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RESEARCH ARTICLE

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Damages to soil and tree species by cable-skidding in Caspian forests of Iran

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Abstract

Aim of study: The main aims of this study were to determine of damage level to residual stand and soil disturbance from mechanized selection logging.

Area of study: Mixed beech stands in Caspian forests, northern Iran.

Material and methods: Point-transect and systematic plot sampling were used for assessing damages to soil and trees, respectively.

Main results: 89% of forest soil area was undisturbed or shallow disturbed, and 5.2% was deep disturbed. Soil bulk density of top 10 cm in the winching corridors, ruts and skid trails were increased 10.7%, 20.6% and 32.1% respectively than controlled area. Frequency of damages to regeneration and trees were 12% and 11.2%. The frequency of damages to regeneration was increased with increasing of their heights, but frequency of damages to trees was decreased with increasing of their diameter. The most type of damages was bole wounds in sizes of 100 to 200 cm^2 within 1 m from the ground level, and deep wounds. The frequency of damages was different in tree species (p = 0.001). The mean size of bole wounds was 174 cm^2, and the mean height of bole wounds was 70 cm from ground level. The intensity of wounds on trees bole were decreased with increasing of their heights from ground level (p = 0.02), while their sizes were increased (p = 0.001).

Research highlights: Winching of logs was the main cause of damages to soil and residual stand. The detailed planning strategy will reduce damage to level which is acceptable and predictable.

Keywords: bole wound; Caspian forests; logging damage; selection cutting; soil disturbance.

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Introduction

Cable-skidding can damage residual trees in natural forests, can disturb soils, and alter potential habitats for regeneration (Sist *et al*., 1998; Iskandar *et al*., 2006; Tavankar *et al*., 2015). However damage to residual stand and to soil is a natural prospect of selective logging, but the level of damage should be minimized to assure future product quality (Majnounian *et al*., 2009). Properly planned logging will minimize adverse impacts on the environment of forest (Picchio *et al*., 2012; Tavankar *et al*., 2013; Marchi *et al*., 2014). Rationalization efforts have resulted in an increasing mechanization of timber harvesting systems (Stehman & Davis, 1997; Limbeck-Lilenau, 2003). However, uncontrolled mechanized logging resulted high damaging on forest structure, composition and regenerating capacity (Sist *et al*., 1998; Picchio *et al*., 2012). Logging operation can also cause soil disturbance in various forms such as compaction, rutting and soil displacement (Arnup, 1999). Soil disturbance by logging can also increase erosion potential (McIver, 2004).

Wounds are the most common form of damage to remaining trees. Wounding can cause stem deformity and loses of volume and value (Meadows, 1993). Often the injuries become an input port for fungi decays (Vasiliauskas, 2001). The literature reviews show that minor damage to the stem of residual trees can have a major impact on the final stand volume as future saw logs (Verissimo *et al*., 1992; Pinard *et al*., 1995; Sist *et al*., 1998). Many factors such as length of time since injury, size of injury, tree species, location of wound on the bole and the vigor of tree are important in development of decay in wounds (Meadows, 1993; Vasiliauskas, 2001). The wound characteristics such as size, location, and intensity are the main factors that influence on the future quality of damaged trees (Vasiliauskas, 2001; Tavankar & Bonyad, 2014). Damages during the selective logging operation may decrease the quality of residual trees and increase stand mortality through insect and disease infestation (Han & Kellogg, 2000).

Soil disturbance due to forest logging may have negative consequence for forest productivity (Binkley, 1991; Curran *et al*., 2005). Murphy *et al*. (2004) reported decreasing height growth of *Pinus radiata* D.Don. due to soil compaction following logging operation. In recent decades, concerns were raised about the protection of soils during forest operation. Soil as a critical element for forest sustainable management is a relatively nonrenewable natural resource (Miller *et al*., 2010).

Logging component cause some degree of soil disturbance (Grigal, 2000). Soil disturbance influences stand growth and yield by affecting seed germination, seedling survival and establishment and root growth. Compacted soil due to forest harvesting has important rule in reducing root growth of plants by restricting access to water and nutrients and reducing air diffusion (Gomez *et al*., 2002). Tavankar *et al*. (2009) found that soil bulk density of top 10 cm on the winching area and skid trails increased 17.5 and 35.6% than controlled area following wheeled skidder skidding during selection cutting in the north of Iran. Williamson & Neilsen (2000) found that a single pass by a rubber-tired skidder increased soil bulk density by 22% in the upper 10 cm in Tasmania. Rutting can have detrimental impacts on site productivity by creating preferential flow patterns for overland water flow, decreasing infiltration and gaseous exchange (Page-Dumroese *et al*., 2009).

The forest service must be able to manage soil disturbance in order to maintain sustainable production of natural resources (Craigg & Howes, 2007). The logging intensity (Sist *et al*., 1998), Logging machines (Han & Kellogg, 2000), road density (Iskandar *et al*., 2006), level of logging operation planning (Pinard & Putz, 1996), site condition and skill of equipment operators (Pinard *et al*., 1995) are important factors that influence on amount of ground-based logging damages to residual stand and soil in forests. Logging studies have shown that poor felling and skidding techniques can result in excessive damage to residual stand (Pinard *et al*., 1995; Sist *et al*., 1998). Careless operations have a high potential for damage the forest soil and residual trees in short time which can lead to depletion of tree vigor and quality and degrade the volume and value of the future forest.

The main aims of this study were to determine of damage level to residual stand (tree and regeneration), and soil disturbance from mechanized selection logging in the Caspian hardwood forests, highlighting the potential applications of the selection cutting.

Material and methods

Study area

This study was conducted in the Caspian forest of Iran. These forests are managing by selection cutting silviculture as close to nature method. The geographical coordinates of the study area were 37° 38' 34" to 37° 42' 21" N and 48° 48' 44" to 48° 52' 30" E. Elevation of the study area is ranged from 1,150 to 1,350 m above sea level. The mean annual precipitation is approximately 950 mm and the mean annual temperature is 9.1°C. The original vegetation of this area is an uneven-aged mixed hardwood forest. Average growing stock in this forest was 312 m^3 ha^{-1} and average number of trees was about 235 stem ha^{-1} above 7.5 cm DBH (Diameter at Breast Height). The soil type is forest brown and soil texture varies between sandy clay loams to clay loam. The number of selected trees to harvest in the study area (42 ha) was 286 stems that volume of these trees was 546 m^3. Chainsaw and cable skidder (Timber jack 450C) was machines for cutting and extraction of marked trees. The length of winching cable was 50 m. The weight of skidder was 9.8 t and its width and length were 3.8 and 6.4 m respectively.

Data collection and analysis

The point-transect method was used for assessing of soil disturbance according to the method developed by McMahon (1995), immediately after logging operation. The disturbance assessment comprises the classification of disturbance types (Table 1) at 5 m intervals within a 30 cm radius along 30 m transects. Two transects were located at grid centers with dimensions of 100 m × 100 m with random start point. A random azimuth was selected for ordination of first transects, and added 90° for the second transect. In addition, 504 points were recorded for assessing visual soil disturbance (B.C. Ministry of Forests, 2001; Solgi & Najafi, 2014). Length, width and deep of ruts (larger than 200, 30 and 5 cm, respectively) that intersected by transects were measured. For assessing soil physical properties, 15 soil samples were taken from each identified areas (Undisturbed, winching corridors, deepest point of ruts

Table 1. Frequency of soil disturbance types

Disturbance class	Disturbance type	Code	Frequency	Percentage
Undisturbed	Litter and understory intact	1	302	59.9
Shallow disturbance	Traces but litter not removed	2	55	10.9
	Litter removed, topsoil intact	3	43	8.5
	Litter and topsoil mixed	4	38	7.5
	Topsoil deposited on litter	5	10	2.0
Deep disturbance	Topsoil removed, subsoil exposed	6	3	0.6
	Erosion feature	7	2	0.4
	Subsoil puddling	8	2	0.4
	Rout depth 5-15 cm	9	9	1.8
	Rout depth 16-30 cm	10	6	1.2
	Rout depth > 30 cm	11	4	0.8
Clarifiers	Skid trail	12	9	1.8
	Non-soil (Dead tree, stump, stone)	13	21	4.2

and skid trails). The cylindrical sampling method was used to determine dry soil bulk density. The soil samples from the 10 cm were collected with a soil hammer and rings (diameter 5 cm, length 10 cm), put in polyethylene bags, and labeled immediately. Surface litter and duff were removed before sampling. The soil samples were dried in an oven under 105 oC for 24 hours to obtain dry bulk density (Lee *et al*., 1983). Sample volumes and weights were corrected for large roots, wood, or gravel. The dry bulk density was calculated from the equation (1):

$$\rho_d = \frac{(W_d - W_c)}{V_c} \qquad (1)$$

where, ρ_d is the soil dry bulk density (g/cm^3), W_d is dry weight of the sampler (g), W_c is weight of the cylinder sampler (g) and V_c is volume of the cylinder sampler (cm^3).

Systematic plot sampling method was used for assessing stand damage (Meadows, 1993; Lotfalian *et al*., 2009; Nikooy *et al*., 2010). Plot centers was same grid centers that used for soil assessment, and area of each circular plot was 1000 m^2. The species, diameter at breast height (DBH) and impact condition (safe or damaged) of all trees (DBH ≥ 7.5 cm) and natural regeneration (DBH < 7.5 cm) were measured and recorded in each plot. Damages were recorded in two types: wounded and destroyed. The natural regeneration on the base of their heights was recorded in three stages: seedling (height < 0.5 m), small sapling (height 0.5-2 m) and large sapling (height > 2 m). The damage location was recorded in three positions: crown, bole and root. The characteristics of wounds such as, intensity, size and height from ground level also were recorded in damaged trees. Bole wounds were recorded in three intensities: 1) bark, 2) bast and 3) wood damage (Picchio *et al*., 2011 and 2012; Marchi *et al*., 2014).

Data analysis

ANOVA and Duncan test by SPSS software version 16 were used for analysis of the soil bulk densities in identified areas, for damages in tree and regeneration species, tree DBH, and growing stages of regeneration, after checking normality of data (Kolmogorov–Smirnov test) and homogeneity of variances (Leven test). Regression analysis was applied to test the relation between wound height and wound size.

Results

Damage to soil

The frequency of soil disturbance types is shown in Table 1. About 5.2% of soils were deep disturbed, and the most disturbance type in this disturbance class was ruts with depths of 5 to 15 cm. About 29% of soils were shallow disturbed and 60% undisturbed.

The soil bulk density in the winching corridors was increased 10.7% than controlled area, but the difference

Table 2. Soil bulk density in identified areas

Areas	Mean ± SD (g.cm^{-3})	Increase (%)
Undisturbed	1.172 ± 0.13^c	-
Winching corridors	1.298 ± 0.12^c	10.7
Ruts	1.413 ± 0.14^b	20.6
Skid trails	1.548 ± 0.13^a	32.1

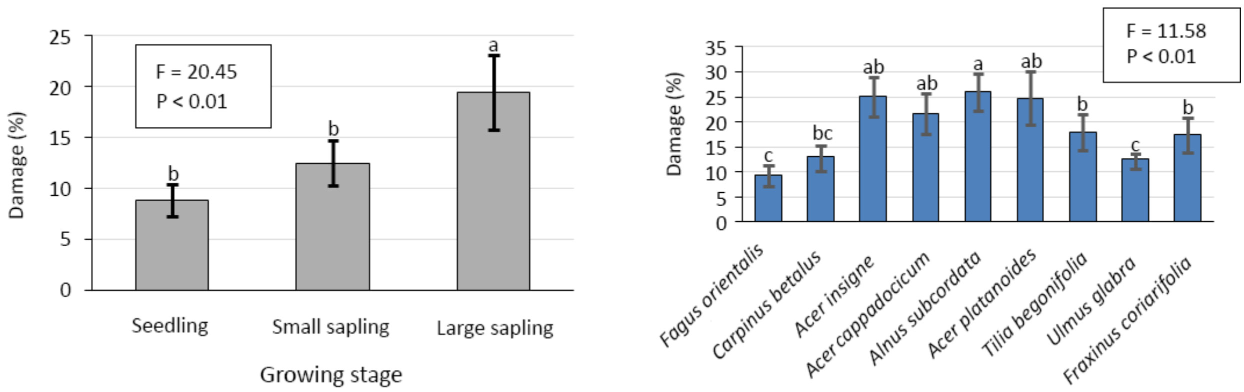

Figure 1. Frequency of damages in growing stages (left) and species (right) of regeneration

was not statistically significant (Table 2). While, the soil bulk density in the ruts and skid trails were significantly increased (20.6% and 32.1%, respectively) than controlled area soils (Table 2).

Damages to regeneration

A 4.9% and 7.1% of total regeneration (1,407 stem ha^{-1}) were wounded and destroyed respectively following logging operation. The frequency damages in growing stages of different species are shown in Fig. 1. The density of seedling, small sapling and large sapling were 723, 438 and 246 stem ha^{-1}, respectively. The mean frequency of damage in seedling, small sapling and large sapling were 8.8%, 12.8% and 19.5%, respectively. The mean damages to large sapling were significantly the highest among other regeneration stages (Fig. 1).

Species of regeneration were comprised, 70.6% *Fagus orientalis* Lipsky*,* 13.4% *Carpinus betulus* L.*,* 3.9% *Acer insigne* Boiss*,* 3.1% *Acer cappadocicum* Gled., 3.7% *Alnus subcordata* C. A. Mey., 1.9% *Acer platanoides* L.*,* 1.6% *Tilia begonifolia* Stev.*,* 1.1% *Ulmus glabra* Huds., and 0.7% *Fraxinus coriarifolia* Scheel. The most frequency of wounded and destroyed regeneration was observed on the *Alnus subcordata* (15.4% and 10.6%, respectively). The damage frequency on the regeneration of *Acer* and *Alnus* species were significantly more than the other species, while damage frequency on the regeneration of *Fagus orientalis*, *Ulmus glabra* and *Carpinus betulus* were less than the other species (Fig. 1).

Damages to trees

A 8.3% of trees were wounded and 2.9% of them were destroyed following logging operation (Table 3). The most frequency of wounded and destroyed trees were observed on the *Alnus subcordata* (16.9% and 4.8%, respectively). The lowest frequency of destroyed trees was observed in *Fagus orientalis* with 2.2%.

The frequency of damage types in tree DBH classes are shown in Table 4. The most frequency of wounded and destroyed trees were observed on the first DBH class (10.4% and 5.5%, respectively), and the lowest frequency of wounded and destroyed trees were observed in the latest DBH class (3.9% and 0%,

Table 3. Frequency of damage types in tree species

Tree species	Density (stem ha^{-1})	Wounded stems (%)	Destroyed stems (%)
Fagus orientalis Lipsky	133.5	7.1	2.2
Carpinus betulus L.	40.5	8.0	2.5
Acer insigne Boiss.	23.3	10.7	3.2
Acer cappadocicum Gled.	21.2	10.6	3.5
Alnus subcordata C.A.M.	20.7	16.9	4.8
Acer platanoides L.	13.2	9.4	3.8
Tilia begonifolia Stev.	11.5	4.3	4.3
Ulmus glabra Huds.	7.5	3.3	3.3
Fraxinus coriarifolia Scheel	5.5	4.5	4.5
All species	276.9	8.3	2.9

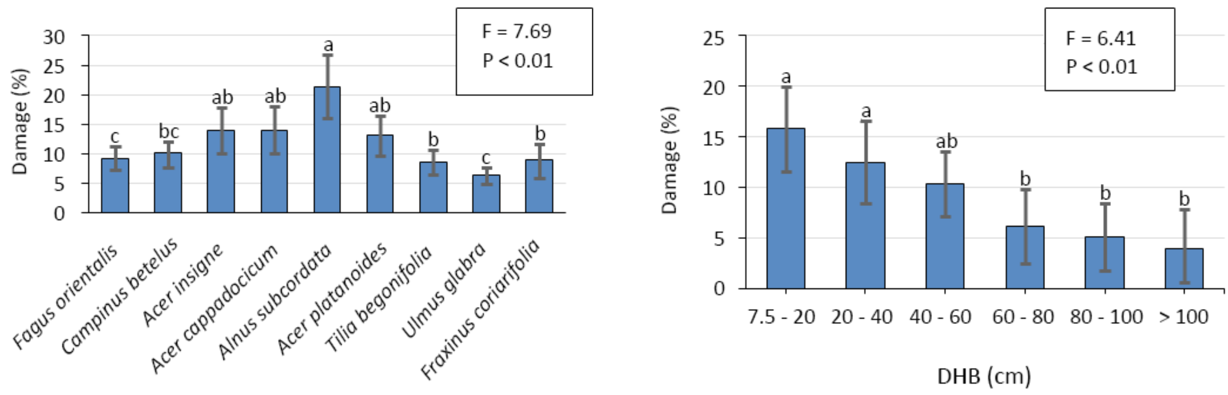

Figure 2. Frequency of damages in tree species (left) and tree DBH (right)

respectively). The results showed that the frequency of damages to trees was decreased with increasing DBH of trees (Table 4 and Fig. 2).

From all of the damaged trees (92 stems), 31 stems (33.7%) were damaged on the crown area, 50 stems (54.3%) were damaged on the bole area and 11 stems (12%) were damaged on the root area (Table 5). In fact, about 2.8% of residual trees were damaged on the crown area, 4.5% were damaged on the bole area and 1% was damaged on the root area.

The mean (±SD) of wounds size on the bole of residual trees was obtained 173.9 (±121.5) cm^2, and the mean (±SD) of wounds height from ground level was obtained 0.70 (±0.60) m. The regression analysis showed the wound size significantly increased with increasing wound height (Fig. 3) (F = 49.7; P < 0.01).

From all of the wounds (50 wounds), the numbers of bark (code 1), bast (code 2) and wood (code 3) damaged stems were 8, 13, and 29 stems, respectively. According to collected data, 0.7% of residual trees were damaged on the bole area with bark intensities, 1.2% with bast intensities and 2.6% with the wood intensities. The mean (±SD) of wound intensity on the bole of residual trees was obtained 2.42 (±0.76). The mean of wounds intensity on the < 0.3, 0.3-1 and > 1 m of trees bole were 2.62, 2.46 and 1.91, respectively (Fig. 4). The ANOVA test showed that the mean of wound intensity on the height classes of wound are significant different (P < 0.05). The wounds intensity was decreased with increasing wound height (Fig. 4).

Table 4. Frequency of damage types in tree DBH classes

Tree DBH (cm)	Density (stem ha^{-1})	Wounded stems (%)	Destroyed stems (%)
7.5 – 20	86.5	10.4	5.5
20 – 40	60.0	8.3	4.2
40 – 60	45.8	9.8	1.1
60 – 80	36.1	6.2	0.6
80 – 100	29.5	5.1	0.0
> 100	19.0	3.9	0.0

Table 5. Frequency of wounds locations in residual trees

Location	Root	Bole	Crown
Wounded (stem)	11	50	31
Wounded (%)	1.0	4.5	2.8

Discussion

Soil disturbance

The results showed that about 5.2% of the forest surface soils were deep disturbed, and about 89% were undisturbed or shallow disturbed following selection cutting and cable-skidding. The extent of soil disturbance was reported 30% by Solgi & Najafi (2014). The results indicated that the soil bulk density in the ruts during winching of logs and in the skid trails are significantly higher than the soil bulk density in the controlled areas. Significantly different bulk density between disturbed and undisturbed areas was found by Marchi *et al.,* (2014). However in other studies, the winching operations do not every significantly affect the bulk density. This is due to utilization methods and appropriate training of the operators (Picchio *et al.,* 2012; Marchi *et al.,* 2014). Krause (1998) reported that compaction from harvesting equipment can reduce water infiltration and air permeability which is detrimental to the establishment and growth of regenerating species. The extent of disturbed soils by ground based logging system was reported 218 m^2 in Brazil forests (Verissimo *et al.*, 1992) and 94 m^2 in Malaysia forests (Pinard *et al.*, 2000) for each harvested tree. The extent and degree of soil disturbance associated with skidder extraction are variable and related to slope (Stuart & Carr, 1991), soil texture (Clayton, 1990; Jusoff, 1991) and soil moisture content

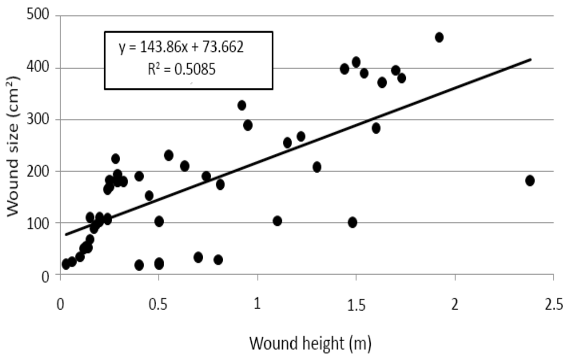

Figure 3. Relation between wound size and wound height

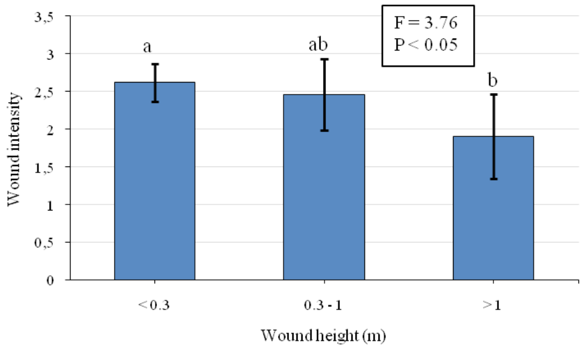

Figure 4. Mean of wound intensity (1: bark, 2: bast and 3: wood)

at the time of logging (Jusoff, 1991). Soil compaction resulting from harvesting operation limit the effective rooting depth of plants by restricting access to water, nutrients and reducing gaseous exchange (Gomez *et al*., 2002).

Damage to regeneration

Forest regeneration is the growth of tree seedlings into large mature trees, an important indicator for forest health. The long term health and economic viability of forest ecosystems is dependent on sufficient tree regeneration. The results of this study showed 4.9% and 7.1% of regeneration was damaged and destroyed by cable-skidding, respectively. Forests depend on adequate regeneration of tree species to be healthy and sustainable. Lotfalian *et al*. (2008) reported damage percentage to regeneration during cable-skidding about 8.0% in the Caspian forests of Iran. Hosseini *et al*. (2000) compared damages to natural regeneration by two logging systems (skidder and arial cable) in the Caspian forests of Iran. They reported that damages to regeneration in skidder system were significantly higher than aerial cable system (11% vs. 5%). Winching is the main cause of damages to regeneration during cable skidder logging (Nikooy *et al*., 2010; Picchio *et al*., 2011). Results of study showed damage to regeneration was increased by increasing of height of regeneration, so damage percentages on seedling, small sapling and large sapling was 8.8, 12.8, and 19.5%. This may be due to reduction of regeneration flexibility with increasing their heights. Nikooy (2007) studied logging damage on regeneration in the Caspian forest and reported that damage rate on the seedling; small sapling and large sapling stage were 20.3, 20.6, and 26.5% in felling gaps. Whitman *et al*. (1997) reported damage level of 15% to seedlings in a single tree selection cutting operation in northern Belize. The logging methods have a big influence on effects on regeneration disturbance. The regeneration survival is significantly higher when using a snatch block in the winching. When block are not used, the impacts are bigger (Picchio *et al*., 2012; Marchi *et al*., 2014).

Damages to trees

The results of this study indicated 11.2% of residual trees were damaged by timber harvesting operation in the study area. This amount of damage to residual trees is considerable. Residual tree damage following selection cutting in the Caspian forests reported 15.5% by Lotfalian *et al*. (2008), 19% by Naghdi *et al*. (2009), 19.7% by Nikooy *et al*. (2010) and 16.9% by Tavankar *et al*. (2015). Differences in the percentage of damages are probably due to ground slope and harvesting intensity. Yilmaz & Akay (2008) in Turkey forests showed 14% of residual trees damaged during felling and skidding operation. Hartsoug (2003) in the north eastern California forests showed that 23% of residual trees damaged during ground based logging operation and smaller trees were more likely to be damaged. The study conducted by Ficklin *et al*. (1997) indicated that skidding operation using wheeled skidder damaged about 22% of the residual trees. The levels recorded in this study are near to those reported for mechanized in Mediterranean European operations with wincing (Vasiliauskas, 2001). Marchi *et al.* (2014) reported that the frequency of wounded trees is highest when winching without a snatch block and decreased when using a snatch block. Operation methodologies with a snatch block allows reducing by one quarter the frequency of wounded trees, which dropped from 50% to about 36% compared to without a snatch block methodology.

Our results indicated that 90% of destroyed trees had diameter less than 40 cm. Studies in West Virginia hardwood stands have shown that most of the damaged and destroyed trees are less than 5.0 inches in diameter

(Lamson *et al*., 1985), so the net loss of residual basal area was only 6%. Our results also showed the shade-intolerant species such as Alder and Maple were more damaged than other tree species. One of the main goals of selection cutting management is the conservation of species diversity. About 2.6% of residual trees were intensive damaged in the crown area. All of crown damages were occurred in the tree felling stage. The results of this study showed 78% of wounds were occurred in the heights of less than 1 m from the ground level on the boles of residual trees. This finding has been supported by researchers by Bettinger & Kellogg (1993), Solgi & Najafi (2007), Lotfalian *et al*. (2008), Naghdi *et al*. (2009), Nikooy *et al*. (2010), Jourgholami (2012), Marchi *et. al* (2014). The highest risk for decay is given for trees with injuries in the area of the felling cut and the root collar.

About 1% of residual trees were wounded on root area. The root wounds can significantly reduce tree growth, especially if they are intensive (Meadows, 1993). Tavankar & Bonyad (2014), reported 67.1% of logging wounds on residual tree boles were closed and 32.8% of the damaged trees were not able to improve their wounds, about 4.2% of wounds caused to tree mortality. Our results indicated that 3.2% of residual trees were damaged with injury sizes of more than 200 cm^2. The residual trees can not able to repair these wounds (Tavankar & Bonyad, 2014).

Conclusion

From this investigation it can be concluded that it is possible to reduce mechanized harvesting damages on forest environment by detailed planning strategy. Proper planning of logging operation can minimize the level of damaging or degrading the residual stand during logging operations. Planning skid trails and log landings carefully, using directional felling to inflict the smallest impact on the surrounding forest and skilled harvester labor are important implications to reduce logging damages. By using directional felling techniques, trees were felled to reduce damage to stand, to facilitate choker hookups in preparation for skidding and to without creating unnecessary large forest disturbance. Operators must be convinced that most damage to residual trees is unnecessary and avoidable. Both training and supervision may be necessary to provide desired results. Pre-harvest planning and identifying the winching area before logging operation can reduce stand and soil damages. To reduce the stand damage, skid trails should be planned before felling operation. An important part of preserving the long-term productivity of a forest is preserving its ecology. Forest soil maintenance is a key factor for sustaining productive forests. Visual assessments of soil disturbance provide a rapid assessment of soil condition that can be useful for monitoring soil disturbance during timber harvesting. In the context of selection cutting management, limiting logging damage to residual trees and soil must be a major objective. For post-harvesting assessment of a logging operation, obtaining an accurate measure of residual stand damage is necessary. More careful logging would have reduced the amount of residual stem damage associated with timber harvesting. The detailed planning strategy will reduce damage to level which is acceptable and predictable.

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