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HARVEST-INFLICTED WOUNDS ON RESIDUAL TREES

Vasiliki Dimou, Elias Milios
Democritus University of Thrace, Laboratory of Department of Forestry and Management of The Environment and Natural Resources
Orestiada, Greece

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ABSTRACT

The present study investigates the damage inflicted on residual trees as a consequence of felling and skidding *Picea abies* Karst. and *Pinus sylvestris* L. timber with the use of a Unimog tractor. The research was conducted in two stages, in July 2013 and May 2014, in a stand of the Elatia forest, Drama, Greece. In July 2013, on both sides of the skidroad, twelve plots measuring 50 X 20 m were established. On these plots the totals of all the trees were found and the best trees regarding stem and crown quality were selected and marked. In the second stage of the study, the trees of each plot that had received felling or skidding injuries were examined. According to the results of the research, 16.86 % of the trees investigated were found to bear wounds. It was also revealed that the best trees that had been marked were better protected against harvest-inflicted damages.

KEYWORDS: Felling wounds, skidding wounds, marked best trees.

INTRODUCTION

During timber harvesting operations, a number of injuries are inevitably caused to residual trees either due to felling or skidding or even delimbing and bucking of the trees into log segments in the stand (Vasiliauskas 2001). As these wounds are to an extent unavoidable, they have to be regarded as side effects of harvesting operations and consequently to be taken as inevitable production losses.

Most of the times, wounds are caused on the bark of standing stems. These bark injuries lead to the creation of a healing tissue or make the tree vulnerable to wood pathogens. Depending on the size of the entry point, wood-destroying fungi can cause timber devaluation or even a reduction in tree growth rates (Heitzman and Grell 2002, Limbeck-Lilienau 2003). Moreover, decreased timber quality has serious impacts on timber processing, e.g. in sawmills. After fungi attacks, forest managers have to deal with quality and quantity losses, which are not directly visible, but will appear in the long term. By all means, both quality and quantity of timber produced play a vital role in the economic viability of a forest management enterprise (Vospernik

2004). Stand merchantability coupled with effective sawmilling practices determine to a great extent future economic success (Nill et al. 2011).

There are two kinds of injuries: a) felling and skidding damages on the stem and b) felling damages on the crown. During felling processes, stem wounds can be caused along a tree's falling route, which is defined by its felling direction, or when felled trees are dragged or transported and they hit standing trees. In both cases, there is damage to the bark or both the bark and the sapwood (Bertault and Sist 1997, Stübner 2005). The deeper the wound on the stem of a standing tree, the greater the reduction of timber value on one hand and on the other the less successful are the defense mechanisms of the tree against infections and fungi attacks (Huth and Ditzer 2001). Wounds mainly appear on standing trees along skidroads and forest roads during dragging and transporting of logs. The number of affected trees and the size of affected areas depend on factors like a) season of harvest, b) site conditions, c) transport method and d) formation into logs (Meng 1978).

Crown injuries are inflicted during the felling process. When one of the dominant trees is felled, it damages adjacent crowns and standing stems. Big branches or entire crowns in neighboring trees can be destroyed.

Felling and skidding injuries cannot be avoided altogether. However, there are a variety of effective methods that enable root or stem or crown wounds to remain as limited as possible.

In addition, as Schütz (1985) mentions, forest protection during harvesting operations can lead to a clash of goals between silviculture and harvesting. Silviculture focuses on long-term planning, frequently along a span of more than 100 years. On the other hand, harvest technology advances at significantly shorter timespans. New techniques and systems appear on the market and pose questions that pertain to silviculture. In this point a question is brought forward: To what extent can the increasing trend towards harvesting justify the existence of injuries and the consequences that result from this e.g. fungi attacks (Schütz 1985).

The aim of the present research is to investigate the protection of best trees that have been marked against wounds caused by harvesting operations as well as to record damages on residual trees during felling and skidding on both sides of skidroads in the experimental plots under study.

The present study is part of a broader research project that registers injuries incurred as a consequence of harvesting activities in other species in Greek forests.

MATERIAL AND METHODS

Field work took place in a stand located in the Western Nestos public Forest of Elatia, Drama, Greece. This is a *Picea abies* stand with *Pinus sylvestris* individuals with a forested area of 25.61 ha. The elevation of the study area ranged from 1200-1480 m. (data from the Forest Service of Drama) with moderately steep to steep and at locations extremely steep slopes.

In the stand under study mainly thinning operations took place undertaken by the local Forest Service in May 2014. In total, 789 m^3 *Picea abies* and 90 m^3 *Pinus sylvestris* timber was produced. Fifty-year-old *Picea abies* and *Pinus sylvestris* constituted the majority of residual trees. Felling and partitioning into logs were performed with the use of chainsaws within the area of the stand. The greatest part of the timber felled (414.26 m^3) was shaped into large-size logs (8 m long) so their skidding from the stump was in the form of roundwood. The rest of the harvest (184.54 m^3) was shaped into small-size logs, approximately 1.20 m long (data from the Forest Service of Drama). Skidding was performed with a two-person crew (operator and assistant) and the use of a Unimog tractor.

Field data collection was performed in two stages, the first in July 2013 and the second in May 2014. In July 2013, a total of 12 experimental plots were established on both sides of the skidroad measuring 50 in length and 20 m in depth. The plots were all placed along the skidroad and were given serial numbers by the authors.

On each plot the totals of all trees were calculated and afterwards the best trees regarding quality of stem and crown (Dafis 1992) were marked and measured. Recording of data took place in the second phase in May 2014, after the completion of harvesting operations. Data recording involved those trees that were damaged either on the stem or the crown. It should be noted that the plots where injuries were recorded were in total 11, since on one plot, specifically on the 6th plot, there was no harvest work done and no trees were felled. Injuries appearing on the stem within less than 1 m of ground level were considered to be skidding injuries, whereas injuries on the stem occurring at a height of above 1 m, along the whole stem as well as on the crown (whether they concerned branches only or the entire crown) were considered to have been caused by felling (Guglhör and Melf 1995, Meng 1978).

The entire length of the study area was 600 m, whereas the total area of each plot was 1000 m^2 and the area of all the plots together was 12.000 m^2. The width of the skidroad ranged from 3.0 to 3.5 m. The research, that is the recording of damages, focused exclusively on the sample plots.

During field data collection, breast height diameters of all injured stems were recorded. Additionally, the length and width of the wound and whether it was a recent or old injury were registered too. Recent is an injury that has been inflicted within a 12 month span and old is a wound whose age is older than 12 months (PEFC 2010).

Additionally, with the use of the method described by Meng (1978), the following were recorded: The location of the wound (root or stem), the height of the wound on the stem, the intensity of the wound, the size of the wound and the distance of the damaged tree from the edge of the skidroad. Subsequently, the total area (in cm^2) of the injuries was calculated with the aid of software AutoCAD 2008 to guarantee their precise assessment. Finally, all trees with wounded crowns were registered too.

The comparisons between the distributions of the percentages of M (marked) trees that had post-harvest damages and the percentages of the rest of the injured trees were made using the Wilcoxon test, while the p – value of the test was calculated by means of the exact method (Ho 2006). The statistical analysis was carried out using SPSS (SPSS Inc USA).

RESULTS

Distribution and frequency of wounds

Throughout the stand, of the total of trees that were monitored, 16.86 % were found to be damaged. These injuries include only recent damages from felling and skidding. Skidding damages were significantly more (75.44 %) compared to felling damages.

As far as wound age is concerned, trees with old injuries (40 %) were separated from those with recent injuries (54.67 %), whereas a percentage of 5.33 % had both old and new wounds.

Fig. 1 presents the separation of felling and skidding injuries and their distribution in relation to whether they are old, new or both new and old on the same tree. The term 'old' denotes injuries that had been inflicted during felling operations carried out ten years before. As far as percentages are concerned, these can only be given in approximation, due to the fact that some individuals bearing older wounds were felled and removed with the recent operations, but they cannot be included in the percentages of the new wounds. However, it can definitely be concluded from Fig. 1 that in both the older and the new harvesting operations skidding damages outnumber felling wounds.

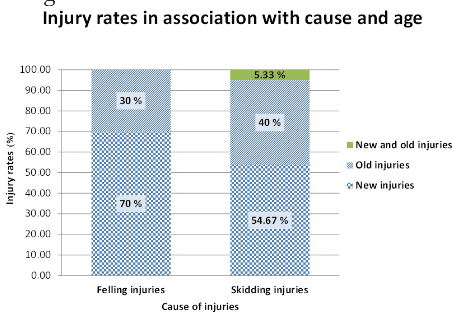

Fig. 1: Distribution of damage in association with the cause and age of the damage.

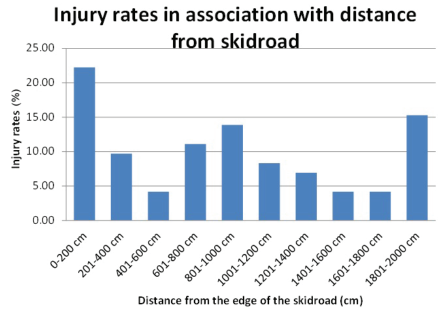

Fig. 2: Distribution of damage according to the distance of the trees from the skidroad.

Fig. 2 shows the distribution of injuries from the edge of the skidroad into a depth of 20 m. The width of each zone was 200 cm.

Distribution and frequency of wounds per plot

Tab. 1 provides the distribution of trees per plot as well the best trees that were selected and marked. It also indicates the percentage of M-trees that were marked per plot and the percentage of trees that were not marked.

Tab. 1: Total of trees per plot, total of M trees per plot, percentage of M-trees and non-marked trees.

Plot	Total of trees	Total of M-trees	Percent (%) of M-trees
1st	40	8	20.00
2nd	35	5	14.28
3rd	37	6	16.22
4th	24	8	33.33
5th	31	6	19.35
7th	29	9	31.03
8th	41	9	21.95
9th	29	8	27.59
10th	20	6	30.00
11th	29	8	27.59
12th	29	4	13.79
Total	344	77	

Fig. 3 shows the number of injuries on M-trees and non-marked trees per plot. M-trees exhibited lower injury rates with statistically significant difference compared to the injury rates of non - marked trees (z=-2.803, p=0.002). Five percent of M-trees received injuries either due to felling or skidding. The injury rates of the rest of the damaged trees that had not been marked were with statistically significant difference quite higher (20.22 %) (these two percentages were calculated using the data of all plots) in comparison with the M-trees that received wounds.

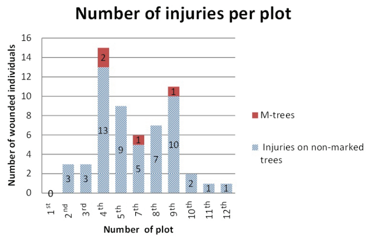

Fig. 3: Number of injuries per plot on M-trees and non-marked trees.

Characteristics of injuries

Fig. 4 presents the distribution of injuries according to their location on the tree.

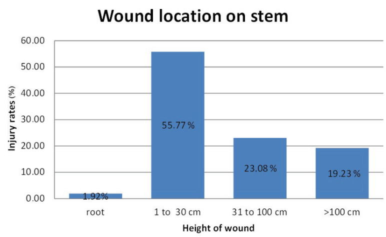

Fig. 4: Distribution of tree damages according to their location on the tree.

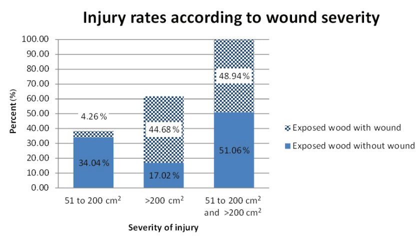

Fig. 5: Distribution of tree damages according to wound area.

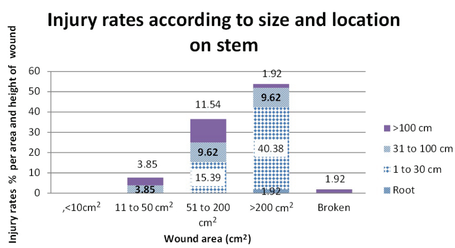

Fig. 6: Distribution of damages in association with the wound area and their location on the tree.

Fig. 5 reveals the distribution of injuries according to their severity in area classes 51-200 cm^2 and >200 cm^2 respectively. The severity of an injury is further divided into two groups: Exposed wood combined with some kind of wound and exposed wood without any other kind of wound. Finally, Fig. 6 indicates the injury rates per wound area in association with the location of the wound on the tree.

DISCUSSION

The injury rate that was found to be equal to 16.86 % is not considered significantly extensive if one takes into consideration statistics from other countries such as Germany (Nill et al. 2011). This low injury rate can be accounted for by the low mechanization degree of Greek harvesting systems. Such low injury rates generally occur in sites logged with systems of low mechanization degree (Field and Granhus 1998). For instance, in Germany a number of national forest inventories have been conducted so far. Research has shown that in the interval between the first inventory in 1990 and the second in 2008 there was an increase in injury rates from 20 to 28 %, which is explained by the increasing use of fully mechanized harvest systems (Nill et al. 2011). In Greece, felling is done with motor-manual chainsaw and skidding, in most cases, with Unimog tractor and winch. The mechanization level in harvest systems is low.

Assessing the second German inventory, Polley and Henning (2005) reported damages on 22 % of the trees in the forests of Baden-Württemberg after a fully mechanized harvest. Han and Kellogg (1997) found injury rates of 31.9-41.3 % in an equivalent harvest system in West Oregon, USA. They also suggested (Han and Kellogg 1997) that the high injury rates in the afore-mentioned studies are justified by the fact that wounds are recorded throughout the stand, by the extensive network of skid trails and the total disturbance of the stand caused by fully mechanized harvest systems.

The above rates confirm an older study in West Oregon, USA, by Bettinger and Kellogg (1993), who reported a percentage of 39.8 % injured trees in fully mechanized harvest systems. From studies conducted in Greek forests, Tsioras and Liamas (2010) found an injury rate of 19.7 % in a 2 m buffer zone on both sides of the skidroad. Also, Dimou (2013), in a previous study conducted in another stand of the same forest as in the present research, found a percentage of damaged trees equal to 11.2 %.

For the Greek forests, where fully mechanized systems are not in use, an injury rate of 16.86 % is not considered particularly high. Most damages were caused by skidding. More specifically, this injury rate was 75.44 and only 24.56 % were felling damages. The equivalent rates that were reported in a similar older research by Dimou (2013) were 72.72 and 24.24 % respectively.

The percentage of 40 % that refers to old skidding injuries does not include trees that had been removed from the stand with harvest works (Fig. 1). It is quite likely that those trees had older wounds, so it cannot be inferred with certainty that there has been an increase in damages during the more recent harvest activity, despite the fact that the difference between older and new damages is small.

The distance class with the highest injury rate is class 0–200 cm from the edge of the skidroad (Fig. 2). It has been proven that trees growing along skidroads receive more wounds that those located inside the stand (Han and Kellogg 2000, Heitzman and Grell 2002). Tsioras and Liamas (2010) and Dimou (2013) also report that most damages occur within a zone of 0-100 cm. The relatively high injury rates in distances from 601 to 800 cm and 801 to 1000 cm as well as 1801 to 2000 cm can be justified by the steep slopes of the stand (35 %) at a depth of 20 m from the edge of the skidroad. In class 0-200 cm, the high percentage of the damages is due to the fact that in this zone logs can cause numerous wounds as they are maneuvered out of the stand into the skidroad. In classes 601-800 cm, 801-1000 cm and 1801-2000 cm the relatively high percentage of wounds can be attributed to the terrain characteristics and slope of the stand; this also explains the fact that there is no gradual increase in damages with the increase in depth. The large length of the logs definitely contributes to the increase in wounds, but since this remains the same for all classes, it is not to be considered as a decisive factor explaining why wound percentages in these classes appear to be increased.

In most sample plots (Fig. 3) marked trees received no damage. Only in three plots injuries occur in four M-trees; more specifically, in plot 4 there are two marked trees with damage and in each of plots 7 and 9 there is one damaged marked tree respectively. Felling and skidding damages are reduced when harvest operations are performed outside vegetative periods, with careful felling (directional), with reducing skidding distances, with bucking into small-size logs and with marking the best trees (NW-FVA 2010). Marking the best trees is a fundamental method of reducing damage to residual trees. M-trees can show forest workers where they should be particularly careful. Besides this, by reducing potential injuries, they contribute to planning skidding works (Warkotsch 2004).

The greatest part of the wounds (55.77 %) is located on the stems at a height of 1-30 cm (Fig. 4), while 19.23 % of the injuries are above 1 m and these are felling injuries. It should be noted that only a small percentage, just 1.92 %, concern wounds on tree roots. Solgi and Najafi (2007) in a study on injuries from the use of forest machinery claimed that root wounds accounted for 12 % of the total injuries.

The greatest percentage of injuries (48.33 %) are big wounds (more than 200 cm^2). In an older paper by Dimou (2013) this percentage was found to be equal to 59.37 %. In general, 80 % of the wounds have an area of more than 51 cm^2. Furthermore, it was found that most of them (77 %) are located within the first 30 cm above ground.

The greatest part of wounds of the area class 51–200 cm^2 had their bark stripped off (Fig. 5), but wood was not damaged. In bigger wounds of the area class > 200 cm^2 the percentage of trees with wood exposure that had wounds is greater (44.68 %) compared to trees with wood exposure without other wounds (17.02 %). In total, in injuries whose area is over 51 cm^2 there is more or less an equal distribution in the occurrence of bark stripping with (48.94 %) and without wounds (51.06 %).

These results confirm those of an older research by Dimou (2013) in which it was found that in the first class (51-200 cm^2) the area occupied by the wounds was not very extensive and the injury rates involving sapwood destruction were quite low. In bigger wounds (> 200 cm^2) it was found that sapwood exposure was significant and as a result injury rates involving sapwood destruction were higher than those in which there was wood exposure without sapwood destruction.

As far as the position of the wounds on the stem is concerned (Fig. 4), it was found that most of the damages (55.77 % of total wounds) were located relatively low, that is from 1 to 30 cm above ground. Over 1 m from groundline are those injuries that are due to felling, which constitute 19.23 % of the total wounds, but only 1.92 % of them are large-size injuries (more than 200 cm^2). In general, very small wounds (<10 cm^2) were not found (Fig. 6). Solgi and Najafi (2007) report in a similar study injury rates of 40 and 42 % for area classes 51-200 cm^2 and more than 200 cm^2 respectively, whereas Limbeck - Lilienau (2003) states that in summer months 47 % of all damages had an area of more than 200 cm^2.

CONCLUSIONS

The present study attempts to investigate damages on the stem and crown of trees after felling and skidding; it also tries to examine whether best trees that are marked before the onset of harvesting operations can be protected more during the harvest. Generally speaking, injury rates were found to be relatively low. It was shown that best trees that had been marked were better protected against felling and skidding in comparison to the rest of the trees that had no mark whatsoever. Injury rates in marked trees were only 5 %, whereas in non-marked trees rates spiked to 20.22 %. Of the total of trees observed in 20.0 m zones on both sides of the skidroad, 16.86 % received wounds in their stem or crown. Also, it was found that there was not much difference between older and new wounds. In total, new injuries were 14.67 % more than old ones (skidding injuries), and if we include trees that were removed and had older injuries it is obvious that this difference can be even smaller. This is due to the fact that harvest methods and systems in Greece have not been mechanized at all over the last 10 years and have remained the same. In addition, injury rates due to skidding and felling are almost the same as those rates found in an older study (Dimou 2013), a fact that reveals similar harvest operations. In this point it should be mentioned that in Greece forest workers are inexperienced laborers who have never received any form of special training. This factor definitely contributes to the increase of injuries; with a more specialized forest crew, tree wounds would be considerably fewer. It should also be pointed out that all research conducted in Greece refers to harvesting operations carried out during the spring and summer months. This consequently reinforces the infliction of damages on residual trees as during this period the bark 'sits' more loosely on the tree and is more vulnerable.

The low injury rates can also be accounted for by the moderately steep to steep slopes as well as by the fact that a percentage of the logs that were transported (about 184.54 m^3) were small size logs.

Although it is obviously impossible to prevent all injuries, measures can be taken that can reduce both their frequency and severity. Marking the best trees is one of these measures, since it was proven that it significantly reduces injury rates. In addition, injury rates are strongly correlated with the degree of mechanization that logging systems are based on (Field and Granhus 1998). Unless this changes in the near future, injury rates are expected to remain unaffected by this parameter in Greece.

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Vasiliki Dimou, Elias Milios
Democritus University of Thrace
Laboratory of Department of Forestry and Management of The Environment and Natural Resources
193 Pantazidou Str., 68200
Orestiada
Greece
Phone: +302552041170
Corresponding author: vdimou@fmenr.duth.gr