Research Article

Long-Term Impact Evaluation of Ground-Base Skidding on Residual Damaged Trees in the Hyrcanian Forest, Iran

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We investigated the long-term effects of ground-base skidding on residual damage severity on the healing of residual damaged trees in forests of northern Iran twenty-years post logging operation. Characteristics examined included wound size, location, severity, height from ground level, number of wound on the damaged tree stems, and distance of damaged tree from centerline of the skid trail on a 8-meter distance alongside the abandonment skid trail. There were some crucial changes in the characteristics of the wounds on the damaged trees stems, which have been investigated on the high traffic intensity and the low traffic intensity. Results showed that an average amount of damaged trees alongside skid trails, which were 100% inventoried, were 18.83%. Results also confirmed that based on the available measurements of a twenty year period, it is too early to make any definite conclusion about how long it will take for occlusion of wounds on tree stems to fully heal from timber operations.

1. Introduction

The development and use of partial-cut systems (i.e., shelter wood and single tree selection) in uneven-aged standard forests management have increased the use of selection logging systems. There are many different ways to transport logs from stump to the log-landing in these forests. Typically, ground-base skidding which is used in mountainous terrains includes crawler and wheel skidders in primary transportation [1]. In applying selection cutting system, inadequate logging operations (i.e., felling and skidding) may be caused unacceptably serious damage to the residual stands due to existence of various tree species with different age classes [2]. These injuries may cause considerable amount of timber volume loss and potential means of entry for organisms causing decay and pitch rings. As a consequence, extreme economic losses may be occurred [3]. When the bark is torn from living trees, as in logging wounds, the vascular cambium cells are removed, and callus starts to develop from around the living bark at the margin of the wound, growing towards the centre of the wound [4]. Even small wounds on residual trees will result in large stains in the wood, and

after some decades, trees with such stains might not be of sufficient value to cover management and harvesting costs Suzuki [5]. Damages imposed by machines may reduce vigor and quality [6], and serve enough to kill the tree Pinard and Putz [7]. According to Suzuki [8] most of the wounds were caused by extraction operation rather than felling of the trees. This research also revealed that more than half of the wounds were on boles less than 1.5-meter in height and few wounds were on boles over 3.5-meter in height. In uneven-aged mixed forests, special felling and skidding operations should be performed to minimize residual stand damage and to secure natural regeneration process [9]. Damage to residual stands from mechanized operations has been studied in short-term by Bettinger and Kellogg [10] and Clatterbuck [11]. Residual stand damages as a result of mechanized logging operations had been found to persist for number of years. Benzie et al. [12] and [13] traced the same wounds of northern hardwoods from skidding operations four and ten years, respectively, after the logging and thinning operations. They concluded that the wounds from timber operations were not fully closed. After five years of study on close of wounds on residual stand damages

post thinning operation by Suzuki [5] in Japan forests. He reported that most wounds of a lighter severity level had already healed by occlusion and were no longer evident, while wounds reflecting heavy damage had healed and were smaller in the horizontal dimension, or width, than those not yet healed. Defect resulting from logging damage usually was minor in small wounds for as long as 10 years, but 20-cm scars in the butt of damaged trees were infected within 20 years and value losses were significant [13]. Several factors such as tree species, slope of skid trail, traffic intensity, log volume, stand density, as well as mechanical equipment affect severity of damages and late occlusion of wounds on stems of trees across the skid trails [14, 15]. Yilmaz and Akay [2] reported that damage to residual stems associated with individual tree selection systems did jeopardize a stand potential to increase diameter growth. Excessive damages occur as a consequence of the increase of traffic intensity during skidding operations. Heitzman and Grell [15] found that about 80% of bark scraped of butt logs occurred at high traffic intensity regardless of tree size. Reviews of literature showed that their much research has focused on short-term impacts of timber skidding on healing of wounds on residual trees in forests; the long-term impact has received little attention. Therefore, to broaden current knowledge of residual stand damage, our study includes the following objectives: to characterize healed wounds on damaged trees 5 to 20 years after logging and (ii) to assess and contrast damage levels on residual trees as influenced by age (years since harvest) and traffic intensity.

2. Materials and Methods

2.1. Study Site. The study site is located in the eastern Mazandaran province in north of Iran $36^{\circ}31'56''$ and $36^{\circ}32'11''$ of northern latitude and $51^{\circ}47'49''$ and $51^{\circ}47'56''$ of eastern longitude. The forest structure in this region is uneven-age standard hardwood. Elevation of the study area was ranged from 1114 m to 1585 m. According to the Ambrejet method, the climate is humid and cold Alijani and Kaviani [16]. Mean annual precipitation is 1250 mm and as the elevation increases it is in the form of snow. The major soil type of the study sites is brown forest with pH more than 7. Using USDA soil taxonomy, soil was described as an Alfisols and Inceptisol. The depth of the soil in these sites ranges from 250 mm to 350 mm and the soil is partly well drained. Slope was relatively gentle, generally more than 15% for ground-based logging system units. The forest is composed of deciduous trees dominated by (*Fagus orientalis* Lipsky and *Carpinus betulus* (L) with companion species *Alnus subcordata* (C.A.M) and *Quercus castanifolia* (C.A. Mey). Silviculture systems were shelter wood and single-tree selection systems in the study area. Harvesting volumes were extracted by ground-based system included TAF and Timberjack 450 C wheel skidders. Logs were extracted to roadside in short/long logs. Table 1 summarizes the locations, elevation of the experimental areas and length of skid trails as well as time of abandonment from logging.

FIGURE 1: Number of damaged trees based on two directions of skid trail (up and downslopes) in different traffic intensity.

FIGURE 2: Distribution of DBH class of all trees in time since harvesting.

3. Data Collection and Analysis

Four certain sampling methods have been used by various authors to assess soil damages disturbances and residual damages on forest areas after ground-base skidding. [17, 18]. These methods include point-transect method, line-intercept technique, aerial photographs and planimetry and ground traverse [19]. Due to sensitivity of forest sites in the present study, a ground traverse method was applied to collect data in the field. If this method is accompanied by field observations, it is well likely to give more accurate estimates of damages on the skid trails than other sampling methods [20]. To achieve this purpose, after several initial surveys in May 2010, data were collected from four skid trails in a chronosequence of 20 years (four 5-year class), with similar conditions, for example, volume log, stand density, slope, and canopy cover. These skid trails were abandoned from ground-base skidding operations 5, 10, 15, and 20

TABLE 1: Summary of the skid trail information.

Compartments	GPS coordinates (latitude and longitude)	Class age (year)	Length (m)	Elevation above sea level (m)
C.91	36°, 21'–36°, 21' N Lat and 53°, 32'–53°, 33' E Long	1–5	1100	1545–1581
C.68	36°, 21'–36°, 21' N Lat and 53°, 32'–53°, 32' E Long	5–10	1200	1375–1439
C.73	36°, 21'–36°, 21' N Lat and 53°, 31'–53°, 31' E Long	10–15	1300	1395–1401
C.72	36°, 21'–36°, 22' N Lat and 53°, 33'–53°, 33' E Long	15–20	1000	1114–1196

TABLE 2: Classification of damage, by location, size, severity, frequency, and distance from centerline of the skid trail imposed by logging operations.

Categories	DC1	DC2	DC3	DC4
Location of damage	Root	<100 cm	100–15 cm	>150 cm
Size of damage	≤100 cm ²	100–1000 cm ²	1000–2000 cm ²	≥2000 cm ²
Severity of damage	Minor	Moderate	Sever	Destroy
Frequency of wound	1	2-3	>3	—
Distance from centerline of the skid trail	1-2 m	2-3	>3 m	—

years ago located in district no. 2 of division no. 7 in Neka-Zalemrood catchment's forests, northern Iran. Skid trails were 4 meters in width by 1000–1300 meters in length; running parallel to the slope (downhill skidding), details of each skid trail are shown in Table 1. Each skid trail was divided into three segments with regard to distance from log landing; high (main trail segment originating from the log landing or primary trail), medium (branched from the primary trail) and low traffic intensity (branched from the secondary trail) skid trail terminating at the stump Rab [21]. Within each skid trail, all damaged and undamaged trees adjacent to the skid trail in viewpoint of traffic intensity locations in upslope and downslope of the skid trail were marked to avoid counting the same tree twice or missing trees. To assess the damage from ground-base skidding, ground traverse or 100% inventory method was applied in the 8-meter distance alongside skid trail (4-meter distance from the centerline of the skid trail to upper and lower sides' of-slope, resp.). Two types of damage were recorded; scarring and root damages. For scarring damage, tree Diameter Breast High (DBH), Basal Area (B.A), scar size, number of the wound on the damaged tree stems, wound severity and wound height from ground level as well as distance of damaged trees from the centerline of skid trail were recorded. A scar was defined as removal of the bark and cambial layer, exposing the sapwood [22]. Each scar was taken by a 12 Mega pixels camera (Ultrasonic Brand); and scar areas were determined with UTHSCSA Image Tools software for Windows (Version 2.00). The distance of each damaged tree from the centerline of skid trails was also recorded by tape-meter. Any visual scarring or severing of the root system was defined as root damages. The division of damage in wound category is shown in Table 2. Suzuki [5]; Clatterbuck [11]. Analysis of variance (ANOVA) test was applied to determine the difference of DBH and BA data in different

traffic intensity categories in each skid trail. Moreover, Chi-square test was also used to determine whether significant differences existed among the number of damaged trees in different levels of traffic intensity and two directions of the skid trail utilizing the SPSS 11.5.

4. Results

General measurements of some characteristics of remaining trees in four abandoned skid trails are summarized in Table 3. Analysis of Chi-square test showed that at all skid trails the numbers of damaged trees in the downslope were significantly greater than the upslope directions (Figure 1). The percentage of damaged trees on the high traffic intensity was considerably greater than low traffic intensity in all skid trails (Table 3). Distribution of residual damaged trees, based on height or location of the wound on the trees' stems from ground level are presented in Table 4. Concerning the location, in each skid trail by about 53.75% of residual trees was damaged at the heights less than 100-cm from ground level (DC2), while only 4.62% of damaged trees were significantly damaged in root (DC1). Distribution of damaged trees with regard to the number of wound on trees' stems based on the Chi-Square test indicated that 55.49% and 12.72% of damaged trees were in DC1 and DC3, respectively, Table 5. About 61.85% of damaged trees had severe wounds (DC3) on their stems, while only 26.59% of the remaining damaged trees had decay wound (DC4) Table 6. At all skid trails parallel to increase of traffic intensity, wound size was also considerably increased. Analysis of Chi-square test showed that 1.16% and 52.02% of all damaged trees had wound size less than 100 cm² (DC1) and 100–1000 cm² (DC2), respectively, Table 7. The numbers of damaged trees were significantly concentrated on the nearest distances of the centerline of the skid trail (DC1) compared to other distances

TABLE 3: General measurement of some characteristics of remaining trees in each abandoned skid trail.

Class of age	Traffic intensity								
	Low			Medium			High		
	Quantitative characteristics *DBH (cm)	*BA (cm ²)	Damage trees (%)	Quantitative characteristics DBH (cm)	BA (cm ²)	Damage trees (%)	Quantitative characteristics DBH (cm)	BA (cm ²)	Damage trees (%)
1–5 yr	35.60 a	0.138 a	30.61	42.57 a	0.207 a	26.53	48.71 a	0.209 a	42.86
5–10 yr	40.25 a	0.209 a	25.64	42.26 a	0.179 a	35.89	47.13 a	0.265 a	38.46
10–15 yr	28.26 a	0.095 a	25.00	35.80 a	0.134 a	42.30	37.54 a	0.134 a	32.70
15–20 yr	44.00 a	0.183 a	39.39	47.71 a	0.174 a	18.18	40.92 a	0.153 a	42.42

* Values of DBH and BA are means. Same letters within each traffic treatments shows nonsignificant differences ($P < .05$).

TABLE 4: Distribution of damaged trees based on location of wound on trees' stems.

Age class	1–5 yr			5–10 yr			10–15 yr			15–20 yr			**DC%
Traffic intensity	*L	*M	*H	L	M	H	L	M	H	L	M	H	
DC1	0	2	2	0	0	0	0	0	2	0	0	2	4.62 [d]
DC2	10	7	6	3	9	7	6	14	9	11	3	7	53.75 [a]
DC3	4	4	12	5	3	5	6	7	5	2	3	4	34.10 [b]
DC4	1	0	1	2	2	3	1	1	1	0	0	1	7.51 [c]

* L, M, and H abbreviations are low, medium and high traffic intensity at all tables.

**Percent of damage code has been calculated by divide number of damaged trees in each code to all damaged trees in each skid trail, regardless of traffic intensity and age skid trail at all tables.

TABLE 5: Distribution of damaged trees' stems based on number of wound on the stem.

Age lass	1–5 yr			5–10 yr			10–15 yr			15–20 yr			**DC%
Traffic intensity	*L	*M	*H	L	M	H	L	M	H	L	M	H	
DC1	6	3	12	5	7	9	6	14	13	9	4	8	55.49 [a]
DC2	8	6	2	4	5	5	7	8	4	1	2	3	31.79 [b]
DC3	1	4	7	1	2	1	0	0	0	3	0	3	12.72 [c]

TABLE 6: Distribution of damaged trees based on severity of damage.

Age lass	1–5 yr			5–10 yr			10–15 yr			15–20 yr			**DC%
Traffic intensity	*L	*M	*H	L	M	H	L	M	H	L	M	H	
DC1	0	0	0	1	1	1	1	1	1	4	2	3	8.67 [c]
DC2	1	0	0	0	0	0	0	1	1	0	0	2	2.89 [d]
DC3	12	13	21	6	6	11	5	11	8	6	2	6	61.85 [d]
DC4	2	0	0	3	7	3	7	9	7	3	2	3	26.59 [b]

TABLE 7: Distribution of damaged trees based on size of wound.

Age lass	1–5 yr			5–10 yr			10–15 yr			15–20 yr			**DC%
Traffic intensity	*L	*M	*H	L	M	H	L	M	H	L	M	H	
DC1	0	1	0	0	0	1	0	0	0	0	0	0	1.16 [c]
DC2	9	9	5	4	6	5	10	14	11	6	4	7	52.02 [a]
DC3	3	1	8	3	4	7	1	5	1	3	2	4	24.28 [b]
DC4	3	2	8	3	4	2	2	3	5	4	0	3	22.54 [d]

TABLE 8: Distribution of damaged trees based on distance from centerline of the skid trail.

Age lass	1–5 yr			5–10 yr			10–15 yr			15–20 yr			**DC%
Traffic intensity	*L	*M	*H	L	M	H	L	M	H	L	M	H	
DC1	2	1	14	0	0	2	6	16	12	2	4	9	39.31 [a]
DC2	10	7	4	7	9	6	7	6	5	2	0	2	37.57 [b]
DC3	3	5	3	3	5	7	0	0	0	9	2	3	23.12 [c]

TABLE 9: Percentage of damaged tree species in 8 m alongside skid trail.

Age lass	1–5 yr			5–10 yr			10–15 yr			15–20 yr		
Traffic intensity	*L	*M	*H	L	M	H	L	M	H	L	M	H
<i>Alnus sub cordate</i>	**NR	NR	2.04	NR	5.13	10.26	NR	NR	NR	NR	3.03	6.06
<i>Carpinus betulus</i>	10.20	NR	12.24	NR	5.13	02.57	NR	NR	NR	6.06	3.03	3.03
<i>Fagus orientalis</i>	20.41	24.49	28.57	25.64	25.64	25.64	25	42.31	32.69	33.33	12.12	33.33
<i>Quercus castanifoli</i>	NR	2.04	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

All above values are percent in each treatment.

**NR namely that, in these location mention species is not recorded.

TABLE 10: All categories of damage by traffic intensity category.

Traffic intensity category	Low	Medium	High
Damage location	30.06 [ab]	31.21 [ab]	38.73 [a]
Damage severity	29.54 [c]	31.73 [b]	38.73 [a]
Damage size	29.64 [c]	31.65 [b]	38.71 [a]
Damage frequency	30.00 [c]	32.00 [ab]	38.00 [a]
Distance of damaged trees from the centerline of skid trail	29.64 [c]	31.70 [b]	38.62 [a]

All above values are percent. Different letters within each traffic treatments shows significant differences ($P < .05$).

Table 8. The damage to tree stems were most common for trees in the <35 cm DBH class of all species (49.11%) except 1–5 years old skid trail, while only 10.06% of >70 cm were damaged except 1–5 years old skid trail Figure 2. Results of data on abundance of trees species, among three different traffic intensity levels and all skid trail age classes showed that beech was the most damaged species (Table 9). The greatest percentage of damaged trees was also concentrated in high traffic intensity regardless of skid trail age class. Analysis of all remaining damaged trees, based on Chi-square test in Table 10 showed that the traffic intensity categories had not only a significant effect on wound characteristics but also the highest percentage of damaged trees were recorded in these treatments compared to the low traffic intensity. Scrutinizing Table 10 implied that 38.73% of damage location, 38.73% of damage severity, 38.71% of damage, size and 38.00% of number of stem wounds of all investigated trees were located on high traffic intensity treatments, where the number of machinery passes was the highest.

5. Discussion

Twenty years after ground-base skidding, residual damaged trees did not significantly heal in high traffic intensity. For this paper, the word “heal” means a successful occlusion of wounds such that the growth of wounded trees covers the scars or damaged areas of the wounds Suzuki [5]. Unsuccessful healing of the wounds on residual tree stems in short term, after thinning and harvesting operations on high traffic intensity, were also reported by others, [5, 12, 13, 23]. Results of the evaluation of the damaged trees showed that twenty years post abandonment of skid trails, most of the slight wounds tended gradually to “heal” to normal in low traffic intensity, while the more severe wounds with exposed cambium were still in a bad state (Figure 3). These may be related to the wound shape [5], wound severity, time

of skidding and type of machinery which was utilized in skidding operation as well as high activities of machinery in these locations following timber skidding. Exposed cambium wounds will callous and produce some decay in the butt logs and remain open to more discoloration, but the damaged trees will rarely ruin because of these wounds [24]. The most common location for wounds on tree stems was less than 100 cm above ground level Table 4. Overall 53.75% of the wounds were in <100 cm (DC2) height from ground level, which agrees with the results reported by Nyland and Gabrel [25]; Reisinenger and Pope [24]. The lowest location of wounds on stem could have detrimental effects not only on stem quality, but also on the tree as a whole resulting in wounds infecting higher up on the stem [26] and Clatterbuck [11]. The wounds that cause the most concern are the large wounds located up on the main stem >150 cm above ground level, and a low percentage of this type of wound was noted Table 4. Han et al. [22] reported that frequency of infection and amount of decay decreased as wound height increased. The height of damages on the residual trees are primarily dependent on the several factors including machinery size and equipment, skidding intensity, machine driver’s competence and strip-road width [27, 28]. Scrutinizing Table 5 implied that 55% of all residual damaged trees had one wound on tree stems (DC1), while 13% of all trees had more than three wounds on tree stems (DC3). This may be due to unprotected crop trees along the skid trail, turning of the log loads and bumper of trees during winching [29, 30]. According to Table 6, it can be said that the exposure of cambium and onset of fungi to tree stems is crucial for residual trees [29]. Slight wounds whereby at most bark is broken, but cambium is intact have little possibility to develop inner wood stains [5]. When a tree is wounded, certain physiological changes and differentiations occur in the area surrounding of the wound, and the wound usually becomes

FIGURE 3: The view of stand damages due to timber skidding in low (a), (b) and high (c), (d) traffic intensity.

sealed off from the rest of the tree [24, 31]. The surface wounds tend to “heal” in short-term. For the present study 52.02% and 22.54% of the wounds had 100–1000 cm² and more than 1000 cm² sizes, respectively, for all investigated damaged trees Table 7. These results could be explained by high concentration activities of machinery especially in high traffic intensity, time of skidding, inadequate equipment and skidding distance, layout of felling operation and size of cut logs as well as methods of skidding [11]. Results match well those of [32] on *Fagus sylvatica* species. they found that by passing 10 to 15 years after logging, wounds whose sizes were about 0.6–1.0 cm² were occluded. Also, in *Stika spruce* species plantations, all stem wounds with an initial wound in size <60 cm² were fully closed over a 15-year period, while none of wounds with an initial wound in size >180 cm² in the same period were occluded Welech et al. [33]. Residually damaged trees were highly concentrated near the centerline of skid trails Solgi and Najafi [30]. Results indicated that 39.31% of all damaged trees belonged to 1–2 m distance from the centerline of the skid trails. Han and Kellogg [34] found that the greatest damage occurred within the 10 ft from

the centerline of the skid trail and skyline. However, with increase distance from the center of the extraction wounds not only closed and also remained (23.12%). The damages to tree stems were more common for trees in the <35 cm DBH class of all species. These results may be explained by susceptibility of young trees bark and relatively low tolerant of their barks to the injuries during skidding operations. It is showed that beech species was dominant species along all skid trails. The greatest damaged trees were in the 50–70 cm DBH class in 1–5 years old skid trail. This may be related to a high proportion of damaged trees in this class. Wounds tended to heal partially to normal state over time in low traffic intensity, while in high traffic intensity, they were still stable and needed over 20 years to be occluded completely. These results match those of [5, 12] studied residual damaged trees in Japan and reported that, in high traffic intensity the wounds of remaining trees along skid trail were smaller in the horizontal dimension or width than those not yet healed within 5 years following timber skidding in a bad state. Our results does not match results of Han et al. [22]; Jackson et al. [35]. The differences in

healing of the wounds on trees damaged by ground-base skidding operation among the above studies may be due to the differences in long period of present study, mechanical equipments, trees species types, harvest volume as well as silviculture methods and tree density. The results also showed that an average amount of damaged trees alongside skid trails, 100% inventoried, was 18.83%. The impact of ground-base skidding on residual stand has to be understood as complex. However, it is too early to come to any definite conclusion about how long it will take for fully occlusion of wounds on tree stems from timber operations based on the available measurements only twenty years after logging. To reduce stand damages in uneven-aged mixed forests during selection cutting operations, residual trees should be kept by plastic material or piles, felling directions should be predetermined. Also, roads and skid trails networks should be well planned, loggers should be experienced and adequately trained, as well as limited skidding operations in 4–5 m buffer areas as permanent pathways. Future studies will be required to with the objective to document effect of slope of skid trail on quality and quantity of residual damaged trees and clarify that how long it will take for wounds of tree damaged to fully occlude from skidding operations.

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