Felling and skidding damage to residual trees following selection cutting in Caspian forests of Iran

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ABSTRACT: The felling and skidding damage to residual trees was investigated in a selectively cutting operation in the Caspian forest of Iran. The logging operation was performed by chainsaw and cable skidder. Prelogging, after felling and skidding operations residual tree injuries (species, DBH and damage) were inventoried by systematic plot sampling. Two types of tree damage were observed: destroyed and injured. In this study felling operations mainly injured trees whereas skidding was the main cause of destruction. The percentage of destroyed and injured residual trees by felling operations was 1.4% and 3.4%, whereas the percentage of destroyed and injured residual trees by skidding operations was 5.2% and 11.1%. About 87% of destroyed trees were found in the DBH class smaller than 22.5 cm. Maple and Alder were the most damaged trees among the other trees species. Damage to the lower bole and wood damaged intensity were the most common type of injury. To reduce the stand damage, skid trails should be planned before felling and felling directions should be predetermined. In the selection cutting management, limiting logging damage to residual trees must therefore remain a major objective.

Keywords: bole injury; logging; skidder; tree damage; uneven-aged stand

The total forest area of Iran is approximately 12.4 million ha, which makes only 7.3% of the total land area (FAO 2005). Hyrcanian forests of Iran are located in the north of Iran and on the south coast of the Caspian Sea, also known as the Caspian forests. These forests which cover 1.8 million hectares of land area and are completely natural and broadleaf forests are the only commercial forests of Iran (FAO 2005). Caspian forests encompass various forest types including 80 woody species (Marvie Mohadjer 2006). Approximately 60% of these forests are used for commercial purposes and the rest of them are more or less degraded (Marvie Mohadjer 2006). These are the most valuable forests in Iran. These forests belong to the most basic resources for wood production and have a big share in supplying wood to the related industries. Recently, 20 years ago, shelterwood cutting was replaced by a close-to-nature silvicultural system as an alternative to logging in Caspian forests of Iran. The main goal of this system is provide the mixed and uneven-aged stand. Selection cutting improves the health of the stand and releases space for young trees to grow. Commercial logging in Caspian forests of Iran is accomplished within the legal framework of Forestry Management Plan (Shamekhi 2010) and annual removal in managed areas (1.2 million ha) is around 1 million m^3 per year (Lotfalian et al. 2011). A cutting cycle of 10 years is established in these forests. In Caspian forests logging operations are generally performed using a ground-based skidding system. Chainsaw and cable skidders are the main logging machines for wood harvesting in these forests. Harvesting in Caspian forests has the potential to damage the trees that are left standing. It is essentially impossible to harvest trees without a certain degree of damage to some of the remaining trees. It is important to minimize damage, both to the number of trees damaged and the extent of damage to any individual. Globally there is a long history of research regarding damage to the residual stand which shows the importance of the issue. Hartsoug (2003) in the northeastern California forests showed that 23% of the residual trees were damaged during ground-based logging operations and smaller trees were more likely to be damaged. Yilmaz and Akay (2008) showed in Turkish forests that 14% of the residual trees were damaged during felling and skidding operations. The study conducted by Ficklin et al. (1997) indicated that the skidding operation using a wheeled skidder damaged about 22% of the residual trees. Damage to residual trees during the selection cutting operation may decrease the quality of residual trees and increase the stand mortality through insect and disease infestation (Han, Kellogg 2000a). The injuries very often become an input port for fungal decays (Vasiliauskas 2001). The amount of decay development is related to the length of the time since injury, size of injury, tree species, location of the wound on the tree and to the vigour of the tree. Wounding can cause stem deformity and significant losses of the final crop volume and value (Meadows 1993). Furthermore, excessive damage to residual trees during logging operation may comprise the aesthetic value of the residual stand (Armstrong 2000). The amount and characteristics of skidding damage in selection cutting are affected by the harvesting intensity (Sist et al. 1998), level of planning in the logging operation (Pinard, Putz 1996), residual basal area (Sist et al. 2003), season of logging (Limbeck-Lilienau 2003), logging machines (Han, Kellogg 2000a), road density (Iskandar et al. 2006), stand conditions and skill of equipment operators (Pinard et al. 1995). Skidding during the winter causes less damage to residual trees (Limbeck-Lilienau 2003). Slope has also been correlated with increased skidding damage (Pinard, Putz 1996). Several studies have evaluated residual stand damage in Caspian forests following the ground-based skidding system and selection cutting. Tavankar (2000) reported that 8.1% of residual trees were damaged by selection cutting in the northern forests of Iran that was skidded using wheeled skidders. Lotfalian et al. (2008) found that 15.5% of residual trees were damaged following selection cutting in the forest of Mazandaran province. Naghdi et al. (2009) reported that 19.04% of residual trees were damaged following selection cutting in the northern forest in Mazandaran province. In a study Tavankar et al. (2010) showed that 13.2% of residual trees were damaged and 2.3% were destroyed when the ground-based logging system was used on a steep slope forest area in the northern forest of Iran. Nikooy et al. (2010) noted that 19.7% of residual trees were damaged following selection cutting in Shafaroud forest. Tavankar et al. (2011) observed that approximately 14.1% of residual trees were damaged and 0.63% were destroyed following selection cutting in Nav-Asalem forest. Estimating the residual stand damage caused by the ground-based logging system can help forest managers to evaluate the success of the harvesting operation in a selection silvicultural method. The aim of this study was to investigate felling and skidding damage to residual trees and to examine the tree damage by considering different factors including tree species, tree DBH, location, size, and type of damage. In this study, the amount and characteristics of damage to residual trees were also compared in two main stages of logging operation (felling and skidding) in the Caspian forests.

MATERIAL AND METHODS

Study area

This study was conducted in parcel 35 in district 1 of Nav forests. The Nav forests are located between 37°38'34" to 37°42'21"N and 48°48'44" to 48°52'30"E. The total surface area of parcel 35 is 39 ha when 7 ha are under protection. The elevation of the study area ranges from 1,350 m to 1,500 m. In the study area, the average ground slope is 30 to 55% and the general aspect of the hillside is west. 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 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 sandy clay loam to clay loam. The results of conducted inventory in this forest showed that the tree density and growing stock above 10 cm DBH (diameter at breast height) were 292 trees·ha^{-1} and 212 m^3·ha^{-1}, respectively.

Logging operation

The logging operation was performed by chainsaw and cable skidder in the study area. Shafaroud, one of the largest forest harvesting companies in the north of Iran, does logging in this region. Total number and volume of marked trees that were scattered in the parcel area were 216 trees (6.75 trees·ha^{-1}) and 688 m^3 (21.5 m^3·ha^{-1}). At first, the marked trees were felled, limbed and topped

Table 1. Felling and skidding damage to residual trees

Damage	Felling		Skidding		Total	
	n	(%)	*n*	(%)	*n*	(%)
Injured	32	3.8	93	11.1	125	14.9
Destroyed	12	1.4	43	5.2	55	6.6

n – number of trees

at a merchantable height by chainsaw. Then the felled trees were bucked to logs (5.2 m) or long logs (7.8 m) in the forest (felling operation). The logs were skidded from near the stumps on the skid trails and were extracted to roadside landings by Timberjack 450 C wheel skidder (skidding operation). The weight of the skidder was 9.8 t and its width and length were 3.8 and 6.4 m. The length of the winch cable was 50 m and its diameter was 20 mm. The skid trails and decks planned by foresters were constructed during the first cutting period in 1980. The decks were located on the top of the hill at roadside and the timbers were extracted uphill to decks. The three skid trails with spaces on average 110 m from each other were branched from the forest road in this parcel and the sum of the lengths of skid trails was 467 m.

Data collection

Systematic plot sampling was used for data collection (Meadows 1993; Ficklin et al. 1997; Han, Kellogg 2000b; Lotfalian et al. 2008; Majnounian et al. 2009; Tavankar et al. 2011). The dimensions of the grid were 100 m by 100 m, plot area was 0.1 ha and plot shape was circular. 28 sample plots (all of cross-sections of the grid in the study area) were established systematically across the logged areas (32 ha) with random starting point. Sampling intensity was 8.75%. Sample plots were inventoried at three phases: before logging, after felling and after skidding operation. At each inventory phase, all trees (DBH equal or greater than 7.5 cm; Zobeiry 1994; Sist et al. 1998) were recorded as untouched and damaged on each plot. Species and DBH of all trees were also identified and measured. Damaged trees were recorded as destroyed and injured. Destroyed trees were recorded as broken stem, completely broken crown and uprooted. The location of injury (crown, bole and root), the height of injury on the bole (< 0.3, 0.3–1 and > 1 m), the injury intensity (bark scratched, bark squeezed and wood damaged) and the injury size (< 10, 11–50, 51–200 and > 201 cm^2) were recorded.

RESULTS

Total damage

The number and percentage of residual trees damaged by felling and skidding (injured and destroyed ones) are presented in Table 1. Totally, 838 trees were analysed on sample plots while 125 trees were injured (14.9% or 44.6 trees·ha^{-1}) and 55 trees were destroyed (6.6% or 19.7 trees·ha^{-1}) by logging operation (Table 1). The number of injured trees by felling operation was 32 trees (3.8% or 11.4 trees·ha^{-1}), while the number of injured trees by skidding operation was 93 trees (11.1% or 33.2 trees·ha^{-1}). The number of destroyed trees by felling operation was 12 trees (1.4% or 4.3 trees·ha^{-1}) while the number of destroyed trees by skidding operation was 43 trees (5.2% or 15.4 trees·ha^{-1}).

Table 2. Logging damage to different tree species

Tree species	DBH* (cm)	Logging damage					
		injured			destroyed		
		n	(trees·ha^{-1})	(%)	*n*	(trees·ha^{-1})	(%)
Fagus orientalis	54.6	58	20.7	14.4	25	8.9	6.2
Carpinus betulus	43.5	28	10.0	12.1	14	5.0	6.1
Acer velutinum	38.8	14	5.0	18.2	6	2.2	7.8
Alnus subcordata	38.0	12	4.3	21.8	5	1.8	9.1
Acer cappadocicum	35.7	9	3.2	22.5	4	1.4	10.0
Other species	40.2	4	1.4	12.1	1	0.4	3.0
Total	–	125	44.6	–	55	19.7	–

*average of diameter at breast height (DBH) before logging, *n* – number of trees

Table 3. Felling and skidding damage to different tree DBH classes

	Damage	DBH class (cm)*											
		7.5 – 22.5			22.5 – 37.5			37.5 – 52.5			> 52.5		
		n	D	(%)	*n*	D	(%)	*n*	D	(%)	*n*	D	(%)
Felling	injured	52	18.6	13.1	18	6.4	6.5	7	2.5	6.9	7	2.5	10.6
	destroyed	19	6.8	4.8	2	0.7	0.7	0	0	0	0	0	0
Skidding	injured	24	8.6	6.1	10	3.6	3.6	4	1.4	3.9	3	1.1	4.5
	destroyed	29	10.4	7.3	5	1.8	1.8	0	0	0	0	0	0
Total	injured	76	27.1	19.2	28	10.0	10.1	11	3.9	10.8	10	3.6	15.2
	destroyed	48	17.1	12.1	7	2.5	0.8	0	0	0	0	0	0

*average of diameter at breast height (DBH) before logging, *n* – number of trees, D – density (trees·ha^{-1})

Table 4. Destroyed trees by felling and skidding operations

Logging operation	Destroyed trees								
	stem broken			completely broken crown			uprooted		
	n	(trees·ha^{-1})	(%)	*n*	(trees·ha^{-1})	(%)	*n*	(trees·ha^{-1})	(%)
Felling	8	2.9	1.0	2	0.7	0.2	2	0.7	0.2
Skidding	10	3.6	1.2	0	0	0	33	11.8	4.0
Total	18	6.5	2.2	2	0.7	0.2	35	12.5	4.2

n – number of trees

Damage to species and diameters

Out of all examined trees (838 trees) on sample plots, damaged species were as follows: 47.9% *Fagus orientalis* (402 trees), 27.6% *Carpinus betulus* (231 trees), 9.2% *Acer velutinum* (77 trees), 6.6% *Alnus subcordata* (55 trees), 4.8% *Acer cappadocicum* (40 trees) and 3.9% other species (33 trees). The logging damage to different tree species is presented in Table 2. The highest percentage of injured and destroyed trees was observed on *Acer cappadocicum* (22.5% and 10.0%), while the lowest percentage of injured and destroyed trees was observed on *Carpinus betulus* (12.1% and 6.1%). The highest density of injured and destroyed trees was observed on *Fagus orientalis* with 20.7 and 8.9 trees per hectare in the total area (Table 2).

In this research, felling and skidding damage to residual trees was analysed in residual trees of different DBH classes. Out of all examined trees (838 trees) on sample plots, the total number of trees with DBH classes of 7.5–22.5 cm, 22.5–37.5 cm, 37.5–52.5 cm and more than 52.5cm (Sist et al. 1998; Pakhriazad et al. 2004) was 395, 276, 101 and 66 trees, respectively. Results showed that the highest percentage of injured trees (19.2% and 27.1 trees·ha^{-1}) occurred in DBH class of 7.5–22.5 cm (Table 3), therefore the highest percentage of destroyed trees (5.2% and 17.1 trees·ha^{-1}) occurred in DBH class of 7.5–22.5 cm (Table 3). All destroyed trees were smaller than 37.5 cm of DBH (Table 3). In all DBH classes the percentage of injured trees by felling operation was higher than the percentage of injured trees by skidding operation (Table 3). The highest percentage of injured trees by felling (13.2%) and skidding (6.1%) operation was observed in the first DBH class (Table 3). The highest percentage of destroyed trees by felling (4.8%) and skidding (7.3%) operation was observed in the first DBH class (Table 3).

Destroyed trees

In this study three types of destroyed trees were observed: stem broken (18 trees), completely broken crown (2 trees) and uprooted (35 trees). Stem broken and uprooted trees were estimated to amount to 2.4% (7.2 trees·ha^{-1}) and 4.2% (12.5 trees·ha^{-1}) of residual trees (Table 4). The highest number of uprooted trees occurred after skidding operation (33 trees, 4.0 % or 11.8 trees·ha^{-1}) and only 2 trees (0.2% or 0.7 trees·ha^{-1}) were uprooted by felling operation (Table 4). Out of all stem broken trees,

Table 5. Location of injuries on residual trees caused by felling and skidding operations

	Injury location					
	crown		bole		root	
	(trees·ha^{-1})	(%)	(trees·ha^{-1})	(%)	(trees·ha^{-1})	(%)
Felling	7.5	2.5	3.2	1.1	0.7	0.2
Skidding	0	0	22.1	7.4	11.1	3.7
Total	7.5	2.5	25.3	8.5	12.1	3.9

Table 6. Location of injuries on the bole of residual trees caused by felling and skidding operations

	Injury location					
	< 0.3 m		0.3 – 1 m		> 1 m	
	(trees·ha^{-1})	(%)	(trees·ha^{-1})	(%)	(trees·ha^{-1})	(%)
Felling	0	0	1.1	0.4	2.1	0.8
Skidding	12.9	4.3	6.4	2.1	2.8	1.0
Total	12.9	4.3	7.5	2.5	4.9	1.7

8 stems (1.2% or 3.6 trees·ha^{-1}) were broken by felling operation and 10 stems (1.2% or 3.6 trees·ha^{-1}) were broken by skidding operation (Table 4). Only 2 trees (0.2 % or 0.7 trees·ha^{-1}) had completely broken crowns, which occurred after felling operation.

Injured trees

Injury location

The location of injuries on residual trees caused by felling and skidding operations is presented in Table 5. For all injured trees (n = 125), the number of trees that were injured in the crown, bole and root area was 21 (17%), 71 (57%) and 33 (26%) trees, respectively. 2.5% of residual trees (7.5 trees·ha^{-1}) was injured during felling operation. The injuries occurred most frequently in the bole area (25.3 trees·ha^{-1} or 8.5% of residual trees), while most of them (22.1 trees·ha^{-1} or 7.4% of residual trees) occurred after skidding operation (Table 5). About 3.9% of residual trees (12.1 trees·ha^{-1}) were injured in the root area, when most injuries (3.7% or 11.1 trees·ha^{-1}) occurred after skidding operation (Table 5).

For all injured trees in the bole area (n = 71), the number of trees that were injured at the height of less than 0.3, 0.5 to 1 and more than 1 m was 36 (51%), 21 (29%) and 14 (20%) trees, respectively. Most injuries occurred at the bole height of less than 0.3 m (12.9 trees·ha^{-1} or 4.3% of residual trees) and all of these injuries were caused by skidding operation (Table 6). The number of injuries at the bole height of 0.3 to 1 m mostly occurred after skidding operation (6.4 trees·ha^{-1} or 2.5% of residual trees) and only 1.1 trees·ha^{-1} (0.4% of residual trees) were injured by felling operation (Table 6). About 1.8% of residual trees (4.9 trees·ha^{-1}) were injured at the bole height of more than 1 m (Table 6).

Injury size

The analysis of injury sizes on the bole of damaged trees showed that 27% of injuries (19 trees) were of the size smaller than 10 cm^2, 46% (33 trees) of the size 11–50 cm^2, 18% (13 trees) of the size 51–200 cm^2 and 8% (6 trees) of the size larger than 201 cm^2. About 2.3% of residual trees (6.8 trees·ha^{-1}) were injured in the bole area with less than 10 cm^2 injury sizes. About 3.9% of residual trees (11.8 trees·ha^{-1}) were injured in the bole area with 11–50 cm^2 injury sizes and 1.8% of residual trees (4.7 trees·ha^{-1}) were injured in the bole area with 51–200 cm^2 injury sizes. Only 0.7% of residual trees (2.0 trees·ha^{-1}) were injured in the bole area with larger than 201 cm^2 injury sizes (Table 7). Most injuries of the size > 201 cm^2 occurred after felling operation, while most injuries of the size < 201 cm^2 occurred after skidding operation (Table 7).

Injury intensity

For all injured trees in the bole area (n = 71), 7 trees (10%) were injured with bark scratched intensity, 17 trees (24%) with bark squeezed intensity and

Table 7. The size of injuries on the bole of residual trees caused by felling and skidding operations

	Injury size (cm^2)							
	< 10		11–50		51–200		> 201	
	(trees·ha^{-1})	(%)	(trees·ha^{-1})	(%)	(trees·ha^{-1})	(%)	(trees·ha^{-1})	(%)
Felling	0	0	0	0	1.8	0.6	1.3	0.5
Skidding	6.8	2.4	11.8	3.9	2.9	0.9	0.7	0.2
Total	6.8	2.4	11.8	3.9	4.7	1.5	2.0	0.7

Table 8. The intensity of injuries on the bole of residual trees caused by felling and skidding operations

	Injury intensity					
	bark scratched		bark squeezed		wood damaged	
	(trees·ha^{-1})	(%)	(trees·ha^{-1})	(%)	(trees·ha^{-1})	(%)
Felling	1.4	0.5	1.1	0.4	0.7	0.2
Skidding	0.7	0.2	3.5	1.2	17.9	6.0
Total	2.1	0.7	4.6	1.6	18.6	6.2

47 trees (66%) with wood damaged intensity. About 0.7% of residual trees (2.1 trees·ha^{-1}) were injured with bark scratched intensity and about 1.6% of residual trees (4.6 trees·ha^{-1}) were injured with bark squeezed intensity, while about 6.2% of residual trees (18.8 trees·ha^{-1}) were injured with wood damaged intensity (Table 8).

Most injuries with bark damaged intensity occurred after felling operation, while more injuries with wood damaged intensity occurred after skidding operation (Table 8).

DISCUSSION

This study was carried out in the Caspian forests of Iran. The aims were to investigate chainsaw felling and ground-based logging damage to residual trees in a selectively logged parcel. The results of this study showed that total damage (felling and skidding) to residual trees was about 14.9% and is similar to results of other researchers (Lotfalian et al. 2008; Naghdi et al. 2009; Nikooy et al. 2010; Tavankar et al. 2011) who reported the damage range of 14.1 to 19.7% in the Caspian forests of Iran. Our results indicated that the majority of the damaged and destroyed trees were smaller than 22.5 cm, which is similar to the results of Lamson et al. (1985) in Virginia hardwood stands. The results of this study showed that Maple (*Acer cappadocicum*) and Alder (*Alnus subcordata*) trees were injured (22.5% and 21.8%) and were destroyed (10% and 9.1%) more than the other species. Our results indicated that more trees were likely to be destroyed during skidding operation, so the careful planning of roads and skid trails should be done to help minimize skidding damage. The selection system requires more roads or skid trails than the other systems. In order to minimize felling damage, directional felling must be applied considering the skid trails. The directional felling is an important technique to reduce logging damage to the residual stand. With the directional felling, trees are felled to reduce damage to the stand, to facilitate choker hook-ups in preparation for skidding and to operate without creating unnecessary large forest disturbance. Preharvest planning and identifying the winching area before logging operation can reduce damage to the stand in these forests. Skid trail planning before felling operation can reduce the skidding damage (Naghdi et al. 2008; Majnounian et al. 2009). Nikooy et al. (2010) reported that not only the proper planning of skid trails prior to felling is an essential stage of forest harvesting, but also the ability of the crew to fell falling trees toward the planned skid trail is necessary. The skidder and chainsaw operators are important factors that can be influential on productivity and environmental impacts during logging operation. So forest workers' training can be useful to reduce logging damage to the residual stand. In this study about 80% of injuries were located below 1 m (injuries with the remainder being located above 1 m). These results have been confirmed by other researchers (Bettinger, Kellogg 1993; Solgi, Najafi 2007; Naghdi et al. 2008; Nikooy et al. 2010). The highest risk of decay exists in trees with injuries in the area of the felling cut and root collar. Injuries of the size smaller than 10 cm^2 have no risk of infection by wood-destroying fungi (Camp 2002; Limbeck-Lilienau 2003). Nikooy et al. (2010) reported that 45% of the injury sizes were smaller than 100 cm^2 size in the Shafaroud forest. Results of our study showed that more injuries caused by skidding operation were of small sizes but more injuries caused by felling operation were of large sizes. The study of Yilmaz and Akay (2008) in a forest of Turkey showed similar results. The majority of hardwood trees such as beech, hornbeam and alder are susceptible to injury infection and variations in the injury infection frequency could be attributed to factors such as difference in size, position of injury on a tree and season of injury (Vasiliauskas 2001; Nikooy et al. 2010). The results of this study showed that 66% of bole injuries were of wood damaged intensity and most of them were caused by skidding operation. Approximately 18.6 trees·ha^{-1} were injured at wood damaged intensity. When external damage to bark occurs, the fungal infection could not be expected (Camp 2002). Infection and subsequent decay mostly occur when the wood is damaged (Limbeck-Lilienau 2003).

CONCLUSION

Selection felling has many advantages in reducing the stand density, improving the stand structure and species composition, increasing the diameter growth of residual trees and having more pleasing aesthetics when compared to shelterwood cutting (Marvie Mohadjer 2006). However, the potential detrimental damage to residual trees should be considered. Residual tree damage is a natural prospect of selective cutting, but the level of damage should be minimized to assure the future stand quality (Nikooy et al. 2010). It must be recognized that controlling logging damage is critical when the selection cutting systems are utilized (Tavankar et al. 2011). Logging studies have shown that poor felling and skidding techniques can result in excessive damage to residual trees. In this study felling operations mainly injured trees whereas skidding was the main cause of destruction. The planning of skid trails before felling operation can reduce skidding damage to residual trees. In the context of selection cutting management, limiting logging damage to residual trees must therefore remain a major objective (Tavankar et al. 2011).

References

Armstrong S. (2000): RIL for real: introducing reduced impact logging techniques in to a commercial forestry operation in Guyana. International Forestry Review, ***2***: 17–23.

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

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

FAO (2005): Global Forest Resources Assessment, Country Reports, Islamic Republic of Iran. Rome, FRA 175: 41.

Ficklin R.L., Dwyer J.P., Cutter B.E., Draper T. (1997): Residual tree damage during selection cuts using two skidding system in the Missouri Ozarks. In: Pallardy S.G., Cecich R.A., Garret H.H., Johnson P.S. (eds): Proceedings of 11th Central Hardwood Forest Conference. Columbia, 23.–26. March 1997. St. Paul, USDA Forest Service: 36–46.

Han H.S., Kellogg L.D. (2000a): Damage characteristics in young Doglas-fir stand from commercial thinning with four Timber harvesting systems. Western Journal of Applied Forestry, ***15***: 1–7.

Han H.S., Kellogg L.D. (2000b): A comparison of sampling method and a proposed quick survey for measuring residual stand damage from commercial thinning. Journal of Forest Engineering, ***11***: 63–69.

Hartsough B. (2003): Economics of harvesting to maintain high structural diversity and resulting damage to residual trees. Western journal of Applied Forestry, ***18***: 133–142.

Iskandar H., Snook L.K., Toma T., MacDicken K., Kanninen M. (2006): A comparison of damage due to logging under different forms of resource access in East Kalimantan, Indonesia. Forest Ecology and Management, ***237***: 83–93.

Lamson N.I., Smith H.C., Miller G.W. (1985): Logging damage using an individual-tree selection practice in Appalachian hardwood stands. Northern Journal of Applied Forestry, ***2***: 117–120.

Limbeck-Lilenau B. (2003): Residual stand damage caused by mechanized harvesting systems. In: Steinmuller T., Stampfer K. (eds): Proceedings of High Tech Forest Operations for Mountainous Terrain. Sclaegl, 5.–9. October 2003. Vienna, University of Natural Resources and Life Sciences [CD-ROM]: 11.

Lotfalian M., Parsakho A., Majnounian B. (2008): A method for economic evaluation of forest logging damages on regeneration and stand (Case study: Alandan and Waston Serries). Journal of Environmental Science and Technology ***10***: 51–62.

Lotfalian M., Mohammadi Samani K., Pirzad Far S. (2011): Investigation the importance and trends of forest yield production considering economical and environmental objectives. Agriculture and Biology Journal of North America, ***2***: 1182–1186.

Majnounian B., Jourgholami M., Zobeiri M. Feghhi J. (2009): Assessment of forest harvesting damage to residual stands and regenerations – a case study of Namkhaneh district in Kheyrud forest. Journal of Environmental Sciences, ***7***: 33–44.

Marvie Mohadjer M.R. (2006): Silviculture. Tehran, University of Tehran: 387.

Meadows J.S. (1993): Logging damage to residual trees following partial cutting in a green ash-sugarberry stand in the Mississippi Delta. In: Gillespie A.R., Parker G.R., Pope P.E., Rink G. (eds): Proceedings of the 9th Central Hardwood Forest Conference. West Lafayette, 8.–10. March 1993. St. Paul, USDA Forest Service: 248–260.

Naghdi R., Rafatnia N., Bagheri I., Hemati V. (2008): Evaluation of residual damage in felling gaps and extraction routes in single selection method (Siyahkal forest). Iranian Journal of Forest and Poplar Research, ***16***: 87–98.

Naghdi R., Bagheri, I., Taheri K., Akef M. (2009): Residual stand damage during cut to length harvesting method in Shafaroud forest of Guilan province. Journal of Environmental Sciences: ***60***: 931–947.

Nikooy M., Rashidi R., Kocheki G. (2010): Residual trees injury assessment after selective cutting in broadleaf forest in Shafaroud. Caspian Journal of Environmental Science, ***8***: 17–179.

Pakhriazad H.Z., Shinohara T., Nakama Y., Yukutake K. (2004): A selective management system (SMS): A cause study in the implementation of SMS in managing the dipterocarp forests Peninsular Malaysia. Kyushu Journal of Forest Sciences, ***57***: 39–44.

Pinard M.A., Putz F.E. (1996): Retaining forest biomass by reducing logging damage. Biotropica, ***28***: 278–295.

Pinard M.A., Putz F.E., Tay J., Sullivan T.E. (1995): Creating timber harvesting guidelines for a reduced impact logging project in Malaysia. Journal of Forestry, ***39***: 41–45.

Sist P., Nolan T., Bertault J.G., Dykstra D. (1998): Harvesting intensity versus sustainability in Indonesia. Forest Ecology and Management, ***108***: 251–260.

Sist P., Sheil D., Kartawinata K., Priyadi H. (2003): Reduced-impact logging in Indonesian Borneo: some results confirming the need for new silvicultural prescriptions. Forest Ecology and Management, ***179***: 415–427.

Shamekhi T. (2010): Regulations and administration of natural resources (Forests and Rangelands), Tehran, University of Tehran press: 463.

Solgi A., Najafi A. (2007): Investigation of residual tree damage during ground-based skidding. Pakistan Journal of Biological Sciences, ***10***: 1755–1758.

Tavankar F. (2000): Logging Damages on Stand and Soil. [Ph.D Thesis.] Tehran, Islamic Azad University: 185. (in Persian)

Tavankar F., Bonyad A.E., Majnounian B. (2011): Investigation of damages to stand caused by selection cutting using skidding system in the Asalem-Nav forest, Iran. Journal of Environmental Sciences, ***37***: 89–98.

Tavankar F., Bonyad A.E., Majnounian B., Iranparast Bodaghi A. (2010): Investigation on the damages to residual trees by ground-based logging system (Case study: Asalem-Nav forest area). Journal of Wood and Forest Science and Technology, ***17***: 57–72.

Vasiliauskas R. (2001): Damage to trees due to forestry operations and its pathological significance in temperate forest: a literature review. Forestry, ***74***: 319–336.

Yilmaz M., Akay A. (2008): Stand damage of a selection cutting system in an uneven aged mixed forest of Cimendagi in Kahramanmarz Turkey. International Journal of Natural and Engineering Sciences, ***2***: 77–82.

Zobeiry M. (1994): Forest Inventory (Measurement of Tree and Stand). Tehran, Teheran University: 401.

Received for publication December 3, 2012
Accepted after corrections May 13, 2013

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