Damage Characteristics in Young Douglas-Fir Stands from Commercial Thinning with Four Timber Harvesting Systems

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ABSTRACT: *Damage to residual trees from commercial thinning was characterized and compared among four common harvesting systems in western Oregon: tractor, cut-to-length, skyline, and helicopter. Six young (30- to 50-yr-old) Douglas-fir* (Pseudotsuga menziesii) *stands with various residual densities were studied. 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 15 ft of skid trails or skyline corridor centerlines. 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. Recommendations for minimizing stand damage are included. West. J. Appl. For. 15(1):27–33.*

Thinning prescriptions are increasingly necessary for intensive management of private and public forestlands in western Oregon. Sessions et al. (1991) reported that within 25 yr, thinning will be required on about two-thirds of industrial lands. In the same survey, the USDA Forest Service and the Bureau of Land Management (BLM) planned to implement intensive management on virtually all of their forested acres allocated to timber production in western Oregon. Unfortunately, thinning activities produce residual stand damage that may adversely affect timber growth and value.

Each harvesting system can cause distinctive damage to remaining crop trees during thinning operations. Most scars from cut-to-length thinning are relatively small (Bettinger and Kellogg 1993). Damage to leave trees was less severe with skyline thinning than with conventional skidding or tractor-based operations (Aulerich et al. 1976, Fairweather 1991). Flatten (1991) also found that helicopter thinning damage was far less than that typically found with skyline systems.

Government agencies and private industry have inconsistent and often ambiguous policies for defining a maximum acceptable damage level and what constitutes a damaged tree. The minimum scar size that qualifies as damage ranges from 1 in.^{2} to 144 in.^{2} (British Columbia Ministry of Forests 1983, Oregon Department of Forestry 1995, Weyerhaeuser Co. 1996, Washington State Department of Natural Resources 1997). The main concern is how a critical size affects tree health and value loss at final harvesting. The maximum acceptable damage level for scarring, crown, and root damage is not consistent either, varying from 3–5% of total residual trees or dependent on an inspector's discretion. Species, logging systems, thinning treatments, timber value, rotation age, and snags for wildlife habitat are factors to consider when determining the maximum acceptable damage level.

Logging injury can be reduced by promoting damage-free efforts, such as suspending thinning during sap flow (Wallis and Morrison 1975, Aho et al. 1983), clearly marking leave trees (Kelley 1983), and matching the logging system to topography and timber size (Aho et al. 1983). Shorter rotations to minimize decay loss after thinning (Lamson et al. 1985), limiting use of drive-to-bunch vehicles to deep-rooted species (Ostrofsky et al. 1986), directional felling (Kellogg et al. 1986), reduced road and trail densities (Hoffman 1990), use of straight skid trails (Hoffman 1990), and temporary rub trees (McLaughlin and Pulkki 1992) also protect residual trees. Potential problems can be identified and resolved but, no matter how well-planned and designed the thinning operation is, success depends on loggers' skills and experience in their efforts to lessen stand damage (Kellogg et al. 1986, Ostrofsky et al. 1986, Hoffman 1990).

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The winter in western Oregon is the rainy season; most logging activities occur during summer and fall. Logging during winter often causes soil disturbances from ground skidding and hauling on unpaved spur roads. In some higher elevation areas, however, snow covers the ground and soils are frozen, allowing winter logging. Root damage from equipment traveling and logs being dragged over the snow is lower, compared with summer logging. Also, because sap flow is less during winter, the stems may be less susceptible then to scarring damage.

To broaden current knowledge of residual stand damage, our study had the following objectives: (1) characterize stand damage sustained from four harvesting methods (skyline, tractor, cut-to-length, and helicopter); (2) quantify damage levels related to thinning prescription and logging system, and discuss variables affecting wounding level; (3) contrast damage from harvester versus forwarder in the cut-to-length system; and (4) recommend practices to reduce thinning damage.

Methods

Study Sites and Thinning Prescriptions

Young stands were commercially thinned on the Siuslaw and Willamette National Forests (NF) in western Oregon (Table 1). The Siuslaw NF sites were near Yachats and Hebo in the Coast Range. Species consisted of 90% Douglas-fir (*Pseudotsuga menziesii*) and others, such as western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*). Trees in skyline units were thinned to one of three densities: (1) wide [60 trees/ac (tpa)]; (2) very wide (30 tpa); and (3) conventional (100 tpa). The conventional thinning helicopter units at Hebo left stand densities of 80–120 tpa.

On the Willamette NF, two cable, one cut-to-length, and two tractor sites were selected at four thinning units. Stands were dominated by Douglas-fir with scattered western hemlock and bigleaf maple (*Acer macrophyllum*). Residual stand densities were (1) heavy thinning (50–55 tpa); (2) light thinning (110–120 tpa); and (3) light thinning with patch clearcuts (approximately 0.5 ac openings). At all sites, selected commercial-value trees removed during thinning were primarily 7–16 in. dbh. Trees left were healthy dominant and codominant Douglas-fir and western hemlock. Intermediate support trees and tailtrees in skyline units, even if heavily damaged, were also left.

Harvesting Systems

Four harvesting systems commonly used in the Pacific Northwest were tested. Each sale was contracted with a different logger. Within an individual company, the work experience varied from less than 6 months to over 10 yr. Timber sale administrators from the USDA Forest Service inspected the logging operations. During thinning, loggers were reminded that excess damage would not be tolerated. Possible penalties included suspending logging until sapflow stopped. Sale administrators could also permit cutting of trees originally designated as crop trees if they were seriously damaged.

1. Skyline logging consisted of manual chainsaw felling, limbing, and bucking, followed by cable yarding with different carriages and yarders—Koller 501 (Yachats and Walk Thin), TMY 40 (Hebo), and Madill 071 (Mill Thin). Carriage outhaul was done by gravity, except at Mill Thin, where a haulback line was used. Skyline roads were marked before felling began. Intermediate supports were used at Yachats and Walk Thin on 38 and 16% of skyline roads, respectively. In most cases, the skyline ran under the remaining canopy with logs partially suspended. At Hebo units, however, some turns were fully suspended in the unit boundary areas where the skyline was above the canopy on portions of each skyline road and was created by anchoring to the opposite side of the hill. Yarding was fan-shaped, with some parallel patterns; average external yarding distance was 600–700 ft.
2. Tractor logging involved manual chainsaw felling, limbing, and bucking. Trees were directionally felled to facilitate winching, then skidded with a small crawler tractor or skidder on designated trails in a branching skid trail pattern. The tractors at Mill Thin were CASE 550 and D-5 CAT crawlers, whereas a John Deere 550 crawler and 540 grapple skidder (only for swinging) were used at Tap Thin. Skidding distance did not exceed 1500 ft. Old skid trails (18–22 ft wide) from the previous clearcut harvest were used as main skidding trails at Mill Thin. Tree pads were used to protect trees along trails at Tap Thin.
3. The cut-to-length system at Flat Thin included a Timberjack 2518 carrier with Waterous 762b hydraulic single-grip harvesting head, and an FMG 910 forwarder. The harvester, on designated skid trails approximately 60 ft apart, felled, limbed, and bucked the trees. Because the harvester

Table 1. National forest study sites and stand descriptions before commercial thinning.*

Site/unit	Logging system	Unit area(ac)	Mean age(yr)	Mean dbh(in.)	Mean ht(ft)	Trees/ac	Basal area(ft^2/ac)	Slope(%)
Siuslaw NF								
Yachats	Skyline	22.6	34	10.6	75	320	210.6	15–70
Hebo	Skyline	26.9	34	11.6	70	238	193.1	15–60
Hebo	Helicopter	82	34	11.6	70	238	193.1	15–60
Willamette NF								
Walk Thin	Skyline	142	45	10.4	74	270	118	5–80
Mill Thin	Tractor	122	43	11.8	78	232	172	0–15
Mill Thin	Skyline	40	43	11.8	78	232	172	0–50
Tap Thin	Tractor	62	46	10.8	73	215	145	0–40
Flat Thin	Cut-to-length	225	45	11.3	77	204	186	0–20

* The stand characteristics were determined from a cruise of trees greater than 5 in. dbh. Commercial thinning occurred between December 1993 and March 1997.

had difficulty with trees over 19–20 in. at the base, some were manually felled. The forwarder transported logs on the same designated trails to the landing or roadside.

4. Helicopter logging consisted of manual chainsaw felling, limbing, and bucking, followed by yarding with a small helicopter (Sikorsky S-58T with 5000 lb maximum external load capacity). Most of the yarding was uphill, but one unit had some downhill yarding. The short yarding distance (775 ft) required multiple choker setters to keep pace with the helicopter. Elevations changed between the hook point and the landing from up 320 ft to downward 80 ft.

Data Collection and Analysis

Damage to residual trees was assessed following commercial thinning. A 100% survey was conducted in each skyline unit on the Siuslaw NF, but helicopter units were sampled with fixed-radius circular plots because of the large area. Most Willamette NF units were large, so fixed-radius circular plots were used, except for a 100% survey in the small, heavy thinning unit at Mill Thin.

A systematic grid was used, with a constant distance between sampling units within equally spaced rows perpendicular to the primary direction of yarding or skidding. For fan-shaped yarding or parallel skidding patterns with two different orientations, the unit was divided into two blocks, with systematic lines in two directions. This precluded locating rows parallel to skyline roads or skid trails where damage to residual trees was concentrated. All damaged trees were numbered, and undamaged trees in each plot were marked with paint to avoid counting the same tree twice or missing trees.

Three types of stand damage were recorded: scarring, crown, and root damage. For scarring damage, tree dbh, scar length, width, and height from ground level were measured. A scar was defined as removal of the bark and cambial layer, exposing the sapwood. Each scar was traced on paper; scar area was determined with a planimeter. Scars that could not be reached were measured by camera (Bettinger and Kellogg 1993). Multiple scars on a tree were numbered, and scarring quadrants on the bole were denoted: facing the landing (#1); facing the corridor (#2); facing the tailtree or tailhold (#3); or opposite to #2 (#4). If gouging had occurred (i.e., wood fibers removed from the scar), the area and depth were categorized by levels: (1) < 25% or < 0.5 in.; (2) 25–50%, or 0.5–1.0 in.; and (3) > 50% or > 1.0 in. The distance of each damaged tree from the centerline of a skid trail or skyline corridor was also recorded. If the tree top was removed, it was considered a broken top. Crown damage was noted if half or more was removed from the base of the live crown to the top. Any visual scarring or severing of the root system was defined as root damage.

Wounding caused by the harvester and forwarder was studied on 9.7 ac of the light thinning unit at Flat Thin. This location included one landing and five equipment trails 1200–2200 ft long. All the trees were immediately inspected for damage after the harvester passed. Harvester-inflicted wounds were marked with paint to differentiate them from those caused by the forwarder. Every tree was checked again after the forwarder operation.

Multiple linear regression analysis was used to see if specific logging systems and thinning intensities resulted in different levels of damage to crop trees. First, the damage levels in skyline logging units were compared with those for tractor units. This comparison was based on four different scar size groups that are often used for the government agencies and private company in the Pacific Northwest. The groups are all sizes, > 24 in.^{2}, > 72 in.^{2}, or > 144 in.^{2} Thinning treatment effect was also tested in this analysis by dividing treatments into two groups: heavy (< 60 tpa left after thinning) and light (≥ 60 tpa left after thinning). The next analysis included all logging systems, with the skyline system as a reference point. Logging systems and thinning treatment were included as indicator variables to determine their effects on damage levels. The interaction terms for the effect of logging systems and thinning treatments were also included in these analyses. The ANOVA F-test was used to determine whether significant differences existed among average scar heights from the ground level.

Results and Discussion

Damage Types

Except in the helicopter and two skyline units at Hebo, scarring accounted for more than 90% of the total damage with every logging system (Table 2). Fan-shaped patterns in skyline yarding caused more multiple impacts to trees around landings than did parallel yarding. For ground-based systems, less damage resulted when a large central landing with a designated log deck was used rather than a roadside landing. In continuous roadside landings with small landing areas, severe scarring from sorting and loading frequently occurred when logs leaned and rubbed against crop trees. Scarring damage can be more serious than other types of wounding because, although it may not affect tree diameter growth, it can decrease future log value (Shea 1967, Ohman 1970).

Rubbing traces were seen on the bark of standing trees; these occurred during felling, skidding, winching, or yarding. Because of its thick bark, Douglas-fir was less susceptible to scarring than was western hemlock. In skyline rigging at Yachats, the lack of tree plates or fiber rigging straps caused the rigging cables on the tailtrees and intermediate support trees to partially or completely crush or remove the cambial layer, causing stem girdling. One-third of the tailtrees and one-half of the intermediate support trees were dead 1 yr after thinning; the rest were severely damaged.

Crown damage was more prevalent in skyline and helicopter logging units. Crown removal and broken tops were caused by lateral excursion of the skyline during inhaul and by lifting of logs in the air during helicopter yarding. Because the skyline at Hebo ran through or above the canopy, crowns were damaged more severely than at the other three skyline sites (Table 2).

Ground-based systems created more severe root damage. Roots were scraped in repeated passes of equipment and dragged logs. Skidder-blading to level the trail surface often severed root systems.

Table 2. Stand damage and average scar characteristics for various logging systems and thinning treatments.

Logging system/unit	Thinning treatment (tpa)*	Number of trees[†] Total	S	R	C	Dbh of damaged trees (in.)	No. of scars/tree	Scar ht (ft)	Area/scar (in.^{2})	Scar area (ft^2/ac)
Skyline										
Yachats[††]	30	48	47	0	1	15.1	3.2	7.7	76.0	16.8
	60	123	121	0	2	14.2	2.3	4.8	59.0	14.3
	100	224	222	0	2	14.2	1.9	5.5	36.6	8.1
Hebo[††]	30	75	54	0	21	13.8	2.5	7.7	30.4	2.7
	60	58	49	0	9	13.7	2.4	7.0	28.4	3.3
	100	81	77	0	4	12.7	2.8	7.0	22.8	5.9
Walk Thin[§]	50–55	36	35	0	1	13.7	2.3	6.8	13.5	1.2
	110–120	43	41	0	2	12.5	1.8	8.4	23.6	2.4
	110–120 w/patches	23	20	0	3	12.1	2.4	8.3	41.2	4.8
Mill Thin[§]	50–55	42	40	0	2	16.8	2.3	7.3	42.5	7.0
Tractor										
Mill Thin[§]	50–55	42	40	0	2	13.9	2.0	3.5	37.5	4.8
	110–120	28	25	1	2	12.6	1.2	3.4	52.3	3.4
	110–120 w/patches	18	12	4	2	13.5	1.2	1.9	55.2	1.9
Tap Thin[4]	50–55	16	15	1	0	14.5	1.1	1.9	50.0	1.0
	110–120	36	32	4	0	13.6	1.7	5.3	48.8	6.6
Cut-to-length										
Flat Thin[§]	50–55	50	47	3	0	15.5	2.2	6.8	28.0	10.6
	110–120	52	50	2	0	14.9	1.7	5.7	17.6	4.9
	110–120 w/patches	46	44	2	0	14.5	1.2	3.0	60.0	11.1
Helicopter										
Hebo[††]	80–120	68	52	0	16	13.3	1.7	17.7	23.9	2.4

* Number of trees/ acre left after thinning.
† Number of trees with scarring (S), root (R), or crown (C) damage, compared with total number of damaged trees. If a tree had scars plus root or crown damage, it was tallied in the root or crown damage categories.
†† Siuslaw National Forest.
§ Willamette National Forest.

Scar Height

Helicopter logging caused scars highest above the ground, followed by skyline, cut-to-length, and tractor logging (Figure 1). On average, scarring from tractor thinning was significantly lower on the bole than for any other logging system ($P < 0.01$ at 99% level). The amount of scarring below 2 ft 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 4 ft, versus 57% of the forwarder-caused scars. Scar height has a significant effect on the extent of decay; frequency of infection and amount of decay decreased as wound height increased (Aho et al. 1989).

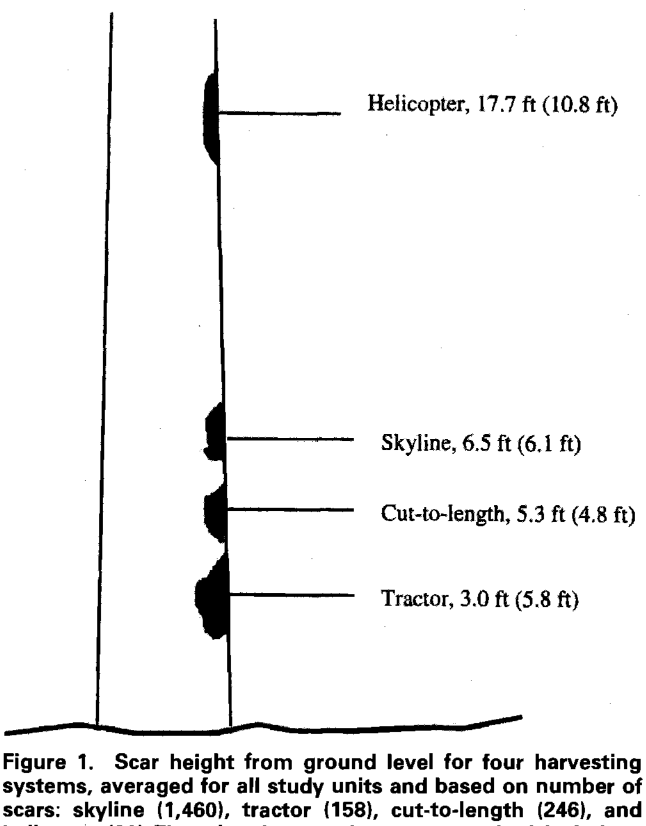

Figure 1. Scar height from ground level for four harvesting systems, averaged for all study units and based on number of scars: skyline (1,460), tractor (158), cut-to-length (246), and helicopter (98). The values in parentheses are standard deviations for the scar heights.

Scarring Quadrants

Scars in tractor logging units were concentrated in quadrant #2, facing the skid trails (Figure 2). For all skyline units, about 75% of all scars were in quadrants #2 and #3, sides facing a tailtree or tailhold. The lowest proportions overall were in quadrants #1, facing the landing, and #4, opposite to #2, where the fewest yarding (skyline) and wood processing (cut-to-length) activities occurred. In the cut-to-length system, the harvester caused equally distributed scarring in quadrants #1, #2, and #3, whereas 45% of the scars caused by the forwarder were located in quadrant #2.

The most vulnerable locations on a tree in each logging system are shown in Figures 1 and 2. Because damage was concentrated along skid trails, rub trees or tree pads could have helped protect trees near the trails. Heavier rubber pads were more durable than the plastic pads; wider and taller ones would have been more effective.

Gouge Damage

Severe gouging of trees along the skid trails or skyline corridors was caused by multiple impact of cable, equipment, or logs. Gouging results in a higher percentage of decay

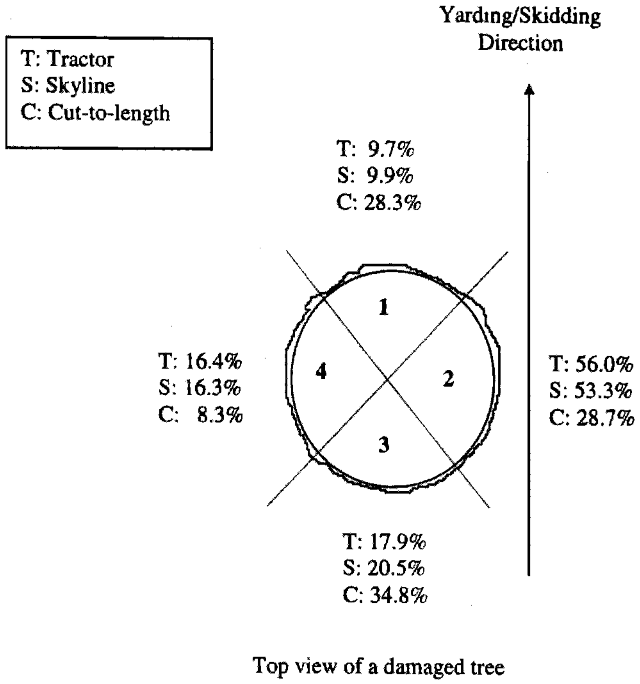

Figure 2. Percent of total scars per quadrant for three logging systems, averaged for all study units.

development than does scarring without gouge damage on the bole (Whitney and Brace 1979). The greatest gouge damage, defined as the ratio of gouged scars to total scars, was caused by tractors (31.8%), followed by cut-to-length (26.3%), and skyline logging (19.7%). No gouge damage was observed in helicopter units. Approximately 11% of the scars from tractor and cut-to-length logging had gouge damage covering at least 25% of the scar area; only 4.0% of skyline scars had the same level of gouging. Less than 4% of all scars in skyline, tractor, or cut-to-length logging had gouges deeper than 0.5 in.

Distance from Skyline Corridor/Skid Trail Centerlines

Damaged trees were more concentrated along the skid trails with tractor logging than with skyline and cut-to-length logging. About 56% of the total damage (any size scar) in skyline, 64% in cut-to-length, and 80% in tractor thinning units were observed within 15 ft of the centerline. The greatest damage occurred within the first 10 ft from the centerline of the skid trails or the skyline corridors. When damage was more narrowly defined as a scar larger than 4 in. wide, concentrations increased to 63, 66, and 85%, respectively.

Damage Levels Compounded by Harvesting Variables

Neither logging system nor thinning treatment significantly influenced damage levels ($0.1563 < P < 0.4538$), regardless of scar size (Table 3). For all types of wounding, skyline thinning tended to cause more wounding than did tractors. Aulerich et al. (1976) and Fairweather (1991), however, had shown that damage was higher with tractors than with skylines. Stand damage increased with greater thinning intensity (30 and 60 tpa treatments) in skyline thinning ($P = 0.0485$). Damage levels from tractor and cut-to-length thinning, however, were somewhat higher with a light thinning treatment, although this was not significant (P = 0.3497 and 0.3580, respectively).

Compounding variables, such as skid trail width, can greatly affect damage. This may explain the lack of any specific trend in damage level among logging systems, thinning treatments, and logging seasons. Two tractor units (50-55 tpa at Tap Thin and 110-120 tpa with patches at Mill Thin) had wide skid trails (average 20 ft). Wounding was rarely seen there, whereas damage was heavily concentrated on trees near trails no wider than 14 ft in other tractor and cut-to-length units. Typical tractor trails are 12–14 ft wide for thinning operations in western Oregon.

Table 3. Logging damage levels* based on minimum accumulated scar size per tree for various logging systems and thinning treatments.

Logging system/unit	Thinning treatment (tpa)	Logging season	% damage levels All	>24 in.^{2}	>72 in.^{2}	>144 in.^{2}
Skyline						
Yachats†	30	Winter	37.3	29.1	19.4	11.9
	60	Winter	31.9	24.7	13.2	9.3
	100	Winter	22.9	13.1	5.4	3.0
Hebo†	30	Winter	25.0	17.0	11.3	9.7
	60	Winter	17.0	13.2	7.9	7.3
	100	Winter	15.8	8.0	3.7	2.5
Walk Thin††	50–55	Winter	18.8	8.3	2.6	1.5
	110–120	Summer	13.5	5.9	3.8	1.6
	110–120 w/patches	Summer	20.2	14.6	8.0	5.6
Mill Thin††	50–55	Fall	26.9	18.6	9.6	5.1
Tractor						
Mill Thin††	50–55	Summer	25.4	18.7	10.0	4.5
	110–120	Summer	18.4	9.8	3.9	3.9
	110–120 w/patches	Summer	9.2	6.6	4.6	3.6
Tap Thin††	50–55	Summer	7.5	3.3	1.9	1.4
	110–120	Spring/summer	20.2	14.6	8.4	5.1
Cut-to-length						
Flat Thin††	50–55	Winter	34.2	19.2	6.8	4.1
	110–120	Winter	41.3	14.3	4.7	2.3
	110–120 w/patches	Summer	31.9	22.2	10.4	6.9
Helicopter						
Hebo†	80–120	Spring	11.0	6.7	3.9	3.0

* Determined by all types of damage: scarring, crown and root damage.
† Siuslaw National Forest.
†† Willamette National Forest.

Wider spacing between skid trails or skyline roads requires increased winching or lateral yarding distance. This increases the chance of wounding trees by a cable or by logs being skidded. Loggers commonly target an average spacing of 120 ft for tractors and 150 ft for skyline thinning. If spacing is greater than approximately 60 ft in the cut-to-length system, harvesters need to operate off the trail because their reach is limited. Old or new high stumps force the skidder to one side of the trail, increasing the risk of damage to nearby trees. Trees along a corner or sharp curve also have high probabilities of being damaged by equipment tires and logs.

Damage Level vs. Minimum Scar Size

Tractor logging caused relatively more severe (larger) scarring to crop trees than did any other system (Table 2). Damaged trees in skyline thinning averaged 2.4 scars each, slightly higher than for other systems. Frequency of scars by size followed an inverse J shape distribution and peaked at scars less than 24 in.^{2} The smallest average scar size was 13.5 in.^{2} in the heavy thinning unit at Walk Thin.

When any size of scar was considered, although this was not significant ($0.1265 < P < 0.2733$), damage from cut-to-length thinning was greatest, followed by skyline, tractor thinning, and helicopter thinning (Table 3). Damage levels were greatly reduced by increasing the defined minimum scar size. This changed the order of logging systems that caused greater stand damage. For example, the damage level in the light thinning unit at Flat Thin dropped from 41.3% to 4.7% if only scars greater than 72 in.^{2} were considered. Most scars (69%) caused by cut-to-length logging were smaller than 36 in.^{2} This pattern was similar to that found by Bettinger and Kellogg (1993), where 39.8% of Douglas-fir trees sustained some damage from cut-to-length thinning, but only 1.8% had scars larger than 100 in.^{2} In contrast, the damage level for the tractor unit (110–120 tpa with patches) at Mill Thin dropped only from 9.2 to 4.6% for scars larger than 72 in.^{2}

The varying minimum scar sizes and other definitions of damage frequently cause disputes between sale administrators and logging contractors when determining excess damage. An acceptable level of damage is related to future stand development. Han and Kellogg (in prep.) noted that for western hemlock and Sitka spruce, scars narrower than 4 in. healed over in 8 yr, with little effect on projected timber value. Future timber volume and quality may also be influenced by scar location, species, rotation age, and site index. For example, tractor logging often causes scarring at the butt log, where tree value is concentrated. These wounds may promote severe decay or pitch ring defects over time and cause a loss in future timber value (Han and Kellogg, in press).

In this study, scars caused by skyline and helicopter logging had little or no gouging. Although the damage level in the Hebo helicopter logging unit (11.0%) was higher than that of the Tap Thin tractor logging unit (7.5%), the future value of the residual trees at Hebo may be less affected because gouging was less severe. Deep scars are associated with a higher percentage loss than are superficial bole injuries (Wallis and Morrison 1975).

Harvester vs. Forwarder

In the cut-to-length system, the harvester damaged more than twice as many residual trees as did the forwarder (63.8 vs. 28.6%). Only 7.6% of the damaged trees were hit by both machines. The forwarder, however, caused a higher average number of scars and larger scars/ tree. The average scar area from the forwarder was larger (27.7 in.^{2}) than from the harvester (22.3 in.^{2}). Root damage also was greater after forwarder passes. Large-diameter trees and wide trail spacing often required the single-grip harvester to be off the trail, increasing the chance of damaging crop trees by the machine body and felling head. Much of the damage caused by the harvester could have been avoided by optimal trail spacing (60 ft or less); straighter trails could have reduced damage by the forwarder.

Recommended Practices for Reducing Stand Damage

The most effective approach to reducing the impact of crop tree wounding on future stand development is to minimize damage to residual trees during thinning operations. Damage can be effectively prevented by well-prepared thinning plans and careful logging. The following are recommendations for minimizing residual tree wounding during thinning, based on our study:

- Plainly flag-designated skid trails and skyline corridors to maximize directional felling and facilitate tractor winching or skyline lateral skidding. Painting a narrow band around skyline corridor edge trees improves directional felling on steep slopes.
- Designate skid trails and skyline corridors before marking crop trees so that no crop tree is left inside the corridor or trail area. Make trails and corridors straight or with minimal curves. Widths should be at least 10 ft (skyline)–14 ft (cut-to-length and tractor) to avoid hitting nearby trees during yarding or skidding.
- Leave low stumps. High stumps on a skid trail force the tractor to one side, wounding the trees next to the trail. High stumps can also cause yarding hangups.
- Use old skid trails, which are usually level, to minimize skidder blading and eliminate root injury. High stumps also are not common on old trails.
- Spacing should be designed to keep equipment on the trails; for example, for our cut-to-length system study, trails should be no more than 60 ft apart because the harvester arm can extend only 32 ft on either side.
- Use parallel rather than fan-shaped skyline yarding where possible to avoid multiple impacts and severe scarring to trees near landings.
- Change tractor position when winching if logs are hitting the crop trees. Never try to use the power of the tractor for overriding the trees. With skyline thinning, using a carriage that can be easily repositioned along the skyline during lateral yarding can help reduce stand damage.

- Use tree pads, tree plates, or fiber straps to reduce skidding and skyline rigging damage. Tree pads may need to be longer and wider than typically used and have improved holding capacity.
- Match the harvester cutting head to the size of the tree being removed.
- Do not choke in the middle of a log to avoid hang-ups on residual trees or stumps during tractor winching or skyline lateral yarding.
- Harvest a severely damaged crop tree, and leave a tree originally marked for cutting, in cooperation with the sale administrator and logging contractor. Severely damaged trees could also be left for wildlife.
- Intermediate supports reduce lateral excursion by skylines during lateral yarding.
- For helicopter thinning, maintain altitude above crowns until reaching a clear landing area, especially for small landings. Bunch logs before choking or minimize the length of choking cable to avoid ground-dragging or logs rolling downhill.

Literature Cited

Aho, P.E., G. Fiddler, and G.M. Filip. 1989. Decay losses associated with wounds in commercially thinned true fir stands in northern California. USDA For. Serv. Res. Pap. PNW-403. 8 p.

Aho, P.E., G. Fiddler, and M. Srago. 1983. Logging damage in thinned, young-growth true fir stands in California and recommendations for prevention. USDA For. Serv. Res. Pap. PNW-304. 8 p.

Aulerich, D.E., K.N. Johnson, and H. Froehlich. 1976. Are tractors or skylines better for thinning young-growth Douglas-fir? World Wood 1:16–17; 2:22–23.

Bettinger, P., and L.D. Kellogg. 1993. Residual stand damage from cut-to-length thinning of second-growth timber in the Cascade Range of western Oregon. For. Prod. J. 43:59–64.

British Columbia Ministry of Forests. 1983. Silviculture branch: Commercial thinning, summary of standards, Appendix 9-10B. 6 p.

Fairweather, S.E. 1991. Damage to residual trees after cable logging in northern hardwoods. North. J. Appl. For. 8(1):15–17.

Flatten, L.B. 1991. The use of small helicopter for commercial thinning in steep, mountainous terrain. M.F. paper, Oregon State Univ., Corvallis. 51 p.

Han, H.-S, and L.D. Kellogg. Scar closure and future timber value losses from thinning damage in western Oregon. (In press)

Hoffman, B., Jr. 1990. Fundamentals of timber harvesting: Logging practices and their relation to forest management. University of Maine, Orono. P.116–129.

Kelley, R.S. 1983. Stand damage from whole-tree harvesting in Vermont hardwoods. J. For. 81:95–96.

Kellogg, L.D., E.D. Olsen, and M.A. Hargrave. 1986. Skyline thinning a western hemlock-Sitka spruce stand: Harvesting costs and stand damage. Oregon State Univ. For. Res. Lab. Res. Bull. 53. Corvallis, OR. 21 p.

Lamson, N.I., H.C. Smith, and G.W. Miller. 1985. Logging damage using an individual-tree selection practice in Appalachian hardwood stands. North. J. Appl. For. 2:117–120.

McLaughlin J.A., and R.E. Pulkki. 1992. Assessment of wounding at two commercially thinned jack pine sites. North. J. Appl. For. 9(2):43-46.

Ohman, J.H. 1970. Value loss from skidding wound in sugar maple and yellow birch. J. For. 68(4):226–230.

Oregon Department of Forestry. 1995. Cline basin thinning timber sale contract No. 341-95-43.West Oregon District, Philomath, OR. P. 29–30.

Ostrofsky, W.D., R.S. Seymour, and R.C. Lemin, Jr. 1986. Damage to northern hardwoods from thinning using whole-tree harvesting technology. Can. J. For. Res. 16:1238–1244.

Sessions, J., K.N. Johnson, J. Beuter, B. Greber, and G. Lettman. 1991. Timber for Oregon's tomorrow. The 1989 update. Oregon State Univ. For. Res. Lab. Corvallis, OR. 184 p.

Shea, K.R. 1961. Deterioration resulting from logging injury in Douglas-fir and western hemlock. Weyerhaeuser For. Pap. 36. Weyerhaeuser Co., For. Res. Center, Centralia, WA. 5 p.

Wallis, G.W., and D.J. Morrison. 1975. Root rot and stem decay following commercial thinning in western hemlock and guidelines for reducing losses. For. Chron. 51:203–207.

Washington State Department of Natural Resources. 1997. Silvicultural guidelines (Draft). Westside smallwood thinning. 7 p.

Weyerhaeuser Co. 1996. Weyerhaeuser Springfield operation service logging contract: Commercial thinning, Exhibit B. Springfield, OR. 15 p.

Whitney, R.D., and L.G. Brace. 1979. Internal defect resulting from logging wounds in residual white pine trees. For. Chron. 55:8–12.