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Residual damage in different ground logging methods alongside skid trails and winching strips

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ABSTRACT: To assess the residual damage a 100% inventory method was employed in pre-hauling and post-hauling, alongside skid trails and winching strips. Inventory was executed within 6 m from each side of the skid trail or winching strip centreline (12 m width). Besides the data analysis to choose the best alternative depending on residual damage the Analysis of Multiple-criteria Approval (MA) was applied. In the winching strip, our results demonstrated that depending on the density of standing residual trees the most unfriendly alternative to standing trees was a short-length method (SLM) which damaged 27.9% of the total standing trees and the best alternative was a tree-length method (TLM) (11.89%). The most unfriendly alternative to regeneration in winching and skidding operations was SLM with damaged 21% and 9% of all seedlings, respectively. In the winching strip TLM is the best alternative depending on the number of damage trees but 72% damage degree was deep. Alongside the skid trails the highest number of damaged trees occurred in TLM (44 stems) and the lowest was in the long-length method (LLM) (10 stems); according to the density of trees also the greatest damage to trees occurred in TLM (16.73%) and the lowest was in LLM (3.13%). In addition (in winching and skidding operations), 14.31, 8.79 and 18.19% of residual trees and 9, 11 and 16% of individuals of regeneration were damaged in TLM, LLM and SLM, respectively. The results of data analysis (by SPSS and MA) indicated that the friendly alternative to residual stand in the north of Iran is a long-length method.

Keywords: long-length method (LLM); short-length method (SLM); skidding and winching operations; tree-length method (TLM)

When developing a feasible harvesting system, the mechanized harvesting machines should be assessed based on their production rates, unit costs and also on their impacts on a forest ecosystem, because mechanized harvesting operations can have a long-lasting effect on a residual stand in the forest. So logging managers need to understand the capabilities of harvesting machines and know how to reduce their damage to the remaining stand (Akay et al. 2006). Today, there is an interest in using alternative silvicultural systems like selection and two-aged management, because the public finds these systems more acceptable than clear cutting. However, repeated entries into a forest stand to remove timber increase the risk of residual stand damage (Ficklin et al. 1997). Ficklin et al. (1997) reported that 22% of the residual trees were damaged by the skidder system while the reported amount by Ezzati and Najafi (2010) was 18.83%, Tavankar et al. (2011) 14.1% of damaged trees and 0.63% of destroyed trees, Tavankar et al. (2010) 13.2% damaged and 2.3% destroyed, Nikooy et al. (2010) reported 19.7%, Naghdi et al. (2009) 19.04%, and Tavankar (2000) 8.1% of trees.

In a Caspian mixed-hardwood forest, logging operations are generally performed by using selective cutting methods including group selection and single-tree selection (Sarikhani 2001; Marvie Mohadjer 2005). Thus, logging in forests often causes physical damage to residual trees through felling and skidding operations (Nikooyi et al. 2010). Behjou and Ghafarzade (2012) evaluated logging damage to residual trees following a logging operation in the Caspian forest. They reported that the most common type of damage was uprooting and damage to trees alongside skid trails was significantly more severe than damage in logging gaps and winching strips (Solgi, Najafi 2007; Ezzati, Najafi 2010; Tavankar 2010). In contrast, some researchers collected data showing that a winching operation is the main cause of destroying the standing residual trees (Jajson et al. 2002; Mosavi 2008; Stanczykiewicz 2010; Tavankar et al. 2012). On average, 9.8 trees were damaged per each tree extracted in the Caspian forest (Behjou, Ghafarzade 2012), when the observed amount in India was 2.6 trees per acre while skidding caused 71% and felling 29% of these injuries (Reisinger, Pope 1991). In the research area of Jakson et al. (2002), on average 44 trees were damaged per each tree extracted, which included 22 trees killed or severely damaged when 6 of them being commercial species. In the study by Tavankar et al. (2010) per each hectare of harvested area, 30 stems of residual trees were damaged and 1.3 stems were destroyed by logging operation. Most of the wounds on the bole of trees occurred below 1 meter height (Solgi, Najafi 2007; Tavankar et al. 2010). Most of deep wounds occurred on the stump area (Han, Kellogg 2000a; Tavankar et al. 2010). Also, the results of their studies showed that per each hectare of harvested areas, 160 stems of stand regeneration were damaged and 227 stems were destroyed by logging operation. About 6% of stand regeneration were damaged and 8% of them were destroyed. Their recent studies demonstrated that the percentage of destroyed and injured residual trees was 5.2 and 11.1%, respectively (Tavankar et al. 2013) and 16.9% of regeneration was damaged by logging operation (Tavankar et al. 2012).

Although several studies about standing tree and regeneration damage by ground systems have been done in Iran until now (as mentioned above), few studies compared these objectives between harvesting alternatives. For instance Mosavi (2008) compared the residual damage caused by LLM and SLM in northern Iran; research results showed that in winching strips, the percentage of damage to residual stand was 32.2 and 37.7% and in skid trails the percentage of damage was 25.7 and 34.9% in short-log and long-log method, respectively. With regard to damage to residual stand, the short-log method was more environmental friendly than the long-log method. Also, Han and Kellogg (2000b) compared damage caused by four common harvesting systems in western Oregon: tractor, cut-to-length (forwarder and harvester), skyline, and helicopter. Scarring was the most typical damage to crop trees, accounting for 90% of the total damage in most cases. Damage levels greatly decreased as the minimum scar size that defines damage was increased. Scarring by ground-based systems was more severe: scars were larger, and gouge and root damage were more prevalent than in skyline and helicopter systems. Damaged trees were concentrated within 4.6 m of skid trails or skyline corridor centrelines. In the cut-to-length system, the harvester caused more wounding (70%) to crop trees than did the forwarder (30%), but forwarder scars were larger and sustained severe gouging. Also, their study indicated that helicopter logging caused scars highest above the ground, followed by skyline, cut-to-length, and tractor logging. On average, scarring from tractor thinning was significantly lower on the bole than for any other logging system. The amount of scarring below 61 cm was 2% in helicopter, 17.5% in skyline, 29.3% in cut-to-length, and 64% in tractor units. In the cut-to-length system, scars caused by the harvester were slightly lower on average than those from the forwarder; 63% of the harvester-created scars were lower than 1.2 m, versus 57% from the forwarder. In the case of the harvesting by a processor, the level of damage to trees was 1.0–5.2% while with the use of winches it was 1.2–5.4%. In the regeneration layer, the level of damage when the processor was used ranged from 5.9 to 17.9% whereas harvesting with the winches caused damage between 11.8 and 17.1% (Stanczykiewicz 2010).

Forest harvesting is composed of four key components including tree felling, primary transportation, loading, and secondary transportation. Primary wood transportation is one of the most important and most expensive parts of forest utilization. Before the 20th century, wood transportation was done by animals (horse, mule…) and water energy but today with machines without considering effects on the environment (Barari et al. 2011). Therefore it is necessary to determine an ecological impact of primary wood transportation in different harvesting methods. The majority of the environment scientific and forest companies in Iran believe that the most economical alternative is TLM and but they do not apply this alternative because they believe that the environmental impact of TLM is higher than that of the CTL method (Sarikhani 2001). The basic questions in this study were related to 3 assumptions: (1) Whether would an environmental impact decrease with a reduction in log length? (2) Which alternative is the best depending on residual damage?

MATERIAL AND METHODS

Site description. This study was conducted in three compartments of the Wood Industry of Farim which belong to Caspian forests. Tree-length method (TLM) was carried out in compartment 46; long-length method (LLM) and short-length method (SLM) were carried out in compartment 107 and 41, respectively (Table 1). Elevation is approximately 445–2,250 m a.s.l. with a north and north-western aspect. The original vegetation of this area is an uneven-aged mixed forest dominated by *Fagus orientalis* and *Carpinus betulus*, with the companion species *Alnus subcordata*, *Acer platanoides*, *Acer cappadocicum*, *Ulmus glabra* and *Tilia rubra*. The soil type is forest brown soil and the soil texture varies between clay-loam and silty-clay. The average annual rainfall recorded at the closest national weather station is 845.5 mm and the mean annual temperature is 11.5°C. At the study site, the silvicultural system was applied as a combination of group selection and single tree selection. The total volume of primary transportation was carried out by skidders to landing areas that were prepared at the border of the road in the lower part of all compartments (46, 107 and 41). Timberjack 450C rubber-tired skidder used in this study was a normal articulated, four-wheel-drive vehicle weighing 10.3 t (55% on the front and 45% on the rear axle) with engine power of 177 hp (132 kW) and engine model of 6BTA5.9. It is equipped with a blade for light pushing of obstacles and stacking of logs. The skidder was fitted with tires of the size 24.5–32 inflated to 220 kPa on both front and rear axles, it had a ground clearance of approximately 0.6 m. Timber bunching was carried out by the winch that was installed in the near part of the skidder from the stump to the skidder and one end of the dragged round wood was in touch with the ground (Jourgholami, Majnounian 2013). Height, length and width of the machine were 3 m, 6.28 m and 3.1 m, respectively.

Data collection. To assess damage to residual standing trees a 100% inventory method was employed in pre-hauling and post-hauling, alongside the skid trails and winching strips. Inventory was executed within 6 m from each side of skid trails or winching strip centreline (width 12 m). Roadbeds of skid trails were clear of regeneration and trees but the ground of winching strips was a part of forest land with regeneration and trees. Therefore seedlings and trees in the skid trails and winching strips were inventoried and evaluated separately.

Prior to carry out a pre-harvesting 100% inventory, skidding operations, landing locations and major extraction and winching routes were identified by the skidder operator or chaser man and marked. The skidding and winching distances were measured by a tape and recorded on paper. For counting the total trees alongside the skid trails, we started walking on the skid trails from the start point of the skid trails (it was close to the landing area) to the end point of the skid trails and also on the winching strips, all trees greater than 12 cm in diameter at breast height (DBH) within 6 m from each side of the centreline of skid trails and winching strips were counted. Total seedlings and regeneration (diameter less than 12 cm) alongside the skid trails and on the winching strips were surveyed.

After finishing the logging operation, a field study was carried out again to analyse the residual trees and stand regeneration. The total number of damaged trees and seedlings was counted alongside the skid trails and winching strips. The wound type of damaged regeneration was classified in two classes: (*i*) severe (broken top, crushed sapling, most parts of the stem are damaged or seedling destroyed), and (*ii*) light (some parts of the stem and leaves are damaged). The damage to standing trees was recorded by the number of damaged trees, number of wounds per damaged tree, number of injuries on one tree, damage location (root and uprooting) and wound degree (intensity) which was classified in two classes: (*i*) light, in light injury damage was caused to the bark of the damaged tree where the bark was scratched or the bark was squeezed, and (*ii*) Deep, in deep damage the bark of the tree was removed and wood or the cambium layer of the tree was damaged or the wound area was larger than 100 cm^2 (Table 2).

Table 1. Characteristics of study compartments

Compartment (alternative)	Compartment area (ha)	Protected area (ha)	Stand density (trees·ha^{-1})	Volume (m^3·ha^{-1})	Total volume of extracted wood (m^3)
46 (TLM)	66	3	205	252	307
107 (LLM)	39	2	153	170	292
41 (SLM)	85	34	260	220	311

TLM – tree-length method, LLM – long-length method, SLM – short-length method

Table 2. Damage classification for individuals of regeneration and trees

Regenerations	Wound type	Severe	Broken top, crushed sapling, most parts of the stem are damaged or seedling destroyed
		light	some parts of the stem and leaves are damaged
Trees	number of damaged trees		–
	number of wounds per damaged tree		–
	number of damage on the one tree		–
	damage location		root
			uprooting (location of wound was on the bole)
	wound degree (intensity)	deep	in deep damage the bark of tree was removed and wood or to the cambium layer of the tree damaged or the wound area was greater than 100 cm^2
		light	damage was to the bark of the damaged tree where the bark was scratched and or the bark squeezed

Statistical analysis. Statistical analyses were performed by SPSS software (SPSS, Tulsa, USA), paired *t*-test was employed to test the pre- and post-harvesting number of healthy residual trees in winching strips and alongside the skid trails with a 95% confidence level.

Multiple-criteria approval (MA). Also, to choose the best alternative depending on residual damage, multiple-criterial approval (1 – analysis of MA, 2 – sensitivity analysis of MA) was used as described by Palander and Laukkanen (2006), and Laukkanen et al. (2004, 2005). Multicriteria approval (MA) is an application of approval voting specifically developed for multicriteria decision support. The basic version of MA is a decision support system for one decision-maker (Lankkanen et al. 2004). In MA, in the first step the criteria values for the alternatives were determined and in the next step approval limits were defined for each criterion. Based on the limits, alternatives are defined to be approved (+) or disapproved (–) with respect to each criterion. The limit between approval (+) and disapproval (–) for each criterion is the mean value, but the median of the criteria values can be used (Palander, Laukkanen 2006). In this study, both limits, i.e. median values and mean values were used. The composite criteria for standing tree damage were: C1 – damage to standing tree by skidding (%), C2 – damage to standing tree by winching (%), C3 – damage to regeneration by skidding (%), C4 – damage to regeneration by winching (%), C5 – total tree damage (%), C6 – total seedling damage (%), C7 – one damaged tree per productivity rate (m^3), C8 – one damaged individual of regeneration per productivity rate (m^3), C9 – degree of damage (tree) (%), C10 – degree of damage (regeneration) (%).

Analysis of MA. To analyse MA, the approval limit was the median for each criterion. In this study, in order to define the approval (+) and disapproval (–) at quantity criteria, for each criterion the value was marked as approved (+) if the value was above the median value or equalled it while it was marked as disapproved (–) if the value was less than the median. At the value which was expressed in percentages (%), the mark was (+) if the value of the criterion was less than the median value or equalled it and above it was (–). To choose the best alternative, approvals (+) for each alternative were added up. That alternative with the highest number was regarded as the optimal alternative.

Sensitivity analysis of MA. In the case of sensitivity analysis of MA, the approval borderline was the mean; if the value of the criterion was above the mean value or equalled it, the mark was set to (+), which means approval, and if it was less than the mean, it was marked as disapproval (–). At the percentage value of criteria, if the value of the criterion was less than the mean value or equalled it, it was (+) and above it was (–).

To choose the best alternative in the analysis of MA and sensitivity analysis of MA with respect to all criteria the alternative that received higher approvals (+) is acceptable between all alternatives. The alternative that was dominant in approval was the best alternative in the sensitivity analysis of MA.

RESULTS

Pre-harvesting and post-harvesting tree inventory on winching strips and skid trails

In the winching area, Table 3 shows the amount of inventoried trees, whole damaged trees, percentage of damaged trees to inventoried trees (%), total wounds on damaged trees and the amount of extracted wood per one tree damage in TLM, LLM and SLM. Table 3 also demonstrates that the worst

Table 3. Results of pre-harvesting and post-harvesting of trees on the winching strip (WS) and alongside the skid trails (ST)

Inventory results	WS			ST		
	TLM	LLM	SLM	TLM	LLM	SLM
Total inventoried trees	328	187	87	263	319	148
Total damaged trees	39*	27	24	42*	10	13
Percentage of damaged trees	11.89	14.44	27.59*	16.73*	3.13	8.78
Total wounds	46	34	59*	70*	16	24
Number of injuries on one tree	1.18	1.26	2.46*	1.6	1.6	1.9*
Amount of extracted wood per one tree damaged	7.87	10.85	12.98	6.98	29.29	23.97

TLM – tree-length method, LLM – long-length method, SLM – short-length method, *indicates the highest amount of damage between alternatives in WS and ST

alternative depending on the percentage of damaged trees, number of injuries on one tree and the amount of wounds on the bole of damaged trees is SLM and the best alternative is TLM in the winching area. But depending on the amount of extracted wood due to damage to one tree SLM is the best alternative and TLM is the worst alternative.

Alongside the skid trails, presented values in Table 3 indicated that the worst alternative depending on the percentage of damaged trees to total trees, amount of wounds on damaged trees and the amount of extracted wood due to one damaged tree is TLM and depending on results of this Table, the best alternative could be LLM in skidding operations.

Location and degree of damage

Table 4 shows the results of the location and degree of injury in TLM, LLM and SLM. About 40, 68 and 71% of injuries occurred in the winching strip while 60, 32 and 29% of injuries occurred during skidding operations; 21, 28 and 32.5 % of injuries were located on the roots whilst about 79, 72 and 66.5% of injuries were located on the bole of trees (uprooting); about 77, 18, 34 of injuries were deep and severe while 23, 82, 66% of the injuries were light in TLM, LLM and SLM, respectively. In total, the statistical analysis showed no significant difference between the numbers of healthy standing trees in pre-harvesting and post-harvesting in the winching strip (P = 0.071) and alongside the skid trails (P = 0.176). As can be seen, the p-value alongside the skid trails is higher than in the winching strip; it shows that the number of damaged trees during skidding operations was lower than in winching operations.

Pre-harvesting and post-harvesting seedling inventory on winching strips and skid trails

The results of pre- and post-harvesting seedling survey alongside the skid trails and winching strip are presented in Table 5. As you can see in Table 5, the highest amount of damage was caused by SLM in the winching strip (21%) and alongside the skid trails (9.4%). Due to winching operations 3.7, 1.7, and 4.3 m^3 of wood and due to skidding operations

Table 4. Location and degree of damage in TLM, LLM and SLM

Alternative	Operation area	Total damage in operation area (%)	Location and degree of damage (%)					
			root			uprooting (bole)		
			damage	severe	light	damage	severe	light
TLM	winching	40	24	100	0	76	100	0
	skidding	60	19	69	31	81	54	46
	total	100	21	83	17	79	72	28
LLM	winching	68	29	20	80	70.5	29	71
	skidding	32	25	0	100	75	9	91
	total	100	28	14	86	72	22	88
SLM	winching	71	39	43	67	61	40	60
	skidding	29	17	0	100	83	6	94
	total	100	33	37	63	67	30	70

TLM – tree-length method, LLM – long-length method, SLM – short-length method

Table 5. Results of pre-harvesting and post-harvesting of seedlings on the winching strip (WS) and alongside the skid trails (ST)

Inventory results	WS			ST		
	TLM	LLM	SLM	TLM	LLM	SLM
Total inventoried trees	1152	2562	698	3143	5123	488
Damaged trees (%)	14	20	21*	7.5	7.5	9.4*
Severe damage (%)	77*	44	49	53*	42	26
Light damage (%)	23	66	51	47	58	74
Amount of extracted wood per one seedling damaged	3.7	1.7	4.3	2.4	1.6	13.5

TLM – tree-length method, LLM – long-length method, SLM – short-length method, *indicates the highest amount of damage between alternatives in WS and ST

2.4, 1.6 and 13.5 m^3 one seedling were damaged in TLM, LLM and SLM, respectively. In the winching strip, about 77, 44 and 49% of the seedling damage was so severe that most parts of the stem were damaged while it was about 53, 42 and 26% alongside the skid trails in TLM, LLM and SLM, respectively (Table 5). The statistical analysis showed that the number of healthy individuals of regeneration in pre-harvesting and post-harvesting in skidding operations (P = 0.149) and winching operations (P = 0.081) was insignificant.

Multiple criteria approval (MA)

Table 6 shows the determined values of criteria for the timber harvesting alternatives and the values of the mean and median.

Analysis of MA and sensitivity analysis of MA

The results of the analysis by MA indicated that if the approval borderline was median, TLM and LLM were dominant in approval (+) and SLM was dominant in disapproval (–). Therefore, the best alternatives are TLM and LLM and the most unfriendly alternative to residual damage is SLM (Table 7). The results of the sensitivity analysis of MA showed that by using the mean as a borderline, LLM was dominant in approval (+), thus the best alternative is LLM, and the most unfriendly alternative to residual damage is TLM (Table 7).

DISCUSSION

Mechanized harvesting operations can have a long-lasting effect on residual trees in the forest stand while the long-term effect of residual stand damage on site productivity is still unclear. Therefore logging managers need to understand the capabilities of harvesting machines and know how to reduce the amount of the residual damage caused by them (Ficklin et al. 1997; Akay et al. 2006).

In the winching strip, the results of this study have shown that the highest number of damaged trees was in TLM (39 trees) and the lowest damage was in SLM (24). In regard to pre-harvesting intensity and area of winching operations the highest density of trees was in TLM (31 stems per 1,000 m^2) and 21 and 2 stems per 1,000 m^2 in LLM and SLM, respectively. In general, residual damage is dependent on the density of residual trees and the production rate, residual damage will increase with the increase in density of residual trees and production rate (Lotfalian 2012). In total, by winching operation 18% and by skidding operation 9.55%

Table 6. Criteria values, mean and median values

Criteria	Alternative			Mean	Median
	TLM	LLM	SLM		
C_1	16.73	3.13	8.78	7.16	8.78
C_2	11.89	14.44	27.59	18	14.44
C_3	7.5	7.5	9.4	8.1	7.5
C_4	14	20	21	18.33	20
C_5	14.31	8.79	18.19	13.76	14.31
C_6	9	11	16	8.66	11
C_7	7.43	20.1	18.48	15.31	18.48
C_8	1.45	0.84	3.25	2.36	1.45
C_9	72	20	30	40.66	30
C_{10}	65	43	37.5	48.5	43

C_1 – damage to standing trees-skidding (%), C_2 – damage to standing trees-winching (%), C_3 – damage to regeneration-skidding (%), C_4 – damage to regeneration-winching (%), C_5 – total tree damage (%), C_6 – total seedling damage (%), C_7 – one damaged tree per productivity rate (m^3), C_8 – one damaged individual of regeneration per productivity rate (m^3), C_9 – degree of damage (tree) (%), C_{10} – degree of damage (regeneration) (%),TLM – tree-length method, LLM – long-length method, SLM – short-length method

Table 7. Results of analysis of MA and sensitivity analysis of MA

MA	Alternative	Criteria									
		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Analysis of MA	TLM*	–	+	+	+	–	+	–	+	–	–
	LLM*	+	–	+	–	+	–	+	–	+	–
	SLM	–	–	–	–	–	–	+	+	–	+
Sensitivity analysis of MA	TLM	–	+	–	+	–	–	–	–	–	–
	LLM*	+	+	–	–	+	–	+	–	+	+
	SLM	–	–	–	–	–	–	+	+	+	+

*the winning alternative, – indicates disapproval, + indicates approval, C_1 – damage to standing trees–skidding (%), C_2 – damage to standing trees–winching (%), C_3 – damage to regeneration–skidding (%), C_4 – damage to regeneration–winching (%), C_5 – total tree damage (%), C_6 – total seedling damage (%), C_7 – one damaged tree per productivity rate (m^3), C_8 – one damaged individual of regeneration per productivity rate (m^3), C_9 – degree of damage (tree) (%), C_{10} – degree of damage (regeneration) (%),TLM – tree–length method, LLM – long–length method, SLM – short–length method

of residual trees were damaged. However, the results of the analysis of the significance showed no significant differences (P = 0.071 and P = 0.176). The statistical analysis showed that the number of healthy individuals of regeneration in pre-harvesting to post-harvesting alongside the skid trails and winching strips (P = 0.149 and 0.081, respectively) is not significant but the p-value of the winching strip is close to 0.05, which shows that the greatest damage to regeneration occurred in the winching strip. Therefore, in all logging operations residual damage (seedling and tree damage) in the winching operation was greater than in skidding operations. It is similar to the results of other researchers who reported that the greatest damage was caused by winching operations (Jakson 2002; Mosavi 2008; Stanczykiewicz 2010). In contrast, a few researchers reported that skid trails were an important contributing factor to residual stand damage (Ezzati, Najafi 2010; Tavankar 2010; Behjou, Ghafarzade 2012).

In addition, 14.31, 8.79 and 18.19% of residual trees were damaged and 9, 11 and 16% of regeneration were damaged by TLM, LLM and SLM in logging operations (in winching and skidding operations), respectively. This range of residual damage is similar to results of Ficklin et al. (1997); Tavankar (2000); Mousavi (2008); Naghdi et al. (2009); Tavankar et al. (2010, 2011, 2012, 2013); Ezzati and Najafi (2010); Nikooy et al. (2010) when they reported that the amount of damage was between 8.1 and 37.7% of the total of trees. In other words, the lowest damage reported by these researchers was 8.1% and the highest damage reported by these researchers was 37.7% of the total of trees. Researchers who have written that for the Forest Resources Association (formerly the American Pulpwood Association) believe that 10% damage is a worthy goal and that damage exceeding 25% in any partial harvest operation is unacceptable in northeastern hardwood stands (Gillespie 2001). In addition, in all operational treatment areas (winching and skidding operations) SLM was the worst alternative and LLM was the best alternative to standing residual trees depending on density (density of standing residual trees). In the winching strip, the best alternative was TLM and the worst alternative was SLM and alongside the skid trail the best alternative was LLM and the most unfriendly alternative was TLM, which is the only alternative that causes greater damage in skidding operations than in the winching area. These results indicated that with a reduction of log length, the environmental impact would not decrease because damage in LLM is lower than in SLM. The analysis of MA and sensitivity analysis of MA indicated that best alternative depending on residual damage is LLM. This result is in contrast with Mousavi (2008) reports, who presented that the best alternative is SLM. Depending on the author's observations, we can execute TLM in the north of Iran, at least for trees whose diameter is less than 40 cm, because much of the skidding damage was caused by carelessness, and could have been avoided (Reisinger, Pope 1991).

Residual damage should not be considered based only on the amount of residual damage and density but also the amount of residual damage relative to the amount of production rates should be considered. In our research one tree damaged to extraction 7.43, 20. and 18.48 m^3 in logging operation and for every damaged regeneration 1.45, 0.84 and 3.25 m^3 in TLM, LLM and SLM, respectively, also some researchers such as Reisinger and Pope (1991); Jakson et al. (2002); Behjou and Ghafarzade (2012), reported that the standing damage amount for every tree extracted. Regarding the production rate, the most unfriendly alternative to environment was TLM and the best alternative was LLM but in regard to damage to regeneration (due to the production rate) the best alternative is SLM and the most unfriendly alternative is LLM. Eroglu et al. (2009) reported that timber harvesting techniques resulted in damage to residual trees, seedlings, and timber products, but the degree of damage caused by the harvesting techniques was significantly different. The highest level of damage was caused by manpower; they suggested that the damage caused by logging can be minimized by the use of proper timber harvesting techniques. Most of tree damage in TLM was deep (72%) whilst in LLM and SLM 20 and 30% of injuries were deep, respectively. In TLM and SLM severe damage was caused to the roots but in LLM it was caused to the tree's bole (we do not know the reason), also in Han, Kellogg (2000b) research the most severe damage occurred to the roots. The major portion of damage occurred on the tree's bole (uprooting) which is similar to other researchers' observations (Han, Kellogg 2000a; Jakson et al. 2002; Tavankar et al. 2010; Behjou, Ghafarzade 2012; Tavankar et al. 2013). On the other hand, the highest number of wounds to the bole of each damaged tree was observed in SLM: about 1.85 wounds/to the bole of one damaged tree in the skidding operation and 2.46 wounds/to the bole of one damaged tree in the winching operation whilst the lowest number of wounds was in TLM, about 1.6 wounds per one damaged tree in the area alongside the skid trail and 1.18 wounds per damaged tree in the winching operation. For the extraction of one tree in TLM only one winching operation is done while in SLM to extract one tree several winching operations are done. Probably, it can be the reason for the highest residual damage in SLM in the winching strip.

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