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Impact of Mechanized Harvesting Machines on Forest Ecosystem: Residual Stand Damage

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Abstract: Mechanized harvesting systems are commonly applied in current forest operations in many parts of the world including Europe, North America and East Asia. These systems satisfy public demand by providing the necessary organic material to the forest, working on smaller operation area, working on selective cuttings and increasing labor efficiency. However, using harvesting machinery can cause damage to the residual vegetation in the forest. This study introduces specific logging machines widely used in mechanized harvesting systems and then presents the environmental impacts of these machines, focusing on the stand damage, based on previously conducted studies. Then, the possible ways of reducing the environmental impacts during the operations are presented to assist logging managers in developing and implementing environmentally friendly harvesting plans.

Key words: Mechanized harvesting systems, stand damage, logging machines

INTRODUCTION

Fully mechanized harvesting systems have replaced the conventional systems using chainsaws and bulldozers in logging operations in many developed countries. The main advantage of mechanized harvesting systems are leaving the limbs and tops in the stand as an organic material, conducting partial cutting, working on smaller landings and improving labor efficiency (Kellogg *et al*., 1992). However, operating the logging machines in the forest has great potential to cause negative environmental impacts, especially damages to residual trees. In order to reduce the environmental impacts while maintaining the advantages of mechanized harvesting systems, the capabilities of the logging machines should be well understood and environmental conservation techniques should be implemented during the logging operations.

There have been many studies that investigated the residual stand damage from various mechanized harvesting systems (Han and Kellogg, 2000; Glode and Sikstrom, 2001; Heitzman and Grell, 2002; Limbeck-Lilienau 2003; Matzka and Kellogg, 2003). The results from the previous studies indicate that damage in the first 3 m of a residual tree from a logging machine may cause detrimental impact on stand structure, wood quality and tree volume (Erdmann *et al*., 1986; Cline *et al*., 1991 and Hassler *et al*., 1999). Hesterberg (1957) found that 53 and 83% of the scars in the first 3 m above ground caused decay in the wood 10 and 20 years after harvest, respectfully. The damages on the butt log during a logging operation may provide of entry for several diseases that will also lead to considerable amount of reduction in wood quality and volume of the infected stand (Seablom and Reed, 2005).

The risk of damaging the residual stand is very high during thinning operations (Fig. 1). However, the type of the harvesting systems used in thinning operation can reflect the amount of residual stand damage (Filip and Schmitt, 1990). Bettinger and Kellogg (1993) reported that the damages on the residual stand can be reduced by using cut-to-length thinning systems. Besides, well trained and motivated machine operators can be a significant factor in keeping the amount of stand damage under the tolerable level.

Estimating the residual stand damage caused by mechanized harvesting equipments can assist logging managers to evaluate the success of the harvesting operations in sustainable forest management (Acar and Unver, 2004). This study aims to first introduce the capabilities of the most common mechanized harvesting machines used in various forest operations (felling, bucking, skidding and forwarding) and then to present their associated residual stand damages in the woods. Based on the previous studies, it also presents some of the practices that can be used to reduce stand damage caused by these machines.

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Fig. 1: Residual stand damage from a thinning operation

Fig. 2: A rubber-tired feller-buncher in felling operation

Harvesting systems

Felling and bucking: Mechanized felling and bucking equipment are divided into two main groups; feller-bunchers that cut trees at the base and bunch them into piles to await skidding; and harvesters that both fell and process -delimb and buck-trees into log lengths (Kellogg and Brinker, 1992).

Feller-bunchers: The feller-buncher cuts the tree using a hydraulic powered cutting head with chain saws, circular saws, or shears. Then, the entire tree can be lifted and accumulated it in a bunch using its hydraulic arms (Fig. 2). The trees are then transported full-length with a skidder to the landing, where a processor delimbs and bucks the tree into logs. Trees can be felled uphill to enable downhill skidding, which improves skidder productivity. The feller-bunchers are not only much faster than fallers working with chain saws but also they provide a much safer environment for the operator compared to manual felling. Even though there are some advanced feller-bunchers that can operate on slopes up to 50%, the ground slope steeper than 35% generally reduces the production rate of the feller-bunchers (Martin *et al.*, 1985). Besides, the capabilities of a feller-buncher are also limited to a maximum timber size of about 60 cm DBH.

In a study conducted by Bruhn (1986), residual stand damage level was estimated at about 22% in a mechanized thinning operation which utilized a feller-buncher and a rubber-tired skidder. Cline *et al.* (1991) reported that 13.7% of the residual stand was damaged during a whole-tree partial cutting operation where a feller-buncher and a grapple skidder were used. Both studies indicated that the most of the stand damage occurred on the stem portion of the residual trees. Matzka and Kellogg (2003) investigated the amount of residual stand damage caused by four different harvesting systems including (1) feller-buncher, (2) partial tree with shovel, (3) log length with shovel and (4) winch line. The results from this study indicated that the least percentage of stand damage was generated by System 4 (20.12%), followed by System 3 (33.74%), System 2 (41.58%) and System 1 (62.62%).

In mechanized felling operations using feller-bunchers, stand damage can be decreased by implementing directional felling techniques. Tree protection devices along the skid trails can also reduce stand damage during the felling operations (Han and Kellogg, 2000a). Cutting heads with chain saws cause relatively less damage on the butt log during felling operation than that of cutting heads with shears (Martin *et al.*, 1985). The studies also suggested that using a falling head with larger grappling device can also help reduce stand damage from a feller-buncher (Matzka and Kellogg, 2003). In order to ensure minimum stand damage, these stand protection techniques should be well understood and applied by skilled and experienced operators.

Harvesters: Harvesters are commonly used in mechanized cut-to-length (log-length) systems in which the harvester fells and processes trees into log lengths and a forwarder transports the logs to the roadside. Harvesters are divided into two groups: single-grip harvester and double-grip harvester (Fig. 3). Single-grip harvester both fell and processes with a single unit (Kellogg *et al.*, 1992). Double-grip harvester severs the tree with a boom-mounted head unit and places it in the carrier-mounted processing unit for delimbing and bucking (Kellogg and Brinker, 1992). According to a study conducted by Kellogg and Brinker (1992), single-grip harvesters have become more popular than double-grip harvesters.

Fig. 3: Delimbing and bucking the trees with double-grip harvester

The most important factors influencing the productivity of a harvester are log size, operator skill and motivation, branch size, number of merchantable trees per unit area, ground slope (up to 35%), terrain conditions and undergrowth density (Makkonen, 1991; Raymond, 1988). For three stems with less than 55 cm diameter, the single-grip harvester is very productive in felling and bucking operations (Brown, 1995). While delimbing the trees, the harvester places all the limbs from the trees on the trail, so the machine can travel on top of these limbs to reduce soil compaction and help accelerate slash decomposition (Martin *et al*., 1985). However, high initial purchase cost, relatively unsafe operation conditions on steep ground slopes and some volume loss during the cutting process are some of the main disadvantages of the felling and bucking operations using harvesters (Kellogg and Brinker, 1992).

Limbeck-Lilienau (2003) measured stand damage from four different mechanized harvesting systems; (1) rubber-tired harvester and forwarder, (2) tracked harvester and forwarder, (3) harvester and cable yarder and (4) chain saw, cable yarder and processor. The results indicated that the least percentage of stand damage was generated by System 1 (4.5% in winter and 13.5% in summer), followed by System 2, System 3 and System 4.

The amount of stand damage caused by a harvester can be reduced by determining the optimal spacing between trails, considering the reaching distance of the harvesters. Han and Kellogg (2000b) suggested that optimal trail spacing of about 20 m can considerably reduce the stand damage. They also reported that the cutting head of the harvester should be selected according to size of the tree. Other studies have emphasized that the amount of residual stand damage can be lowered by highly skilled and motivated harvester operators (Lageson, 1997).

Fig. 4: A rubber-tired chained skidder in skidding operation

Fig. 5: Ground skidding with a crawler tractor using grapple

Skidding and forwarding: Mechanized skidding and forwarding equipment are divided into two main groups; skidders that drag the material either completely in contact with the ground or partly in contact with the ground; and forwarders that transport the material completely off the ground (Kellogg and Brinker, 1992).

Skidders: The skidding operations are usually done by using a grapple to hold the load ends clear of the ground, or by dragging logs using wire rope to hold the load. Skidders are divided into two types; rubber-tired skidders that are equipped with an articulated frame and crawler tractors that are equipped with steel track (Fig. 4 and 5) (Kellogg *et al*., 1992).

Rubber-tired skidders are less expensive, faster and lighter than crawler tractors. Their traction can be improved by installing chains over the tires. Rubber-tired skidders have the advantages of operating with higher production rate and lower unit costs; however, they can cause significant amount of residual stand damage and soil disturbance (Martin *et al.*, 1985). The study conducted by Ficklin *et al.* (1997) indicated that skidding operation using rubber-tired skidder damaged about 22% of the residual trees. According to Butora and Schwager (1986), 25% of the residual trees were damaged in skidding with skidders on trafficable terrain, 33% in ground skidding, 34% in cable crane and 38% in hand skidding.

Yilmaz (2001) investigated the relationship between silvicultural practices and forest transport techniques, by considering the residual stand damage of a logging system which integrated rubber-tired skidder with man power. The results indicated that the residual stand damage was approximately 11.19% in which over 60% of the damage occurred at the butt logs during skidding operation in an unevenaged mixed stand. It was also reported that some species with thin barks (such as fir and hemlock) are subject to damages more than other species with thicker barks (such as pines).

Crawler tractors have a lighter ground pressure than rubber-tired skidders due to larger ground contact area, which leads to reduced soil compaction (Martin *et al.*, 1985). They have better traction and maneuver ability in mud, on slippery soils and in heavy brush. With better traction and heavier machine weight, they can pull more load than rubber-tired vehicles. However, crawler tractors are limited to maximum uphill ground slope of 15%, while rubber-tired skidders can operate up to uphill slope of 25% (Martin *et al.*, 1985). They also have a higher potential to damage residual trees in thinning operations. Han and Kellogg (2000b) investigated characteristics of stand damage from four different thinning systems including; skyline, crawler tractor, cut-to-length involving a harvester and a forwarder, skyline and helicopter. The results indicated that ground-based system using crawler tractor generated severe root damages. Besides, crawler tractor logging can also cause relatively larger scarring on residual trees than that of other three systems.

In order to improve the efficiency of the skidding operation, skid trail locations should be predetermined before directional felling takes place in the woods (Simmons, 1979). Designated skid trails and optimal trail width can significantly affect the amount of residual stand damage from skidding operation. According to a previous study, tractor logging with wide skid trail (average about 7 m) had very low damage on the residual stand (Han and Kellogg, 2000b). They reported that trail width should not be less than about 5 m to prevent damage on the trees near trails. Skid trails should be kept as straight as possible since the trees located on a corner have higher potential of being damaged by skidding equipment. They also suggested installing tree protection devices where residual damages are expected along the skid trail.

Fig. 6: Forwarders equipped with a hydraulic grapple loading arm

Forwarders: Forwarders are rubber-tired machines that carry short logs to the roadside (Fig. 6). They are equipped with grapple loading arm, which can pick up logs from the side of the trail and load truck trailers at the landing or place the logs on the side of the road (Martin *et al.*, 1985). Forwarders are commonly used in a cut-to-length system combined with a harvester (Kellogg *et al.*, 1992). They can travel at higher speed than rubber-tired skidders; therefore, forwarders require a higher quality trail than the skidder. Since the harvester leaves limbs and tops on the trail, the forwarder travels on the slash, which may significantly reduce soil compaction and rutting (Akay and Sessions, 2001). Optimal forwarding operations usually consist of longer traveling distance, which reduces the trail density and generates less overall soil disturbance. Besides, forwarding larger payloads at higher speeds along the longer trails can provide higher production rate and lower unit cost, compared to skidding operations. However, larger payloads may cause more soil damage than that of a skidder or a tractor does (Kellogg *et al.*, 1993). The forwarders are limited to maximum ground slope of 30% (Martini *et al.*, 1985).

Residual stand damage from forwarders is very low because the logs are transported off the ground. Seablom and Reed (2005) conducted a study where residual stand damage from four different mechanized harvesting systems were evaluated; harvester and skidder, processor and forwarder, chainsaw and skidder and chainsaw and forwarder. The results indicated that the residual stand damage caused by a system using the forwarder varied from 2.9 to 14.4%. In other study, Franklin (2003) reported that using forwarder with skilled operator caused only minimal residual stand damage in a partial cutting operation. Heitzman and Grell (2002) conducted a study in which eight thinning operations using a processor and a forwarder combination were evaluated for residual stand damage. They reported that the total residual stand damage caused by the thinning operation ranged from 25 to 46%. The results also indicated that damage was higher on the trees located along the forwarder trails. According to Han and Kellogg (2000b), the residual stand damage caused by a forwarder (28.6%) was approximately half of the damage caused by a harvester (63.8%). They reported that the size of the scars and the amount of root damage from the forwarder was more than from the harvester. It was also indicated that using straight forwarder trails with optimal spacing can reduce the amount of stand damage.

DISCUSSION

In developing a feasible harvesting system, the mechanized harvesting machines should be considered based on not only their production rates and unit costs but also their impacts on forest ecosystem. Mechanized harvesting operation can have long lasting effect on residual vegetation in forest. Therefore, logging managers need to understand the capabilities of the harvesting machines and know how to reduce their damages on the residual vegetation. This study presented commonly used machines in mechanized harvesting systems and provided a review of the previous studies that investigated their associated stand damage. It can be concluded from this review that;

- The harvesting systems should be well suited with silvicultural treatments.
- The harvesting machines should be carefully selected according to tree sizes, terrain conditions, stand characteristics and topography.
- Selection of cutting and grappling device is also crucial to decrease stand damage.
- Directional felling should be implemented and skid trails and forwarder trails should be planned ahead of logging operation.
- Relatively wider and straight skid and forwarder trails should be considered to reduce stand damage.
- Tree protection devices should be placed along the skid trails to reduce stand damage.
- The machine operators must be adequately trained prior to operation and supervised during the operation.
- In a cut-to-length operation with harvester, harvester trails spacing should be carefully planned, considering the optimum reaching distance of the harvesters.

It is anticipated that this synthesis would help a logging manager to select economically feasible and environmentally friendly harvesting plans. In future studies, long lasting effects of the stand damage on residual trees should be investigated. Severely damaged trees are subject to be infected by deteriorating agents such as decay fungi and insects. Due to deterioration, the commercial trees loss their recoverable volumes and economic values quickly and dramatically within couple of years based on tree species, tree size and deterioration types. Therefore, damaged trees should be extracted prior to regular rotation period to recover their economic values. Besides, decreasing the number of trees per unit area in a stand can provide the healthy residual trees with increased growth rate.

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