

of comparison with Central Europe, the project could be complemented by attitudes of forestry workers from North European countries. We would ask for a grant within the European Union.

This paper was elaborated and published thanks to the financial support of the research objective of the Mendel University of Agriculture and Forestry "Sustainable forests and landscape management – from concept to realisation", identification number CEZ: MSM434100005, interim task No.13 "Perception of forest environment as a condition for proper work with the environmentally friendly technologies".

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ANALYSIS OF INJURIES OCCURRING IN TREES AS A RESULT OF TIMBER HARVESTING

The research was located in three regions of southern Poland which differ in their topographical features and, consequently, in the degree of accessibility of tree stands. Harvesting was carried out in coniferous and deciduous stands, composed of the main forest species: pine in the lowlands; spruce, fir and beech in the uplands. The technologies used for this research were characteristic of the above-mentioned regions, where difficult topographical conditions, limited access to stands and insufficient equipment of workers who carry out harvesting for the state forests make fully mechanized work difficult. Considering the degree of work mechanization, the technologies used were manual-mechanized [4]. The latter technology applied manual labour for most activities, including the stage of logging.

Keywords: manual-mechanized timber harvesting, tree injuries.

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Аналіз пошкоджень дерев, спричинених лісозаготівельною діяльністю

Дослідження проводилося в трьох регіонах південної Польщі, що різняться своїми топографічними особливостями і ступенем доступності лісових масивів.

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Лісозаготівля здійснювалася в хвойних та листяних лісах, головні породи яких склали: сосна – в низинах; смерека, ялиця і бук – в гористій місцевості. Згадані вище умови не давали змоги повністю механізувати виконання лісозаготівельних технологічних операцій. Мета дослідження полягає в визначенні і порівнянні кількісних та якісних характеристик пошкоджень дерев внаслідок застосування ручних чи машинних способів лісозаготівлі.

Ключові слова: ручний і машинний спосіб лісозаготівлі, пошкодження дерев.

Introduction, aim and scope of research

Timber harvesting has always caused and will always cause damage in the forest environment. Such damage is practically unavoidable. It occurs in every layer of the stand, from soil and undergrowth, through the supling layer, both natural and influenced by man, to mature trees.

The present paper presents selected results of several years' research conducted in the Department of Forest and Wood Utilization, Agricultural University of Cracow. The aim of the research was to try to determine and compare injuries occurring on trees as a result of the use of manual and mechanical technologies within two systems of timber harvesting in varying physiographical conditions.

The scope comprised the quantitative and qualitative character of damage, including the so-called 'more severe damage', occurring on standing trees which remained after cutting which was carried out at the height of the vegetation season. What is understood by 'more severe damage' is low injuries, reaching up to 0.1 m on the tree stem, large injuries with an area of over 100 cm² or occupying over 1/8 of the stem diameter in the affected place, as well as deep injuries in which wood tissue has been broken [2, 7, 11]. Such injuries are considered to be particularly dangerous because they are characterized by the greatest likelihood of an infection and the development of fungi causing discolouration and rot [11].

The first stage of field research was conducted in typically mountainous conditions in the forest district of Jeleśnia, which has the highest located commercial forest stands in Poland. Moreover, due to a very similar character of the accessibility of stands and similar topographical characteristics, part of the research concerning the mountainous region was carried out in the Forest Experimental Station in Krynica. The second stage was conducted in the upland region, in the forest district of Gromnik. The third one was carried out in the typically lowland part of the forest district of Krzeszowice.

In each of the regions of southern Poland the research was located in three mature stands in which late thinnings were planned as well as in three stands in which early thinning was to be performed. This was the method of selecting 27 plots, 9 of which were located in the mountainous region, another 9 in the uplands and 9 in the lowlands.

Harvesting was carried out by means of basic processing technologies using various technological means. Differences between these means concern mainly the performance of logging because the stages of cutting, felling, delimbing and cross-cutting were performed using the chain saw. The basic logging means were the horse and the farm tractor adapted in various ways to work in the forest as well as the specialist logging tractor of the 'skidder' type. Logging was performed

using the horse or the farm tractor with logs being hauled or fully suspended (in all stands designed for early thinnings in the lowland region). The specialist cable skidder performed logging by means of a collecting rope with logs being half-suspended. Each time logging was a single stage operation. Technical means used in its course moved over whole sample plots. In rather few cases, the already existing old operational tracks were used. In the course of the field research, it was not observed that felling areas had been made accessible prior to logging by preparing technological tracks.

On the basis of the classification which is commonly used in Poland [4, 9, 10] and taking into consideration the order in which particular technological operations were performed in field, two basic systems of timber harvesting were distinguished. The first one is the so-called short wood system (SWS), which consists in performing all activities after felling the tree, i.e. delimbing, manipulation and cross-cutting immediately on the spot in the stand, and then logging such already prepared sections of timber towards operational tracks and to timber yards. The other system used was the length wood system (LWS). As opposed to the SWS system, here all activities which remained to be done after felling, delimbing and cutting off the tree top at the diameter of 7 cm over bark were performed after the whole log had been transported to the track or to the timber yard.

Methods of field research

Field research was carried out in two stages. The first one consisted in laying out a network of squares with sides of 25m each. At the nodes of the network were set up permanent, well marked, circular sample plots with the diameter of 5.64 m and the area of 1 are. Altogether they comprised 16 % of each hectare of the area under research. The arrangement of circular plots was chosen on the basis of the rules of the statistical and mathematical system of forest inventory-making [8]. After delimiting and marking the network nodes, an inventory was made of all trees, in each circular plot, which exceeded the breast-height diameter of 7 cm. The breast-height diameter of all trees and the height of the trees to be removed was measured in each circular plot.

In the second stage, which followed directly after completing the harvesting, the sizes and quality of damage was estimated. Injuries on all trees remaining on stem were measured as to the height of their location, vertical length and horizontal width. In the cases in which injuries had an irregular shape, measurements of width were taken in places where the parameters varied significantly and the area of an injury was calculated using the arithmetical mean of the measurements taken. For each injury it was also noted whether wood tissue had been damaged or only uncovered.

Methods of calculation

It was assumed that the areas of injuries caused in the course of harvesting would be calculated by means of formulas for the area of an ellipsis or a rectangle, depending on the identified shape of an injury [1]. The girth of stems of a damaged tree at the height of an injury was calculated assuming the normal taper of trees, i.e. 1 cm/1 m and on the basis of the measured breast-height diameter.

The numerical data received in these calculations formed sequences of variables, characterizing tree injuries. Preliminary data analysis included verification of the H_0 hypothesis concerning the accordance of empirical distributions with the normal distribution for the following variables:

- the area of injuries occurring on trees, including their stems and roots;
- the height of location of injuries on stems.

Statistical verification of the above H_0 hypotheses was based on the Shapiro-Wilk's test. Further analysis consisted in the determination of differences between the parameters of injuries resulting from the use of different technologies within the two systems of timber harvesting in varied topographical conditions (categories of area) as well as varied stand conditions (categories of utilisation). The assumed hypothesis was: H_0 : the average values of the areas of injuries and the height of location of injuries on stems are equal (on the significance level $\alpha=0.05$).

It was determined that the t-Student test should be applied to verify H_0 in the case of the accordance of the empirical distributions with the normal distribution. In the case of a lack of accordance, the Mann's-Whitney's U test would be used.

Research results and discussion

The result of field research was the setting up of 291 permanently delimited circular plots in the mountainous region, 357 ones in the upland region and 275 ones in the lowland region. The inventory-making included, altogether, 923 circular plots in 25 stands. Altogether over 7.5 thousand trees were assessed twice in all plots. In the course of harvesting, nearly 1.5 thousand trees were removed and over 400 trees were damaged, which amounts to almost 7 % of all recorded trees. After cutting, almost 10 % of trees in mountainous stands, over 6 % in upland stands and over 3 % in lowland stands were damaged. Over 680 injuries were found on damaged trees, which means on average 2 injuries per each tree. Over 43 % of all injuries were the 'more severe' ones, almost $\frac{2}{3}$ of which occurred in mountainous stands. Among the 'more severe' injuries, the large ones, with an area of over 100 cm² or the ones which occupied over $\frac{1}{8}$ of the tree's girth in the affected place, were the most common and occurred also mostly in the mountains. The results are presented in table 1.

Table 1. Structure of tree injuries depending on the category of area [items (%)]

Number of recorded trees in circular plots after cuttings – 6244 (100)		
lowland	upland	mountains
1903 (30,5)	1863 (29,8)	2478 (39,7)
Number of injured trees – 424 (6,8)		
62 (3,3)	122 (6,5)	240 (9,7)
Number of recorded injuries – 868 (100)		
127 (14,6)	239 (27,5)	502 (57,9)
Number of recorded 'more severe' injuries (low, deep, large injuries) – 377 (43,5)		
50 (13,3)	102 (27,0)	225 (59,7)
Number of recorded large injuries (over 100 cm ² , over $\frac{1}{8}$ of stem girth) – 317 (84,0)		
36 (11,3)	98 (30,9)	183 (57,8)

Considering the utilisation categories, the largest percentage of injuries (over 10 %) was recorded in mature stands, and the smallest percentage (over 2 %) was found in stands where early thinning were planned. Among 'more severe' injuries, over 80 % occurred in stands belonging to older age classes. The above results are presented in table 2 below.

Similarly to research [3], of all recorded injuries, almost 12 % occurred in roots below 0.1 m, almost $\frac{1}{3}$ occurred between 0 and 0.3 m, and over half of them were found between 0 and 0.5 m. Similar distribution of injuries was noted in the research by [1, 5, 6], who showed that about 50 % of injuries in spruce stands occurs in the root collar of trees.

The results of the Shapiro-Wilk's test did not show any accordance of empirical distributions with the normal distribution in the case of both of the variables under analysis. That is why the non-parametrical Mann's-Whitney's U test was used in order to determine the differences between the average values of the empirical distributions under analysis (cf. table 3).

Table 2. Structure of tree injuries depending on the category of utilization [items (%)]

Number of recorded trees – 6244 (100)		
ET ¹	LT ²	MS ³
2550 (40,8)	2255 (36,1)	1439 (23,1)
Number of injured trees – 424 (6,8)		
61 (2,4)	211 (9,4)	152 (10,6)
Number of recorded injuries – 868 (100)		
127 (14,6)	239 (27,5)	502 (57,9)
Number of recorded 'more severe' injuries (low, deep, large injuries) – 377 (43,5)		
52 (13,8)	174 (46,1)	151 (40,1)
Number of recorded large injuries (over 100 cm ² , over $\frac{1}{8}$ of stem girth) – 317 (84,0)		
38 (12,0)	144 (45,4)	135 (42,6)

¹ ET – stands in which early thinnings were planned; ² LT – stands in which late thinnings were planned; ³ MS – mature stands (group felling and gradual felling)

The results of analyses concerning the comparison of average areas of injuries caused by the use of different technologies within the two systems of timber harvesting allowed for the conclusion that the average area of injuries caused by the use of the technologies involved in the SWS system amounted to 72 cm². Injuries resulting from the use of the technologies in the LWS system had an area of 101 cm². The U test, which was conducted, did not provide any basis for the rejection of the H_0 hypothesis about the equality of average areas of injuries ($Z=1.856$; $p=0.063$). In the case of the average height of location of injuries, the test results ($Z=2.444$; $p=0.014$) justified the rejection of the H_0 . Therefore it should be assumed that the average height of location of injuries occurring in the SWS technology (0.86 m) is significantly higher than the average height of location of injuries in the LWS technology (0.57 m).

The differences noted here may probably result from the use of different logging means because, in logging by means of the horse, the highest located injuries are caused by hitting tree stems with the swingletree whereas in the case of mechanical logging by means of the skidder or the farm tractor injuries resulted al-

so from hitting tree stems with parts of these machines, which are situated higher, or due to scratching with ropes being rolled onto the reels of cable winches.

In the category of area, the average area of injuries ranged from 59 cm² in lowland stands through 78 cm² in upland stands to 95 cm² in mountainous stands. The average height of location of injuries on tree stems ranged from 0.5 m in the mountains, through 1.2 m in the uplands to 0.8 m in the lowlands. The lowest location of injuries in the mountains was probably due to the fact that logging in this region was performed in the form of hauling with the use of the horse. In lower located regions, mechanical logging by means of the tractor or the skidder was possible more frequently. Analysis of the significance of differences between the variables under research in the category of area, presented in table 3, justifies the rejection of the H_0 hypothesis and the conclusion that the differences are statistically significant both in the case of the areas of injuries and in the case of the height of their location on tree stems.

In the category of utilization, analysis of injuries shows that the average area of injuries in mature stands amounted to 140 cm² and was significantly higher than in the stands where thinnings were performed. In late thinnings, the average area of injury was 57 cm² while in early thinnings it was 35 cm². Analysis results, presented in table 3, show that the comparison of differences between the average heights of location of injuries gives no basis for the rejection of the H_0 hypothesis. Therefore it can be concluded that the differences noted here are not statistically significant and that the height of location of injuries in all categories of utilization remains on a comparable level.

Table 3. Results of Mann's-Whitney's U test of significance of differences between variables under analysis (area of injuries and height of their location)

Stands		Variable	n	Z_{emp}	p	H_0
Category of area	lowland ¹	area of injuries	127 / 239 ²	-6,254	0,000	-
	upland ²	height of injuries	127 / 239 ²	-2,586	0,010	-
	lowland	area of injuries	127 / 502	-3,953	0,000	-
	mountainous	height of injuries	127 / 502	4,671	0,000	-
	upland	area of injuries	239 / 502	4,447	0,000	-
	mountainous	height of injuries	239 / 502	8,239	0,000	-
Category of utilization	mature	area of injuries	290 / 481	5,510	0,000	-
	late thinnings	height of injuries	290 / 481	-0,677	0,498	+
	mature	area of injuries	290 / 97	2,073	0,038	-
	early thinnings	height of injuries	290 / 97	0,268	0,789	+
	late thinnings	area of injuries	481 / 97	-2,318	0,021	-
	early thinnings	height of injuries	481 / 97	0,649	0,516	+

code: n – sample dimension, Z_{emp} – value of statistics of normal distribution, p – calculated probability for statistics Z_{emp} , H_0 – zero hypothesis (+ accept; – reject)

The greatest probability of depreciation of timber due to the development of rot of the butt end exists in the case of surface damage of roots, caused both by logging technologies and by the transported log itself. Comparative analysis of average areas of injuries with relation to their location on the tree showed that the significantly larger injuries ($Z=12.216$; $p=0.000$) occurred on roots. The average area of root injuries was 297 cm² whereas the average area of injuries on the tree

stems turned out to be five times smaller (57 cm^2). It must be noted here that the average area of root injuries seems to be very large and is almost four times larger than in research done by other authors [1]. Moreover, over $\frac{3}{4}$ of root injuries were recorded in mountainous stands, half of them in stands which underwent late thinnings. The injured trees will probably not be able to heal such large injuries. It is therefore to be expected that in future rot will develop in them and the most valuable part of their stems will become depreciated and, in consequence, will lose its value. It should be added that, in the course of logging with logs being hauled or half-suspended, no devised or tools such as skidding tongs, skidding cones or fenders were used and none of the trees which were the most exposed to being injured were protected.

For the purpose of summing up, figures 1 and 2 provide graphic representations of the above research results.

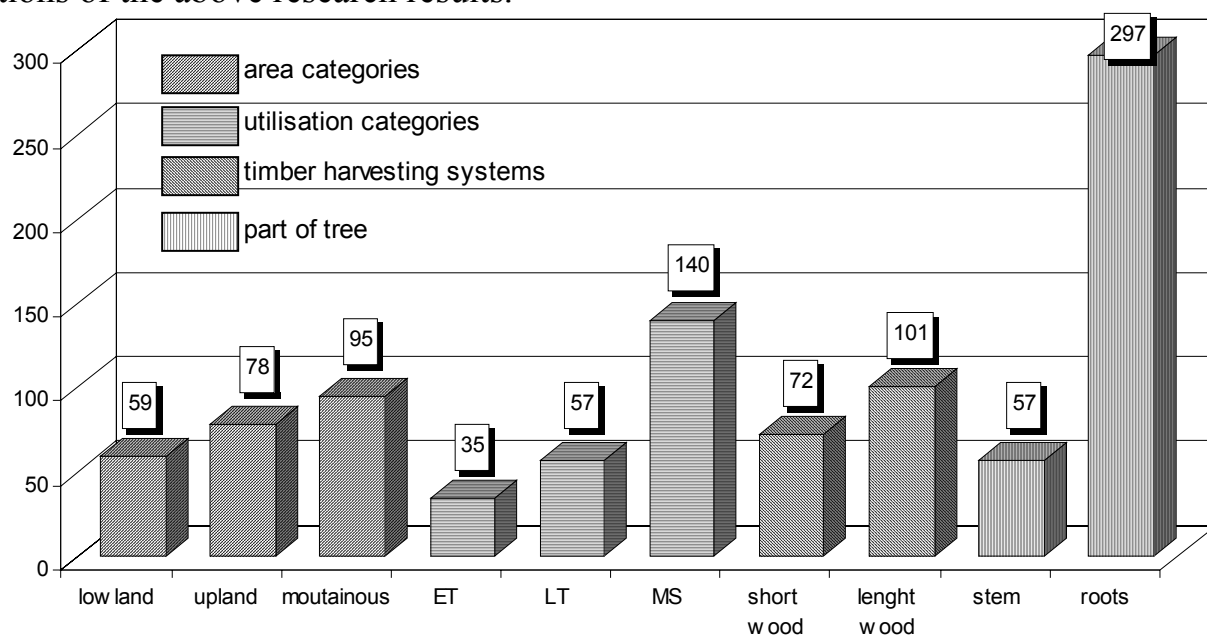


Figure 1. Average areas of injuries [cm^2]

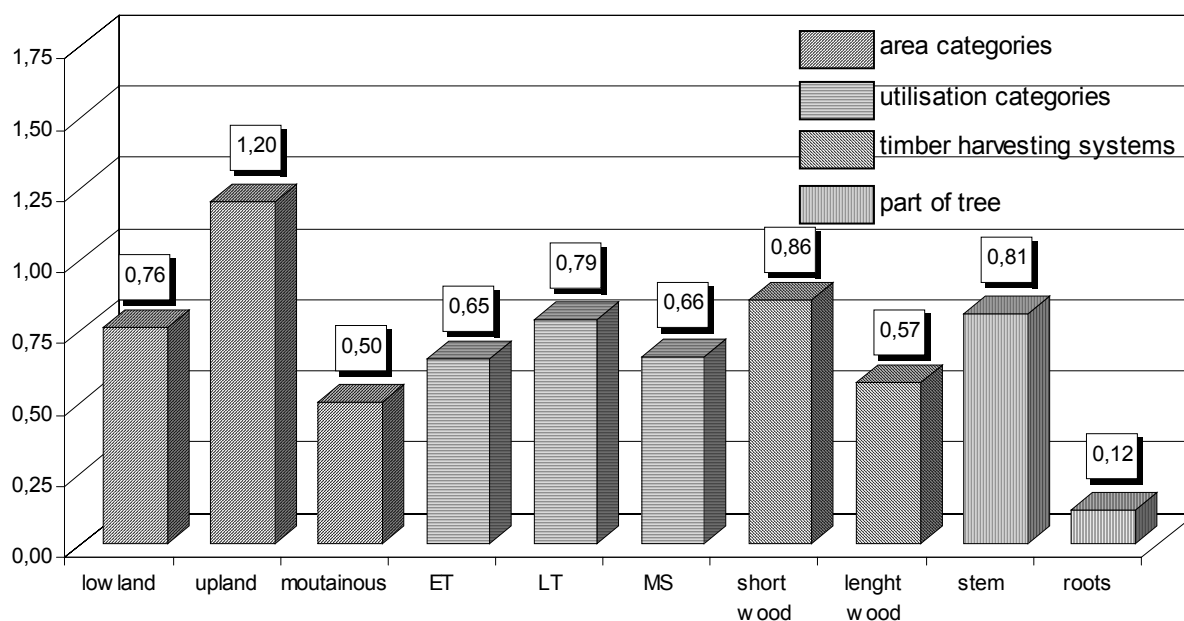


Figure 2. Average height of location of injuries [m]

Conclusions

In the category of area, the highest level of damage was noted in mountainous stands and the lowest in lowland stands. The same tendency was noted for 'more severe' injuries and large injuries.

In the category of utilization, the highest level of damage was noted in mature stands and the lowest in stands where early thinnings were planned. The greatest share of 'more severe' injuries and large injuries in stands where late thinnings were planned was due to the greatest intensity of cutting which, from the point of view of cultivation, is characteristic of stands in middle age classes. In the stands mentioned above, almost $\frac{1}{4}$ of trees were removed while in the remaining younger and older stands the intensity of cutting did not exceed 15-20 %.

A comparison of the influence of timber harvesting in the two work organization systems identified here revealed significant differences in the height of location of injuries on tree stems. The highest location of injuries was recorded in the stands in which the technologies within the short wood system were applied. No significant differences in the average area of injuries were noted between the short wood system and the length wood system.

Injuries which were four times larger, found on roots, constitute an increased threat of infections caused by pathogenes of fungi and reduce the resistance of trees to attacks of harmful insects. They also reveal the need to prepare such harvesting technologies in which, considering conditions in Poland, a harvested log will have a limited contact with the ground or at least its face will not go so deep into the ground. The authors emphasize the necessity to promote the use of additional logging tools such as skidding tongs or cones.

It is supposed that, if stands were made more easily accessible thanks to networks of skidding tracks, the level of damage in the stands would be lower, which is also suggested by other authors [7, 11].

The authors suggest the need to conduct research, based on the methods applied in the present study, in stands where harvesting is performed in a totally mechanized way. It will then be possible to fully compare the influence of the different timber harvesting technologies used in Poland on the level of tree damage, since the data which already exist in the References were collected using different methods of research.

The results presented here show the need to conduct research in all possible area and stand categories using the same methods, which is particularly important because the differences revealed in the level of damage are significant.

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INTEGRATION OF TECHNOLOGY WITH ECONOMICS & ECOLOGY TO ENSURE INTEGRITY OF FOREST ECOSYSTEMS

It may seem farfetched, but it has all the scientific backing that sustainability of forest is synonymous with 'ecosystem approach in its management'. The famous ecologist Odum [1] defined ecosystem approach in forest management as integration of ecology with economics. The author of this paper took Odum's definition further by stating that ecosystem approach in forest management lied in integrating ecology with economics as well as with technology [2]. This paper examines the role of technology in maintaining ecosystem integrity.

Keywords: Ecosystem, Sustainability, Ecology, Economics, Technology

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Інтеграція технології, економіки та екології – гарантія цілісності лісових екосистем

Сталий розвиток лісового середовища є синонімом екосистемного підходу в лісовому господарюванні – це твердження може здаватися надуманим, але водночас воно має наукове підґрунтя. Знаменитий еколог Одум [1] визначив екосистемний підхід в лісовому господарюванні як інтеграцію екології та економіки. Автор статті трактує визначення Одума, що екосистемний підхід в лісовому господарюванні полягає в інтеграції екології, економіки, а також і технології. Окреслюється роль технології в сталому розвитку екосистеми.

Ключові слова: екосистема, сталий розвиток, екологія, економіка, технологія

Introduction

Forest management, be it natural forests, or plantations, is a multidimensional process. The dimensions are: ecological, technical (including silvicultural), social, economic, and institutional. The primary goals in management, again be it natural forests or man-made, are three: *stability* and *productivity* of the physical environment, and *equity* in social environment. The dimensions and goals form a vital matrix. The sustainability of forests depends on balanced functioning of the matrix.