Research paper

# Characteristics and Occlusion of Logging Wounds in *Fagus orientalis* Lipsky

Farzam Tavankar,[1,3] Amireslam Bonyad[2]

【Summary】

Characteristics of logging wounds (size, intensity, location, and agent) and their conditions after 12 yr (closed, open, decayed, and tree destroyed) in Oriental beech trees were investigated in 3 logged compartments in the Iranian Caspian forests. The results indicated that the winching of logs was the main cause of stem wounding, especially intensive wounds at heights of < 0.3 m from ground level. The wound conditions after 12 yr were as follows: 67.3% had closed, 18.9% were open, 9.4% had decayed, and 4.4% were the cause of tree mortality. The rate of wound occlusion was related to the size and intensity of the wound, stem diameter (diameter at breast height; DBH), and ratio of wound size to stem basal area (RSA). Young stems (DBH < 40 cm) were more sensitive to logging wounds, while trees with a DBH of 40~60 cm had the highest wound occlusion rate. The maximum wound size that stems were able to occlude in the DBH classes of > 20, 20~40, 40~60, and 60~80 cm were 72, 295, 444, and 757 $cm^2$, respectively. The maximum RSA that stems were able to occlude in phloem- and wood-damaged wounds were 0.28 and 0.26, respectively. Logger training, organization, and use of adequate logging equipment with respect to forest environmental condition can reduce logging damage to acceptable levels.

**Key words:** logging wounds, *Fagus orientalis*, selection cutting, wound occlusion, Caspian forests.

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研究報告

# 東方山毛櫸伐採傷口之特徵與癒合

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## 摘 要

本文檢驗伊朗裡海森林三個伐採林班之東方山毛櫸(*Fagus orientalis* Lipsky)於伐木12年後傷口之情形(大小、強度、位置與致傷媒介)。結果顯示樹幹傷口的主要成因，特別是於離地< 0.3 m處的強度裂傷，係以絞盤搬動原木所致。12年後傷口情形如下：67.3%已癒合、18.9%仍有傷口、9.4%已腐朽、以及4.4%已使林木死亡。傷口癒合的速率視大小與強度、樹幹直徑(胸高直徑，DBH)、以及傷口大小對樹幹基部面積之比例(RSA)而定。年輕樹幹(DBH < 40 cm)對於伐木傷口較敏感；而40~60 cm DBH之樹幹則有最高的傷口癒合率。依胸高直徑級> 20、20~40、40~60及60~80 cm的樹幹，其能癒合的最大傷口分別為72、295、444與757 $cm^2$。韌皮部與木質部受傷後可再癒合的最大傷口對樹幹基部面積比，分別為0.28與0.26。順應森林環境而調整的伐木工訓練、組織及使用適當伐採設備等，均可減低伐採傷害至可接受的程度。

**關鍵詞**：伐採致傷、東方山毛櫸、擇伐、傷口癒合、裡海森林。

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## INTRODUCTION

The oriental beech (*Fagus orientalis* Lipsky) is the most important commercial species in the Caspian forests of Iran (Tavankar et al. 2015). The Caspian forests are located in the north of Iran and south coast of the Caspian Sea. These forests extend from coastal areas of the Caspian Sea to an elevation of 2800 in the Alborz Mountain belt. The area of these forests is about 2 million ha. About 60% of these forests are used for commercial purposes, and the remainder is degraded (Mossadegh 1996). They are suitable habitats for a variety of hardwood species (approximately 80 woody species), including many forest types (Marvi-Mohadjer 2005). Mixed and pure beech stands occupy about 20% of these forests and produce more than 35% of the total wood stock volume of the Caspian forests (Soltani 2003). The beech is a large tree and is common in highlands at elevations of 800~2000 m. It is most common on northern mountainside slopes, in cool areas, and in rich soils throughout the Caspian Sea region of Iran (Bonyad et al. 2012). Selective cutting is the main silvicultural method in these forests. The most common is the short-wood harvesting system. Logging operations are generally performed using a ground-based skidding system. The chainsaw and cable skidder (winching and skidding) are 2 main logging machines for wood harvesting in these forests.

In selective cuts, removal trees often need to be moved around standing trees before they reach the skid trail. Residual stand damage is an avoidable risk of selective cutting, but the level of damage should be minimized to assure future product quality (Tavankar et al. 2013). Tree winching has a high potential for residual stand damage (Picchio et al. 2011, 2012, Marchi et al. 2014). Logging, if uncontrolled, can have a highly damaging effect on the forest structure, composition, and regenerating capacity (Sist et al. 1998). It is important to minimize damage, both to the number of trees damaged and the extent of damage to any individual tree. Damage to residual trees during the selective cutting operation may decrease the quality of residual trees and increase the stand mortality through insect and disease infestation (Han and Kellogg 2000). Wounding can cause stem deformities and significant losses of the final crop volume and value (Meadows 1993, Lo Monaco et al. 2014), although another study on coniferous stands showed little influence of damage on tree ring growth (Picchio et al. 2011). All wounds, regardless of cause, are susceptible to decay. Injuries very often become an input port for fungal decay (Vasiliauskas 2001). Wood-rotting fungi do not always develop when trees are damaged during logging. Baxter and Hesterberg (1958) reported that fungi associated with decay in logging wounds were increasing in 10~20-yr-old sugar maple logging scars. Hesterberg (1957) indicated that exposed sapwood wounds of at least 967 $cm^2$ in sugar maple had an even chance (50%) of developing decay within 20 yr.

In the Iranian Caspian forests, many studies focused on primary logging damage (immediately after logging operations) (Hoseini et al. 2001, Lotfalian et al. 2008, Naghdi et al. 2008, Majnounian et al. 2009, Nikooy et al. 2010, Tavankar et al. 2013), and very few studies were done on secondary logging damage (after several years). Wound characteristics such as the size, location, and intensity are the main factors that influence the future quality of damaged trees (Meadows 1993, Han et al. 2000, Vasiliauskas 2001, Ezzati and Najafi 2010). The lowest location of wounds on the stem can have detrimental effects on stem quality (Ezzati and Najafi 2010). Han et al. (2000) reported that the frequency of infection and amount of decay decreased as the wound height increased. Studies in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) showed a volume loss of 0.5~0.75% annually due to damage measuring 900 $cm^2$ or greater (Wallis and Morrison 1975). Smith et al. (1994) studied closure of logging wounds after 10 yr in an Appalachian forest and reported that many small wounds, < 322 $cm^2$ in size, closed at 5~10 yr after logging. Yilmaz and Akay (2008) reported that damage to residual stems associated with individual tree selection systems did jeopardize a stands potential to increase diameter growth. A literature review showed that minor damage to stems of residual trees during logging operations can have a major impact on the final stand volume as future saw logs (Whitney 1991, Vasiliauskas 1993).

In the Caspian forest, the future of logging wounds in beech trees is unclear. The objectives of this study were to: 1) study characteristics of logging wounds in beech trees; 2) study wound conditions of beech trees 12 yr after logging damage; and 3) investigate the effect of wound characteristics (size, location, and intensity) on wound conditions.

## MATERIAL AND METHODS

### Study area

The study area is located in 3 compartments 27, 35, and 42 in district 1 of the Asalem Nav watershed in the Iranian Caspian forests. The Nav watershed is located between 37°-38’-34”~37°-42’-21”-N and 48°-48’-44”~48°-52’-30”-E. Elevations of the study area ranged 800~1350 m. The mean annual precipitation is approximately 950 mm, and the mean annual temperature is 9.1℃.

The original vegetation of this area was an uneven-aged mixed forest dominated by *Fagus orientalis* Lipsky (56%) and *Carpinus betulus* L. (28%), with companion species of *Alnus subcordata* C.A. Mey. (7%), *Acer platanoides* L. (4%), *Acer cappadocicum* A.E. Murray (3%), *Ulmus glabra* Huds. (1%), and *Tilia rubra* Rupr. (1%). The soil type is forest brown, and the texture ranges between sandy clay loams to clay loam. The results of conducted an inventory in this forest showed that the tree density and growing stock above 10 cm diameter at breast height (DBH) were 270 trees $ha^{-1}$ and 205 $m^3$ $ha^{-1}$, respectively. In these forests, the main silvicultural method is selective cutting applied through a shortwood harvesting system by ground-based logging. During December and January 2000, marked trees were felled using a manual chain saw, topped at a merchantable height or 20 cm diameter inside bark (dib), and skidded in the shape of logs (5.2 m) or long logs (7.8 m) from the stump area to roadside landings by a Timber-jack 450 C wheeled skidder. The weight of the skidder was 9.8 t, and its width and length were 3.8 and 6.4 m, respectively.

**Collection of data**

Immediately after logging (in 2000), mechanical damages to residual trees were assessed by systematic (100×100 m) sample plots (0.1 ha), and all wounded beech trees (185 stems) were selected, numbered and marked. These wounded beech trees constituted 7.2% of the residual beech trees and 6.7% of the total residual trees in the sample plots. The positions of selected trees were identified on a topographical map by a global positioning system (GPS). On each wounded tree, the following parameters were recorded: DBH measured by dendrometric calipers; wound intensity (i.e., bark, phloem, and wood fibers); agent of wounding (i.e., felling or winching); and the position and size of the wounds. The wound size was determined by measuring the maximum length and width with a ruler (to a 1-mm accuracy) and calculating the ellipsoid surface area (Picchio et al. 2011). Wound sizes were then classified into 4 classes: < 25, 25~100, 100~1000, and > 1000 $cm^2$. The position of the wound was determined with a tape measuring the distance between the wound center and the ground. The position of the wounds was recorded in 3 classes, < 0.3, 0.3~1, and > 1 m (Limbeck-Lilenau 2003). After 12 yr (in 2012), 159 wounded trees were identified, and the condition of the wounds was reexamined and recorded as 4 types: closed, open, decayed, and tree destroyed (Han et al. 2000). The remaining trees (26 stems) had been felled during silvicultural operations.

**Analysis of data**

An analysis of variance (ANOVA) and Duncan tests were used for comparing means of wound sizes (at wound occurrence time, in 2000) for each wound characteristics (agent, DBH, location and intensity). The normality of the data distribution was examined by the Smirnov-Kolmogorov (S-K) test. Since the value S-K did not prove significant in any characteristic ($p > 0.05$), the data were normally distributed. The means of wound sizes at 2 assessments (in 2000 and 2012) for each wound characteristic were compared by a paired-sample *t*-test. A nonparametric Chi-squared test of contingency tables was applied to determine whether significant differences existed among the number of each wound condition (closed, open, decayed, and destroyed) and wound intensities (bark, phloem, and wood) for different wound characteristics (Eq. 1). Tests were not conducted if the expected frequency in any cell of the contingency table was < 5.

$$x^2 = \sum_{i=1}^{k} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}; \quad (1)$$

where $O_{ij}$ is the sample number of the $i$th row and the $j$th column in the contingency table, $E_{ij}$ is the theoretical number of the $i$th row and the $j$th column in the contingency table, and the degree of freedom, df = $(k - 1)\times(r - 1)$.

The ratio of wound size to stem basal area ($RSA$) at the wound occurrence time (in 2000) was calculated by Eq. (2):

$$RSA = \frac{WS}{SBA}; \quad (2)$$

where $WS$ is the wound size ($cm^2$), and $SBA$ is the stem basal area ($cm^2$).

The wound occlusion rate ($WOR$) was calculated by Eq. (3):

$$WOR = \frac{n_c}{N} \times 100; \quad (3)$$

where $n_c$ is the number of closed wounds, and $N$ is the total number of wounds.

A regression analysis was applied to test the following relations: i) between the WOR and WS for DBH classes and ii) between the WOR and RSA for wound intensities. All analyses were performed using SPSS 19 (SPSS, Chicago, IL, USA).

## RESULTS

### Wounds characteristics in 2000

Results showed that about 28.9% (46 wounds) of stem wounds on residual beech trees were caused by felling and 71.1% (113 wounds) were caused by winching operations (Table 1). Of all wounds, 15.1% (24 wounds) occurred on trees with a DBH of < 20 cm, 28.3% (45 wounds) on trees with a DBH of 20~40 cm, 30.2% (48 wounds) on trees with a DBH of 40~60 cm, 15.1% (24 wounds) on trees with a DBH of 60~80 cm, and 11.3% (18 wounds) on trees with a DBH of > 80 cm. The most wounds occurred with an intensity

**Table 1. Wound size ($cm^2$) in relation to wound characteristics (in 2000)**

| Wound characteristic | $n$ | Mean | SD | $F$ |
|---|---|---|---|---|
| Agent of wounding | | | | |
| Felling | 46 | 388.6$^a$ | 282.4 | 49.76** |
| Winching | 113 | 165.7$^b$ | 117.2 | |
| Tree DBH (cm) | | | | |
| < 20 | 24 | 45.6$^d$ | 23.7 | 56.37** |
| 20~40 | 45 | 115.4$^d$ | 81.1 | |
| 40~60 | 48 | 205.8$^c$ | 109.2 | |
| 60~80 | 24 | 385.1$^b$ | 167.3 | |
| > 80 | 18 | 636.7$^a$ | 334.3 | |
| Wound intensity | | | | |
| Bark | 32 | 319.4$^a$ | 187.8 | 11.17** |
| Phloem | 62 | 241.0$^b$ | 154.4 | |
| Wood | 65 | 176.8$^c$ | 92.1 | |
| Location from ground (m) | | | | |
| < 0.3 | 73 | 172.4$^b$ | 76.5 | 38.28** |
| 0.3~1 | 54 | 202.6$^b$ | 92.6 | |
| > 1 | 32 | 409.5$^a$ | 240.9 | |

DBH, diameter at breast height; SD, standard deviation.
Different letter in means of each wound characteristic indicate significant difference at α = 0.05.
**, significant at α = 0.01.

of damaged wood (41%). The percentages of phloem, and bark-damaged wounds were 39 and 20%, respectively. Heights of < 0.3 m on stems had the highest percentage of wounds (46%), while the 0.3~1 and > 1 m of stems had 34 and 20% of wounds, respectively.

The means of wound size in relation to wound characteristics (DBH, agent, intensity, and location) are shown in Table 1. The mean size of felling wounds (388.6±282.4 $cm^2$) was significantly greater ($p < 0.01$) than the mean size of winching wounds (165.7±117.2 $cm^2$). The means of wound size significantly differed among DBH classes ($p < 0.01$), so that as the DBH class increased, the mean wound size also increased. The means of wound size also significantly differed in intensities and locations of the wounds ($p < 0.01$). The mean size of bark-damaged wounds (319.4±187.8 $cm^2$) was significantly greater ($p < 0.01$) than the mean sizes of phloem-and wood-damaged wounds (241.0±154.4 and 176.8±92.1 $cm^2$, respectively). The mean of wound size at heights of > 1 m of stems (409.5±240.9 $cm^2$) was significantly greater ($p < 0.01$) than the mean of wound sizes at < 1 m on stems.

Wound intensities in relation to wound characteristics are shown in Table 2. From all felling wounds, 23 wounds (50%) occurred with a bark-damaged intensity, 18 wounds (39.1%) occurred with a phloem-damaged intensity, and only 5 wounds (10.9%) occurred with a wood-damaged intensity. Among all winching wounds, 60 wounds (53.1%) occurred with wood-damaged intensity. Percentages of wood-damaged wounds increased with increasing DBH classes. The lower parts of stems (height < 1 m) had the highest percentage of wood-damaged wounds. Results of the Chi-squared tests showed that the number of each wound intensity (bark, phloem, and wood) significantly differed ($p < 0.01$) among the agent and location of wounds, and tree DBH classes.

**Wounds conditions in 2012**

Results of the secondary assessment (in 2012) showed that 107 wounds (67.3%) had closed, 30 wounds (18.9%) were open, 15

**Table 2. Wound intensity in relation to wound characteristics (in 2000)**

| Wound characteristic | Bark (%) | Phloem (%) | Wood (%) | Chi-squared |
|---|---|---|---|---|
| Agent of wounding | | | | |
| Felling | 50.0 | 39.1 | 10.9 | 42.96** |
| Winching | 8.0 | 38.9 | 53.1 | |
| Tree DBH (cm) | | | | |
| < 20 | 41.7 | 50.0 | 8.3 | 26.70** |
| 20~40 | 15.5 | 55.6 | 28.9 | |
| 40~60 | 18.7 | 29.2 | 52.1 | |
| 60~80 | 12.5 | 25.0 | 62.5 | |
| > 80 | 16.7 | 27.8 | 55.5 | |
| Location from ground (m) | | | | |
| < 0.3 | 8.2 | 26.1 | 65.7 | 49.82** |
| 0.3~1 | 18.5 | 63.0 | 18.5 | |
| > 1 | 50.0 | 28.1 | 21.9 | |

DBH, diameter at breast height.
**, significant at α = 0.01.

wounds (9.4%) had decayed, and 7 wounds (4.4%) were the cause of tree mortality (Fig. 1).

The number and percentage of wound conditions in relation to wound characteristics are shown in Table 3. The highest percentages

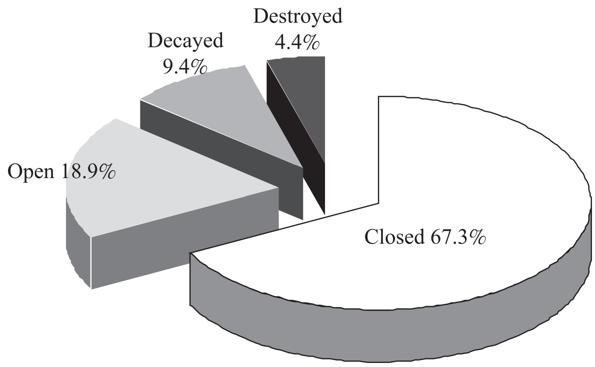


**Fig. 1. Wound conditions after 12 yr from their occurrence.**

**Table 3. Wound condition after 12 yr in relation to wound characteristics at their occurrence time**

| Wound characteristic (in 2000) | Wound condition (in 2012) | | | | | | | | Chi-squared |
|---|---|---|---|---|---|---|---|---|---|
| | Closed | | Open | | Decayed | | Destroyed | | |
| | (*n*) | (%) | (*n*) | (%) | (*n*) | (%) | (*n*) | (%) | |
| Tree DBH (cm) | | | | | | | | | |
| < 20 | 20 | 83.3 | - | - | - | - | 4 | 16.7 | 100.65** |
| 20~40 | 38 | 84.4 | 5 | 11.1 | - | - | 2 | 4.5 | |
| 40~60 | 42 | 87.5 | 3 | 6.3 | 2 | 4.2 | 1 | 2.0 | |
| 60~80 | 7 | 29.2 | 11 | 45.8 | 6 | 25.0 | - | - | |
| > 80 | - | - | 11 | 61.1 | 7 | 38.9 | - | - | |
| Wound size ($cm^2$) | | | | | | | | | |
| < 25 | 44 | 93.6 | 3 | 6.4 | - | - | - | - | 43.46** |
| 25~100 | 49 | 83.1 | 8 | 13.5 | 2 | 3.4 | - | - | |
| 100~1000 | 14 | 43.7 | 10 | 31.3 | 5 | 15.6 | 3 | 9.4 | |
| > 1000 | - | - | 9 | 42.9 | 8 | 38.1 | 4 | 19.0 | |
| Wound intensity | | | | | | | | | |
| Bark | 32 | 100 | - | - | - | - | - | - | 35.99** |
| Phloem | 47 | 75.8 | 10 | 16.1 | 4 | 6.5 | 1 | 1.6 | |
| Wood | 28 | 43.1 | 20 | 30.8 | 11 | 16.9 | 6 | 9.2 | |
| Wound location from ground (m) | | | | | | | | | |
| < 0.3 | 43 | 58.9 | 16 | 21.9 | 10 | 13.7 | 4 | 5.5 | 6.18 |
| 0.3~1 | 38 | 70.4 | 10 | 18.5 | 4 | 7.4 | 2 | 3.7 | |
| > 1 | 26 | 81.2 | 4 | 12.5 | 1 | 3.1 | 1 | 3.1 | |
| Agent of wounding | | | | | | | | | |
| Felling | 33 | 71.7 | 9 | 19.6 | 3 | 6.5 | 1 | 2.2 | 1.52 |
| Winching | 74 | 65.5 | 21 | 18.6 | 12 | 10.6 | 6 | 5.3 | |

**, significant at $\alpha = 0.01$.

of closed wounds were observed for wounds in the DBH class of 40~60 cm (87.5%), wounds of < 25 $cm^2$ (93.6%), wounds with a bark-damaged intensity (100%), wounds at > 1 m of stems (81.2%), and wounds from the felling agent (71.7%). Wounds of the DBH class of > 80 cm, > 1000 $cm^2$, wood-damaged intensity, a height of < 0.3 m, and due to winching agents had the lowest percentages of closed wounds (0, 0, 43.1, 58.9, and 65.5%, respectively). The highest percentages of open and decayed wounds were observed in the DBH class of > 80 cm (61.1 and 38.9%, respectively). The highest percentages of destroyed trees were observed in wounds with sizes of > 1000 $cm^2$ (19%). The Chi-squared tests showed that the DBH class, wound size, and wound intensity had significant effects on wound conditions ($p < 0.01$), but the wound location and the agent of wound have no significant effect on wound conditions.

Results of comparisons of the means of wound sizes at 2 assessments (in 2000 and 2012) for different wound characteristics are shown in Table 4. The means wound sizes of the felling agent, DBH of > 20 cm, bark-and phloem-damaged intensities, and heights of > 0.3 m of stems in 2012 were significantly smaller than their means of wound sizes in 2000 ($p < 0.01$). But the means of wound sizes of the winching agent, DBH of < 20 cm, wood-damaged intensity, and heights of < 0.3 m did not significantly differ with their means of wound sizes in 2000.

Relationships between wound occlusion and wound size in DBH classes are shown in Fig. 2 and Eqs. 4~7. According to Fig. 2, the percentage of wound occlusion decreased with an increasing wound size in the all DBH classes ($p < 0.01$). The maximum wound size that beech trees could occlude (in a period of 12 yr) in DBH classes of > 20, 20~40, 40~60,

**Table 4. Comparison of the means of wound sizes at 2 assessments**

| Wound characteristic | Mean of wound size ($cm^2$) (in 2000) | Mean of wound size ($cm^2$) (in 2012) | Paired *t*-test |
|---|---|---|---|
| Agent of wounding | | | |
| Felling | 388.6 | 124.7 | 21.23** |
| Winching | 165.7 | 160.8 | 1.07 |
| DBH | | | |
| < 20 | 45.6 | 50.3 | 0.56 |
| 20~40 | 115.4 | 22.5 | 8.23** |
| 40~60 | 205.8 | 101.2 | 9.19** |
| 60~80 | 385.1 | 253.0 | 17.3** |
| > 80 | 636.7 | 561.7 | 7.41** |
| Wound intensity | | | |
| Bark | 319.4 | 11.1 | 24.20** |
| Phloem | 241.0 | 183.2 | 10.04** |
| Wood | 176.8 | 187.6 | 0.63 |
| Wound location from ground (m) | | | |
| < 0.3 | 172.4 | 175.0 | 0.44 |
| 0.3~1 | 202.6 | 86.5 | 19.12** |
| > 1 | 409.5 | 201.3 | 20.18** |

**, significant at $\alpha = 0.01$.

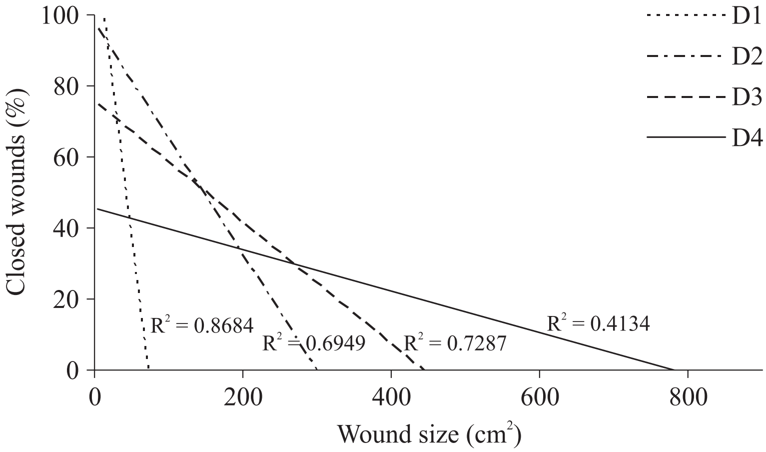


**Fig. 2. Relationships between wound occlusion and wound size in various DBH classes (D1: < 20, D2: 20~40, D3: 40~60 and D4: 60~80 cm).**

and 60~80 cm were 72, 295, 444, and 757 cm$^2$, respectively. The occlusion probability of wounds in a size of 200 cm$^2$, in DBH classes of > 20, 20~40, 40~60, and 60~80 cm were 0, 31.5, 41.4, and 33.4%, respectively.

D1: DBH < 20 cm; CW (%) = 120.9 – 1.67 (WS) (4)
($R^2$ = 0.87; SE = 8.9; $F$ = 145.2; $p$ < 0.01)

D2: DBH, 20~40 cm; CW (%) = 97.5 – 0.33 (WS) (5)
($R^2$ = 0.69; SE = 12.9; $F$ = 102.5; $p$ < 0.01)

D3: DBH, 40~60 cm; CW (%) = 75.5 – 0.17 (WS) (6)
($R^2$ = 0.73; SE = 13.2; $F$ = 157.0; $p$ < 0.01)

D4: DBH, 60~80 cm; CW (%) = 45.4 – 0.06 (WS) (7)
($R^2$ = 0.42; SE = 21.7; $F$ = 14.7; $p$ < 0.01)

Relationships between wound occlusion and the RSA in wound intensities are shown in Fig. 3 and Eqs. 8 and 9. According to Fig. 3, the percentage of wound occlusion decreased with an increasing ratio of RSA in wound intensities ($p$ < 0.01). The maximum RSA that beech trees could occlude (in a period of 12 yr) in phloem-and wood-damaged wounds were 0.28 and 0.26, respectively. The occlusion probability of wounds with an RSA of 0.15 at phloem-and wood-damaged intensities were 54 and 35%, respectively.

PI: phloem intensity; CW (%) = 118.1 – 426.2 (RSA) (8)
($R^2$ = 0.89; SE = 10.8; $F$ = 502.1; $p$ < 0.01)

WI: wood intensity; CW (%) = 81.7 – 311.4 (RSA) (9)
($R^2$ = 0.73; SE = 14.7; $F$ = 168.7; $p$ < 0.01)

## DISCUSSION

Results indicated that the winching of logs was the main cause of wounding (71.9% of wounds) in residual beech trees during ground-based logging operations. However, the sizes of winching wounds were smaller than felling wounds, but the intensity of winching wounds were more severe than the intensity of felling wounds. These findings confirm results of Vasiliauskas (1993), Han (1998), Froese and Han (2006), Kosir (2008), Picchio et al. (2011), and Tavankar et al. (2013). Nikooy et al. (2010) studied residual tree damage during the felling, winching, and skidding stages in the Iranian Caspian forests, and reported that the majority of damage occurred at the winching (44%) and skidding

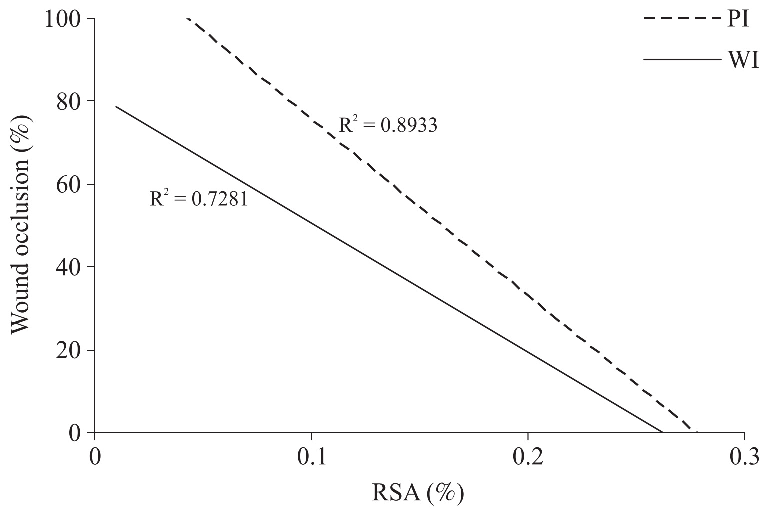


**Fig. 3. Relationships between wound occlusion and the ratio of wound size to stem basal area (RSA) in wound intensities (PI phloem intensity; WI wood intensity).**

(41%) stages. In a study conducted by Solgi and Najafi (2007), 80% of residual trees were damaged by winching stripes in the Iranian Caspian forests. Our results showed that the size and intensity of wounds increased with an increasing stem DBH. Most wounds (41%) occurred with a severe intensity (wood damaged). The results indicated that the size of wounds decreased with increasing wound intensities. The results showed that most wounds (46%) occurred at < 0.3 m from ground level. However, the sizes of these wounds were smaller than the sizes of wounds at > 0.3 m, but their intensities were more severe than the intensities of wounds at > 0.3 m. About 80% of wounds occurred within 1 m from the ground on the boles of residual beech trees. This finding was supported by Bettinger and Kellogg (1993), Solgi and Najafi (2007), Lotfalian et al. (2008), Naghdi et al. (2008), Nikooy et al. (2010), Tavankar et al. (2011) and Jourgholami (2012).

In this research, long-term effects of ground-based logging damage to residual beech trees was also studied. Results showed that after 12 yr, 67.3% of wounds had closed, 32.7% of damaged trees were unable to heal bole wounds, 9.4% of wounds had decayed, and 4.4% were the cause of tree mortality. These were caused by skidder-logging operations. Results of the Chi-squared test showed that wound size, intensity, and location had significant effects on the future value of beech trees. Similar results were shown by Smith et al. (1994) and Han et al. (2000).

Results of this study showed that beech trees with a DBH of < 40 cm were more sensitive to logging wounds than those with a DBH of > 41 cm, so that 83% of damaged trees with a DBH of < 20 cm and 46% of damaged trees with a DBH of 21~40 cm died. The highest rates of closed wounds (71%) were observed on trees with a DBH of 41~60 cm. However, no large-diameter injured trees (DBH > 81 cm) were destroyed by logging wounds, but they had the lowest wound healing ability and had the highest wood decaying rate. Tavankar et al. (2013) reported that the highest ground-based logging damages occurred on sapling and young trees in Caspian forests.

Our study indicated that wounds near the ground had a greater incidence of decay compared to wounds at greater heights. About 93.3% of decayed wounds were located at < 1 m of the tree bole. This result confirmed findings by Hunt and Krueger (1962), Aho et al. (1989), and Han et al. (2000). Wounds from ground-based logging operations usually occur on the lower part of residual tree boles (Naghdi et al. 2008, Tavankar et al. 2010). Overall, results of this study indicated that any major wound located in the lower section of a tree has the potential to greatly reduce the quantity and quality of future wood products by causing staining or decay in high-value butt logs. Residually damaged trees were highly concentrated near the skid trails (Solgi and Najafi 2007, Ezzati and Najafi 2010). Han and Kellogg (2000) suggested that artificial tree protection rigging such as rub pads should be used to prevent damage to stumps and stems.

The wound size is one of the most important characteristics related to decay (Hunt and Krueger 1962, Han and Kellogg 2000). Results showed that wounds of < 25 $cm^2$ had the greatest ability to heal, and about 90% of them had closed, and none of these wounds had decayed or caused tree mortality. As to wounds of > 1001 $cm^2$, about 51% of wounded beach trees had died. Larger wounds on the upper part of tree boles occur at the tree felling stage. In order to minimize felling damage, directional felling must be applied considering the skid trails. Directional felling is an important technique to reduce logging damage to residual stands. With directional felling, trees are felled to reduce damage to the stand, facilitate choker hook-ups in preparation for winching, and operate without creating unnecessary large forest disturbances (Tavankar et al. 2013, Marchi et al. 2014). This study indicated that injuries of < 25 $cm^2$ on beech trees had no risk of infection by wood-destroying fungi.

About 95% of bark-squeezed intensity of wounds were closed and 5% were open. Bark-squeezed and bark-removed intensities of bole wounds did not cause tree mortality, while about 31% of wood-damaged intensity wounds caused tree mortality, and 38% of them caused wood decay. These findings are similar to those of Camp (2002), who reported that when external damage to bark occurs, fungal infections are not expected.

Beech (*Fagus orientalis* Lipsky) is the most industrial commercial tree species among more than 80 broadleaf trees and shrubs in Caspian forests. Logging studies have shown that poor felling and skidding techniques can result in excessive damage to residual trees (Pinard et al. 1995, Sist et al. 2003). Pre-harvest planning and identifying winching areas before logging operations can reduce damage to stands in these forests. Skid trail planning before felling operation can reduce skidding damage (Naghdi et al. 2008, Majnounian et al. 2009). The skidder and chain saw operators are important factors which can influence productivity and environmental impacts during logging operations. So training forest workers can be useful to reduce logging damage to residual stands. All workers should be made aware of the purpose of selective cutting, and that both minor and major injuries to residual stands as well as excessive ground disturbance may result in significant volume losses (Davis and Nyland 1991) and natural regeneration of the forest (Picchio et al. 2012, Marchi et al. 2014).

## CONCLUSIONS

Beech stands are the most economically valuable in the Caspian forests and produce the most timber in Iran. Results of this study indicated that beech trees are very susceptible to wood-intensity wounds. Young beech trees have low resistance against logging wounds. The ratio of wound size to stem basal area is an important factor. In the context of selective cutting management, limiting logging damage to residual trees must therefore remain one of the major objectives. An important part of preserving the long-term productivity of a forest is preserving its ecology. Proper planning of logging operation can minimize the level of damage or degradation to residual stands during logging operations. Operators must be convinced, through adequate training, that most damage to residual trees is unnecessary and avoidable. Detailed planning strategies can reduce damage to a level which is acceptable and predictable. Pre-harvest planning and identifying the winching area before logging operations can reduce stand and soil damage. To reduce stand damage, skid trails should be planned before felling operations. Both training and supervision may be necessary to provide desired results. For post-harvesting assessment of a logging operation, obtaining an accurate measure of residual stand damage is necessary (Stehman and Davis 1997). Recommendations for selective cutting management include long rotations and careful, detailed logging operations in these stands.

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