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The Characteristics of Residual Stand Damages Caused by Skyline Thinning Operations in Mixed Conifer Stands in South Korea

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Abstract

A tree-length harvesting system using the HAM300, which is mounted on a farm tractor prototype machine, have been recently introduced in South Korea for thinning old (>30 years) forests. However, no research has previously been conducted on the characteristics of residual stand damage associated with cable yarding systems on thinning treatment stands in South Korea. Therefore, there were assessed on the degree and quantity of residual stand damage caused by felling and yarding process to broaden the knowledge of residual stand damage on semi-mechanized skyline thinning operations. This study investigated scar size, direction, area, shape type and their distribution on the residual stand damage caused by felling and yarding operations. Damage to residual trees was generated for 7.4% and 6.9% of residual trees in felling and yarding operations, respectively. Damaged direction of scars was located in front-side (38.9%) and up-side (34.7%) for felling operations while the highest scar damage was found on down-side (44.6%) for yarding operations. Scar heights of felling damage were higher than those of yarding damage. In yarding operation, the most of the scars was located within l0m from the center of the skyline corridor. These results should be useful information for forest managers and landowners to reduce residual stand damages and retain valuable timber volume from thinning treatments.

Key Words: tree-length harvesting system, HAM300, manual felling, cable yarding

Introduction

The forest stands in South Korea were mostly planted in 1970s and currently old trees (>30 years; range 30-60 years) are dominantly covered as 73% of total forest lands (Korea Forest Service 2017). In these overstocked forest stands, thinning prescriptions are increasingly required for intensive management that effectively reduces high levels of fuel connectivity and also allows the production of greater timber volume with good quality for residual trees. For example, this technology can improve tree diameter and height growth of the remaining stand because of less influence by competition for light, water, and nutrients (Cole 1983; Bettinger and Kellogg 1993; Reich et al. 2006). In addition, this option can reduce a fire hazard, increase residual stand health, vigor, and growth (Franklin and Johnson 2012; O'hara et al. 2015). However, when thinning treatments is implicated with conventional and mecha-

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nized timber harvesting systems, physical damage in residual trees is often produced by contacting with harvesting machinery and falling trees.

Residual stand damage has been described as a direct result of any logging treatments that reduces future timber growth and value in thinning stands (Han and Kellogg 2000; Hwang et al. 2018). The frequency, type, location, and patterns of damage to residual trees are varied with stand characteristics, thinning prescription, and harvesting system, equipment, and planning (Bustos et al. 2010). The type of residual stand damage includes root abrasion and breakage, bole wounds, and broken branches and tops (i.e., crown damage). The most common damage to the residual trees is bole wounds including scarring and gouging. A scar is defined as removal of the bark, exposing the sapwood in residual trees while a gouge is described as removal of wood fibers with the scar.

There have been various studies of stand damage associated with common types of harvesting equipment and systems, including the cable yarding, ground-based skidding and forwarding, and shovel logging operations (Bettinger and Kellogg 1993; Landford and Stokes 1995; Egan 1999; Dwyer et al. 2004; Bustos et al. 2010). Behjou (2014) conducted the level of residual stand damage with different thinning intensities in small-scale forestry, and found that a lower level of stand damage was found in medium and lower thinning treatment stands. In addition, Picchio et al. (2019) studied the impact of slope steepness on residual stand damages after winching operations and reported that larger wounds and more wounded trees were found on steeper slopes. In addition, wound intensity also depended on the gradient of the slope. Fairweather (1991) and Han and Kellogg (2000) reported that the cable yarding damage is less than conventional skidding, forwarding, of tractor-based operations. On the other hand, residual stand damage occurs not significantly different among logging technologies, including the chainsaw felling/skidder, feller-buncher/mini-crawler extraction, and harvester/forwarder (Becker et al. 2006). As a result, wounding of some of the reserve trees can cause by any of the harvesting activities.

In South Korea, thinning treatments on steep slopes (＞40%) have been often used with the small-scale cable yarding systems such as farm tractor mounted tower yarder (e.g. HAM300, Koller K301-3; Cho et al. 2014, 2016; Han et al. 2014; Jeong et al. 2017). These thinning activities are commonly applied with the tree length harvest system, which is comprised of a chain saw for felling and processing in stand, and cable yarder for yarding to move a landing. However, no research has previously been conducted on the characteristics of residual stand damage associated with cable yarding systems on thinning treatment stands. In this study, therefore, there were assessed on the degree and quantity of residual stand damage caused by felling and yarding process to broaden the knowledge of residual stand damage on semi-mechanized thinning operations. This research investigated the characteristics of stand damage for felling and yarding operations including scar size, direction, area, and form, and their distribution on the bole by each process.

Materials and Methods

Study site and harvesting system

This study was conducted on conifer forest site in the Eoheul-ri, Seong san-myeon, Gangneung-si, Ganwon-do, South Korea (37°72’36”N 128°80’22”E). Study site was 3.4 ha at an elevation of 150 m and was dominantly composed of Korean red pine (*Pinus densiflora*). Slopes throughout the study site were approximately 40%. Before thinning treatments, stand density was 594 trees per hectare (ha), and an average diameter at breast height (DBH) and tree height was 40 cm and 16 m, respectively. Thinning operations were performed form June to July in 2014. Thinning prescription was to remove the dead trees and increase spacing within trees for encouraging stand health and growth for residual trees. After thinning, stand density was 377 trees per ha and 36.5% of trees were harvested with thinning treatments.

In thinning treatments, tree-length harvesting operations were applied with a small-scale cable logging system including manual tree felling and delimbing at the stump using a chainsaw, and cable yarding with HAM300. The HAM300, which is designed by National Forestry Cooperative Federation, is a small-scale tower yarder. This technology was mounted to a farm tractor with a 59 kW (79 hp) and rigged in a running skyline system. Small-scale cable yarding operation was applied with uphill yarding method. In the study site, three different corridor lines was

Table 1. Characteristics of yarding operations on thinning treatment stands

# Of corridor	Distance of corridor line (m)	Number of yarding cycle (times)	Yarding distance (m)		Lateral distance (m)	
			Max.	Ave.	Max.	Ave.
1	110	27	82	31	24	12
2	100	42	88	47	26	10
3	100	44	66	34	21	7

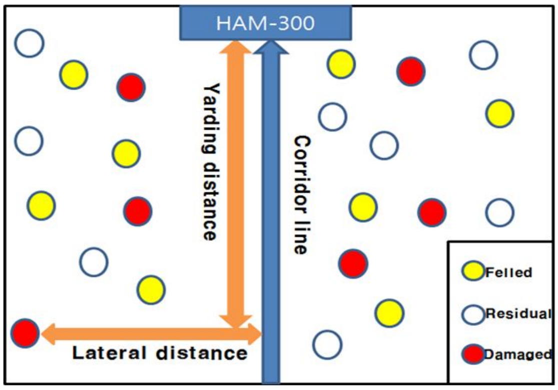

Fig. 1. Schematic representation of yarding and lateral distance with corridor line.

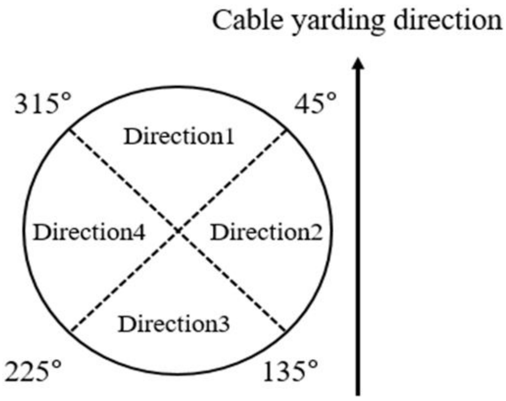

Fig. 2. Classification of damage direction based on corridor line.

designed for yarding operation. Average yarding distance was 37 m and average lateral yarding distance was 9.7 m (Table 1).

Data collection and analysis

In this study, residual stand damage was defined as the removal of the bark and cambial zone with bigger than 6 cm at the width of damage, caused by any harvesting operations (Han and Kellogg 2000; Froese and Han 2006).

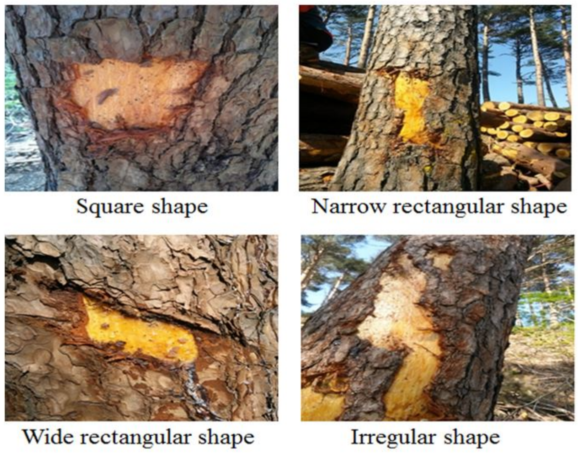

Fig. 3. Scar shape types of residual stand damage.

Damage to residual trees was surveyed separately by thinning operation phases. Felling damages data were immediately collected after felling operation. Damaged parts in trees were checked and painted before trees had been yarded to separate damages caused by the yarding operation. The different colors were painted on felling and yarding damages respectively. To investigate the characteristics of felling and yarding damage, heights, size (width and length), direction, and shape of the scar were measured. Especially, yarding damage data were additionally collected with yarding distance and lateral distance (Fig. 1).

Scar height was measured as the length from the ground level to the bottom point on the scar using a tape. Scar length and width was determined with maximum distance. Scar width was collected any size bigger than 6 cm and the length was collected with no limitation. The size of scars was calculated with maximum value of length and width of scars. If scars that could not be reached were measure with a Vertex Hypsometer. Damage direction was classified with four directions (Direction 1: 315-44°, Direction 2: 45-134°, Direction 3: 135-224°, Direction 4: 225-314°; Fig. 2), based on corridor line for yarding operation.

Shape of scars was classified into irregular and rectangular shape. Rectangular shape was additionally defined as square shape, narrow and wide rectangular shape based on length and width ratio (square shape=1: 0.5-2, narrow rectangular shape=1: 2<, wide rectangular shape=1: 0.5; Fig. 3).

The SPSS package (IBM Co., New York, USA., v. 22.0) was used for the data analysis. Stand damage data collected in each corridor was separately analyzed. Data were evaluated for normality test before running the analysis but the data was not normally distributed. Therefore, the Wilcoxon signed-rank test that is a non-parametric statistical method was used to compare the characteristics of residual stand damage between felling and yarding operations.

Results and Discussions

Residual scar damage after felling

Post-thinning/pre-yarding stand density was 377 trees/ha, and 36.5% of trees were felled and delimbed by manual felling method. Felling activity by chainsaw resulted in 7.4% of residual trees (28 trees) having scar damage, and these trees had an average of 2.6 scars per tree (total scars: 72). This is similar to the results reported by Kellogg et al. (1986) and Bustos et al. (2010), in which only 3.1-6.5% of the scars measured were caused by felling activities. However, our results were slightly higher than those of past studies because of feller's low skills and experiences (less than 5 years). Past studies were also highlighted for importance of operator's skill on residual stand damage. Hwang et al. (2018) showed that harvester operator having lower logging experience created a greater number and lager sized scars. Kelly (1983) also found that different operators could create the different amount of up to 16% in scar damage.

In this study, damage directions of scars were measured to investigate the major locations of stand damage caused by harvesting operations. In felling operation, the highest damage was found in direction 2 (front-side, 38.9%), and direction 1 (up-side, 34.7%), while the lowest damage was founded in direction 4 (back-side, 7%; Fig. 4). This result was related with felling direction that a tree was felled from up to down, and the most of damages were occurred from felling scratch from felled trees to residual trees.

Scar height on the tree is also one of the important factors as well as scar directions in residual stand damage study. As reported from several past studies, occurrence of decay in the scars is strongly related to scar size and height and decay in the scars increased with the height of the scar above ground (Kellogg et al. 1986; Han and Kellogg 2000; Froese and Han 2006). In our study, felling scars ranged from 0.5 to 11.8 m and were mainly located in over 5 m (Fig. 4). In particular, 18.1% and 12.5% of total scars was occurred at 6 to 7 m and over 9 m, respectively. In addition,

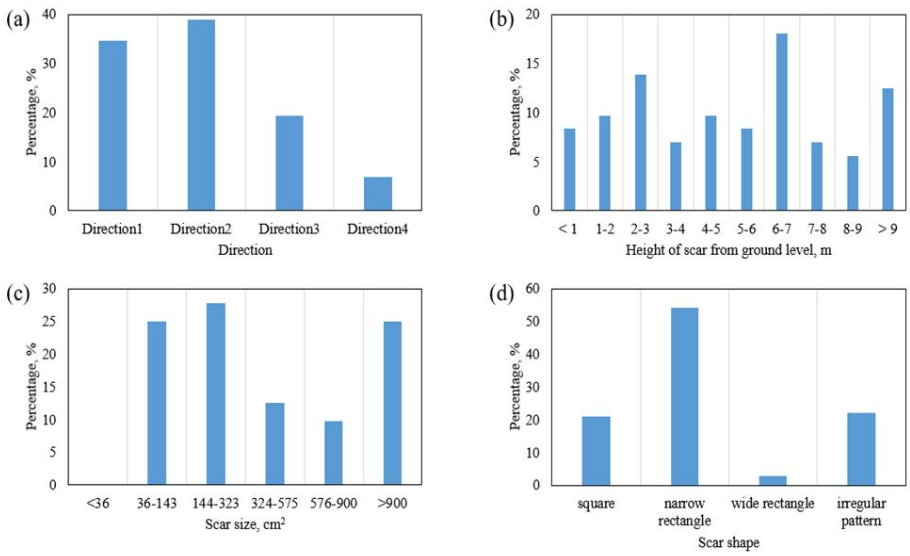

Fig. 4. Scar distribution percentages by manual felling operation as related to (a) direction, (b) height, (c) scar size, (d) scar shape.

scar damage in higher height of residual trees was located with the closer distance between felled and residual trees.

Scar size is also important for determining incidence of decay on the scars. After felling operation, scar size on all damaged trees ranged from 36 to over 900 cm^2 (Fig. 4). There was no scar with less than 36 cm^2 in scar size because most of the scars had over 6 cm in the width and length of the scar. In felling operation, longer length of scars was mainly created when a felled tree rubs along the bole of a residual tree with inadequate felling directions. More than 50% of the scar size on residual trees was in 36-324 cm^2. Bettinger and Kellogg (1993) found that significant scar size for future probability of decay was defined as larger than 903 cm^2. Hunt and Krueger (1962) also reported that scar size with decay (903 cm^2) was five times as great as scars without scar (177 cm^2). In our study, greater than 900 cm^2 in scar size was 25% of total scars.

In shape of scars, the narrow rectangle shapes were dominantly occurred with 54% of total scars and wide rectangular shape was founded at lowest level (2.8% of total scars; Fig. 4). These results were often attributed by hang-up problems of felling activities on thinning operations. In overstocked and dense thinning stands, felled trees had often hung up to residual trees and then fallen down along the stem of a residual trees, and created longer shape of scars. In addition, the narrow rectangle shape scar having smaller scar width could be easily closed.

Residual scar damage after yarding

After cable yarding activity, 6.9% (26 trees) of total residual trees were damaged during yarding operations. These damaged trees had a total 56 scars with an average of 2.2 scars per trees. Kellogg et al. (1986) reported that yarding activities in skyline thinning operations damaged 12% of the residual trees on the strip treatment stand and 47 and 61% of the residual trees on narrow and wide spacing treatment stands, respectively. Our results were slightly lower than those of past studies due to smaller yarding cycles (37 cycles) and shorter lateral yarding distance (9.7 m), compared to those (423 cycles and 36 m) of the previous study.

During yarding operation, the highest scar damage was found in direction 3 (down-side, 44.6%), while the lowest damage was found in direction 4 (back-side, 10%; Fig. 5). This result was related to yarding direction because a log was mainly hauled from down to up and positioned parallel and vertical to yarding direction in uphill yarding. In addition, 80% of total scars were located less than 3 m height above ground and the frequency of scar damage decreased with increasing the height of the scar. These results could be contributed by ground skidding of a log during lateral yarding operations. Kellogg et al. (1986) also found the similar results that scar height above ground ranged from zero to 11.4 m but 82% of total scars were located within 2.1 m.

After yarding operation, 70% of scar sizes on all dam-

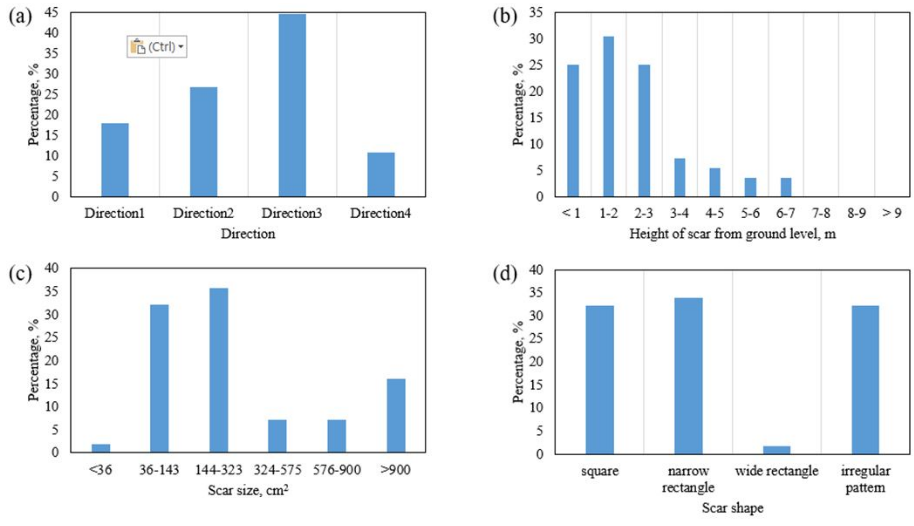

Fig. 5. Scar distribution percentages by cable yarding operation as related to (a) direction, (b) height, (c) scar size, (d) scar shape.

aged trees were in 36-324 cm^2 and major scar size (>900 cm^2) having the severity of future decay were only 14% of total scars (Fig. 5). In damage shapes, narrow shapes were dominantly occurred (33.9%). Square shape and irregular shape have evenly occurred as 33%. Wide rectangular form was rarely generated as only less than 2% of the total scars due to small diameter of residual trees. The wide rectangular shape on the scars should have often found large diameter trees and could be close at a slower rate than narrow rectangular shape scar (Han and Kellogg 2000).

Most of the damage (53.6%) occurred on trees that were within 30 m of a corridor line, even though thinning was uniform during the distance classes, since the carriage moves have increased in yarding distance such as ranged from 30 to greater than 80 m. A small portion of the damage generated from 30 to 60 m, and greater than 80 m (Fig. 6). Howard (1996) also found that the severity of tree damaged decreased with increasing distance from skyline corridor. In addition, the lateral yarding may cause severe tree damage (Howard 1996). In our study, 38% of residual trees damaged were occurred within 5 m from the center of corridor line and the percentage of residual trees damaged in lateral distance classes (5 to 10, 10 to 15, 15 to 20, >20 m) were 36, 7, 7, and 13%, respectively (Fig. 6). As a result, most of the scars were created within 10 m of lateral distance from the center of corridor due to swinging of the cable and chocking lines (Howard 1996). In past studies, Kellogg and Olsen (1984) and Kellogg et al. (1986) both found that tree damage was gathered within 5 m because of swing action when in-hauling from the stump to the carriage. Thus, the residual stand damage was associated with the relative short lateral distance in logs hauling process.

Comparison of residual stand damage between felling and yarding operations

The comparison of residual stand damage between felling and yarding operations was analyzed using the Wilcoxon signed-rank test as a non-parametric statistical method. Amount of stand damage to residual trees was varied with harvesting methods and machine operations. In past study, the majority of stand damage occurred during yarding operation (12-61% of total residual trees) and felling and loading damages were only 3.1 and 7.9%, respectively (Kellogg et al. 1986). In our study, felling and yarding damages were 7.4 and 6.9%, respectively, and there was not significantly different between felling and yarding damages ($p > 0.001$). The different results compared to other studies should be attributed by small size of research unit including smaller yarding cycles and shorter lateral distance, which might create fewer amounts of scar damages during yarding operations.

Stand damage directions and heights were also investigated to find the scar location of residual damaged trees caused by harvesting operations. In our study, there was significantly different between felling and yarding damage directions and heights ($p < 0.001$). Most of the scar damage during felling operations was created in direction 2 (front-side, 38.9%) and direction 1 (up-side, 34.7%), while most of the yarding damage was occurred in direction 3 (down-side, 44.6%). In addition, felling damage was mainly located in over 5 m while most of yarding damage was located within 3 m above ground. These results could be explained by the operational characteristics of each harvesting activities. Trees was usually felled from up to down in felling operations while a log was mainly hauled from down to up in uphill yarding operations. Especially, lower location of scars in yarding damages was contributed by ground skidding of logs during in-hauling operation.

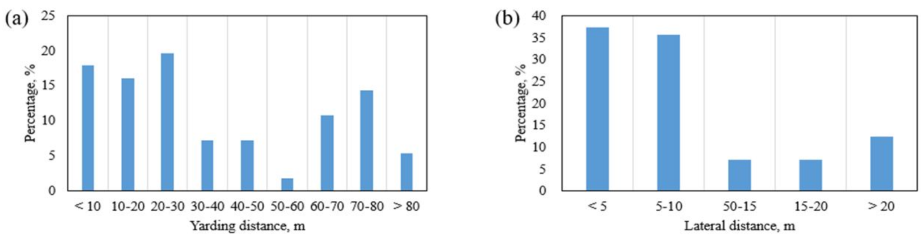

Fig. 6. Scar distribution percentages along the yarding distance classes (a) and lateral distance classes (b).

Scar size and shape in felling damages were statistically similar with those in yarding damages ($p > 0.001$). Most of the felling and yarding damages was 36-324 cm^2 in scar size and has narrow rectangle shape. In yarding damages, however, square shape and irregular shape were also evenly created in 33%.

Recommendation for reducing stand damage

In thinning treatments, conventional and mechanized timber harvesting systems are usually applied and often cause severe physical damage on residual trees by contacting with harvesting machinery and falling/yarding trees.

The first procedure to reduce these stand damages during harvesting operations should be starting with conscientious planning and layout on harvesting and thinning sites. Especially, layout of skyline corridors is more important when skyline systems are applied in thinning treatments. Parallel corridor layouts can usually reduce stand damage by minimizing the amount of side hill yarding compared to fan-shaped corridor layout in skyline system (Kellogg et al. 1986). In addition, a skyline should be straight and placed on the center of corridor. If a skyline is skewed to either side of the corridor, the severe amount of damage to residual trees would be created on especially the side of corridor line (Kellogg et al. 1986). All of these problems could be modified and resolved during the planning and layout procedures.

In felling operations, directional and herringbone felling pattern can minimize severe stand damage by reducing log swing during lateral yarding of logs (Han and Kellogg 2000). Trees on the skyline and lateral yarding corridors must be felled with lower stump to reduce stand damages by hang-up problems.

In yarding operations, skyline height and carriage position are critical to reduce stand damage in thinning treatments. High skyline must run through tree crown or tops with fully suspended logs during yarding operations and can increase stand damage to residual trees (Han and Kellogg 2000). It could be solved by the use of intermediate supports or leaving rub trees in yarding operations. Skyline carriage is often repositioned or moved during lateral yarding. Incorrected skyline carriage position should increase hang-up problems and stand damage to residual trees. In addition, small log angle between mainline and logs can help to provide less chance for stand damage to residual trees (Kellogg et al. 1986).

Conclusion

Recently, thinning prescriptions on dense and overstocked forest stands are increasingly required to increase residual stand health and growth and reduce high levels of fuel connectivity. However, when thinning treatments is implicated with conventional and mechanized timber harvesting systems, physical damage in residual trees is often produced by contacting with harvesting machinery and falling trees. In this study, the degree and quantity of residual stand damage caused by felling and yarding operations were investigated to broaden the knowledge of residual stand damage on semi-mechanized skyline thinning operations.

In this study, felling and yarding damages were 7.4 and 6.9%, respectively, and there was not significantly different between felling and yarding damages. Scar directions and heights between felling and yarding damage have different results. Most of the scar damage during felling operations was created in direction 2 (front-side) and direction 1 (up-side), while most of the yarding damage was occurred in direction 3 (down-side). In addition, felling damage was mainly located in over 5 m while most of yarding damage was located within 3 m above ground. Scar size and shape in felling damages were statistically similar with those in yarding damages. Most of the felling and yarding damages was 36-324 cm^2 in scar size and has narrow rectangle shape. In yarding damages, however, square shape and irregular shape were also evenly created in 33%.

This study also addressed the operational recommendations and practices to reduce residual stand damage for skyline thinning operations. In thinning planning and layout, application of parallel corridor layouts can usually minimize stand damage by reducing the number of side hill yarding operations. A skyline should be also straight and placed on the center of corridor because severe scar damages were usually created when skyline is often moved into the out of the corridor centerline. During felling operations, the decision of optimal felling pattern is important based on stand characteristics, terrains and harvesting systems. In skyline harvesting systems, directional and herringbone felling pattern are usually minimizing stand damage by reducing log swing during lateral yarding of logs. In yarding operations, skyline height and carriage position are critical to reduce stand damage in thinning treatments. Small log angle between mainline and logs can help to provide less chance for stand damage to residual trees while the use of high skyline can increase stand damage to residual trees. All of these recommendations should be helpful to reduce residual stand damage. However, conscientious planning and layout of forest managers and careful operation of operators should be more important with considering the severity of residual stand damage in ecological and economical aspects.

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