber harvesting from marshlands, which can be an alternative to ground-based timber extraction.

Time consumption and working time structure are important aspects of the study of timber harvesting, as they provide information on the time taken by workers to perform particular tasks. According to Sowa and Szewczyk [33], this information can be useful in planning technological processes, and evaluating technological operations. It also helps choose the right technology to increase labour efficiency.

Working time structure has been studied by numerous researchers, because working time consumption depends on many factors. Câmpu and Ciubotaru [34] and Ciubotaru and Câmpu [35] studied timber harvesting using chainsaws in Carpathian mountain stands. Wójcik and Petrów [36] investigated the impact of loggers' experience on productivity and labour consumption during the harvesting of timber from mature stands. Lindroos [37], in turn, studied the impact of mechanisation on time consumption during logging for firewood. Naskrent et al. [28] studied the labour time required for forwarding from pine stands subject to thinning, using a farming tractor with a forest trailer and crane, noting a significant dependence of time consumption on the distance of timber skidding. Additionally, Behjou [38], in research on working time structure in timber skidding with the use of a Timberjack 450C skidder in mountain stands in northern Iran, showed a significant influence of the skidding distance and the winching distance on the duration of the operation. In turn, Pszenny et al. [39] conducted similar research involving so-called snapshot surveys.

Studies of the influence of season on timber harvesting are mainly concerned with the occurrence of damage in the stands [15,40–42]. Surprisingly, there is little research on the impact of season on the productivity and time consumption of timber harvesting. Chmielewski and Porter [25] studied the effectiveness parameters of timber harvesting using two methods (cut-to length—CTL and length-to-cut—LTC) in the thinning of pine stands in winter and summer.

The purpose of the present study was to fill the existing gap and to increase knowledge about the impact of season on productivity and time consumption in timber harvesting from young alder stands subject to thinning.

2. Materials and Methods

2.1. Study Area

The research was conducted in the Płaska Forest District, Okop Forest Division (Regional Directorate of State Forests in Białystok, NE Poland). The survey area was located in two adjacent forest compartments (101h and 132c) in pure alder stands growing on a typical marshy alder forest site. Both stands were located in flat areas. The selected stands were aged 38 (101h) and 40 (132c) years, originated from planting, and presented moderate canopy closure. The average tree height was 18.0 m (101h) and 17.0 m (132c). The average diameter at breast height in both stands was 15 cm. The mean volume of timber was 249 m^3/ha in compartment 101h and 241 m^3/ha in compartment 132c [43].

A total of 24 square survey plots were established, with side length 50 m and area 0.25 ha. The survey plots were numbered according to the order in which work was performed within them. The limits of the working plots were marked on trees which were not a part of the study area. A skid trail was designated on each plot, running through the middle and along the border (Figure 1). The distance between the skid trails was 25 m.

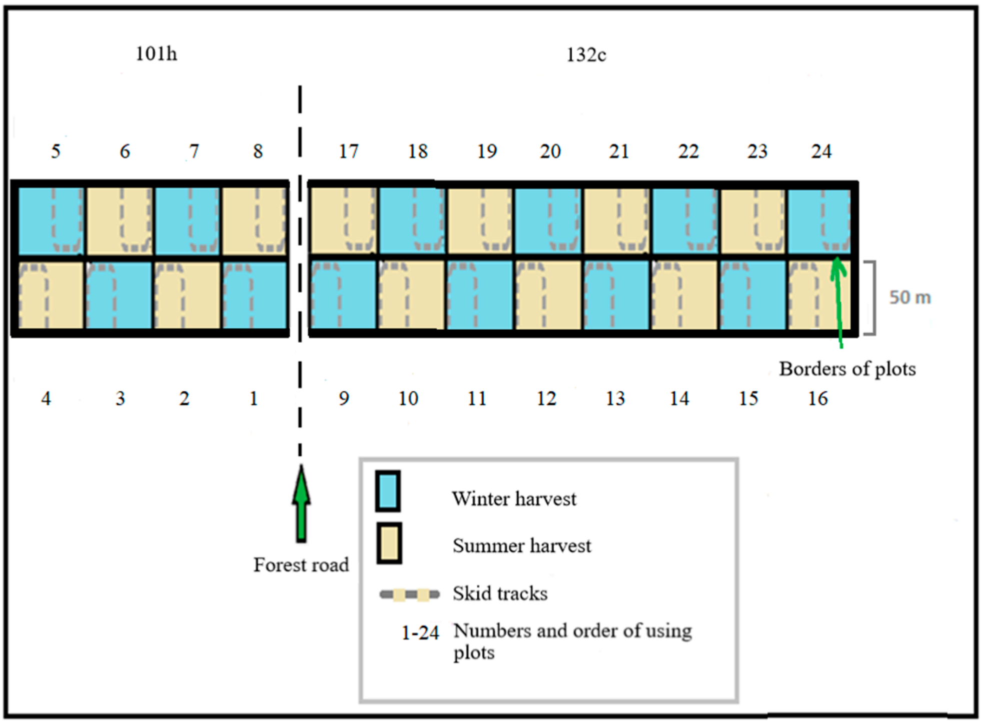

Figure 1. Scheme of research plot set-up [28].

2.2. Description of the Timber Harvesting Operation

The study concerned felling and forwarding during early thinning—it was the first commercial thinning in these stands. The process was carried out using the cut-to-length method. Timber harvesting consisted of tree felling with chainsaws (Makita DCS520-45 and Makita EA5000P38D), delimbing, and bucking into logs with lengths of 1.2 and 2.5 m. Forwarding involved the use of a Zetor

7045 (65 HP) farming tractor and a trailer. The loading and unloading operations were performed manually. The distance between the place of forwarding and the landing location ranged between 270 and 820 m (545 m on average) in both seasons. The thinning intensity was 13.12% of stand volume.

Two teams of two persons worked simultaneously in the survey areas during both felling and forwarding. Felling and processing were conducted by two qualified and experienced loggers with their assistants, who subsequently carried out forwarding of the timber.

The timber harvesting process in the survey areas was conducted in an alternating system. Half of the plots were in use in winter (January) and half in summer (August). In winter, the timber harvesting operations were performed on frozen ground (the air temperature was between –17.6 and –5.6 °C) with a snow layer with an average thickness of approximately 32 cm. Summertime work was performed in August when the groundwater level was low enough for harvesting.

2.3. Study Procedure

The timber harvesting operations in the individual study plots were recorded on video in both of the study seasons. Video recordings were used to establish the duration of particular tasks during felling and processing, and of forwarding in individual plots, as well as the working time structure for the particular jobs: logger, assistant logger, loader/tractor driver, and assistant loader. The mean working time and mean volume of harvested timber were used to calculate the productivity and labour consumption of the felling and forwarding operations, separately for summer and winter.

Working tasks were defined for particular jobs in order to determine their duration (Table 1). Subsequently, with an accuracy to one second, the unit durations of the defined tasks in individual study plots were determined by analysis of the recordings, and average values were calculated for particular operations and seasons.

Table 1. Particular working tasks for the studied jobs.

Tasks	Definitions
Logger and Assistant Logger	
Felling	Time from the start of the undercut to the fall of the tree
Delimbing	Time from the start of cutting the first branch to the cutting off of the top
Bucking	Time from the start of the first log cut to the end of the last cut
Skid trail preparation	Time from the start of removing branches and undergrowth from the skid trail to the start of another task
Transition	Time to move to the next tree or task
Technological break	Time of waiting to perform another task (e.g., waiting of feller's assistant for the fall of a cut tree)
Maintenance time	Time of maintenance of the machine (e.g., fuel filling, sharpening of chainsaw)
Piling up of wood	Time from the start of the piling up of wood to the last log being laid
Felling assistance	Time from the start of the undercut to the start of the fall of the tree
Loader and Assistant Loader	
Empty run transport	Time of the run from the landing site to the loading place
Timber loading	Time from the taking of the first log to the finishing of loading
Full load transport	Time of the run of the loaded machine to the place of unloading
Timber unloading	Time from the taking of the first log to the finishing of unloading
Maintenance time	Time from start to finish of maintenance of the machine
Transition	Time to move from one log to another during loading or unloading operations

Calculation of the basic measures of process efficiency and productivity requires as a parameter the volume of harvested timber, which was determined by a forestry employee according to the standards enforced by State Forests National Forest Holding.

2.4. Statistical Analyses

Statistical analyses using the nonparametric Mann–Whitney U test were conducted to establish whether the time required to perform the individual tasks associated with each operation differed between winter and summer. A Student's *t*-test was applied to establish differences in productivity and labour consumption between the two seasons. Statistical analyses were carried out for each individual repetition of the performed tasks.

3. Results

3.1. Time Consumption

The time required for felling, delimbing, and bucking in individual study plots ranged from 2.07 h (summer) and 2.16 h (winter) to 3.87 h in both summer and winter. The time of forwarding was between 1.17 and 3.10 h in winter and between 1.18 and 1.69 h in summer. On average, almost 11 h per hectare were needed for felling and processing, while the average time for forwarding from 1 ha was slightly over 7 hours.

The average time required for felling and processing in a survey plot (0.25 ha) is presented in Table 2. No statistically significant differences between summer and winter were identified in the time required for tree felling and processing. Forwarding was found to require significantly more time in winter than in summer ($p < 0.01$).

Table 2. Effectiveness characteristics of timber harvesting operations.

Operation	Season	Mean (s)	Standard Deviation	Z Test	*p*-Value
Time consumption (h/0.25 ha)					
Felling	Winter	2.67	0.46	0.68	0.503
	Summer	2.81	0.57		
Forwarding	Winter	2.09	0.63	3.10	0.009 **
	Summer	1.51	0.15		
Labour consumption (h/m^3)					
Felling	Winter	0.37	0.08	0.17	0.863
	Summer	0.36	0.13		
Forwarding	Winter	0.28	0.07	3.87	0.001 **
	Summer	0.19	0.05		
Productivity (m^3/h)					
Felling	Winter	2.83	0.54	0.87	0.402
	Summer	3.22	1.46		
Forwarding	Winter	3.81	1.22	2.96	0.007 **
	Summer	5.70	1.84		

** Differences are statistically significant at $p < 0.01$.

3.2. Structure of Working Tasks

The percentage shares of the particular tasks accounting for the overall timber harvesting process defined for the studied jobs (logger, assistant logger, loader/tractor driver, assistant loader) are presented in Figures 2 and 3.

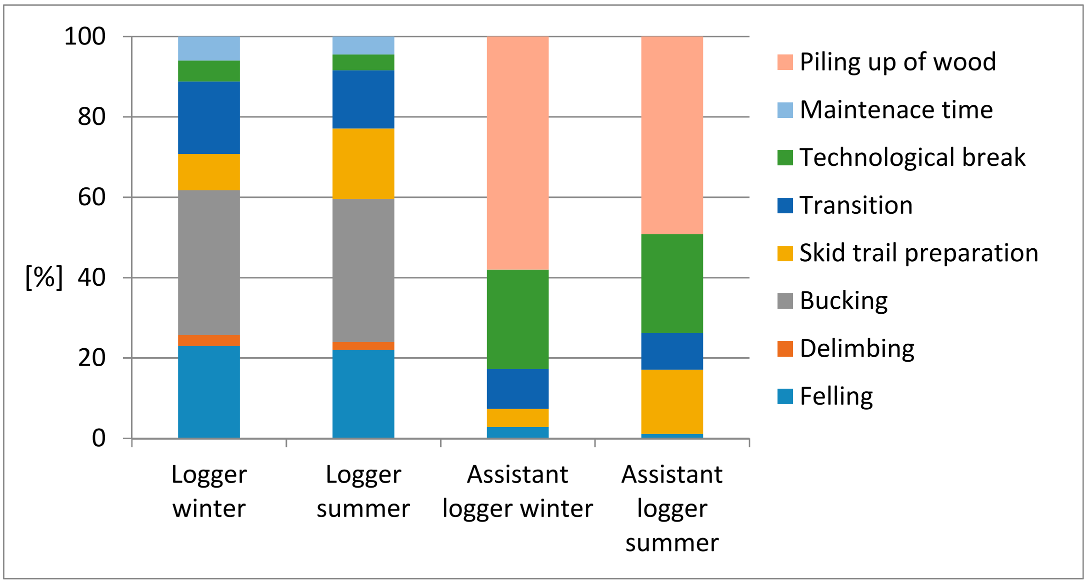

Figure 2. Percentage shares of particular working tasks of loggers and assistant loggers.

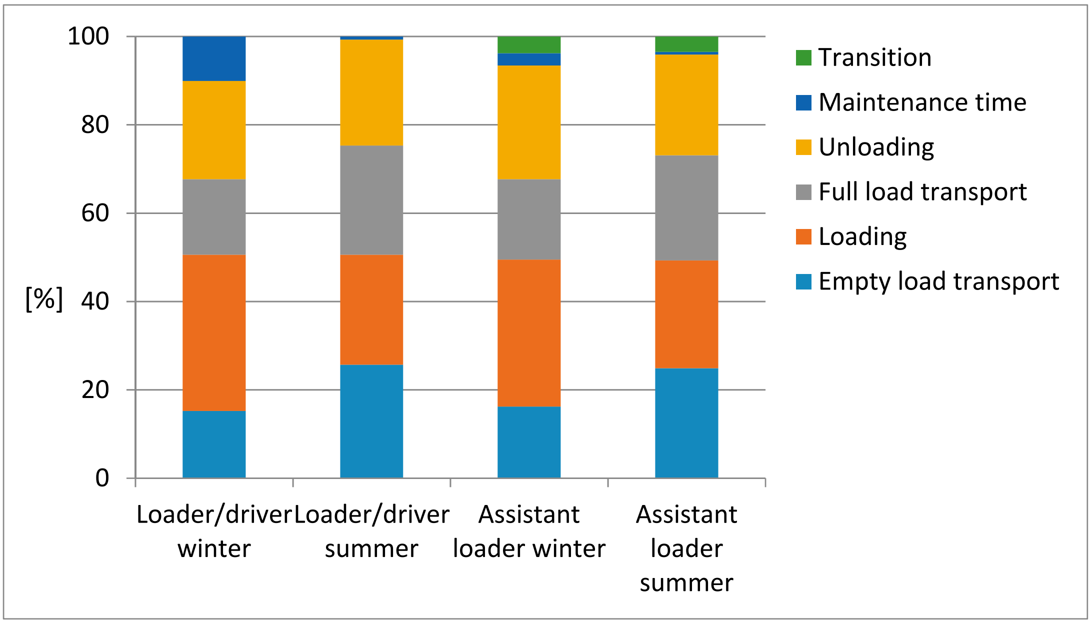

Figure 3. Percentage shares of particular working tasks of loaders and assistant loaders.

For loggers, tree felling, delimbing, and transitions from tree to tree took significantly more time in winter than in summer ($p < 0.05$) (Table 3). For assistant loggers, assistance in tree felling required significantly more time in winter than in summer ($p < 0.001$) (Table 4). The preparation of skid trails was considerably longer in summer than in winter: almost twice as long in the case of loggers, and almost four times as long in the case of assistant loggers ($p < 0.001$).

Table 3. Duration of particular working tasks of loggers.

Task	Season	Mean (s)	Standard Deviation	Z Test	*p*-Value
Felling	Winter	1702	220.12	1.99	0.045 *
	Summer	1477	280.91		
Delimbing	Winter	201	85.40	2.11	0.033 *
	Summer	135	74.23		
Bucking	Winter	2657	366.56	1.67	0.101
	Summer	2383	386.31		
Skid trail preparation	Winter	670	326.43	3.35	<0.001 ***
	Summer	1175	314.16		
Transition	Winter	1326	217.23	2.37	0.017 *
	Summer	972	289.74		
Technological break	Winter	385	287.72	1.21	0.242
	Summer	260	220.02		
Maintenance time	Winter	447	198.56	1.88	0.060
	Summer	302	145.35		

* dDifferences are statistically significant at $p < 0.05$; *** differences are statistically significant at $p < 0.001$.

Table 4. Duration of particular working tasks of assistant loggers.

Task	Season	Mean (s)	Standard Deviation	Z Test	*p*-Value
Piling up of wood	Winter	5495	1411.20	0.69	0.514
	Summer	4975	1674.32		
Felling assistance	Winter	268	72.09	3.93	<0.001 ***
	Summer	108	43.46		
Transition	Winter	940	322.40	0.09	0.932
	Summer	918	272.00		
Skid trail preparation	Winter	423	154.55	4.16	<0.001 ***
	Summer	1616	544.54		
Technological break	Winter	2347	946.22	0.17	0.887
	Summer	2503	567.01		

*** Differences are statistically significant at $p < 0.001$.

Statistical analysis of the duration of each individual repetition of the tasks performed showed that statistically significant differences in the time required for timber extraction tasks in summer and winter were recorded for the jobs of loader/tractor driver and assistant loader (Tables 5 and 6). In winter, timber loading and unloading by the tractor driver took much longer than in summer ($p < 0.001$). For the assistant, similarly, timber loading ($p < 0.05$) and unloading ($p < 0.001$) required more time in winter than in summer. The tractor driver also needed significantly more time for maintenance in winter than in the summer season ($p < 0.01$).

Table 5. Duration of particular working tasks of loader/tractor drivers.

Task	Season	Mean (s)	Standard Deviation	Z Test	p-Value
Empty run transport	Winter	1266	362.60	0.56	0.616
	Summer	1346	365.45		
Timber loading	Winter	2927	695.02	3.37	<0.001 ***
	Summer	1304	169.86		
Full load transport	Winter	1422	625.33	0.37	0.750
	Summer	1294	157.63		
Timber unloading	Winter	1847	494.73	3.19	<0.001 ***
	Summer	1232	134.56		
Maintenance time	Winter	840	761.98	2.80	0.007 **
	Summer	37	59.01		

** Differences are statistically significant at $p < 0.01$; *** differences are statistically significant at $p < 0.001$.

Table 6. Duration of particular working tasks of assistant loaders.

Task	Season	Mean (s)	Standard Deviation	Z Test	p-Value
Empty run transport	Winter	1266	362.60	0.56	0.616
	Summer	1346	365.45		
Timber loading	Winter	2606	1293.54	2.25	0.024 *
	Summer	1322	172.89		
Full load transport	Winter	1422	625.26	0.37	0.750
	Summer	1294	157.63		
Timber unloading	Winter	2004	449.22	3.37	<0.001 ***
	Summer	1239	122.74		
Transition	Winter	296	64.35	1.92	0.053
	Summer	187	107.94		
Maintenance time	Winter	216	192.38	1.90	0.083
	Summer	33	43.75		

* Differences are statistically significant at $p < 0.05$; *** differences are statistically significant at $p < 0.001$.

3.3. Labour Consumption

The average labour consumption of tree felling and processing was 0.36 ± 0.11 h/m^3 (0.27–0.53 h/m^3 in winter, 0.14–0.64 h/m^3 in summer). The average value of this parameter for forwarding was lower, at 0.24 ± 0.07 h/m^3. The labour consumption of extraction in individual survey plots ranged between 0.15 and 0.37 h/m^3 in winter and between 0.10 and 0.25 h/m^3 in summer.

No statistically significant differences in the labour consumption of tree felling and processing were identified between winter and summer (p = 0.863). The value was similar in both seasons (Table 2). The time consumption of forwarding was significantly higher in winter (0.28 h/m^3) than in summer (0.19 h/m^3, p = 0.001).

3.4. Productivity

The average productivity of tree felling and processing amounted to 3.02 ± 1.09 m^3/h (1.89–3.71 m^3/h in winter, 1.57–6.93 m^3/h in summer). The average productivity of forwarding amounted to 4.76 ± 1.80 m^3/h, and was higher than the average productivity of tree felling. Extraction productivity ranged between 2.69 and 6.51 m^3/h in winter and between 3.95 and 10.42 m^3/h in summer.

The productivity of felling and processing in winter (2.83 m^3/h) did not differ significantly from the corresponding value in summer (3.22 m^3/h) (Table 2). For forwarding, the productivity in summer (5.70 m^3/h) was significantly higher than in winter (3.81 m^3/h, $p < 0.01$).

4. Discussion

According to the analysis of loggers' specific tasks, there were significant differences between winter and summer in the times required for tree felling, delimbing, and transitions from tree to tree. These tasks lasted considerably longer in winter. The presence of snow cover played a significant role in increasing the duration of these tasks, as it affected the speed of particular actions, especially transition. The low temperatures may also have been a factor. Perhaps frozen timber is harder to cut, which may have increased the processing time, though no marked difference was recorded in the time required for timber bucking in winter and summer.

Tree felling, delimbing, and bucking per hectare of alder stands subject to thinning required much more time (11 h on average) than the extraction of the processed timber harvested from the same area (7 h/ha). Chmielewski and Porter [25] obtained similar results for early thinning of pine stands using the cut-to-length method. They concluded that the tree felling, delimbing, and bucking processes required more time than forwarding in both winter and summer, with an extraction distance of 200 m.

The labour consumption of timber harvesting from the analysed alder stands subject to thinning was 0.60 h/m^3. The tree felling and processing operations required more labour (0.36 h/m^3 on average) than forwarding (0.24 h/m^3). It is interesting to note that the time consumption of felling and processing during early thinning in the alder stands was practically the same irrespective of season. For forwarding, the labour consumption in winter was almost 50% higher than in summer. This was probably caused by the thick snow cover in winter, which impeded movement during loading and unloading of the trailer—these being the main tasks during forwarding (Tables 5 and 6).

In the studied alder stands, the average time consumption of forwarding was 0.24 h/m^3, which is almost 15 min/m^3. In an analysis of extraction using a horse in the early thinning of pine, beech, fir, and spruce stands, Szewczyk [23] obtained a result of 15.56 min/m^3 on average with a maximum extraction distance 50 m. The values for individual species ranged from 10.79 min/m^3 for spruce to 22.05 min/m^3 for beech. The author ruled out the possibility that the species of tree harvested is the only factor affecting time consumption, and established that the differences resulted more from the stand and timber characteristics (tree density, volume per ha, branching) of each of the aforementioned species.

In a study of cut-to-length forwarding in pine stands using a farming tractor and forest trailer with a crane, Naskrent et al. [28] measured time consumption at 6.55 min/m^3 in 54- and 61-year-old stands, with an average skidding distance of 690 m, and 5.48 min/m^3 in 74–75-year-old stands, with an average skidding distance of 874 m. According to Manner et al. [44], the productivity and time consumption of extraction may be affected by numerous factors, including the extraction method and distance or the concentration of logs.

Molendowski [45] presented arguments to show that the site type is the determining factor for values of economic indices for timber harvesting. His research, which included five types of mountain forest site, indicated that the time consumption of timber harvesting increases as the fertility of the site increases. The lowest index was obtained for the lowest-grade mixed mountain woods, while the highest was obtained in sites of mountain forest type, the most fertile of those analysed. The higher labour consumption on fertile sites may result from the greater level of moisture and lush vegetation in the lower forest layers, which unquestionably hinders the forwarding process. Since alder forests are of this type, this may be one of the factors which had an impact on the high time consumption of timber harvesting from the studied alder stands.

The reverse of labour consumption is productivity. In the present study, the average productivity of tree felling and processing was 3.02 m^3/h, and the productivity of forwarding was 4.76 m^3/h. Season had an effect only on the productivity of forwarding, which was almost 2 m^3/h lower in winter than in summer. The productivity of felling and processing was similar in summer and in winter. In productivity, we can observe the highest variability of values for forwarding as well as felling operations. This is the result of differences in the volume of timber harvested from particular plots, though the studied stands were quite homogenous.

These productivity results are higher than those obtained by Chmielewski and Porter [25] for cut-to-length timber in both felling and forwarding, despite the fact that those authors conducted their research in age class three (41–60-year-old) pine stands on a mixed fresh forest site. Similar patterns were noted in the analysis of the impact of season on timber harvesting. Most likely, the decisive factor in the lower productivity in pine stands was the fact that it takes more time to delimb a pine trunk than an alder trunk.

In an investigation of extraction using sets of skidding equipment, Spinelli et al. [46] measured the productivity at 13.4 m^3/h in eucalyptus plantations, with an average forwarding distance for a tractor with a trailer of 174 m, and 6.8 m^3/h in mountain stands [47]. Gülci et al. [48] carried out research on forwarding with manual loading and electric winch loading in Turkey, and obtained results of 3.40 m^3/h with manual loading and 4.25 m^3/h with electric winch loading. In turn, Kaakkurivaara and Kaakkurivaara [49] conducted research on steep slopes in Thailand concerning timber extraction using manpower, mules, and a log chute. They recorded productivity of 2.29 m^3/h for the log chute, 0.45 m^3/h for mules, and 0.30 m^3/h for manpower.

The results obtained suggest that—in terms of the aspects analysed—it is preferable to harvest timber from alder stands in summer. Arguments for this include the lower time consumption and higher productivity obtained in summer, especially in the case of forwarding. As there are more and more winters without heavy and lasting frost or snow cover, it may be expected that alder stands will be more accessible for harvesting in summer than in winter. Drier summers may also make alder stands more and more accessible for mechanised timber harvesting technologies. Knowledge on the influence of season on timber harvesting effectiveness in stands of other tree species and during different types of cutting is still very poor, and so further research in this area is suggested.

5. Conclusions

1. More time was found to be required for tree felling, delimbing, and bucking than for forwarding. The time taken for forwarding was significantly higher in winter than in summer. The time required for felling and processing was comparable in the two seasons.

2. The dominant task in a logger's work was timber bucking. For an assistant logger, the dominant task was preparing short wood for extraction. For loaders, there was no dominant task.

3. Season had an impact on the duration of individual tasks. For loggers, the times required for tree felling, delimbing, and transition were significantly higher in winter, while the proportion of time spent on the preparation of skid trails was higher in summer. For assistant loggers, assistance in tree felling took more time in winter, and the preparation of skid trails took more time in summer. For loaders, timber loading and unloading times were significantly longer in winter.

4. The average time consumption of tree felling and processing was higher than that of forwarding. The season had no effect on the labour consumption of felling and processing, while the labour consumption of forwarding was significantly higher in winter.

5. The season had a significant impact on the productivity of forwarding, which was higher in summer than in winter. For tree felling and processing, productivity was similar in both seasons.

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