Drewno 2017, Vol. 60, No. 199
DOI: 10.12841/wood.1644-3985.200.05

Farzam Tavankar, Rodolfo Picchio, Mehrdad Nikooy, Angela Lo Monaco, Rachele Venanzi, Afraz Iranparast Bodaghi

HEALING RATE OF LOGGING WOUNDS ON BROADLEAF TREES IN HYRCANIAN FOREST WITH SOME TECHNOLOGICAL IMPLICATIONS

The wound healing rate (WHR) was investigated in 234 wounded trees in Iranian forests and was found to range from 6.4 to 24.0 mm·yr^{-1}. Tree species, slope aspect, elevation, wound age, and wound type had significant effects on the WHR. The mean of the WHR in the Fraxinus excelsior (24 mm·yr^{-1}), Alnus subcordata (18.9 mm·yr^{-1}) and in the Fagus orientalis (17.9 mm·yr^{-1}) were significantly higher than in the Acer insigne (15.7 mm·yr^{-1}), Acer cappadocicum (14.6 mm·yr^{-1}), Carpinus betulus (13.7 mm·yr^{-1}), and Tilia begonifolia (6.4 mm·yr^{-1}). In addition, the mean of the WHR on northern slopes (17.5 mm·yr^{-1}) was significantly higher than on southern slopes. Moreover, the parameters that positively influenced tree growth showed a similar effect on the wound healing rate. The WHRs of 5-, 10- and 15-year-old wounds were 19.3, 16.9 and 10 mm·yr^{-1}, respectively. The WHR increased the higher the wound from ground level. The WHR for horizontal wounds (18.4 mm·yr^{-1}) was significantly higher than for vertical wounds. The highest WHR was estimated in a stand with a canopy closure of 60-80%. The WHR decreased according to increasing wound width. Wounds affect future income, lowering the number of trees that potentially provide a higher quality of saw and veneer logs.

Keywords: forest operation, tree damage, selection cutting, wood quality

Introduction

Forest managers are concerned about the potential damage to residual trees from thinning operations and/or selective cutting [Vossbrink and Horn 2004; Picchio

---

Farzam Tavankar (*tavankar@aukh.ac.ir*), Department of Forestry, Khalkhal Branch, Islamic Azad University, Khalkhal, Iran; Rodolfo Picchio (*r.picchio@unitus.it*), Department of Agriculture and Forest Sciences, Tuscia University, Viterbo, Italy; Mehrdad Nikooy (*nikooy@guilan.ac.ir*), Department of Forestry, University of Guilan, Somehsara, Iran; Angela Lo Monaco✉ (*lomonaco@unitus.it*), Department of Agriculture and Forest Sciences, Tuscia University, Viterbo, Italy; Rachele Venanzi (*venanzi@unitus.it*), Department of Agriculture and Forest Sciences, Tuscia University, Viterbo, Italy; Afraz Iranparast Bodaghi, Ph.D candidate in the Department of Forestry, University Campus 2, University of Guilan, Rasht, Iran

et al. 2012; Tavankar et al. 2015a]. Timber harvesting techniques and worker training are factors that significantly affect damage to residual trees [Han and Kellogg 2000; Sist and Nguyen-Thé 2002; Eroglu et al. 2009; Behjou and Mollabashi 2012, Bembenek et al. 2013a, Bembenek et al. 2013b]. Injuries occur during forest operations such as final felling (selective cutting) or thinning, mostly during the cutting, felling, extraction and collecting of timber along trails. They are caused by the mechanical impact of forest machines on the stem or root system or on other trunks. In selective cutting particularly, the removal of trees often requires movement around standing trees to reach the skid trail, and surrounding trees are frequently knocked. Residual stand damage is an unavoidable risk of selective cutting, but the level of damage should be minimized in order to assure future product quality [Tavankar et al. 2013]. Selective harvest methods may adversely impact the quality of the residual trees and increase the potential for future disease and insect infestations. Tree wounding is the most common type of logging damage, representing more than 90% of the total damage [Tavankar et al. 2013; Marchi et al. 2014].

Roads or strip roads in the forest are useful for limiting diffuse damage to the soil, but they may lead to the modification of neighbouring tree conditions, enhancing irregular ring growth or irregular crown shape. However, in a 34-year-old spruce stand, Bembenek et al. [2013c] observed no significant impact on the pith eccentricity, taper and ovality of trees growing along strip roads five years after their opening. Nevertheless, they observed signs of tree shape modification due to incremental growth in the middle of the trunk. Damage may be caused to the soil by compression, to the roots and stems by the repeated passage of machines or by skidding the trunks [Edlund et al. 2013; Kleibl et al. 2014; Cambi et al. 2015]. Crown injuries, stem breakage and uprooting are mainly due to felling [Picchio et al. 2011; Behjou and Mollabashi 2012; Tavankar et al. 2013]. Hecht et al. [2015] found that the wounds at crown level on Beech showed a significantly slower closure rate and a greater area of discolouration than skidding wounds at butt level. Damage on the bole may be on the outer stem surface, exposing the living inner tissue of the bark, or may occur more deeply in the cambial tissues or the xylem, producing wounds that develop into scars. During exposure to outside influence, pathogenic attacks are more likely. Logging wounds may decrease the quality of residual trees and increase stand mortality through insect and disease infestation [Han and Kellogg 2000]. The frequency of wounded trees and the intensity of the wounds during logging operations can have a detrimental impact on stand growth. Branch breakage and severe wounds to stems reduce tree vigour and produce favorable conditions for disease and tree mortality, factors which trigger the accumulation of wood debris and standing dead trees. However, to a certain degree, they contribute to the biodiversity in forest ecosystems [Tavankar et al. 2014]. Wounding can cause stem deformities and significant losses in final crop volume and value [Meadows 1993; Lo Monaco et al. 2015]. Logging wounds on residual trees often become an opportunity for fungal or other biological attacks [Vasiliauskas 2001], especially in wounds that are near ground level or root wounds [Bettinger and Kellogg 1993; Camp 2002]. Wound closure (healing) on forest trees may be a very important factor, restricting the colonization of wound-invading fungi [Vasiliauskas 2001].

Wound closure not only prevents further infection, but may also stop subsequent fungal development in already infected wounds [Vasiliauskas 2001]. The wound healing rate is related to tree species and wound severity [Picchio et al. 2011]. Normally, the required time for the healing of logging wounds in fast-growing tree species is lower than slow-growing tree species [Vasiliauskas and Stenlid 2007]. The ability of trees to heal logging wounds not only depends on the time which has elapsed from wound occurrence, but also on site conditions, tree species, tree age, and wound characteristics [Vasiliauskas 2001; Tavankar et al. 2015b]. Wound characteristics, such as the size, location, and intensity, are the main factors influencing wound healing rate and the future quality of the damaged trees [Meadows 1993; Vasiliauskas 1994; Han et al. 2000; Ezzati and Najafi 2010]. Even in the case of rapid healing, it is not possible to re-establish the xylem continuity and it is not easy to predict the extent of discolouration, which is frequent, for example, in beech wood [Hecht et al. 2015].

The objectives of this study were: 1) to investigate the healing rate of logging wounds in different tree species, 2) to investigate the effect of geographic conditions (slope aspect and elevation) on wound healing rate, and 3) to investigate the effect of wound characteristics (width, position and type) on wound healing rate in the Hyrcanian forests of Iran, highlighting the defects that may affect timber quality in the future.

Materials and methods

Study area

This study was conducted in the Hyrcanian forests of Iran (fig. 1). These forests, also known as the Caspian forests, are located in the north of Iran, along the south coast of the Caspian Sea, and cover 1.8 million hectares. The Hyrcanian forests are natural broadleaf forests and are the only commercial forests in Iran [FAO 2005]. These forests encompass various forest types, including 80 woody species [Marvie Mohadjer 2006], and are the most valuable forests in Iran. These forests are considered one of the most basic resources for wood production and they have an important role in supplying wood to related industries.

The silvicultural method applied is single-tree selection cutting. Logging operations in the Hyrcanian forests are generally performed using a ground-based skidding system. Chainsaws and cable skidders are two of the main logging machines for harvesting wood. The activities of tree felling and log skidding in these forests have the potential to damage the residual standing trees.

Fig.1. Study area in the Hyrcanian forests

The study area was located in Nav watershed forest area between 37° 38' 34" to 37° 42' 21" N and 48° 48' 44" to 48° 52' 30" E. The elevation in the study area ranged from 350 to 1,650 m a.s.l. The mean annual precipitation in this area is approximately 1050 mm, while the mean annual temperature is 9.1°C. The original vegetation of this area is an uneven-aged mixed forest. The soil type is forest brown, and the texture varies between sandy clay loam to clay loam.

Data collection and analysis

In the summer of 2015, 234 injured trees from different tree species, with one wound on their boles, were randomly selected. On each wounded tree the following parameters were recorded: diameter at breast height (1.30 m DBH), and tree diameter at the centre of the wound height (DWH), measured in cm using a dendrometric calliper; wound age (WA), determined according to logging year in the study area, based on logging plans; cause of damage (i.e. felling or bunched extraction); position (wound height (WH) from ground level), determined using a tape measuring the vertical distance between the wound centre and the ground; primary wound width was detected at the beginning of the damage (PWW) and secondary wound width in the year, 2015, (SWW) measured using a ruler (with an accuracy of 1 mm).

PWW was recorded in six classes: < 10, 10-20, 20-30, 30-40, 40-50 and > 50 cm. The type was recorded as either horizontal or vertical.

For each wounded tree selected, the following geographic conditions were recorded: slope aspect (northern or southern) determined using a compass, elevation above sea level determined using an altimeter, divided into three classes: low elevation (< 800 m), middle elevation (800-1200), and high elevation (> 1200 m); canopy closure (crown closure), as a representation of the amount of sky obscured by the canopy, divided into four classes: < 40, 40-60, 60-80 and > 80 percent.

The wound healing rate (WHR) for each wound was calculated using equation (1):

$$\mathrm{WHR} = \frac{\mathrm{PWW} - \mathrm{SWW}}{\mathrm{WA}} \tag{1}$$

Where, WHR is wound healing rate ($mm \cdot yr^{-1}$), PWW and SWW are primary and secondary wound width (mm), and WA the age of the wound (yr), respectively.

After checking for normality (Kolmogorov-Smirnov test) and homogeneity of variance (Levene test), the following tests were used to compare the averages of the WHR and the relationship between the wound healing rate (WHR) and the independent variables using SPSS 19 (IBM, NY, USA): ANOVA and Duncan tests were used to analyze the effect of the tree species, wound age, wound type, wound width classes, elevation classes, canopy closure classes, and slope aspect on the WHR. The relationship between the wound healing rate (WHR) and wound position was analysed using a correlation test and regression.

Results

The ANOVA tests showed that tree species, slope aspect, elevation, wound age, and wound type had a significant effect on the wound healing rate WHR (tab. 1).

The wound healing rate (WHR) ranged from 6.4 to 24.0 $mm \cdot yr^{-1}$, with a mean of 15.6 $mm \cdot yr^{-1}$ in the observed species (tab. 1). The highest value of WHR was estimated in *Fraxinus excelsior* L. (24 $mm \cdot yr^{-1}$), and the lowest in *Tilia begonifolia* Stev. (6.4 $mm \cdot yr^{-1}$). The wound healing mean ratio in *Alnus subcordata* C. A. Mey. (18.9 $mm \cdot yr^{-1}$) and in *Fagus orientalis* Lipsky (17.9 $mm \cdot yr^{-1}$) was significantly higher than the mean of the WHR in the *Acer insigne* Boiss. and Buhse (15.7 $mm \cdot yr^{-1}$), *Acer cappadocicum* Gled. (14.6 $mm \cdot yr^{-1}$), and *Carpinus betulus* L. (13.7 $mm \cdot yr^{-1}$).

The mean of the WHR in species with a northern aspect (17.5 $mm \cdot yr^{-1}$) was significantly higher than the mean of the WHR in those with a southern aspect (12.4 $mm \cdot yr^{-1}$).

Table 1. Factors affecting wound healing rate and results of ANOVA and Duncan tests

Factor	Wound (n)	Wound Healing Rate Mean value ± SD ($mm \cdot yr^{-1}$)	Confidence at 95% ($mm \cdot yr^{-1}$)	F	P-Value
Tree species				32.8	< 0.001
Fagus orientalis L.	55	17.9 ± 5.2[b]	16.5 – 19.3		
Carpinus betulus L.	42	13.7 ± 3.4[c]	12.7 – 14.8		
Acer insigne Boiss and Buhse	35	15.5 ± 4.3[c]	14.0 – 17.0		
Acer cappadocicum Gled.	33	14.6 ± 2.9[c]	13.6 – 15.6		
Alnus subcordata C.A.Mey.	32	18.9 ± 5.7[b]	16.8 – 20.9		
Tilia begonifolia Stev.	24	6.4 ± 3.7[d]	5.0 – 8.1		
Fraxinus excelsior L.	13	24.0 ± 3.1[a]	22.1 – 25.8		
Slope aspect				7.2	< 0.001
Northern	148	17.5 ± 5.5[a]	16.6 – 18.4		
Southern	86	12.4 ± 4.9[b]	11.4 – 13.5		
Elevation				39.3	< 0.001
< 800	54	19.7 ± 5.7[a]	18.2 – 21.3		
800 – 1200	127	15.8 ± 4.7[b]	14.9 – 16.6		
> 1200	53	11.1 ± 5.2[c]	9.6 – 12.5		
Wound age				47.6	< 0.001
5	74	19.3 ± 5.3[a]	18.1 – 20.5		
10	112	16.9 ± 5.2[b]	15.9 – 17.9		
15	48	10.0 ± 5.2[c]	8.4 – 11.4		
Wound Type				6.8	< 0.001
Horizontal	136	18.4 ± 5.3[a]	17.5 – 19.3		
Vertical	98	11.6 ± 4.7[b]	10.7 – 12.5		
All wounds	234	15.6 ± 5.8	14.9 – 16.4	–	–

The WHR decreased as elevation increased, therefore the mean of the WHR in the < 800, 800-1200 and > 1200 m a.s.l. was 19.7, 15.8 and 11.1 $mm \cdot yr^{-1}$, respectively.

The results indicated that the WHR was higher in the primary stage after wound occurrence, therefore the mean of the WHR in the wounds aged 5, 10 and 15 years was 19.3, 16.9 and 10 $mm \cdot yr^{-1}$, respectively (figs. 2, 3, 4).

The mean of the WHR in the horizontal wounds (18.4 $mm \cdot yr^{-1}$) was significantly higher than the mean of the WHR in the vertical wounds (11.6 $mm \cdot yr^{-1}$).

a b c

Fig. 2. Closed wounds 5 years after wound occurrence in *Acer cappadocicum* (a), and *Fagus orientalis* (b and c)

a b c

Fig. 3. Open wounds 10 years after wound occurrence in *Alnus subcordata* (a), *Fraxinus excelsior* (b), and *Carpinus betulus* (c)

a b c

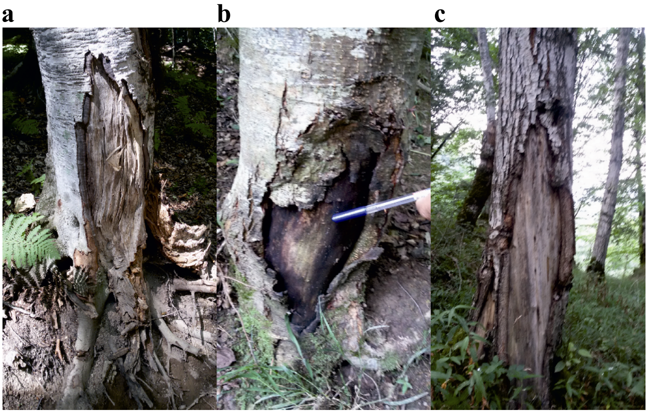

Fig. 4. Decayed wounds 15 years after wound occurrence in *Acer insigne* (a), *Fagus orientalis* (b), and *Alnus subcordata* (c)

The regression analysis showed that the wound healing rate (WHR) increased according to wound height from ground level (fig. 5 and equation (2)).

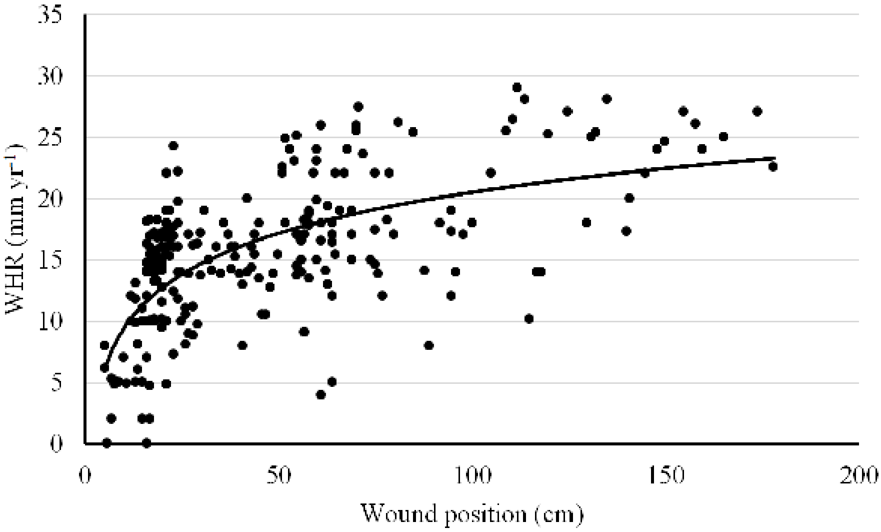

Fig. 5. Relationship between wound healing rate (WHR) and wound position

$$WHR = 4.82 \cdot \text{Ln}(WP) - 1.66 \quad (2)$$

R^2Adjusted = 0.408; SE = 4.51

F = 161.3; P-Value < 0.001

Where WHR is wound healing rate ($mm \cdot yr^{-1}$), and WP is wound position (cm).

In addition, the results of the ANOVA test showed that the primary wound width had a significant effect on the WHR (fig. 6). The mean of the WHR decreased with increasing primary wound width: the larger the wound, the lower the healing rate.

The results of the ANOVA test also showed that the stand canopy closure had a significant effect on the WHR (fig. 7). The highest value of the WHR was estimated in the stand with a canopy closure of 60-80% (18.2 ±5.4 $mm \cdot yr^{-1}$). The lowest value was estimated in the stand with a canopy closure of < 40% (10.2 ±3.0 $mm \cdot yr^{-1}$).

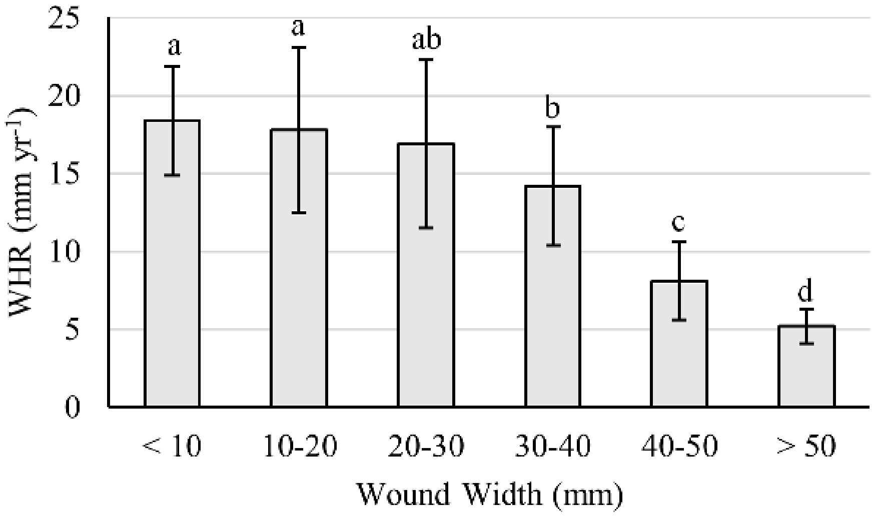

Fig. 6. Wound healing rate (WHR) in wound width classes

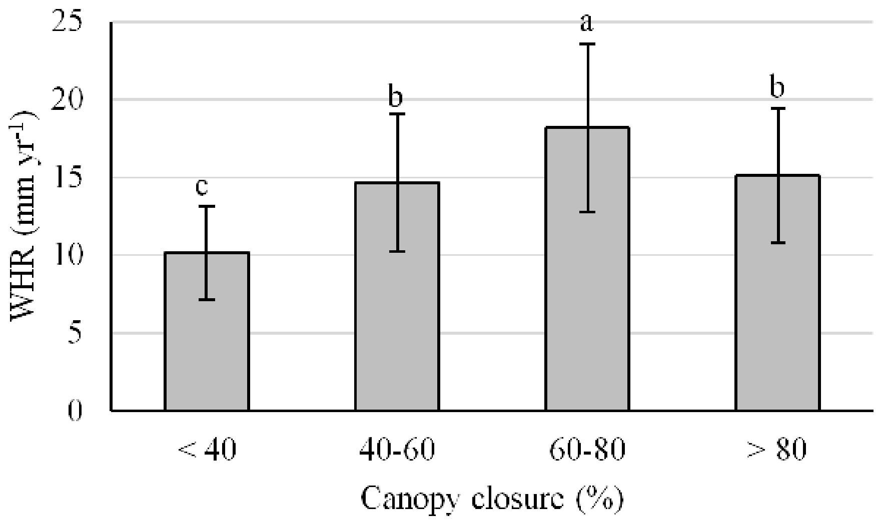

Fig. 7. Wound healing rate (WHR) in canopy closure percentage

Discussion

The results demonstrated that tree growth rate was the driving force behind the wound healing rate (WHR). In addition, the results indicated that the WHR depended on the tree species, confirming other research results [Vasiliauskas 1998; Picchio et al., 2011]. The WHR was recorded at approximately 2-4 mm·yr^{-1} in *Picea abies* [Vasiliauskas 1994), 20 mm·yr^{-1} in *Acer saccharum*

[Skilling 1958], 13-15 mm·yr^{-1} in *Eucalyptus* spp. [White and Kile 1994], and 10 mm·yr^{-1} in *Quercus rubor* [Vasiliauskas 1998]. In this study, the WHR in the *Fraxinus excelsior* and *Alnus subcordata* was higher than the other tree species analysed. This may be due to the fast growth of these species [Vasiliauskas and Stenlid 2007]. The WHR in the *Fraxinus excelsior* was estimated at 24 mm·yr^{-1}, while the WHR in *Fraxinus americana* L. was reported at 12 mm·yr^{-1} [Neely 1970]. Moreover, the WHR in the *Fagus orientalis* was estimated at 17.9 mm·yr^{-1}, which was similar to *Alnus subcordata*, with rapid closure behaviour. The WHR in *Fagus sylvatica* was recorded as 6-10 mm·yr^{-1} [Neely 1970] and 2.7-4.1 mm·yr^{-1} [Hecht et al. 2015], values markedly lower than those found in the Nav Forest. Dujesiefken et al. [2005] observed that European Beech closed wounds later than white and red oaks, due to the faster growth of oaks.

The results showed that the WHR in trees on northern aspect slopes was higher than on southern aspect slopes. This may be due to the higher rate of tree growth on the northern slopes in the Hyrcanian forests than on the southern slopes. The amount of air moisture and the number of fast growing tree species (such as *Alnus subcordata*, *Fraxinus excelsior* and *Fagus orientalis*) on the northern slopes in the Hyrcanian forests was higher than on the southern slopes [Marvie Mohadjer 2006]. Attarod et al. [2007] reported a growth rate of 9.55 m^3·ha^{-1} on northern slopes and 9.16 m^3·ha^{-1} on southern slopes in Shafarod in the Hyrcanian forests – this data was estimated in sylve, an unusual but conventional unit to measure the volume of forest stock through a tariff system.

In addition, tree density, stand volume and canopy closure on northern slopes are higher than on southern slopes [Marvie Mohadjer 2006].

The results showed that the WHR increased according to increased wound height from ground level. This may be due to the intensity of logging since the number of wounds decreases the higher they are from ground level. Although the vigour or growth rate of trees affects the WHR, the severity (extension and depth) of the wound is another focal point. Usually damage to the stump or in the lower part of the trunk, generally caused by the skidder during extraction, is more severe than that at a greater height, which is generally caused by felling operations [Tavankar et al. 2017].

Smith et al. [1994] studied the closure of logging wounds after 10 years in an Appalachian forest and reported that many small wounds, < 322 cm^2 in size, closed 5-10 years after logging. Vasiliauskas [1994] suggested a 25-50 year healing period for a 10 cm wide wound in Norway spruce. Welch et al. [1997] indicated a 15 year period for the complete healing of < 60 cm^2 wounds in Sitka spruce. Vasaitis et al. [2012] reported that, on average, it took 3.6, 5.5, 10.4, 12.7 and 14.7 years, respectively, to occlude wounds ranging in size from 1 to 5 cm wide in *Picea abies* stems.

Selective logging needs a more careful planning of roads, skid trails, and winching corridors. Pre-harvest planning and the marking of winching paths before logging operations begin can reduce damage to the stand in these forests.

Nikooy et al. [2010] reported that the skilled operation of a skidder can decrease the level of damage. Picchio et al. [2012] studied improved winching techniques designed to decrease stand damage in the forests of central Italy. They reported that the use of a snatch block decreased by one-quarter the frequency of wounded trees from 50% to 36%. Therefore, the training of forest workers and adequate technologies may be effective in reducing logging damage on a residual stand. Late damage effects may be recognizable some time later and injuries may appear on a stem which was hit years previously [Picchio et al. 2011].

The features of wounded areas are both structurally and aesthetically much less desirable. Trees react actively to wounds due to the live parenchyma cells of phloem and sapwood forming a mass of traumatic tissue [Armstrong et al. 1981; Tsoumis 1991], called callus or wound wood. The mark of the injury remains on the bark for a long time testifying to the trauma suffered (fig. 2). New tissues formed at the wound edge can be easily recognized by ridges on the bark (fig. 3 and 4). After injury, the xylem tissues are exposed to the air and they are likely to be subject to moisture loss. They may be easily prone to biological attacks [Annesi et al. 2015; Szewczyk 2015], mostly when the healing time extends for years. The vessels may be subjected to embolism which deactivates the transport functions. Rapid healing ensures the restoration of the original defences. Nevertheless, air access to the healing wound and metabolic activity can produce discolouration. Secondary metabolites have a role both in wound healing and in discouraging pathogenic access in the compromised tissue [Eyles et al. 2003, Kiser 2011]. Even gum deposits are induced by a defence phenomenon due to wounding [Chungu et al. 2007]. On beech, higher amounts of total phenols, flavonoids and proanthocyanidins were found in the zone with a compartmentalization function than in sound sapwood. These extractives seem to protect the wood from fungi [Vek et al 2013]. However, the colour of the wood can be modified. The length of discolouration in oak was significantly connected with the period of exposure [Dujesiefken et al. 2005]. During healing, bark can be included in the wood, originating as bark pockets or stone pockets, a defect difficult to detect many years later if the wound was produced in a young tree. New wood covers the wounded area, but the disjunction between the old and the new tissue continues to exist, producing a discontinuity such as a ring shake. In addition to discontinuity in the wood, sometimes irregular stem forms, local grain deviations [Gjerdrum and Bernabei 2009] and colour variations, not necessarily pathological, can be observed. Bark inclusions reduce the mechanical strength and the aesthetic of artifacts, therefore, they are not accepted in timber for packaging and for flooring.

In sapwood, the vessels of an injured tree may be partially or completely occluded with tyloses [Bigio et al. 2010]. In sapwood, tyloses lead to lower permeability, which restricts the loss of moisture and embolism; in living trees these are positive elements aimed at ensuring the functionality of woody tissues and the tree's life. In contrast, the low permeability of timber sapwood is a negative factor, because it makes drying difficult and adversely affects the penetration of preservative substances.

Visual grading is the process of classifying lumber using rules that establish the dimension and quantifies the effect of each defect in the timber, according to the quality required for a particular use. Standards have been developed for grading structural use saw lumber and veneer lumber, or lumber for an unknown final use. Grading is the process of classifying timber for a particular use according to the quality. For sale purposes, each trunk is classified according to the dimensions and the presence, size and distribution of specific characteristics or defects [Knoke et al. 2006]. In a general qualitative classification, the worst defect downgrades the log to a lower class. European standards assess some features for grade lumber, and among these, discolouration, insect attack and wood ring discontinuity are deemed unacceptable for the best class. Cassens [2004] states that no surface indicators of interior defects are permissible in a quality veneer tree or log. The wood quality standard in Iran does not allow any damage, discolouration, defect or decay for first class wood.

Some defects, which cause a decrease in grading, can be removed during the delimbing at landing. The position of scars influences volume loss. According to local practices, the volume of the products obtainable by sawing the trunk is considered, rather than the effective volume. As a result defects can be accounted as deduction factors of the log volume or size [Han et al. 2000].

Superficial and limited injuries can be eliminated in early processing, resulting mainly in a reduction of the manufacturing yield. Highly damaged trees, both in depth and in the longitudinal direction, supply logs which may be unsuitable for any type of processing. These may be used exclusively for firewood [Maesano et al. 2014].

Karaszewski et al. [2013] observed that in beech stands logs of the highest class were only 3% of the crop by volume. Alderman et al. [2004] argued that the highest quality hardwood trees that produce saw logs are less than 1%, and among these, the best-quality logs for veneer can achieve prices from 1.5 to 6 times the best graded saw logs.

Wound damage subtracts value from the future harvest and raises concern for forest health. It affects future income, lowering the number of trees that potentially provide higher quality saw and veneer logs.

Conclusions

Tree species, slope aspect, altitude, wound age, and wound position had a significant effect on the wound healing rate. These parameters, which influence tree growth positively, determined similar effects on the wound healing rate. Timber from the Iranian forest is an important resource and the growing interest in it is due to the increasing demand for quality hardwood timber for sawing and for the production of veneer or derived composites [Behjou 2012; Bayatkashkoli et al. 2016]. An assessment of the effects of forest management activities on trees and on wood quality is carried out through the evaluation of tree growth, which is considered a proxy for the quality of the wood [Cutter et al. 2004]. However, tree diameter, height, and other dendrometric parameters do not significantly affect timber quality [Brunetti et al. 2000; Riesco Munoz et al. 2013]. Quality attributes, among which wounds already healed must surely be included, are not adequately considered - they are contemplated at the time of processing or sale, when it is too late. The forest manager should be familiar with the grading standards for the quality of timber produced by the different tree species of the forest.

Limiting logging damage to residual trees must remain a major objective in the selective management of forests [Tavankar et al. 2015a]. Logging workers must be convinced, through adequate training, that most damage to residual trees is unnecessary and avoidable.

References

Alderman D., Wiedenbeck J., Peter P., Brinberg D. [2004]: Key attributes associated with veneer quality timber that may be impacted by forest management practices. Proceedings of: 14th Central Hardwood Forest Conference, 16-19 March 2004. Wooster: 140-147

Annesi T., Calienno L., Picchio R., De Simone D., Lo Monaco A. [2015]: Degradation of some technological features in the wood of ornamental species caused by *Inonotus rickii* (Pat.) Reid. Drewno 58 [195]: 5-18. DOI: 10.12841/wood.1644-3985.136.01

Armstrong J.E., Shigo A.L., Funk D.T., McGinnes E.A., Smith D.E. [1981]: A macroscopic and microscopic study of compartmentalization and wound closure after mechanical wounding of Black walnut trees. Wood and Fiber 13 [4]: 175-291

Attarod P., Bayramzadeh V., Shirvany A. [2007]: Effect of ecological aspects on the quantitative variables of mixed broadleaf forests using multivariate statistical method. Asian Journal of Plant Sciences 6 [6]: 927-933

Bayatkashkoli A., Sharefpour M., Shamsian M. [2016]: Visual grading of small-diameter poplars for peeling use. Drewno 59 [196]: 31-37. DOI: 10.12841/wood.1644-3985.145.03

Behjou F.K. [2012]: Economic analysis of log damage during logging operation in Caspian Forests. Journal of Forestry Research 23 [4]: 699-702

Behjou F.K., Mollabashi O.G. [2012]: Selective logging and damage to unharvested trees in a Hyrcanian forest in Iran. BioResource 7 [4]: 4867- 4874

Bembenek M., Giefing D.F., Karaszewski Z., Mederski P.S., Szczepańska-Álvarez A. [2013a]: Uszkodzenia drzew w następstwie trzebieży wczesnych w nizinnych drzewostanach świerkowych (Tree damage in lowland spruce stands caused by early thinnings). Sylwan 157 [10]: 747-753

Bembenek M., Giefing D.F., Karaszewski Z., Mederski P.S., Szczepańska-Álvarez A. [2013b]: Uszkodzenia drzew w nizinnych drzewostanach świerkowych podczas zabiegu trzebieży późnej (Tree damage in lowland spruce stands because of late thinning). Sylwan 157 [12]: 892-898

Bembenek M., Giefing D.F., Karaszewski Z., Łacka A., Mederski P.S. [2013c]: Strip road impact on selected wood defects of Norway spruce (*Picea abies* (L.) H. Karst). Drewno 56 [190]: 63-76. DOI: 10.12841/wood.1644-3985.055.05

Bettinger P., Kellogg L. [1993]: Residual stand damage from cut-to-length thinning of second growth timber in the Cascade Range of western Oregon. Forest Products Journal 43: 59-64

Bigio E., Gärtner H., Conedera M. [2010]: Fire-related features of wood anatomy in a sweet chestnut (*Castanea sativa*) coppice in southern Switzerland. Trees 24: 643-655. DOI: 10.1007/s00468-010-0434-9

Brunetti M., Macchioni N., Pollini C. [2000]: Visual grading of standing trees: first trials on Norway spruce from Trentino region. L'Italia Forestale e Montana 55 [1]: 13-25. [In Italian]

Cambi M., Certini G., Neri F., Marchi E. [2015]: The impact of heavy traffic on forest soils: a review. Forest Ecology Management 338: 124-138

Camp A. [2002]: Damage to residual trees by four mechanized harvest systems operating in small diameter, mixed conifer forests and steep slopes in northeastern Washington: A case study. Western Journal of Applied Forestry 17 [1]: 14-22

Cassens D.L. [2004]: Factors determining the suitability of trees and logs for the face veneer industry. Proceedings of: 14th Central Hardwood Forest Conference, 16-19 March 2004. Wooster: 130-139

Chungu D., Muimba-Kankolongo A., Roux J., Malambo F.M. [2007]: Bark removal for medicinal use predisposes indigenous forest trees to wood degradation in Zambia. Southern Hemisphere Forestry Journal 69 [3]: 157-163

Cutter B.E., Coggeshall M.V., Phelps J.E., Stokke D.D. [2004]: Impact of forest management activities on selected hardwood wood quality attributes: a review. Wood and Fiber Science 36 [1]: 84-97

Dujesiefken D., Liese W., Shortle W., Minocha R. [2005]: Response of beech and oaks to wounds made at different times of the year. European Journal of Forest Research 124: 113-117. DOI: 10.1007/s10342-005-0062-x

Edlund J., Keramati E., Servin M. [2013]: A long-tracked bogie design for forestry machines on soft and rough terrain. Journal of Terramechanics 50 [2]: 73-83

Eroglu H., Öztürk U.O., Sönmez T., Tilki F., Akkuzu E. [2009]: The impacts of timber harvesting techniques on residual trees, seedlings, and timber products in natural oriental spruce forests. African Journal of Agricultural Research 4 [3]: 220-224

Ezzati S., Najafi A. [2010]: Long-term impact evaluation of ground-based skidding on residual damaged trees in the Hyrcanian forest, Iran. International Journal of Forestry Research 1 [1]: 1-8. DOI:10.1155/2010/183735

Eyles A., Davies N.W., Mohammed C. [2003]: Wound wood formation in Eucalyptus globulus and Eucalyptus nitens: anatomy and chemistry. Canadian Journal of Forest Research 33: 2331-2339

FAO [2005]: Global Forest Resources Assessment, Country Reports, Islamic Republic of Iran. Rome, FRA: 42

Gjerdrum P., Bernabei M. [2009]: Three-dimensional spiral grain pattern in five large Norway spruce stems. Silva Fennica 43 [3]: 457-464

Han H.S., Kellogg L.D. [2000]: Damage characteristics in young Douglas-fir stand from commercial thinning with four timber harvesting systems. Western Journal of Applied Forestry 15: 27-33

Han H.S., Kellogg L.D., Filip G.M., Brown T.D. [2000]: Scar closure and future timber value losses from thinning damage in western Oregon. Forest Products Journal 50 [1]: 36-42

Hecht U., Kohnle U., Nill M., Grüner J., Metzler B. [2015]: Bark wounds caused by felling are more susceptible to discoloration and decay than wounds caused by extraction in European beech. Annals of Forest Science, Springer Verlag/EDP Sciences 72 [6]: 731-740

Karaszewski Z., Bembenek M., Mederski P.S., Szczepańska-Alvarez A., Byczkowski R., Kozłowska A., Michnowicz K., Przytuła W., Giefing1 D.F. [2013]: Identifying beech round wood quality – distributions and the influence of defects on grading. Drewno 56 [189]: 39-54. DOI: 10.12841/wood.1644-3985.041.03

Kiser J. [2011]: Histochemical and geometric alterations of sapwood in coastal Douglas-Fir following mechanical damage during commercial thinning. Silva Fennica 45 [4]: 729-741

Kleibl M., Klvač R., Lombardini C., Porhaly, J., Spinelli, R. [2014]: Soil compaction and recovery after mechanized final felling of Italian coastal pine plantations. Croatian Journal of Forest Engineering 35 [1]: 63-71

Knoke T., Stang S., Remler M., Seifert T. [2006]: Ranking the importance of quality variables for the price of high quality beech timber (*Fagus sylvatica* L.). Annals of Forest Science 63 [4]: 399-413 399. DOI: 10.1051/forest:2006020

Lo Monaco A., Calienno L., Pelosi C., Balletti F., Agresti G., Picchio R. [2015]: Technical properties of beech wood from aged coppices in central Italy. iForest 8: 82-88. DOI: 10.3832/ifor1136-007

Maesano M., Drigo R., Lasserre B., Chirici G., Marchetti M. [2014]: Forest biomass for bioenergy: opportunities and constraints for good governance. A case study from Italy. Drewno 57 [192]. DOI: 10.12841/wood.1644-3985.S09.04

Marchi E., Picchio R., Spinelli R., Verani S., Venanzi R., Certini G. [2014]: Environmental impact assessment of different logging methods in pine forest thinning. Ecological Engineering 70: 429-436. DOI: 10.1016/j.ecoleng.2014.06.019

Marvie Mohadjer M. [2006]: Silviculture. Tehran University Publishing, Tehran

Meadows J.S. [1993]: Logging damage to residual trees following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. Proceedings of: 9th Central Hardwood Forest Conference, 8-10 March 1993. West Lafayette

Neely D. [1970]: Healing of wounds on trees. Journal of the American Society for Horticultural Science 95: 536-540.

Nikooy M., Rashidi R., Kocheki G. [2010]: Residual trees injury assessment after selective cutting in broadleaf forest in Shafaroud. Caspian Journal of Environmental Sciences 8 [2]: 173-179

Picchio R., Magagnotti N., Sirna A., Spinelli R. [2012]: Improved winching technique to reduce logging damage. Ecological Engineering 47: 83-86. DOI: 10.1016/j.ecoleng. 2012.06.037

Picchio R., Neri F., Maesano M., Savelli S., Sirna A., Blasi S., Baldini S., Marchi E. [2011]: Growth effects of thinning damage in a Corsican pine (*Pinus laricio* Poiret) stand in central Italy. Forest Ecology and Management 262: 237-243. DOI: 10.1016/j.foreco. 2011.03.028Riesco

Riesco Munoz G., Remacha Gete A., Gasalla Regueiro M. [2013]: Variation in log quality and prediction of sawing yield in oak wood (*Quercus robur*). Annals of Forest Science 70: 695-706. DOI: 10.1007/s13595-013-0314-8

Sist P., Nguyen-Thé N. [2002]: Logging damage and the subsequent dynamics of a dipterocarp forest in East Kalimantan 1990-1996. Forest Ecology and Management 165: 85-103

Skilling D.D. [1958]: Wound healing and defects following northern hardwood pruning. Journal of Forestry 56 [4]: 19-22

Smith H.C., Miller G.W., Schuler T.M. [1994]: Closure of logging wounds after 10 years. USDA Technical Bulletins 692: 1-6

Szewczyk W. [2015]: Wood decomposition by Porodaedalea pini strains from different regions of Poland. Drewno 58 [194]: 127-134. DOI: 10.12841/wood.1644-3985.086.10

Tavankar F., Bonyad A., Majnounian B. [2015a]: Affective factors on residual tree damage during selection cutting and cable-skidder logging in the Caspian forests, Northern Iran. Ecological Engineering 83 [8]: 505-512. DOI: 10.1016/j.ecoleng.2015.07.018

Tavankar T., Bonyad A., Marchi E., Venanzi R., Picchio R. [2015b]: Effect of logging wounds on diameter growth of beech (*Fagus orientalis* Lipsky) trees following selection cutting in Caspian forest of Iran. New Zealand Journal of Forestry Science 45 [19]: 1-7. DOI: 10.1186/s40490-015-0052-9

Tavankar F., Picchio R., Lo Monaco A., Bonyad A. [2014]: Forest management and snag characteristics in Northern Iran lowland forests. Journal of Forest Science 60 [10]: 431-441

Tavankar F., Majnounian B., Bonyad A. [2013]: Felling and skidding damage to residual trees following selection cutting in Caspian forests of Iran. Journal of Forest Science 59 [5]: 196-203

Tavankar T., Nikooy M., Picchio R., Bonyad A., Venanzi R. [2017]: Effect of logging wounds on Caucasian Alder trees (*Alnus subcordata* C.A. Mey.) in Iranian Caspian forests. Croatian Journal of Forest Engineering 38 [1]: 73-82

Tsoumis G. [1991]: Science and technology of wood. Chapman and Hall, London

Vasaitis R., Lygis V., Vasiliauskaite I., Vasiliauskas A. [2012]: Wound occlusion and decay in *Picea abies* stems. European Journal of Forest Research 131 [4]: 1211-1216

Vasiliauskas R. [1994]: Wound healing rate and its influence on spread of decay in spruce. Proceeding of the Lithuanian Forest Research Institute 34: 207-212

Vasiliauskas R. [1998]: Patterns of wounding and decay in stems of *Quercus robur* due to bark peeling. Scandinavian Journal of Forest Research 13: 437-441

Vasiliauskas R. [2001]: Damage to trees due to forestry operations and its pathological significance in temperate forest: a literature review. Forestry 74: 319-336. DOI: 10.1093/forestry/74.4.319

Vasiliauskas A., Stenlid J. [2007]: Discoloration following bark stripping wounds on *Fraxinus excelsior*. European Journal of Forest Pathology 28 [6]: 383-390. DOI: 10.1111/j.1439-0329.1998.tb01192.x

Vek V., Oven P., Humar M. [2013]: Phenolic extractives of wound-associated wood of beech and their fungicidal effect. International Biodeterioration and Biodegradation 77: 91-97

Vossbrink J., Horn R. [2004]: Modern forestry vehicles and their impact on soil physical properties. European Journal of Forest Research 123: 259-267

Welch D., Scott D., Staines B.W. [1997]: Bark-stripping damage by red deer in a Sitka spruce forest in Western Scotland. III. Trends in wound condition. Forestry 70 [2]: 113-120

White D.A., Kile G.A. [1994]: Breakdown of barrier zones and prediction of the spread of discoloration and decay resulting from stem wounds in *Eucalyptus regnans* and *E. obliqua*. European Journal of Forest Pathology 24: 71-78

Submission date: 11.01.2017

Online publication date: 3.07.2017