AN ABSTRACT OF THE THESIS OF

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Title: Factors Influencing Residual Stand Damage Levels Due to Cable Thinning of Coniferous Stands in Western Oregon.

Abstract Approved: ______________________________

Eldon Olsen

The purpose of this study was to determine the significant variables influencing the damage levels sustained by the residual stand after skyline thinning of coniferous stands. Damage levels were measured in ten study areas in western Oregon that had received their first commercial thinning.

For this post-logging study, 38 units consisting of one side of a corridor were chosen. Damage levels and characteristics of stand damage were measured using a transect method designed to account for the high variability in the distribution of damaged trees. Ten independent variables were measured in three categories: harvesting system, stand conditions and topography. Total scar area per acre (ft^2/acre) was used as the dependent variable to indicate the damage level.

As a result of regression analysis, three variables were shown to be significant. These variables are the percent of western hemlock in the stand, the volume removed per acre (ft^3/acre) and whether the unit

had been logged conventionally or by prebunching and swinging. Damage levels ranged from 0.4 to 64.4 square feet of scar area per acre. Individual scars ranged in size from 0.02 to 12 square feet.

This paper provides an indication of the important variables influencing stand damage levels including several variables that could not be incorporated in the regression equation due to statistical limitations. Information on some of the characteristics of stand damage such as location of damaged trees with respect to the corridor and damage types is also included.

Factors Influencing Residual Stand Damage Levels Due to Cable Thinning of Coniferous Stands in Western Oregon

by

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I. INTRODUCTION

As second growth stands and thinning become more and more common in the Pacific Northwest, concern about stand damage is also increasing. Damage levels as high as 74 percent of the residual stand have been reported (Burditt, 1981). This damage may cause residual trees to lose value due to decrease in grade, loss of volume to decay or loss of growth. In one Douglas-fir thinning in western Washington observed by Hunt and Krueger (1962), 42 percent of the wounded trees had decay. Losses due to damage may offset growth gains after release by thinning and raise questions as to the advisability of thinning.

Damage to the residual stand is unavoidable if economically feasible levels of production are to be maintained. An important question is: How does a forest manager control the amount of damage that will occur? If there is to be any control, there must be more known about the important variables that influence the level of damage sustained by the residual stand. That is the main objective of this study.

To carry out this study, areas that had been thinned previously as part of the smallwood harvesting research at Oregon State University were revisited to collect data on damage levels. The types of damage observed were scarring, breakage and leaning of the boles of the residual trees caused directly by harvesting activities. Ten independent variables were measured. These variables included information on the harvesting system, silvicultural treatment and topography. This data was collected over a range of conditions in areas scattered throughout western Oregon.

The results of this study include a summary of damage levels observed and an analysis of the factors affecting the damage levels. Also included are observations on the location of damaged trees and the types of scars.

II. LITERATURE REVIEW

STAND DAMAGE STUDIES

Several studies have looked at the amount of damage that occurs during partial cuts and the factors that are important for determining the damage levels, but there is still much to learn about residual stand damage. Some of the studies have been done in other parts of the United States in conditions unlike those found in the Pacific Northwest, but they provide important background information on the topic.

A recent study by Burditt (1981) in Montana and Idaho attempts to provide models for predicting the amount of residual stand damage that will occur during skyline logging. Variables similar to those used in production studies were considered. Two classes of damage were used. Regression equations were developed to predict the number of stems per acre with less than one-quarter of the circumference scarred and more than one-quarter of the circumference scarred. Damage levels as high as 74 percent of the residual stems were observed with an average of 53.8 percent damaged. Landing size, tail tree height, number of cut trees per acre, number of logs per thousand board feet and chordslope were determined to be the important variables.

Aulerich, Johnson and Froehlich (1974) compared tractors and skylines for thinning in Oregon State University's McDonald Forest. For the skyline units they found that 15 to 30 percent of the residual stems had wounds larger than 9 square inches. Seven percent had wounds larger than 72 square inches. Most of the wounds occurred close to the ground and 40 percent of the scarred trees were within five feet of a skyline corridor.

Damage to the residual stand due to skyline logging was studied in a western larch and Douglas-fir shelterwood cut in Montana by Benson and Gonsior (1981). The variables that they considered important were residual stand density, logging specifications (provisions for protection of trees), slope, side slope and the load capacity of the skyline system. For the leave trees greater than 7 inches DBH they observed that 23 percent had been killed. It should be noted that they considered that any of the marked leave trees that were missing, had been used as spar trees or determined to have no chance of surviving were considered to be killed. Of the remaining trees that were not considered killed, 66 percent were damaged.

In addition to determing the feasibility of a release conversion of a Douglas-fir, bigleaf maple and grand fir stand using a small cable yarder, Scherer (1978) also investigated stand damage levels. Several interesting indexes of damage were used. Scarring damage was indicated by the bark damage index, top breakage was indicated by the top damage index. The bark damage index was calculated by dividing the surface area of the scar by an approximation of the total bark surface area and multiplying by 100. The top damage index was calculated by dividing the diameter of the stem at the break by the DBH of the tree and multiplying by 100. A bark damage index greater than 3.5 was considered fatal. A top damage index greater than 25 was considered fatal. Overall, on 7.3 acres, 32.6 percent of the residual trees were considered lost after yarding and windrowing.

In a hardwood stand partially cut with ground skidding, Nyland and Gabriel (1971) found that 27 percent of the residual trees 2 inches and larger were damaged. Fifteen percent of the residual stems were damaged by felling and 12 percent were injured by skidding. Twenty percent of the damaged trees had what they considered major wounds with the majority of these due to felling.

Gottfried and Jones (1975) found that 65 percent of the residual trees, large seedlings to small pole size, were lost during an overstory removal of 70 percent of the initial stand in Arizona. In a selection cut, where 34 percent of the initial stand was removed, 50 percent of the residual stand was lost. The percent of the surviving trees rated good after logging in the overstory removal and selection cut was 43 and 55 percent respectively. The area was logged with crawler tractors and rubber tired skidders.

These studies clearly show that damage levels can be high. It appears that more information is required before we have a good understanding of the factors that influence these levels.

EFFECTS OF RESIDUAL STAND DAMAGE

Little is known about the effects of logging damage on the residul stand, particularly in young, vigorous stands that have been thinned. Much of the research has been conducted in older stands. Thinning damage can affect a stand in many ways including reduction in growth and wood quality or mortality. Effects of stand damage vary with the species. This literature review will concentrate on the effects of scarring damage in Douglas-fir, western hemlock and the true firs. Determining the incidence of decay in logging scars has been the primary aim of many of the studies, but several have also looked at growth reduction.

Douglas-fir is generally thought to suffer less from logging damage than the other coniferous species in the Pacific Northwest. Effects of damage may be significant though. In a study done by Shea (1961) in a stand with an average age of 114 years in southwest Washington, decay was very significant. Ten years after an intermediate cutting, 1.4 percent of the total gross volume was decayed and 86 percent of the cubic volume increment was decayed. Shea noticed an adverse effect on diameter increment, but could not prove it conclusively. In a later study (Shea, 1967) trees were artificially injured over ten, twenty and forty percent of the bole circumference at a height of 4.5 feet in a 60 and 100 year old stand. Shea noted "no significant effects of treatment (percent of bole circumference damaged) on diameter growth were found" after five years of study. Hunt and Krueger (1962) studied a younger stand in the Puget Sound area. In a 45-year old stand that had been horse-logged they found that 13 percent of the scars had decay. Average scar age was 7 years. The decayed volume was 0.3 percent of the gross volume and 0.1 percent of the net periodic annual increment per acre. In another area with a 57-year old stand, 42 percent of the wounds had decay 6 years after thinning resulting in a loss of 1.2 percent of the gross cubic volume and 2.7 percent of the annual increment.

In all of the studies reviewed that had information for both Douglas-fir and western hemlock, the hemlock sustained greater decay losses. In the same study as described above, Shea (1961) found that 92 percent of the western hemlock scars had decay which accounted for six percent of the total gross volume and 142 percent of the growth increment in ten years after the partial cut. In an earlier study, Shea (1960) had noticed that a 90-year old stand partially cut 17 years earlier had decay associated with 55 percent of the scarred trees. This decay accounted for one percent of the total merchantable cubic volume. Hunt and Krueger measured decay in a 61-year old hemlock stand and found that 61 percent of the scars had decay after six years. The decay volume was 3.4 percent of the gross cubic volume and 5.5 percent of the annual increment. A regression equation to predict decay volume from scar age and scar area was developed by Wright and Isaac (1956). In the stands they studied, 63.5 percent of the scars were decayed. The regression equation, listed below, is based on scar area and scar age.

$$Yc = 0.0944\, x_1 + 0.4910\, x_2 - 0.0929 \qquad (R^2 = 0.4717)$$

Yc = estimated rot volume in cubic feet

x_1 = scar age in years

x_2 = scar area in square feet

A second growth stand in coastal British Columbia was studied by Wallis and Morrison (1975). For scars larger than 0.97 square feet they predicted a 0.5 to 0.75 percent loss of gross cubic volume. Decay accounted for 2.2 percent of the merchantable cubic volume after ten years in a 40 to 120 year old stand studied by Goheen et al. (1980).

The true firs also appear to have a high incidence of decay in logging scars. In a study by Bergstrom (1980) in Northern California, all of the true firs had decay after thinning. The decay volume accounted for 4.5 percent of the merchantable cubic foot volume. In precommercial thinnings in eastern Oregon, 53 percent of the wounds had decay accounting for 2.5 percent of the cubic volume. Wright and Isaac (1956) found that 90 percent of the old-growth true firs had decay in partial cuts in eastern Oregon and Washington.

In all of the studies it was noted that most of the scarring and decay occurred in the more valuable butt logs. Shea (1961) had 81 percent of the scars in the first 4.5 feet. Hunt and Krueger (1962) noticed that 75 percent of the wounds in contact with the ground had decay. The amount of decay varies widely between the different studies and although the cost of the decay has not been determined, it appears that it may be significant.

III. OBJECTIVE

The main objective of this study is to determine the significant variables affecting residual stand damage levels due to cable thinning of coniferous stands in western Oregon. This will be accomplished by developing a predictive equation using regression analysis. Factors to be investigated include harvesting system, stand and topographical characteristics of the thinned area. Damage will be indicated by the scar area per acre.

Two secondary objectives of the study are:

1. To determine the characteristics of stand damage. The level of stand damage will be indicated by the number of damaged trees and measurements of scar size. The distribution of damaged trees in the stand will be determined. Causes of the damage will be indicated by the summary of damage types.

2. To develop a valid method for measuring stand damage levels. Time study and timber cruising techniques are not directly applicable to a stand damage study due to the high variability and uneven distribution of damage with respect to the corridor. A method had to be developed specifically for this type of study that could handle the variability and allow efficient collection of the data.

IV. S C O P E

In order to determine the factors influencing stand damage, ten areas that had received their first commercial thinning were observed. The time of thinning ranged from 1974-1981. Most of the areas had been thinned during the summer. Small to medium-sized cable yarders were used with horsepower ranging from 47 to 284 and tower height ranging from 0 (on cable winches used for prebunching) to 48 feet. Three types of carriages had been used; clamping, stop and haulback. The yarding lines were rigged in live or standing skyline configurations. Both single and multi-span corridors were observed. A herringbone cutting pattern was used on all of the units except for the steeper secton of one unit in the Cascades where the trees were felled parallel to the contour. Both uphill and downhill logging units were sampled. Slopes ranged from 0 to 94 percent, with most of the average corridor slopes in the 20 to 30 percent range.

Douglas-fir was the most common species in the harvested units. Western hemlock, grand fir and Pacific silver-fir were frequently part of the stands. The average age of most of the stands was 35 to 40 years. The average DBH of the stands ranged from 5.7 to 17 inches, with most of the stands in the 10-12 inch average DBH range. During thinning, 30 to 50 percent of the stand had been removed.

V. STUDY DESCRIPTION

GENERAL APPROACH

The general method by which this study was carried out was to return to stands that had been thinned previously to collect data on independent variables and damage levels. Since it was a post logging study, some of the required information had to be collected from records kept on the thinning activities. For this reason, only areas that had been thinned for past production studies in the smallwood harvesting program at Oregon State University were used. The required information was obtained from publications and theses written for the studies and from records kept at the Forest Engineering Department.

An important point to mention is the definition of the residual stand. The residual stand was considered to be only those trees larger than six inches DBH left after harvesting activities were completed. Only damage to these trees was measured. If some of the marked leave trees in a stand that had been prepared by marking were missing, they were not considered.

The only types of damage that were considered were scarring or breakage of the bole of the tree or pronouncced leaning of the bole due to yarding or felling. Damage to roots or branches was not measured. Secondary effects of thinning such as sunscald, or increased susceptibility of the stand to windthrow or insect and disease damage was not considered nor was soil compaction.

SELECTION OF VARIABLES

An important part of this study was the selection of variables. The process of variable selection was hindered by the fact that little is known about which factors have an important influence on stand damage. Observations of cable thinning operations indicated many of the variables that appeared to be important. A review of the literature reinforced these initial observations and also added several more variables. Conversations with other people familiar with cable thinning completed the list.

Variables were selected that would give a general but complete description of the stand, topography, silvicultural treatment, harvesting system and damage levels. In order to ensure that the most significant factors were studied, a fairly large number of variables were selected.

Independent Variables

The independent variables can be grouped into three categories. The harvesting system, the stand and the topography.

HARVESTING SYSTEM -

Yarder Horsepower - defined as the net or rated horsepower of the yarding engine. As yarder horsepower increases logs can generally be moved at a higher speed through the stand. Higher log speeds will decrease the reaction time available to a choker setter who sees that a log may damage a residual tree. With larger engines there is also more power available to pull logs that are hung up against residual trees past or over the obstruction. Increased forces on the tree may results in bark removal, uprooting or breakage of the standing tree.

Carriage Type - Three types of carriages are generally used for skyline thinnings. The differences stem from the method of holding the carriage in place while yarding logs into the corridor. Carriage positioning is very important for selecting a path to move the logs through the residual trees without damaging them. The clamping carriage utilizes a mechanical device to hold it to the skyline thus eliminating any carriage movement up and down the skyline during lateral yarding. The stop-type carriage is held in place with a separate stop that clamps to the skyline. The stop is generally positioned in one spot for several turns unlike the clamping carriage which can fairly easily be positioned anywhere along the skyline each turn. The third type of carriage is held in place with a haulback line. The haulback usually allows the carriage to drift towards the landing as it is pulled taut by the force of the mainline during lateral yarding.

Harvesting Method - Prebunch and swing and strip thin are two alternatives to conventional yarding. Prebunching and swinging consists of yarding logs to decks that are spaced at various intervals along the corridor. Logs may be brought in at a poor lead angle for swinging. Logs may be piled against residual trees. After prebunching, generally with a small machine, the logs are swung to the landing, generally with a larger yarder.

In a strip thinning, strips of trees in the stand are clearcut. The only place logs can come into contact with the residual stand is at the edges of the clearcut area, especially at the corners where logs turn into the central corridor.

Corridor Width - Many of the previous stand damage studies indicate that damage is highest near the corridor (Scherer, 1978; Aulerich, Johnson and Froehlich, 1974; Nyland and Gabriel, 1971). At the corridor, logs usually must make a turn towards the landing. Wider corridors may result in easier turning of logs. In addition, it is likely that only the small end of the log will come into contact with the trees lining the corridor.

THE STAND -

Residual Stand Density - The residual stand density is indicated by the average number of trees per acre. As residual stand density increases, the ease of finding a path to move the log to the corridor decreases. High residual stand density is likely to cause more hang-ups and abrasion of logs against the residual trees due to the decreased likelihood of finding a straight path from stump to corridor.

Residual Tree Species - Western hemlock and the true firs, because of their thin bark, may be more susceptible to logging damage than the thicker barked species. This has been shown in several studies (Shea, 1961; Wright and Isaac, 1956; Wallis and Morrison, 1975).

Average Log Size - Large logs are generally more difficult to maneuver out of the stand. As either diameter or length increases there is usually a greater tendency for the log to come into contact with residual trees due to increased difficulty in redirecting the log.

Removal Volume - As the volume removed per acre increases generally the number of logs to be moved through the stand will increase. This could result in a greater probablility of the residual trees being damaged.

TOPOGRAPHY -

Slope - As the slope in a unit increases logs have a greater tendency to roll from their intended path into residual trees. For this study, slope was measured along the corridor and perpendicular to the corridor (side slope) to give an idea of its effect on stand damage levels.

Uphill vs Downhill - Logs being yarded downhill to a landing have a tendency to move faster due to the component of their weight acting downhill. As when yarder horsepower increases, faster log speed leaves less reaction time and increases the likelihood of damage upon contact with residual trees.

Variables Not Selected

Several independent variables that were thought to be related to damage could not be used in this study. The crew is probably a factor in stand damage. Inexperienced or unconcerned crews may cause much more damage than a well trained crew. No method could be developed to quantify the crew ability in a post logging study. Most of the corridors included in this study were logged by the same company under the guidance of OSU researchers, thus controlling the crew influence to some extent.

The bark of most trees is generally looser and easier to remove in the spring. Therefore, the season during which thinning occurred could be a significant factor. Season of harvest was dropped when it was realized that only two of the thinnings had occurred in any other season besides the summer.

The various rigging configurations may result in different damage levels, especially if there is a haulback line. This variable was also dropped because of lack of variability. Nearly all of the areas studied had been rigged with a live skyline, gravity carriage system. The effect of the haulback was accounted for in the carriage type and uphill-downhill variables.

Dependent Variable

The role of the dependent variable in this study is to indicate damage sustained by the stand. Damage has been defined as scarring, breakage or pronounced leaning of the bole of the trees remaining after thinning operations are completed. Other damage such as sunscald, root damage, soil compaction and susceptibility to windthrow or insect attack have not been considered.

The dependent variable must be well related to potential losses of volume, growth or quality. The effects of scarring damage can be predicted by several characteristics. The height of the scar above the ground appears to affect the ease with which decay organisms can enter the scar (Wright and Isaac, 1956; Wallis and Morrison, 1975). Width and length of the scar are important in that long, narrow scars may be less susceptible to decay than wide scars (Wallis and Morrison, 1975). In scars where some of the inner wood has been removed or frayed, healing may be slower (Bergstrom, 1980; Wallis and Morrison, 1962). Perhaps the most significant of scar measurements is scar surface area. Scar area has been fairly well related to decay losses in several studies (Hunt and Krueger, 1962; Wright and Isaac, 1956).

The ideal choice of a dependent variable would have been a combination of the five measurements that could be shown to be well related to potential losses. This has not been done and would probably take a fairly large study conducted by a person very familiar with tree physiology and decay. Instead, scar area was selected as the best indicator of damage based on the practical limitations of this study.

In order to get a good perspective on the actual level of damage within a stand, total scar area per acre was chosen. Putting it as a per acre figure allows comparison between different sized units. This figure does not take into account any threshold size of scar below which losses will not occur because this threshold level has not and maybe can not be determined. Another limitation is that broken and leaning trees have not been accounted for, but since they make up such a low percentage (2.0% of all damaged trees in this study) they may not be significant.

On the other hand, scar area is a much better indicator of damage than several others that have been tried. The percent of residual trees that have been damaged does not indicate intensity of damage very well considering the differences between the effects of small and large scars. For example, if two stands have the same percent of residual trees damaged, but one has much larger scars, the stand with the larger scars is likely to sustain much greater losses of volume, growth or grade. The percent of residual stems damaged is completely dependent on the number of stems per acre, which makes comparison of different stands difficult. Using the total number of damaged trees per acre results in inaccuracies similar to those of the previous method.

DATA COLLECTION

In a post logging study of stand damage there are two types of variables for which data has to be collected, office and field variables. Data collection methods vary for the two types.

Office Variables

Information on the office variables was collected from reports and graduate theses written about each study area. The variables along with the information required are listed below:

Yarder horsepower - rated horsepower of yarding engines

Carriage type - clamp, stop or haulback

Harvesting method - conventional, prebunch and swing, or strip thin

Volume removed - gross cubic feet per acre

Log size - average gross cubic foot volume per log

Uphill / downhill - whether the unit had been yarded uphill or downhill to the landing

Of the six office variables, the two volume variables caused the most difficulty. For some study areas it was possible to collect volume data specific to one unit. In other areas information averaged for several units had to be used.

Field Variables

The remainder of the data had to be collected at the site of the thinning. Information for these field variables was collected with a method designed for quick and easy measurement considering the variability of the damage within a stand.

The data collection method was based on thirty foot wide (horizontal distance) transects. All of the field variables were collected in or between the transects. The transects ran perpendicular to the corridor from the corridor to the edge of the unit. Running the transects to the edge of the unit eliminated problems with variability in the location of damaged trees with distance from the corridor (see figure 1).

Initially, the plan was to space the transects randomly along the corridor using enough of a sample to get a statistically valid determination of damage levels. A trial run of the method showed that the variability was high enough to require a 90 to 92 percent sample for a confidence interval of 95 percent and allowable error of 10 percent of the mean. This was determined with the following equation:

$$n = \frac{Nt^2C^2}{NA^2 + t^2C^2} \qquad \text{(Dilworth, 1980)}$$

N = maximum possible number of plots

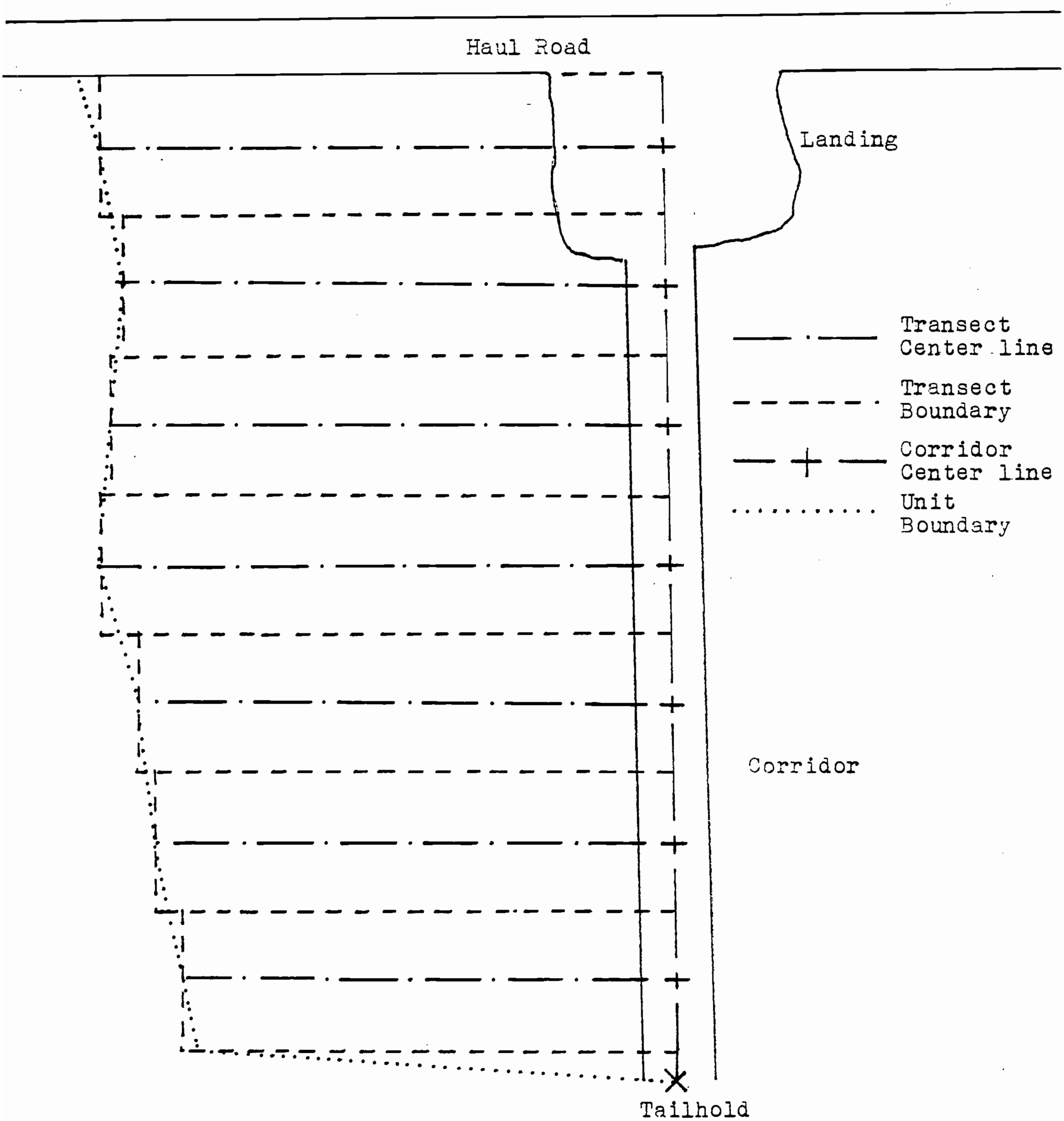
t = number of standard errors

A = allowable error - % of mean

C = coefficient of variation calculated by standard deviation ÷ mean of sample

It was then decided that a unit would be totally sampled by

Figure 1. Data Collection Transects



running the transects adjacent to each other from the landing to the tailtree (see figure 1). Calculations made later in the study using the same equation as above supported the initial conclusions.

The field variables were measured as follows:

RESIDUAL STAND DENSITY - All of the trees in each transect were counted. The area of the unit was determined by converting the transect length (measured slope distance) to horizontal distance and multiplying it by the thirty foot transect width. The total number of trees in the unit was divided by the sum of the transect areas to get trees per acre. Counted trees were marked with a spot of paint to prevent recounting.

RESIDUAL TREE SPECIES - Tree species was noted at the time of counting and later converted to a percent figure.

CORRIDOR SLOPE - The average corridor slope was determined by measuring the percent slope along the corridor between transect points.

SIDE SLOPE - Side slope was measured along the transect line sighting from the center line of the corridor to the edge of the unit.

CORRIDOR WIDTH - Measured at every second transect point starting just outside of the landing area. The average width was measured at a specific point by sighting between trees bounding the corridor (see figure 2).

SCAR DATA MEASUREMENTS - Measurements were taken on every scarred, broken and leaning tree greater than six inches in DBH (outside bark) (see figure 3).

Figure 2. Corridor width measurements

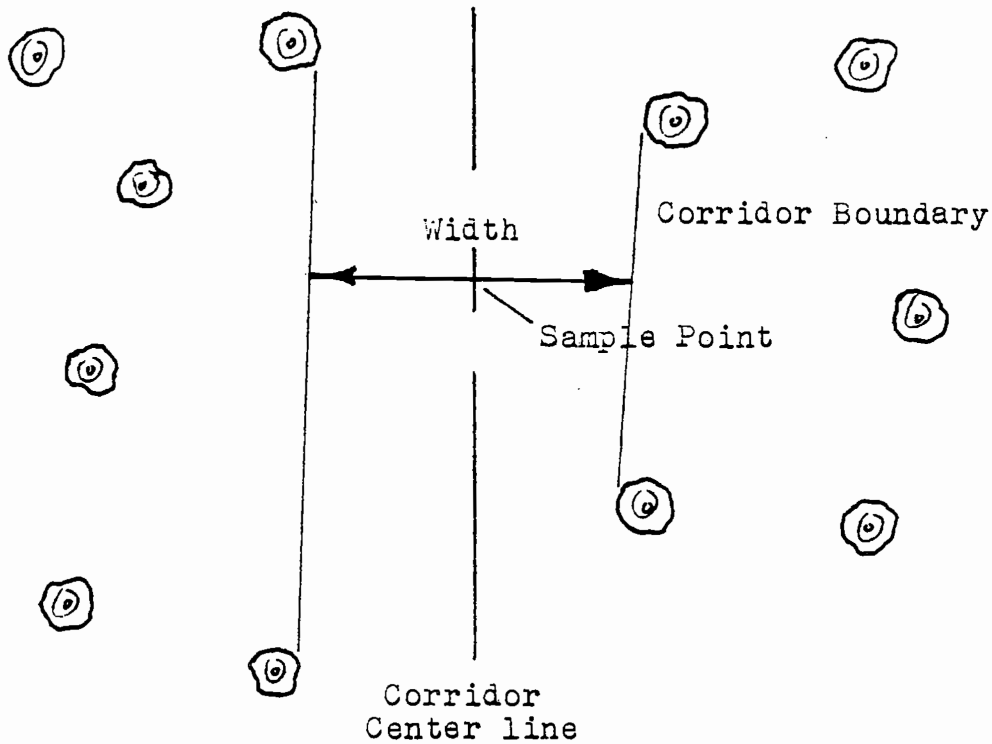
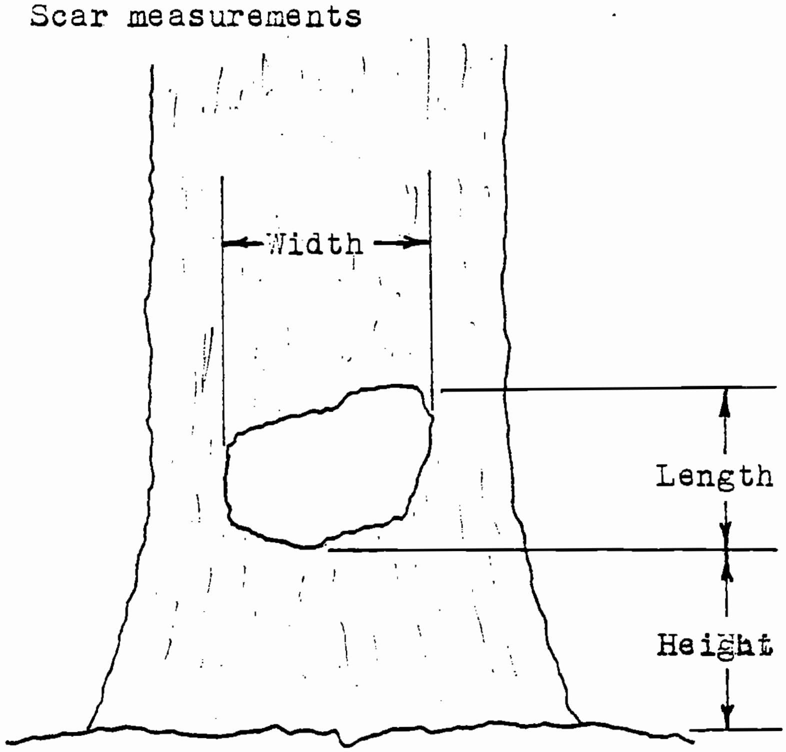


Figure 3. Scar measurements



Height - vertical distance in feet between base of scar or break and ground surface.

Width - widest horizontal distance between edges of scar in feet.

Length - longest vertical distance between edges of scar in feet.

Area - surface area of scar in square feet measured by counting squares on a mesh area gage (see figures 4 and 5).

Depth - three classes

0 - Bark Removed - cambium exposed

1 - Bark Removed - sapwood partially removed over 20% or more of the scar surface area

2 - scar is healed over

Some information was collected that was not used in the analysis of variables affecting stand damage, but considered useful for an understanding of stand damage. This included the type of damage, the location of the damaged tree and the landing area.

The type of damage was determined as accurately as possible by observation. Damage types are defined in table 1 (see figures 6-11).

The location of each damaged tree was measured to get an understanding of the distribution of damaged trees within a thinning unit. The position of the tree was described by two measurements; the distance away from the corridor and the distance down the corridor. The distance down the corridor was measured from the landing to a line drawn perpendicular to the corridor from the corridor to the tree. The distance away from the corridor (DSTFC) was measured along the

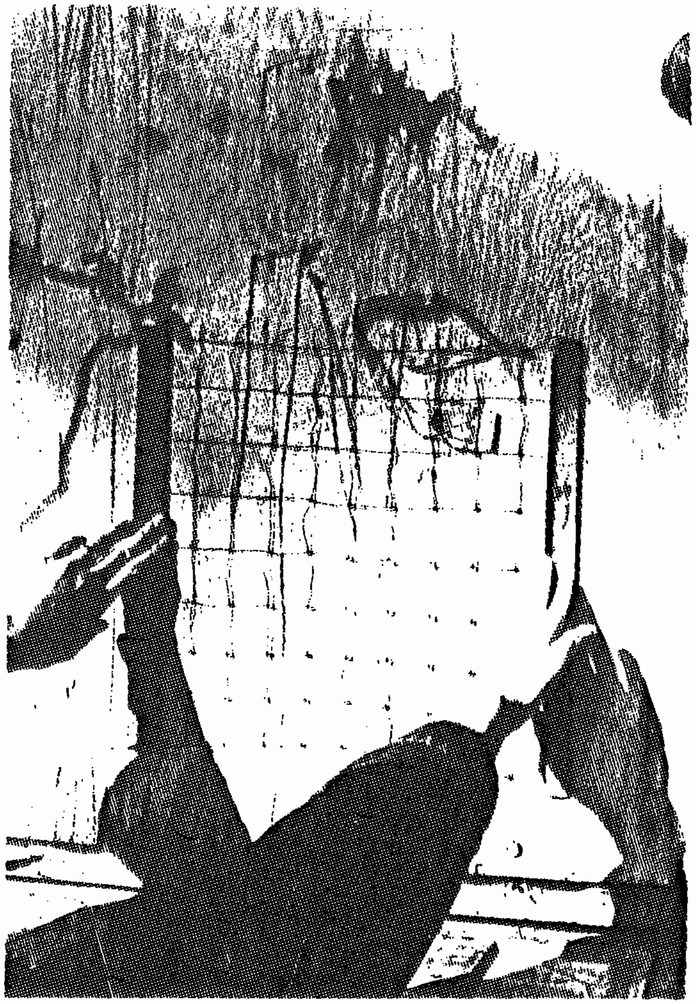


Figure 4. Area Gage

Figure 5. Scar area measurement

Table 1. Damage Types

Damage Type	Cause	Location	Shape	General Comments
Yarding Scar	logs hitting or rubbing against tree	generally low	varied	generally found on the side of the bole that faces the area that logs are coming from
Cable Scar	cable rubbing against tree	generally high	long, narrow	most commonly found on corridor trees, often fairly deep, with frayed bark on edges of scar
Falling Scar	falling tree scrapes or gouges standing tree	generally high	long, narrow	often a gouge caused by branch stubs
Landing Scar	caused by machinery or piling of logs	low-medium height	irregular	located only on trees around landing, often large and deep caused by repeated contact - especially when logs are being swung by a skidder
Road Scar	road construction machinery	low	irregular	often very deep, usually older than other scars, located only along road, counted, but not measured for study
Yarding Break	N/A		N/A	complete break of bole, usually accompanied by scars, caused by yarding of log over the tree - generally on smaller trees
Yarding: Knocked Over	N/A		N/A	leaning bole, partial or complete uprooting caused by yarding - usually accompanied by scars
Falling Break	Not Observed			
Falling: Knocked over	Not Observed			

Figure 6. Yarding scar

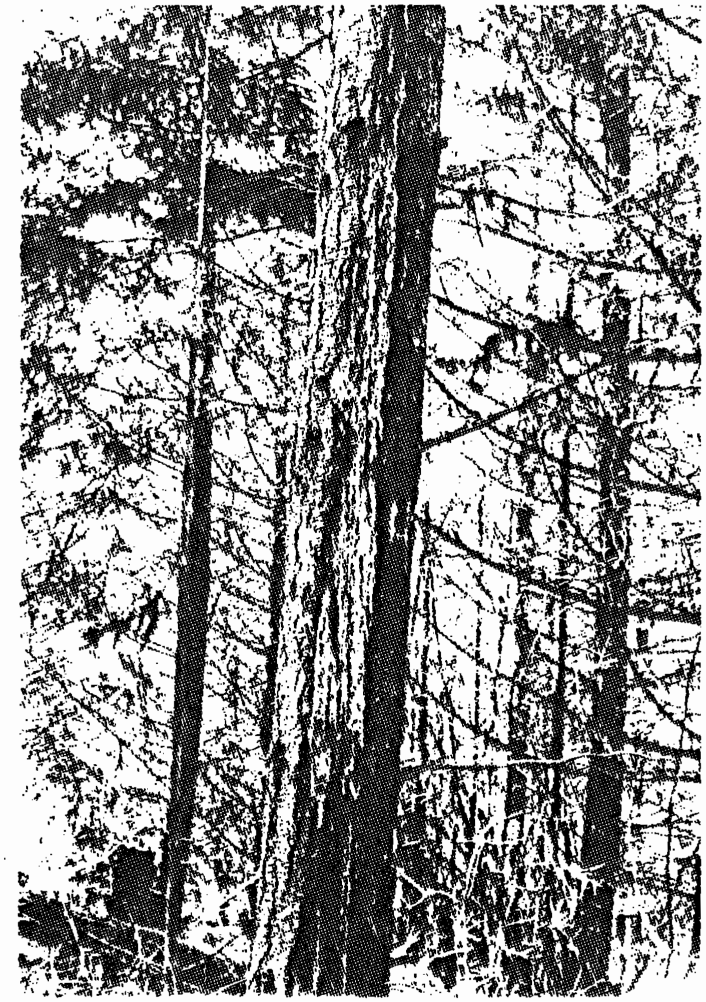


Figure 7. Cable scar

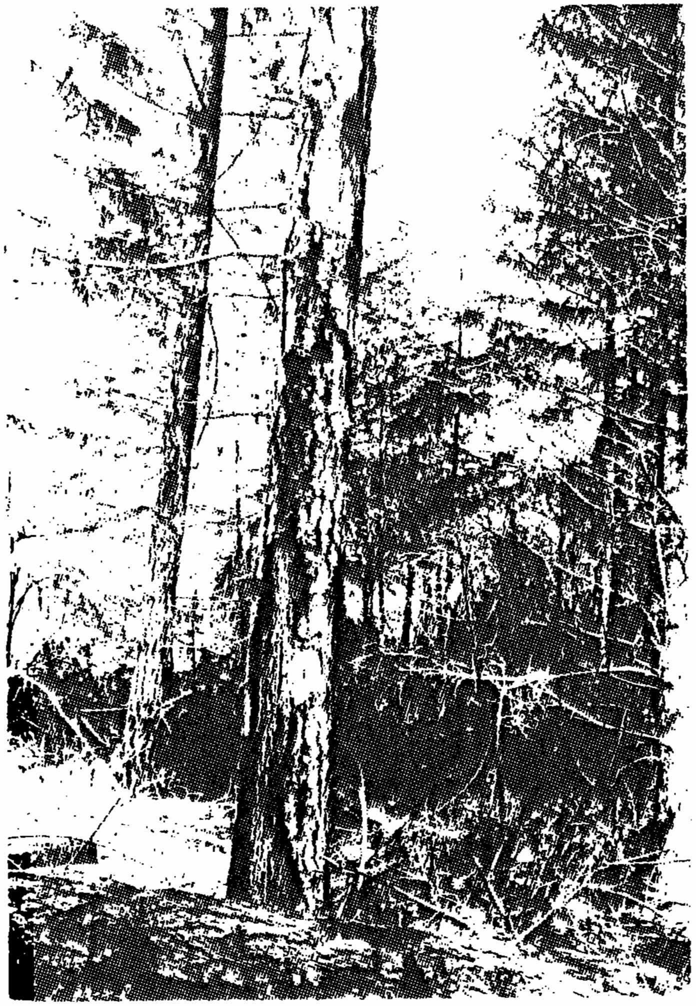


Figure 8. Landing scar

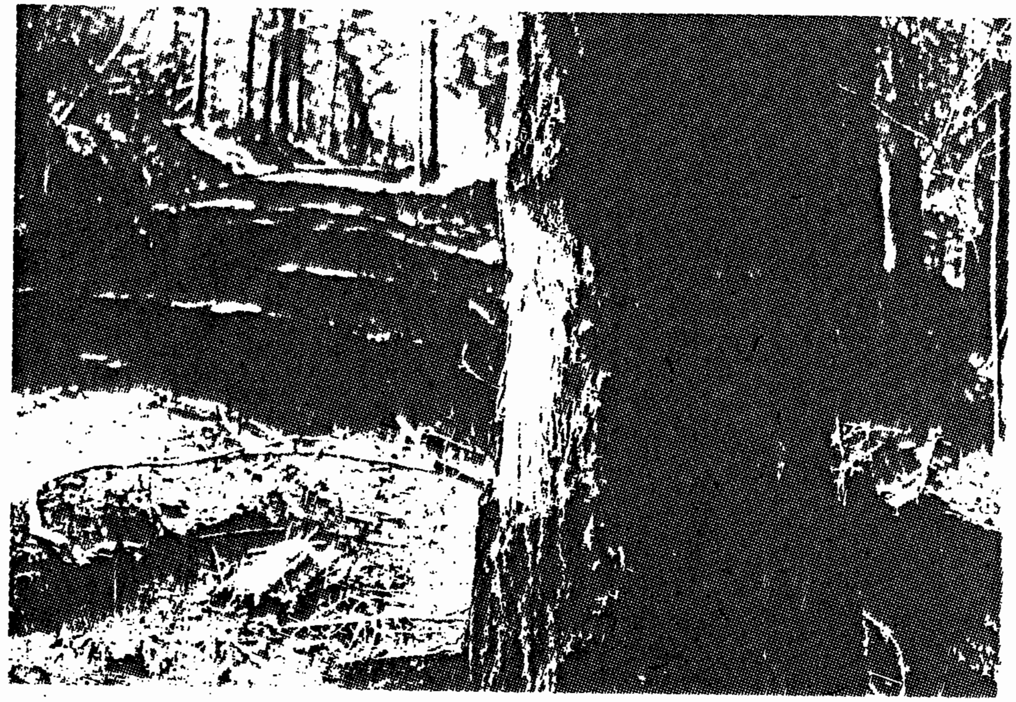


Figure 9. Road scar

Figure 10. Yarding breaks

Figure 11. Tree knocked over during yarding

tape laid out for measuring the transect length. The perpendicular distance from the transect length tape to the damaged tree was measured using a bucking tape and added to or subtracted from the distance down the corridor of the transect point to get the distance down the corridor to the damaged tree (DSTDC) (see figure 12). A sample data form is shown in figure 12A.

LOCATION OF STUDY

Unit Size

The size of the unit was chosen to minimize averaging of the independent variables in order to determine their true effect. The initial plan was to use a whole thinning corridor for a unit. After data had been collected on several corridors, it was noticed that some of the variables, such as side slope and residual stand density, were varying a large amount between the two sides of the corridor. At that time the decision was made to use one side of a corridor as a unit. Replication of units proved impossible due to the same problems with variability. In order to be consistent, an attempt was made to sample approximately one acre for each set of independent variables.

Whenever information was available corridors were selected to give a large, well-distributed range of the independent variables typical of thinning conditions found in western Oregon. If little or no information was available, corridors were selected randomly.

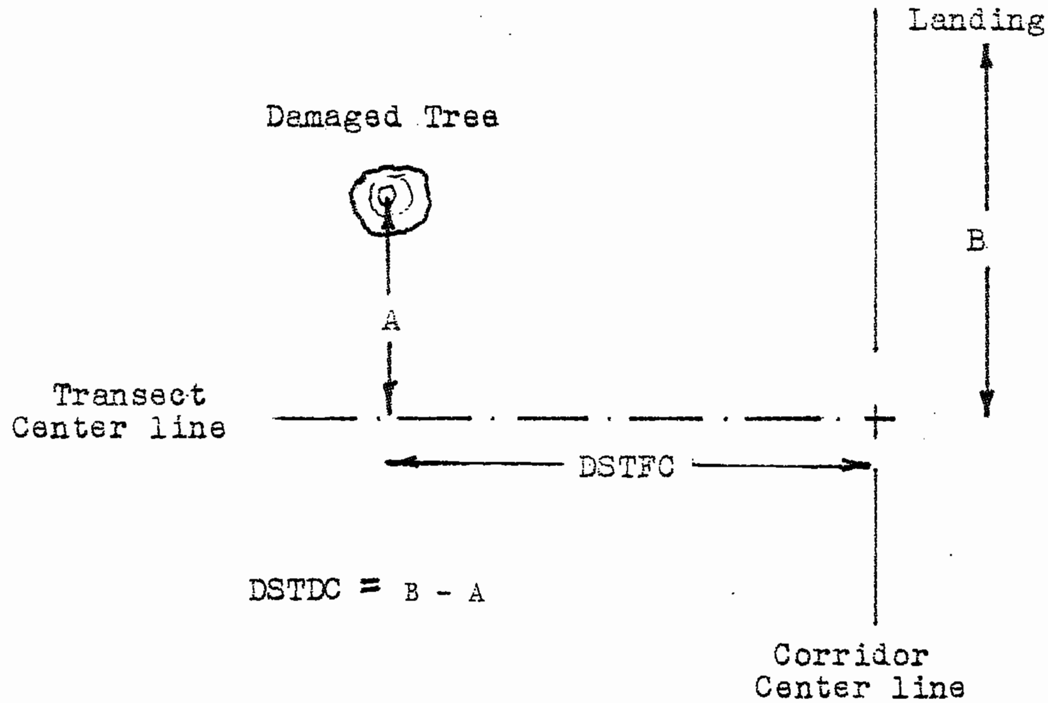


Figure 12. Location of damaged tree measurement

Figure 12A. Sample data form

Study ______________________ Landing size _____ x _____ Form number __________

Location ____________________ width length Page _____ of _____

Corridor Number _______________ Date _____/_____/_____

Count	Cls	DBH	Ht	Wdth	Lgth	Area	D	Dist fr Corr.	Dist dn Corr.				

Study Areas

As previously described, the study was carried out in stands that had been thinned as part of the smallwood harvesting research program. These stands are scattered throughout western Oregon (see figure 13). The stands had been thinned by several different contractors and under several different forest management techniques. The following is a list of the ten areas with a short description of each.

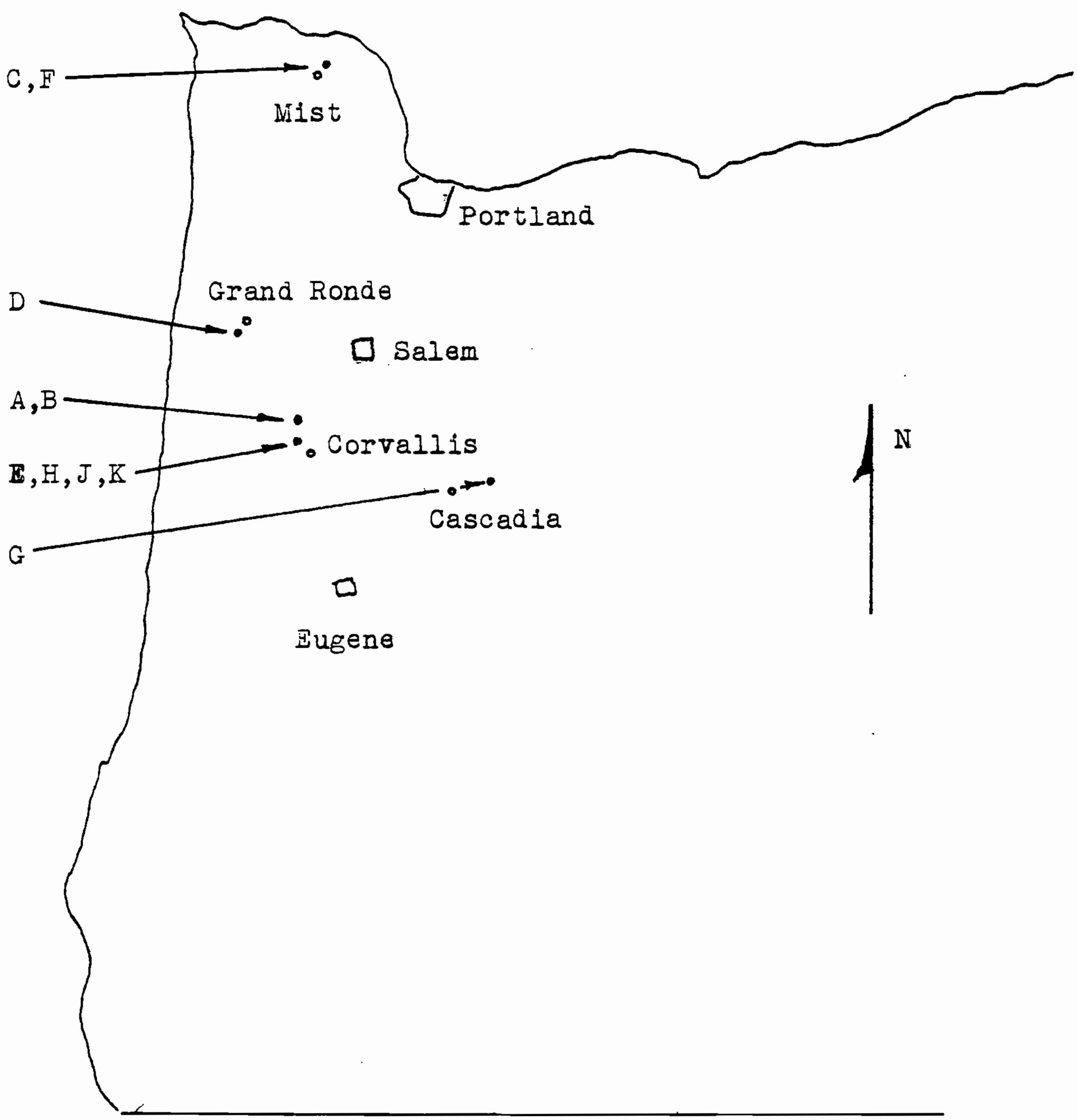
A. Koller - Bantam - summer of 1980 - Thirty-eight corridors were logged in Dunn Forest for this study. A Bantam T350 with a Christy carriage was used for conventional thinnings and for prebunching and swinging. Two downhill corridors were logged conventionally. The effect of varying crew size was tested with a Koller K-300 yarder. Eight corridors were sampled for the residual stand damage study.

B. Koller Bantam - summer of 1981 - The feasibility of whole tree and tree length yarding was studied using a Bantam T-350 with a Wyssen carriage. Thirty corridors were logged in the Dunn Forest. A Koller K-300 was studied using a cut and yard technique. Five units were sampled at this site.

C. Trailer Alp - summer of 1977 - An Igland-Jones trailer alp was used to thin seven corridors in the Blodgett tract. Two units were selected from this study (Nielson, 1978).

D. Smallwood - summer of 1979 - A medium sized yarder, the Skagit SJ2-R with a Christy carriage was used to thin very small wood

Figure 13. Study areas



(average DBH = 5.7 in.) in a mixed Douglas-fir, western hemlock stand. Six corridors wre thinned on land owned by International Paper southwest of Grande Ronde. Several different choker setups were tested along with the feasibility of thinning young stands (Gabrielli, 1980). Two units were selected for the stand damage study.

E. Prebunching Study - winter of 1975 - The feasibility of prebunching with a small, single drum, radio controlled winch and then swinging with a Bantam T-350 was studied for this project. One corridor was thinned in the McDonald Forest (Kellogg, 1976).

F. Prebunching Study - summer of 1979 - An Igland-Jones trailer alp was used for prebunching with a West Coast yarder used for swinging and compared to a West Coast yarder thinning conventionally. Several different carriages were used including a Christy, West Coast and two Trailer Alp carriages. Six corridors were thinned in the Blodgett tract, three units were sampled (Keller, 1980).

G. Prebunching Study - summer of 1979 - Eight corridors were thinned in an older stand (60-90 years) on the Willamette National Forest near Cascadia. Prebunching was done with a truck mounted Skagit GU-10. A Madill 071 with a Danebo S-40 carriage was used for swinging. One unit was selected from this study.

H. Tractor / Skyline - summer of 1974 - To compare the costs and effects of skyline systems and tractor logging, thirty-five corridors were thinned in the McDonald Forest. A Bantam T-350 was utilized to thin the skyline corridors. A wide range of thinning intensities were used, but due to the difficulties of collecting accurate information in a stand that was thinned eight years before, only two units were chosen.

J. Strip Thin - summer of 1974 - The feasibility of strip thinning was studied for this study. Four corridors were thinned in the McDonald Forest using a Bantam T-350 with a Ross carriage. Two units were studied for the stand damage study.

K. Trailer Alp - Downhill - winter of 1978 - An Igland Jones trailer alp was used for logging nine corridors downhill. The study took place in the McDonald Forest. Two corridors were chosen from this study.

DATA ANALYSIS TECHNIQUES

Damage levels and some of the characteristics of stand damage were summarized using the Statistical Interactive Programming System (SIPS) on Oregon State University's CYBER 70/73 computer. To determine the important variables that influence the damage levels in the residual stand, regression analysis was used. Regression analysis was not used as it usually has been for forest engineering applications such as production studies. Since very little is known about the influence of the factors affecting stand damage it seemed more appropriate to determine which variables were important rather than develop a precise predictive equation. Regression analysis was used as a screening technique to choose the significant variables, i.e, those that could be shown statistically to influence the damage level.

The regress subsystem of the SIPS package was used to perform forward selection, backward selection and true stepwise search procedures. A linear model was constructed in the form:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n + \epsilon$$

In order to determine the validity of the model, several tests were performed. The coefficient of multiple determination (R) was tested with the following equation:

$$t = \frac{r}{\frac{1 - r^2}{n - 1}} \qquad \text{(Steel and Torrie, 1980)}$$

Each of the coefficients was tested using the t statistic. The hypotheses were

$$C_1 : b_k = 0$$

$$C_2 : b_k \neq 0$$

If $t^* \leq t(1 - \frac{\alpha}{2}, n - p)$ then C_1 is true, otherwise C_2 is true and the coefficient is valid (Neter and Wasserman, 1974).

VI. RESULTS

A summary of the independent variables collected for this study is presented in table 2. A five digit code number was developed to identify the units. The first digit indicates the production study associated with the unit. These letters correspond to the study locations described on pages 33-36. The second digit describes the study location with the following code:

1. McDonald/Dunn Forest, near Corvallis, Oregon.
2. Blodgett Tract, near Mist, Oregon.
3. Coast Range, near Grand Ronde, Oregon.
4. Cascades, near Cascadia, Oregon.

The third and fourth digits are reserved for the corridor number. This corridor umber corresponds to that used for the production study. The fifth digit indicates which side of the corridor was sampled. Left (L) and right (R) are defined for a person standing at the landing facing the tailhold.

DAMAGE LEVEL SUMMARY

The level of damage in the stand was indicated by the measurement of scar height, width, length and area. Although only the total scar area per acre could be used as the dependent variable, the other

Table 2. INDEPENDENT VARIABLES - SUMMARY

Corridor Number	Yarder	HP PB or Conv	HP Swing	Carr Type	Harv Meth	Corr Width Ft	Resid St Den Tree/AC	% NDF	Avg Log Size Ft	Vol/AC Rem Ft /AC	Slope %	Side Slope %
A120L	Koller	60		CL	CN	18.8	64	0	17.94	1338	14.6	- 6.0
A120R	Koller	60		CL	CN	18.8	104	0	17.94	1338	14.6	-10.3
A121L	Koller	60		CL	CN	21.3	68	0	16.18	1774	31.7	7.7
A121R	Koller	60		CL	CN	21.3	94	16.0	16.18	1774	31.7	-10.1
A123L	Bantam	100		ST	CN	12.0	133	0	14.26	2029	25.0	3.3
A123R	Bantam	100		ST	CN	12.0	88	0	14.26	2029	25.0	7.1
A124L	Bantam	100	100	ST	PS	12.9	112	5.0	14.75	1894	12.0	9.7
A124R	Bantam	100	100	ST	PS	12.9	98	5.3	14.75	1894	12.0	- 5.6
A131L	Bantam	100		ST	CN	15.1	170	0	13.48	1369	20.7	4.4
A131R	Bantam	100		ST	CN	15.1	155	0	13.48	1369	20.7	4.4
A132L	Bantam	100	100	ST	PS	19.3	158	0	13.20	2656	21.2	- 3.9
A132R	Bantam	100	100	ST	PS	19.3	149	0	13.20	2656	21.2	- 8.4
A137L	Bantam	100		ST	CN	19.0	164	0	11.93	1641	-23.1	1.1
A137R	Bantam	100		ST	CN	19.0	160	4.0	11.93	1641	-23.1	- 5.4
A138L	Bantam	100		ST	CN	15.2	147	0	10.04	1904	-21.8	- 3.5
A138R	Bantam	100		ST	CN	15.2	140	0	10.04	1904	-21.8	- 4.9
B103L	Koller	60		CL	CN	16.1	144	0.7	12.43	1726	23.2	- 3.3
B103R	Koller	60		CL	CN	16.1	166	0.8	12.43	1726	23.2	-10.2
B105L	Bantam	100		CL	CN	20.4	115	0	13.76	1406	18.5	-14.1
B105R	Bantam	100		CL	CN	20.4	110	0	13.76	1406	18.5	17.7
B120R	Bantam	100		CL	CN	23.7	125	1.2	17.55	1775	25.9	5.1

Table 2. INDEPENDENT VARIABLES - SUMMARY (cont.)

Corridor Number	Yarder	HP PB or Conv	HP Swing	Carr Type	Harv Meth	Corr Width Ft	Resid St Den Tree/AC	% NDF	Avg Log Size Ft	Vol/AC Rem Ft /AC	Slope %	Side Slope %
C204R	Minialp	70		HB	CN	16.6	122	11.7	12.96	1850	15.2	10.9
C205L	Minialp	70		HB	CN	16.7	116	25.8	12.96	1850	13.3	- 9.9
D304L	SJ2-R	123		ST	CN	19.5	198	39.0	9.35	1501	33.1	11.0
D305R	SJ2-R	123		ST	CN	18.1	197	58.4	7.84	1667	31.3	11.4
E105L	Minyard	47	100	HB	PS	15.5	136	0	15.51	2123	26.4	- 4.5
F201R	W.coast	239		HB	CN	24.3	126	58.9	9.67	766	14.9	-12.7
F24BL	MA/WC	70	239	HB/CL	PS	20.0	130	53.7	12.40	766	17.3	5.7
F28AR	MA/WC	70	239	ST/CL	PS	15.7	236	81.5	13.00	1442	13.9	- 4.6
G404R	GU10/071	175	284	HB	PS	30.0	40	0	26.40	1818	36.0	-28.4
H127R	Bantam	100		HB	CN	17.9	140	0	15.14	2281	31.9	-22.5
H128L	Bantam	100		HB	CN	18.3	107	0	15.14	2281	37.3	0.8
J102L	Bantam	100		HB	ST	27.2	187	0	11.70	1380	27.2	4.2
J103R	Bantam	100		HB	ST	25.1	172	0	11.70	1380	24.0	- 4.7
K101L	Minialp	70		HB	CN	17.2	166	0	18.97	1944	-21.1	25.5
K101R	Minialp	70		HB	CN	17.2	157	0	18.97	1944	-21.1	-32.1
K102L	Minialp	70		HB	CN	17.6	162	0	20.10	1302	-22.7	21.1
K102R	Minialp	70		HB	CN	17.6	152	0	20.10	1302	-22.7	-26.8

measurements are included to give a more complete indication of the damage sustained.

Over the whole range of units, the height of the bottom of the scar ranged from a minimum of zero feet (ground level) to a maximum of 52 feet above the ground. The width of the scar ranged from 0.1 feet to 3.2 feet. The length of the scar ranged from 0.1 to 19 feet. Area per scar ranged from 0.02 square feet to 12 square feet. The total scar area per acre ranged from 0.4 square feet per acre on the least damaged unit to 64.4 square feet per acre on the unit that was most heavily damaged.

The minimum, mean and maximum values of scar height, width, length and area are listed in table 3. The units are arranged in order of increasing total scar area per acre. Some idea of the relationshp between the important independent variables and the damage levels can be obtained from the descriptive columns at the left side of the table. These columns include information on the percent of western hemlock and true fir in the residual stand (% NDF), the volume removed per acre (VOLREM), whether the stand was yarded conventionally or by prebunching and swinging (CNPS) and the horsepower for prebunching or conventional yarding (LATHP) and for swinging (SWHP). The classes for each variable are described below

	L - low	M - medium	H - high	
% NDF	0 - 15%	15 - 50%	50%+	
VOLREM	0 - 1500	1500 - 2000	2000+	cubic ft/ acre
LATHP,SWHP	0 - 75	75 - 150	150+	horsepower
CNPS	CN = conventional		PS = prebunch and swing	

REGRESSION ANALYSIS

Regression analysis yielded the following equation:

SCAR AREA = -23.6120 + 0.659223 WH + 0.0221402 VOLREM - 7.84103 CNPS

(Ft^2/acre) % western hemlock (Ft^3/acre) CN = 0, PS = 1

$R^2 = 0.6346$

This equation is based on the data collected from 38 units.

The minimum allowable t value for the coefficients at a 95% confidence interval is 1.96. The t values obtained are listed below.

Constant	- 3.113
WH	7.406
VOLREM	5.141
CNPS	- 1.973

Table 3. Damage levels

CORR. #	% NDF	VOL REM	CN/PS	LAT HP	SW HP		SCAR AREA PER SCAR	TOTAL SCAR AREA PER ACRE	SCAR HEIGHT	SCAR WIDTH	SCAR LENGTH
						MIN					
K102L	0	L	CN	L		MEAN	0.105	0.396	1.6	0.3	0.6
						MAX					
						MIN	0.018		1.5	0.1	0.2
A121R	M	M	CN	L		MEAN	0.094	1.148	13.80	0.13	0.63
						MAX	0.176		22.0	0.2	0.9
						MIN	0.018		0.3	0.1	0.1
J102L	0	L	CN	M		MEAN	0.146	2.160	3.66	0.57	0.38
						MAX	0.651		30.0	1.7	0.9
						MIN	0.070		1.8	0.2	0.4
A120L	0	L	CN	L		MEAN	0.580	2.193	2.55	0.55	1.50
						MAX	1.090		3.3	0.9	2.6
						MIN	0.035		0.9	0.2	0.1
J103R	0	L	CN	M		MEAN	0.369	3.142	4.68	0.45	1.30
						MAX	1.407		9.5	0.7	5.0
						MIN	0.035		0.5	0.1	0.2
K102R	0	L	CN	L		MEAN	0.200	4.507	8.67	0.30	1.06
						MAX	0.422		38.0	0.5	2.6
						MIN	0.035		1.1	0.1	0.2
A131R	0	L	CN	M		MEAN	0.431	5.029	1.90	0.53	0.88
						MAX	1.160		3.6	1.1	2.0
						MIN	0.053		0.1	0.2	0.3
A121L	0	M	CN	L		MEAN	0.285	6.425	2.44	0.36	0.92
						MAX	0.791		4.3	0.7	2.2
						MIN	0.028		0	0.1	0.3
A124L	L	M	PS	M	M	MEAN	0.333	6.990	1.20	0.45	0.76
						MAX	1.333		2.4	1.0	1.9
						MIN	0.035		0	0.2	0.2
F201R	H	L	CN	H		MEAN	0.391	8.399	2.25	0.46	1.11
						MAX	1.002		10.0	1.0	2.4
						MIN	0.018		0.4	0.1	0.2
G404R	0	M	PS	H	H	MEAN	0.302	9.277	15.39	0.46	0.81
						MAX	1.495		52.0	1.0	1.8

Table 3. CONTINUED

CORR. #	% NDF	VOL REM	CN/PS	LAT HP	SW HP	SCAR AREA PER SCALE		TOTAL SCAR AREA PER ACRE	SCAR HEIGHT	SCAR WIDTH	SCAR LENGTH
						MIN	0.018		0.1	0.1	0.1
B103R	L	M	CN	L		MEAN	0.193	9.758	6.57	2.78	0.68
						MAX	1.266		22.0	0.6	2.2
						MIN	0.018		0.6	0.1	0.1
K101L	0	H	CN	L		MEAN	0.216	11.234	5.43	0.25	0.98
						MAX	1.354		35.0	0.4	4.5
						MIN	0.018		0.6	0.1	0.3
A131L	0	L	CN	M		MEAN	0.302	11.660	2.85	.38	0.84
						MAX	1.020		7.5	0.7	1.5
						MIN	0.018		0	0.1	0.1
K101R	0	H	CN	L		MEAN	0.189	11.693	4.13	0.28	0.81
						MAX	1.125		22.0	0.7	2.8
						MIN	0.070		0	0.1	0.5
A120R	0	L	CN	L		MEAN	0.472	12.439	7.14	0.42	1.38
						MAX	1.899		18.0	1.0	3.8
						MIN	0.028		0	0.2	0.2
A124R	L	M	PS	M	M	MEAN	0.437	13.605	2.15	0.53	1.10
						MAX	2.667		9.5	2.4	3.2
						MIN	0.018		0	0.1	0.1
B103L	L	M	CN	L		MEAN	0.239	13.680	4.53	0.32	0.71
						MAX	5.503		23.0	1.1	6.0
						MIN	0.035		0	0.1	0.1
A132R	L	H	PS	M	M	MEAN	0.481	15.502	2.53	0.74	0.68
						MAX	4.554		25.0	3.1	2.4
						MIN	0.018		0	0.1	0.1
B120R	L	M	CN	M		MEAN	0.521	15.618	5.10	0.40	1.30
						MAX	4.009		24.0	1.2	6.5
						MIN	0.018		0.4	0.1	0.1
B105L	0	L	CN	M		MEAN	0.476	15.649	7.97	0.24	2.27
						MAX	3.798		28.0	0.5	19.0

Table 3. CONTINUED

CORR. #	% NDF	VOL REM	CN/PS	LAT HP	SW HP	SCAR AREA PER SCAR		TOTAL SCAR AREA PER ACRE	SCAR HEIGHT	SCAR WIDTH	SCAR LENGTH
						MIN	0.035		0.2	0.1	0.1
E105L	0	H	PS	L	H	MEAN	0.536	15.898	2.92	0.42	1.01
						MAX	9.020		8.5	1.7	8.2
						MIN	0.028		0.3	0.1	0.2
A123R	0	H	CN	M		MEAN	0.517	18.171	6.98	0.60	1.33
						MAX	2.806		50.0	2.9	10.0
						MIN	0.018		0	0.1	0.1
A138L	0	H	CN	M		MEAN	0.314	20.052	9.65	0.32	1.01
						MAX	3.604		35.0	1.0	9.0
						MIN	0.035		0.2	0.1	0.3
B105R	0	L	CN	M		MEAN	0.390	20.499	8.48	0.35	1.52
						MAX	1.916		33.0	0.8	12.0
						MIN	0.055		0	0.2	0.4
A123L	0	H	CN	M		MEAN	0.528	20.592	3.72	0.52	1.26
						MAX	1.556		2.15	1.0	3.8
						MIN	0.035		0.2	0.1	0.1
A132L	0	H	PS	M	M	MEAN	0.358	21.530	3.64	0.40	0.80
						MAX	2.426		13.0	1.8	2.9
						MIN	0.018		0	0.1	0.2
C204R	L	M	CN	L		MEAN	0.642	23.235	3.08	0.45	1.42
						MAX	6.716		16.7	1.3	9.6
						MIN	0.018		0	0.1	0.1
A137L	0	M	CN	M		MEAN	0.447	23.490	4.25	0.38	1.42
						MAX	3.393		22.0	1.4	17.0
						MIN	0.035		0.2	0.1	0.1
A137R	0	M	CN	M		MEAN	0.396	24.885	5.62	0.40	1.04
						MAX	4.993		32.0	1.2	10.0
						MIN	0.018		0	0.1	0.1
F24BL	H	L	PS	L	H	MEAN	0.431	27.938	2.54	0.58	1.12
						MAX	2.690		29.0	2.9	6.2

Table 3. CONTINUED

CORR. #	% NDF	VOL REM	CN/PS	LAT HP	SW HP	SCAR AREA PER SCAR		TOTAL SCAR AREA PER ACRE	SCAR HEIGHT	SCAR WIDTH	SCAR LENGTH
						MIN	0.035		0	0.1	0.1
H128L	0	H	CN	M		MEAN	0.506	29.026	4.03	0.49	1.26
						MAX	7.209		21.0	1.5	18.0
						MIN	0.035		0	0.1	0.2
A138R	0	H	CN	M		MEAN	0.459	30.094	6.22	0.44	1.35
						MAX	2.092		30.0	1.6	4.0
						MIN	0.035		0	0.1	0.3
C205L	M	M	CN	L		MEAN	0.690	30.857	7.19	0.50	1.81
						MAX	3.534		29.0	1.9	6.8
						MIN	0.018		0	0.1	0.1
D304L	M	M	CN	M		MEAN	0.372	31.388	5.21	0.44	0.99
						MAX	2.444		31.0	2.0	3.5
						MIN	0.035		0	0.1	0.1
H127R	0	H	CN	M		MEAN	0.714	47.872	4.95	0.48	1.88
						MAX	6.031		30.0	2.5	17.0
						MIN	0.018		0	0.1	0.2
D305R	H	M	CN	M		MEAN	0.560	51.318	5.82	0.37	1.6
						MAX	5.996		22.0	1.5	10.0
						MIN	0.018		0	0.1	0.1
F2BAR	H	L	PS	L	H	MEAN	0.715	64.379	4.97	0.51	1.51
						MAX	12.009		40.0	3.2	15.0

The error obtained with this analysis is calculated with the following formula:

$$E = \frac{t\ Se}{\sqrt{n}}$$

For the regression equation chosen the standard error of the estimate of the scar area per acre is 1.94 square feet. This works out to be an error of 16.8 percent of the mean. The mean value of the dependent variable, total scar area per acre is 17.94. Estimation limits for a 95 percent confidence interval are 15.00 to 20.87 square feet per acre.

The influence of the independent variables can be roughly indicated by observing the change in damage level for a given change in the value of the independent variable. For example, if each of the independent variables are increased above the mean value, while the other variables are held constant the following results are obtained:

VARIABLE	INCREASE IN INDEPENDENT VARIABLE	INCREASE IN SCAR AREA ABOVE MEAN VALUE	
		FT^2 / ACRE	PERCENT
WH	10 %	6.59	36.75
VOLREM	100 ft /acre	2.21	12.34
CNPS	CN - PS	-7.84	-43.71

Several other variables entered into regression models, but had coefficients that could not be proven to be different from zero. This can be attributed to the fairly strict specifications of significance. Some of the variables that would have entered into the model if specifications had been lowered include the yarder horsepower, residual stand density, log size and strip thin. In fact, field observations gave a preliminary indication of the importance of these variables.

SPECIES

The species variables, percent non-Douglas-fir (NDF) and percent western hemlock (WH), turned out to be the most significant variables. By themselves, NDF and WH had correlation coefficients of 0.587 and 0.592 with the total scar area per acre. To show the influence of the percent of easily damaged trees in the residual stand, bar charts were drawn up. The percent of each species in the residual stand is contrasted against the percent of that species in the total number of damaged trees. This has been done for each unit that had any other species besides Douglas-fir (see figures 14 and 15).

Care should be taken when interpreting the results for units with very low or very high percentages of the species in the residual stand or on units that have a small sample size. These units include A121R, B103R and B120R for the grand fir and F28AR for the western hemlock.

Although results are not very conclusive, it seems that western hemlock and the true firs sustain more damage than their percent in the stand would indicate. In western hemlock, there seems to be a threshold at about 50 percent. When the stand is made up of more than 50 percent hemlock, the hemlock suffers more damage then its percent of the stand would indicate.

Figure 14. Western hemlock damage

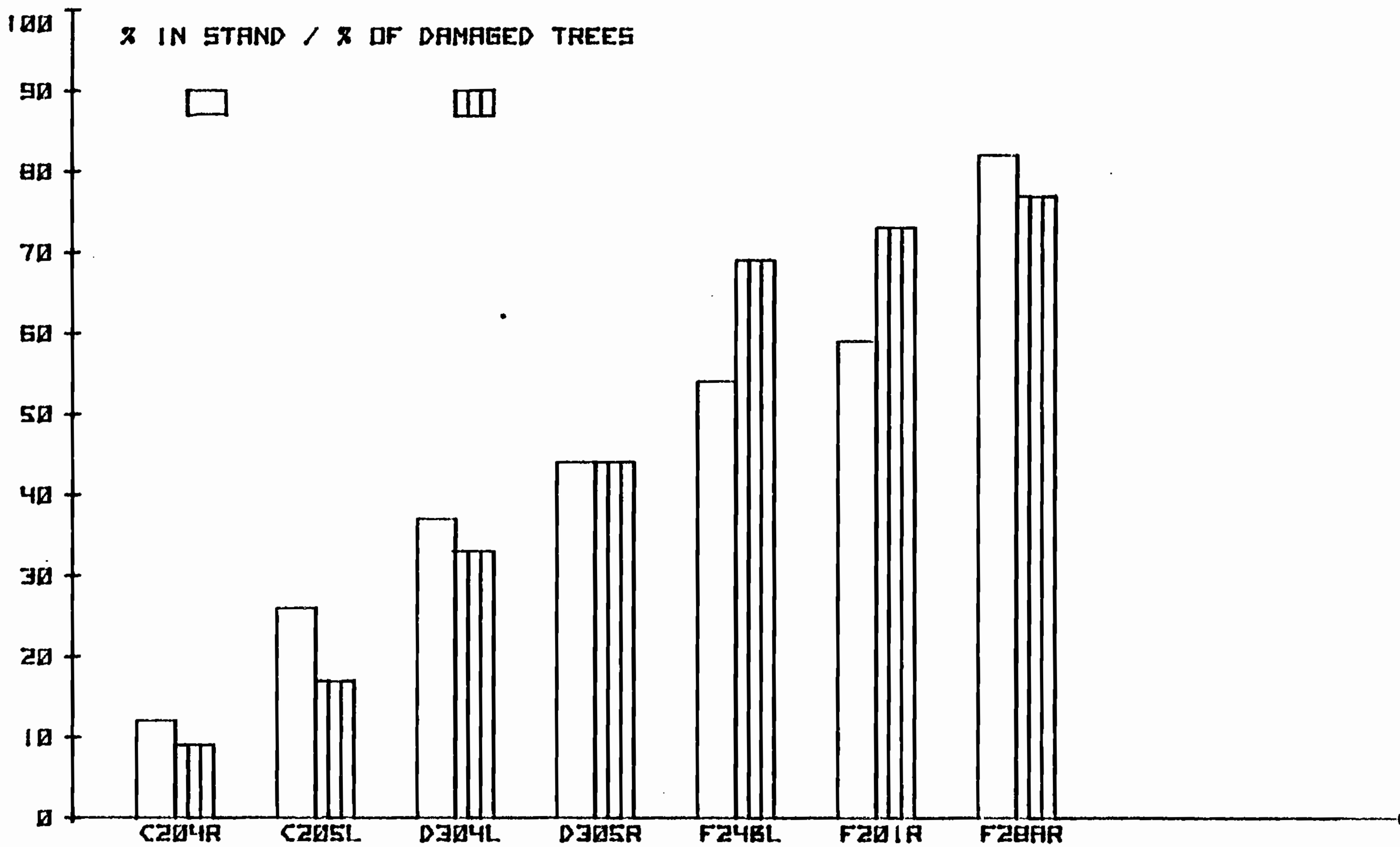
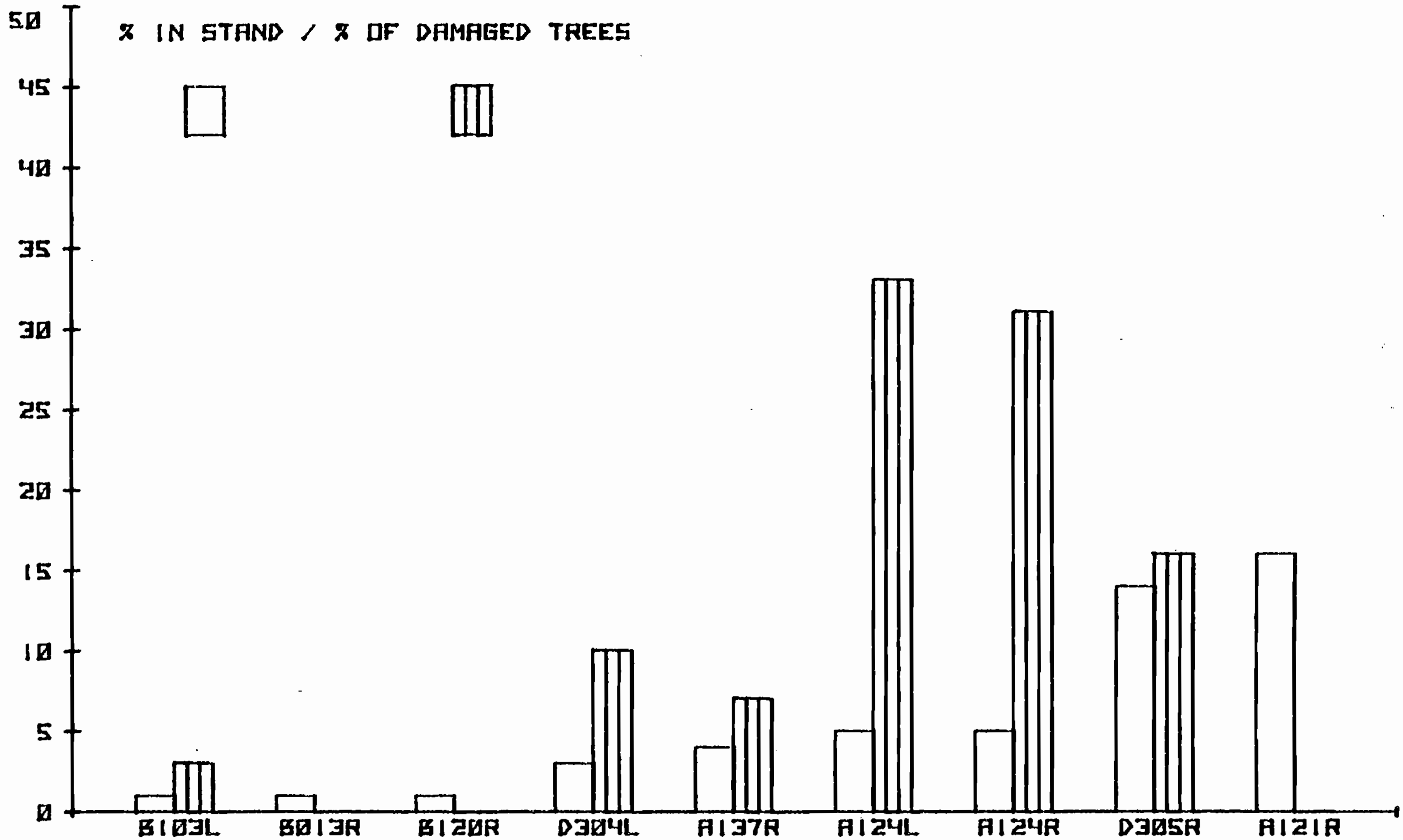


Figure 15. True fir damage



SCAR TYPES

During the data collection, damage was classified into 7 types. Out of a total of 1357 scars measured the majority (66.1%) were classified as yarding scars. Cable scars accounted for 27.1 percent of the scars. The rest of the scar types were not observed as frequently; falling scars (4.6%), landing scars (0.4%), road scars (0.7%). Yarding breaks or leans accounted for 2.0 percent of the 791 damaged trees observed or 1.2 percent of all of the scar types observed. On the average, there were 1.75 scars per damaged tree.

Scar types have been summarized in the following charts (see figure 16). No relationship between the occurrence of the different scar types and the independent variables was observed.

DEPTH CLASS

Three classes for depth were observed during data collection. Depth class 0 included scars in which the bark was removed and the sapwood was damaged over less than 20 percent of the scar surface area. Depth class 1 was reserved for scars with bark removed and sapwood damaged over 20 percent or more of the scar surface area. On six of the units some of the scars were healed. Healed scars were designated as depth class 2 since they could not be determined to be in either of the other two classes.

Figure 16. Scar types

YS - Yarding Scar
CS - Cable Scar
FS - Falling Scar
LS - Landing Scar
RS - Road Scar
YK - Knocked Over During Yarding
YB - Broken During Yarding

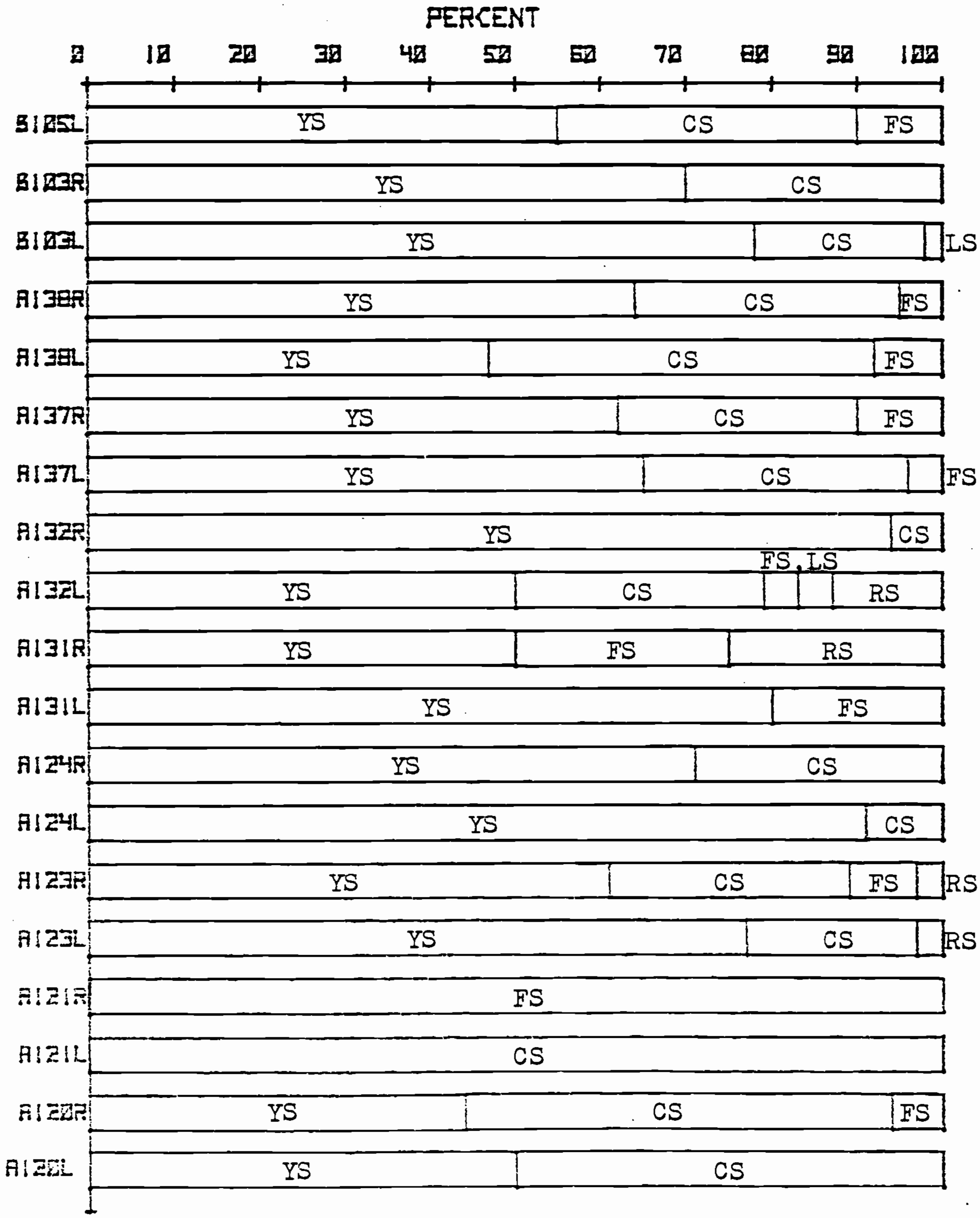


Figure 16 (cont.). Scar types

YS - Yarding Scar
CS - Cable Scar
FS - Falling Scar
LS - Landing Scar
RS - Road Scar
YK - Knocked Over During Yarding
YB - Broken During Yarding

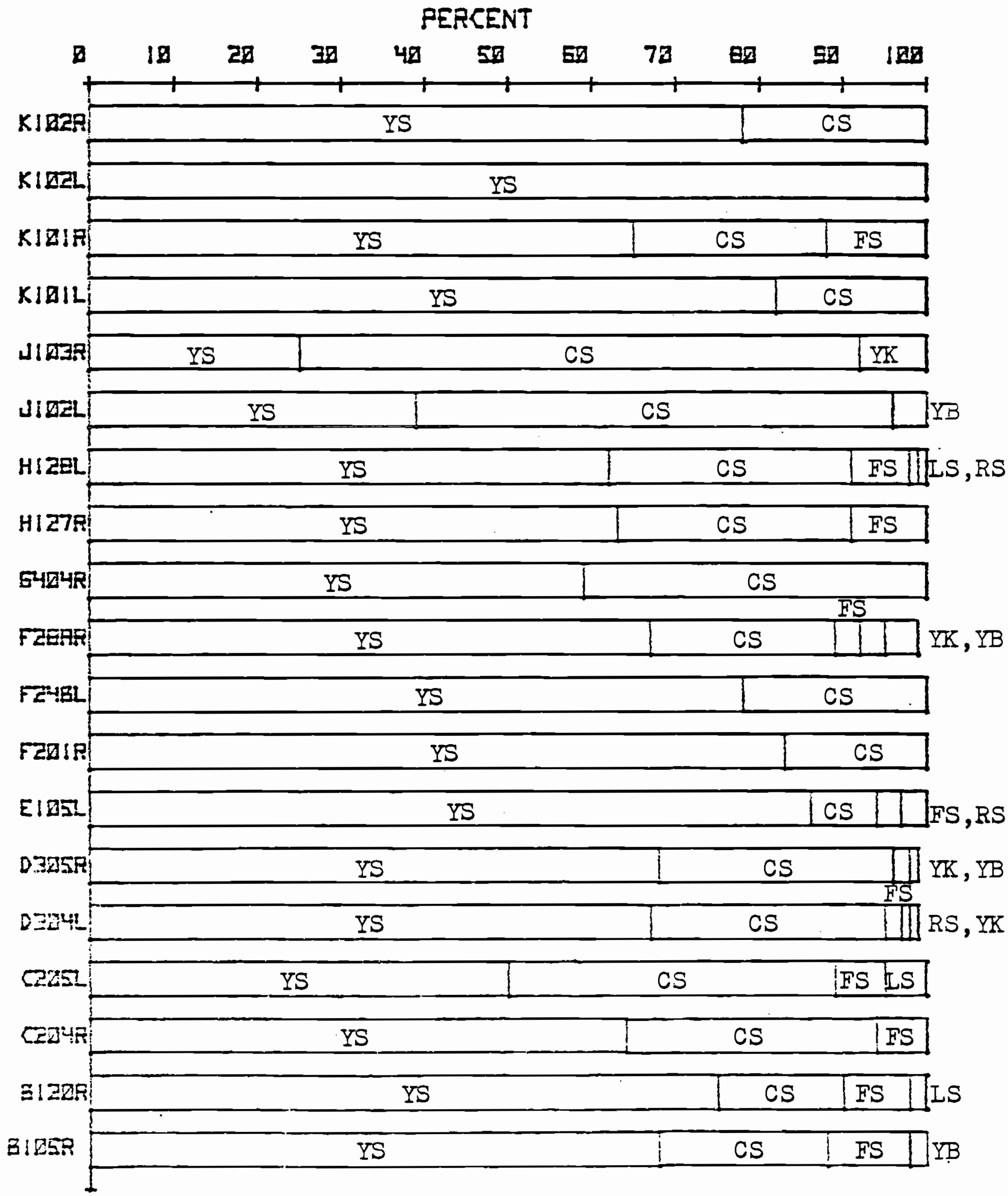


TABLE 4. Depth Class Observations

Corridor Number	Depth Class 0 %	Depth Class 1 %	Depth Class 2 %
A120L	50.0	50.0	
A120R	94.1	5.9	
A121L	100.0		
A121R	100.0		
A123L	93.3	6.7	
A123R	71.4	28.6	
A124L	100.0		
A124R	71.4	28.6	
A131L	100.0		
A131R	100.0		
A132L	95.5	4.5	
A132R	94.4	5.6	
A137L	93.9	6.1	
A137R	96.0	4.0	
A138L	100.0		
A138R	88.1	11.9	
B103L	80.0	20.0	
B103R	82.6	17.4	
B105L	95.0	5.0	
B105R	82.5	17.5	
B120R	87.2	12.8	
C204R	93.9	6.1	
C205L	97.2	2.8	
D304L	89.5	10.5	
D305R	97.6	2.4	
E105L	28.6	5.7	65.7
F201R	87.5	12.5	
F24BL	84.9	15.1	
F28AR	84.5	14.7	0.9
G404R	100.0		
H127R	34.1	3.5	62.4
H128L	34.8	6.7	58.4
J102L	13.6	13.6	72.7
J103R	9.1		90.9
K101L	87.5	12.5	
K101R	100.0		
K102L	100.0		
K102R	87.5	12.5	

The majority of the scars were in depth class 0. For all of the scars, 79 percent were class 0, 9.5 percent were in depth class 1 and 11.5 percent were in depth class 2. All of the healed scars (class 2) occured in stands that had been thinned six or more years before data collection with the exception of one, small four-year old scar.

The occurence of the different depth classes is listed for each corridor in table 4. Several of the units have fairly small sample sizes and their results should be used with caution. These units include A120L, A121L, A121R, A131R and K102L.

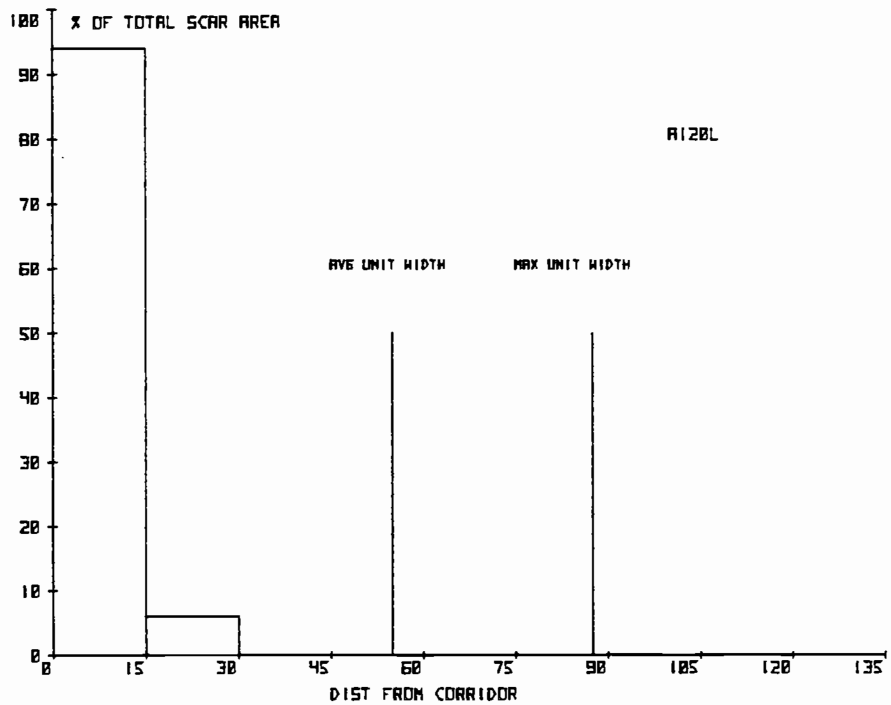
DISTANCE SUMMARY

It has generally been observed that most of the damage occurs near the skyline corridor. This holds true for this study with 68.9 percent of the total scar area occurring within 15 feet of the edge of a skyline corridor. The histograms on the following pages show the distribution of the scar area for each unit (see figure 17).

A point that usually is neglected is the distribution of scar damage along the length of the unit. During the field measurements it was often noticed that the damage was highest in the denser parts of the residual stand. Histograms of a few typical corridors have been drawn up for the distribution of damage along the corridor (see figure 18).

Several fairly typical plots of the location of damaged trees within the unit have been included. These plots clearly show how many

Figure 17. Distribution of Damage with Respect to Distance Down Corridor



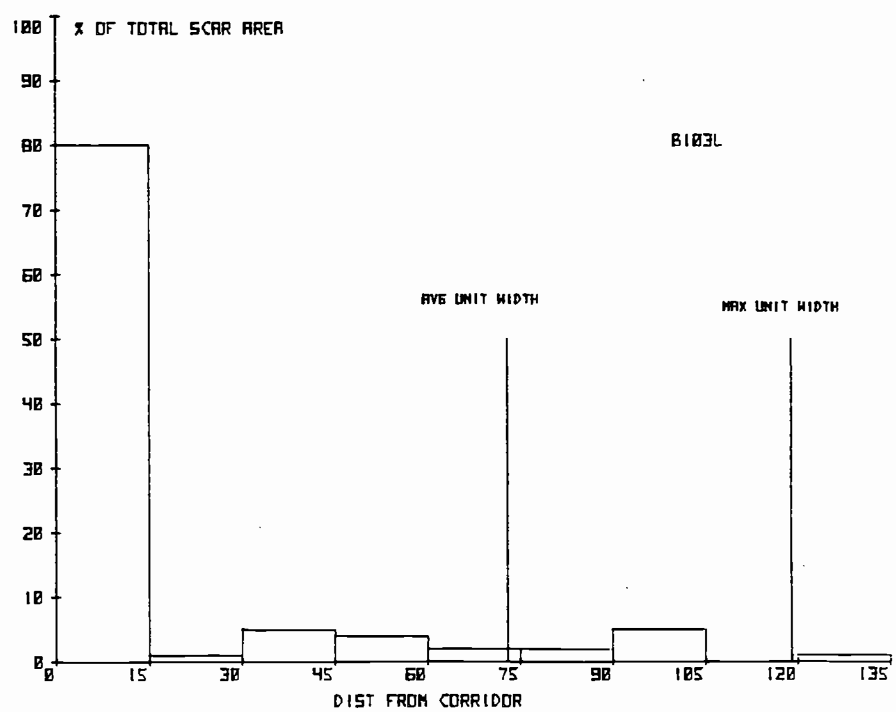
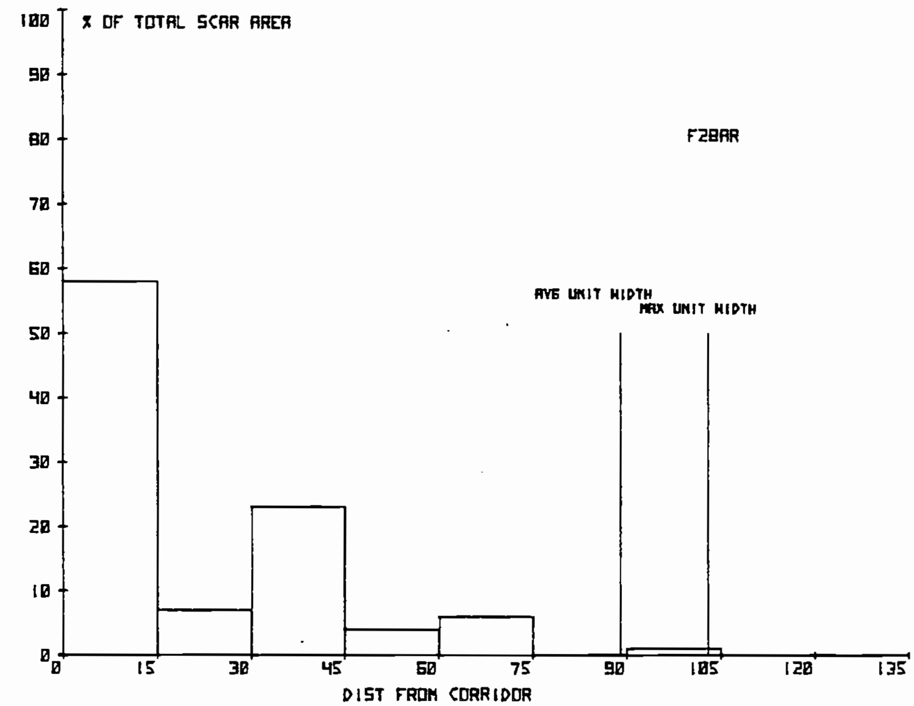


Figure 17 (cont'd). Distribution of Damage with Respect to Distance from Corridor



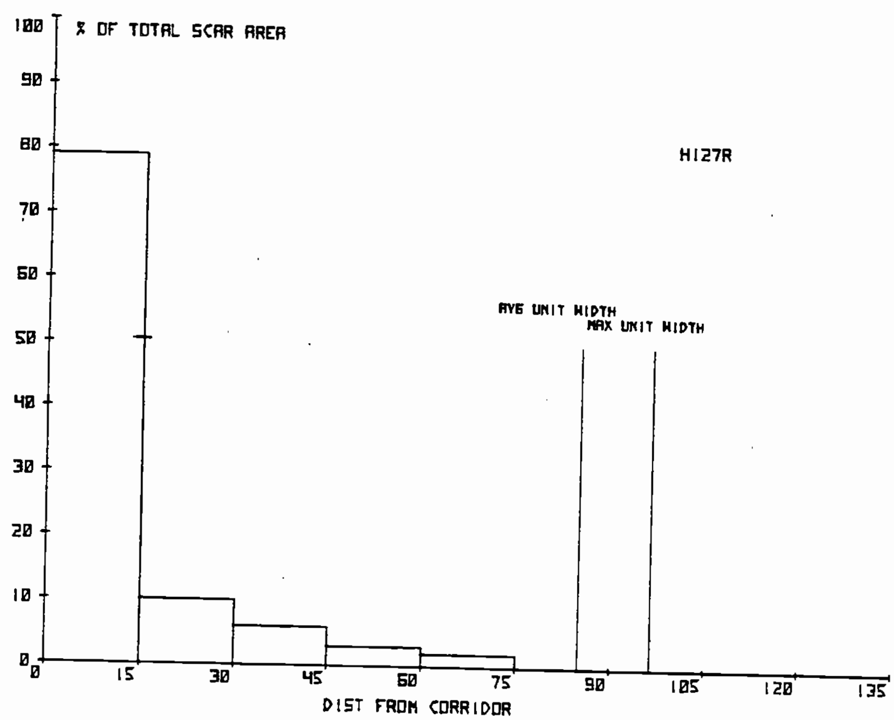
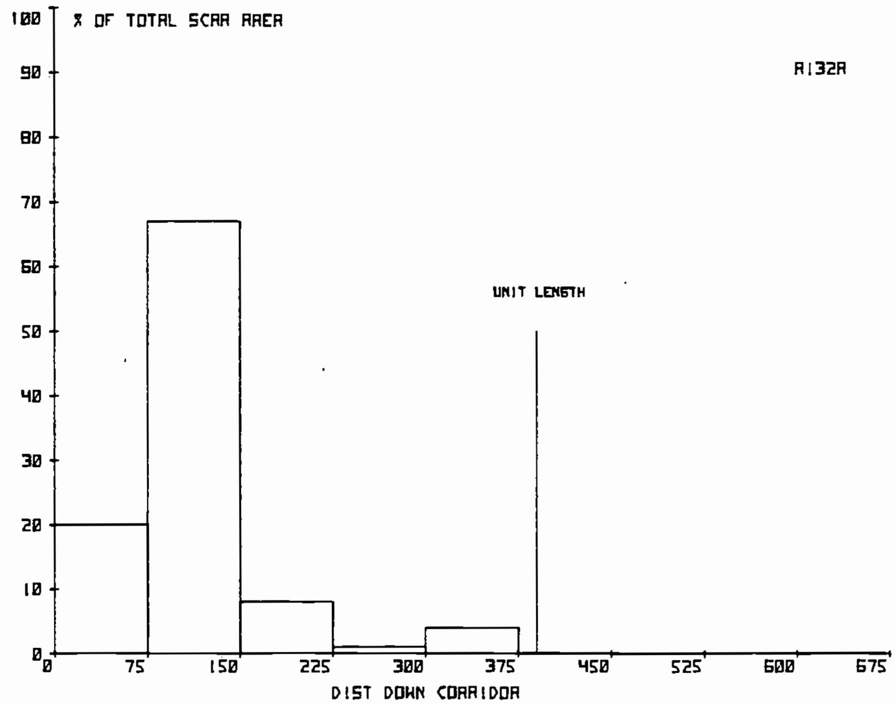


Figure 18. Distribution of Damage with Respect to Distance Down Corridor



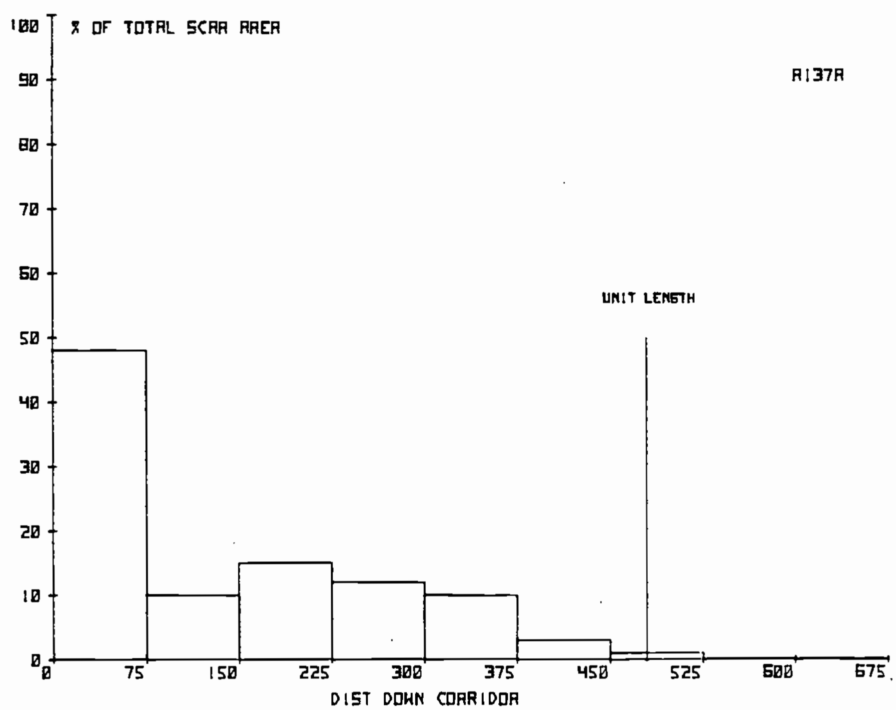
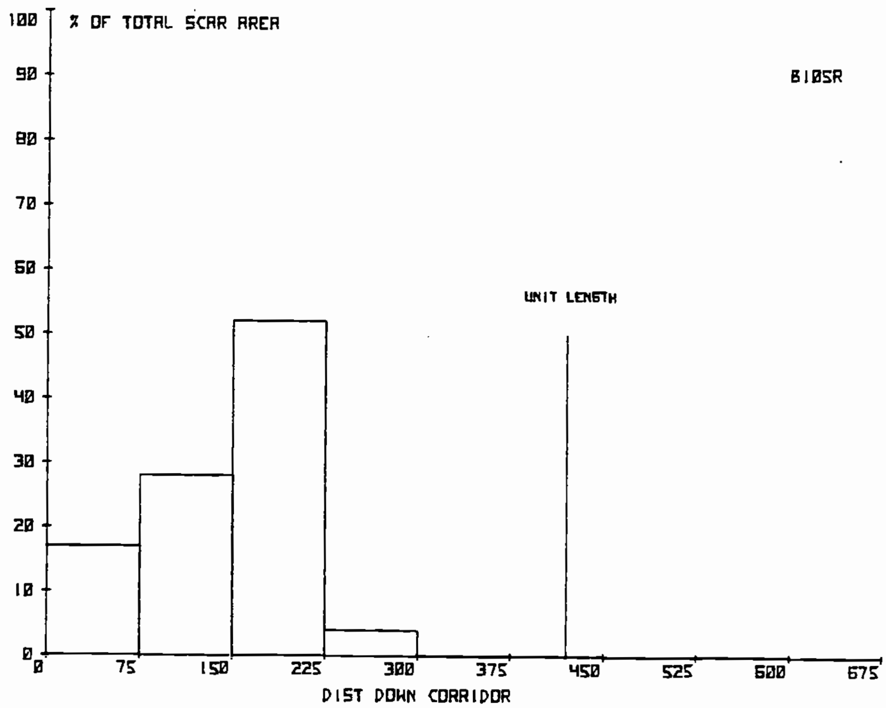
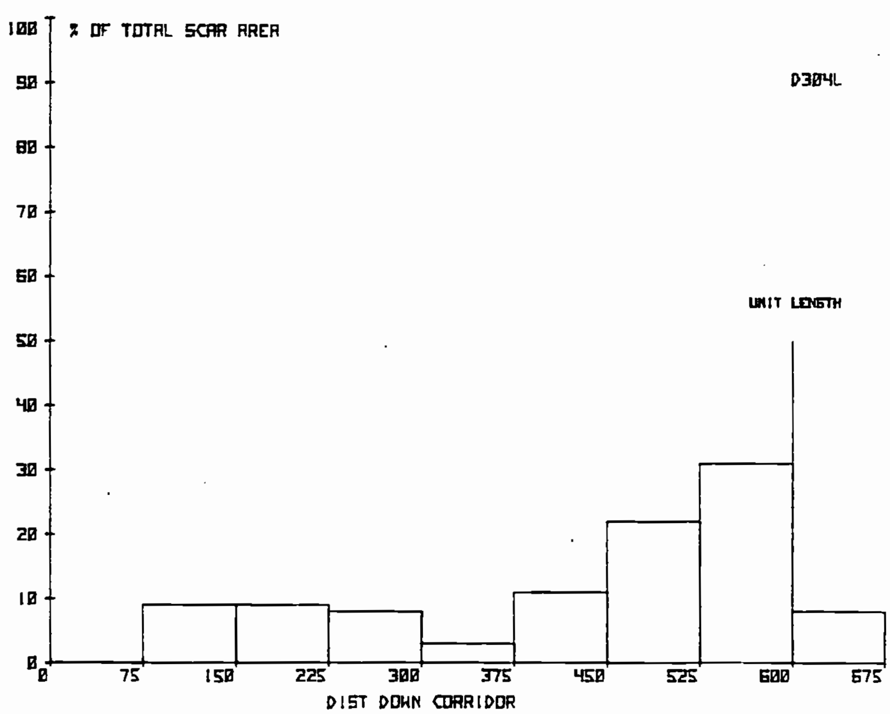


Figure 18 (cont'd). Distribution of Damage with Respect to Distance Down Corridor

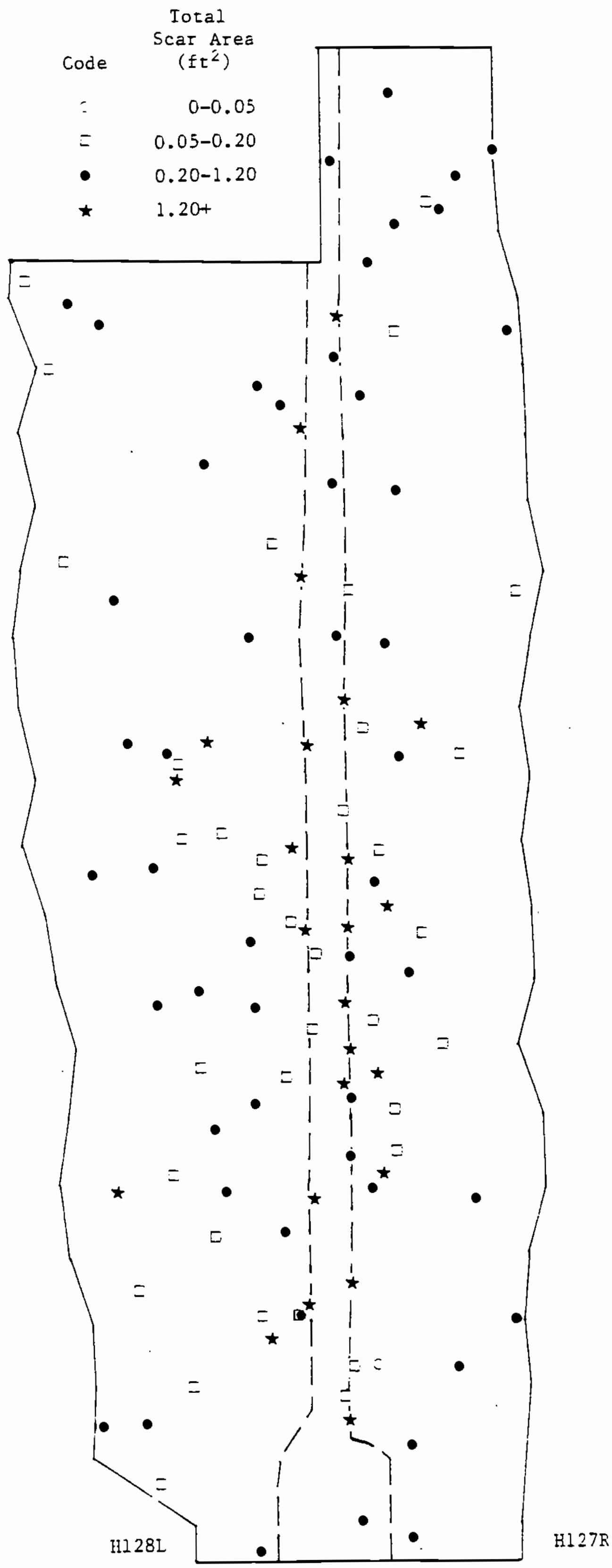




of the more heavily damaged trees are located near or along the corridor (see figure 19).

As an extension of the main damage study, an attempt was made by David Perry of the Forest Research Laboratory at Oregon State University to relate the damage measurements to the growth of the damaged trees. Unpublished results show no clear relationships.

Figure 19. Plots of Damaged Tree Locations



VII. SUMMARY

As a result of the regression analysis, the variables that were determined to have the most significant influence on stand damage levels were the percent of western hemlock in the residual stand, the volume of timber removed and whether the unit was logged conventionally or with prebunching and swinging. A regression equation has been developed but the reader should be cautioned about the use of this equation for several reasons:

1. The equation was developed from data obtained from production study thinnings. The research thinnings may or may not approximate actual operations.

2. The effect of the crew has not been considered. Many of the units had been thinned by one contractor.

As with any regression equation the results should not be extrapolated beyond the range of conditions studied. Many of the variables studied were not included in the regression equation due to statistical specifications. There is a possibility that this is true only for the units studied and that other areas may have different relationships. Although it did not show up as a result of the regression analysis, from field observations it was noticed that damage is probably reduced by using smaller yarders and by strip thinning and damage is likely to be higher in denser residual stands. In this paper damage levels have been presented along with equipment names. This is not meant as an endorsement for any specific pieces of equipment.

The distribution of damage within a stand was observed to be highly variable. Any data collection method used to collect information on stand damage should be designed to account for this variability. No variability problem was observed for the data collection method used for this study.

Damage levels due to cable thinning can be very high. A maximum of 64 square feet of scar area per acre was observed on one unit. This level of damage will probably be very significant especially considering the fact that it is in the more easily decayed western hemlock. Stand damage should be considered when planning skyline thinnings, although setting arbitrary limits in the logging contract may not be the answer. Careful planning with a knowledge of the important factors would be the most effective method for reducing damage levels.

SUGGESTIONS FOR FUTURE RESEARCH

Probably the most badly needed research in the area of stand damage concerns the effects of stand damage. Although there has been quite a bit of research concerning the levels of stand damage and a little research on the factors influencing these levels, no one has studied the cost of the damage. What is needed is research that would relate some measurement or combination of measurements of stand damage to the economic losses caused by the damage.

A method for quantifying the effect of the crew would be a useful development. Damage levels can be higher than they should be when there is an inexperienced crew or one that does not make any attempt to leave the residual stand unscarred. Training a crew to take the time and make an effort to avoid damaging the stand could result in smaller losses due to decay, but what effect would this have on productivity? This would be another useful and interesting topic to research.

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