DAMAGE TO THE RESIDUAL STAND
DUE TO SKYLINE YARDING

by

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The use of partial cutting in the western conifers has become popular in the last decade. This has resulted in an increase in the amount of damage to the residual stand due to skyline logging. The purpose of this study is to provide models to predict the percent of a stand which can be expected to incur damage during skyline yarding.

Data was collected over a four year period on eight National Forests in Region 1, USDA Forest Service. Seventy-one corridors were partial cut and yarded uphill. Regression analysis was used to develop models based on the following classifications: silvicultural prescription, number of logs per thousand board feet, and type of yarding system.

The analysis of the data identified some of the variables which have an impact on the amount of damage. Those which had the most impact on the amoune of damage are: landing size, tail tree height, number of cut trees per acre, number of leave trees per acre, and chordslope.

The paper provides an initial estimate of the amount of damage to the residual stand due to skyline logging. Further research is necessary to fully identify the manner in which variables affect damage and determine which other conditions influence damage to the residual stand.

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I. INTRODUCTION

There has been an increase in the number of partial cuts made in western conifer stands during the past few years. This has followed a pattern of environmental awareness in the forestry community. Much of the virgin forest was selectively logged for high value trees. Three decades of clearcutting have occurred after that initial cut. The number of partial cuts has recently increased as a result of complex management objectives and environmental concerns. The use of partial cutting has resulted in many unanswered questions as to their effects -- on damage to the residual stand, on costs, on wildlife, and on other management concerns.

During a study to determine yarding production data, Region 1 of the USDA Forest Service also collected post logging data on the amount of damage to the residual stand. This study covers areas which were logged between 1975 and 1979 in northern Idaho and western Montana. The purpose of the study was to determine those factors which affect skyline yarding production rates and which would be available to Forest Service personnel at the time of sale layout and appraisal (Gorsh, 1980).

This paper examines the data on residual stand damage collected with the yarding production data. The parameters examined are limited to those which would be available to personnel at the time of layout. At the present time, the intent of the silvicultural prescription may not be met due to damage incurred by the leave trees during logging operations. It would be useful to land managers to have an estimate of the expected damage at the time a silvicultural prescription is formulated. This would allow adjustments to the prescription in order to achieve the desired

II. OBJECTIVES

The objective of this paper is to analyze the collected stand damage information to provide predictive equations for residual stand damage in partial cut areas. The specific objectives are as follows:

1. Develop equations to predict residual stand damage using the critical parameters upon which damage is determined to be dependent.
2. Determine if there is a significant difference in damage according to percent of stand removal, skyline yarding system, or the number of 16.4' logs per thousand board feet.
3. Describe the characteristics of the data collection to demonstrate the possibility of using a wide variety of situations to develop an equation which is applicable to a wide geographical region.
4. Recommend further areas of interest which should be considered when predicting damage.

III. LITERATURE REVIEW

The majority of studies concerned with damage to the residual stand have covered tractor skidding (Gottfried, 1975; Nyland, etal, 1971; Nyland, etal, 1972; and Nyland, etal, 1977) and the differences in damage due to rubber tired skidders versus crawler tractors. As the popularity of skyline logging systems has increased, some studies have made comparisons of the residual stand damage for skyline logging versus tractor logging (Aulerich, etal, 1974; Scherer, 1978).

Aulerich's study determined the number of wounds sustained by leave trees and the size of the wounds. He found that 25% to 30% of the leave trees had wounds over 9 sq. in. and that 7% of the stems had wounds greater than 72 sq. in. in size. He determined that the largest number of wounds occurred near the skyline corridor (40% of the wounds were within 5 feet) and that the number of wounds increased with increasing slope.

Scherer generated regression equations for the following categories- no damage, fatality, bent, lost, and survived. He found that the closer the trees are to the corridor, the greater the chance of a tree being lost or becoming a fatality. The greater the distance the trees were from the corridor, the greater the possibility that they would incur no damage. He also found that as slope increased the percentage of bent trees decreased.

Froelich (1976) noted that an uninfected wound on a tree stem will generally cause very little loss in wood production. The major concern for damage to the residual trees is the potential loss of merchantable wood due to infected wounds.

IV. SCOPE

Data analyzed for this study was taken from a USDA Forest Service Region 1 collection obtained during 1975, 1976, 1977, and 1979. The data was collected by Forest Service personnel and was obtained for areas on eight National Forests. The data collection represents a wide range of silvicultural prescriptions, landscape designs, terrain, timber types, and weather conditions found in the West Side Zone of Region 1 (Figure 1).

This paper covers residual stand damage results for live, standing, and running skyline configurations. The data was recorded for 143 skyline corridors with a total of 9247 turns (Table 1). There were 51 clearcut corridors and 92 partial cut corridors. The data was recorded on the following National Forests:

Clearwater	Nez Perce
Flathead	Panhandle
Kootenai	Payette
Lolo	St. Joe

There were ten different machine types observed during the study (Table 2). The number of corridors yarded by each machine are included in Table 2. It may be noted that some of the machines yarded very few corridors. These may still be included in the analysis because machine type will not be a variable in models or between models.

A detailed summary of the area yarded by the various systems according to silvicultural prescription is contained in Table 3.

Table 1. Number of skyline corridors and number of turns by yarding system and yarding direction.

	Uphill		Downhill	
	#Turns	#Corridors	#Turns	#Corridors
Live	1980	37		
Running	2783	41	1505	30
Standing	2149	22	830	13

Table 2. Machine types and the number of corridors yarded by each machine type.

Machine Type	#Corridors Yarded
Skagit GT-3	32
Skagit SJ-7	8
Skagit TY60	6
Linkbelt 98	23
Linkbelt 108	1
Washington 78	44
West Coast Falcon	5
Wyssen	3
Madill MK-26	16
Madill 071	5

V. DATA COLLECTION AND STUDY PROCEDURES

A. DATA COLLECTION

The procedure for data collection was the same at each site. As a sale became available for observation, it was added to a master list. Sales were then visited according to the order on the list. Information was recorded on the data collection sheet (Figure 2).

Production time data, stand data, and setting condition (physical characteristics) were obtained for each corridor as listed in Figure 3. A yarding configuration and rigging diagram was drawn for each corridor. When yarding of a corridor was completed, a profile was run from the yarder to the tailhold to obtain horizontal span, external yarding distance, and tail tree height (Figure 4). From these, chord slope and midspan deflection were calculated. One-fifth acre circular plots were spaced from the tail-hold to the yarder to determine ground and brush conditions and to measure the percent of residual stems sustaining damage (Figure 5). Damage to residual stems was recorded in two classes -- percent of stems with damage to less than one quarter of the circumference and percent of stems with damage to more than one quarter of the circumference.

When necessary, recorded data was accompanied by detailed drawings of the landing, the guyline configurations, the yarder, and the carriage. Drawings were also made of the corridors at each landing. Approximately one half of the corridors were rectangular settings and one half of the corridors were fan shaped settings.

The data was collected by Forest Service personnel and different recorders were utilized each year.

V. EQUIPMENT

A. Make and model of yarder ____________________

B. Yarding configuration ____________________

C. Type of carriage ____________________

D. Type of tail hold ____________________

E. (Other) ____________________

THREE SAMPLE SCALED LOADS FROM THE UNIT

Truck Ticket	Gross Volume	Net Vol.	No. of Pieces	Ave. Piece Length

VI. SKETCH yarding configuration and rigging diagram

Plan, Profile and Tail Anchor

VII. REMARKS - fan shaped or rectangular setting, crew efficiency, comparison to previous pay periods production, silvicultural prescription, weather, was landing and corridor prepared in advance, what items were prerigged, log handling technique on landing, how many times were the logs handled and by whom, crew paid by the piece, hour or MBM, chokers preset, etc.

Figure 2 continued. Data collection sheet.

USDA-FOREST SERVICE

R1-2430-10 (11/72)

SKYLINE ROAD PROFILE DATA SHEET

Sale Name ____________________ Sheet ____ of ____

Ranger District ____________ Date ________ Crew ________

Harvest Unit No. ____________ Skyline Rd. No. ____________

Azimuth or Bearing ____________________

Sta. No.	Slope Dist Ft.	Profile Slope ±%	Lateral Slope ±% Lt.	Lateral Slope ±% Rt.	REMARKS: Type & Size of Stand, Anchors, Spars, Rock Outcrops, Roads, Streams, etc.

WATER PROOF

Figure 4. Skyline profile sheet.

PIECES/TURN & PIECE LENGTH
(Subsample)

SALE NAME____________________________________
SKYLINE SAMPLE # _____ DATE__________________

Turn #	Approx. EYD	Turn Time	# of Pieces	Piece Lengths

Figure 6. Tally sheet for turns and number of pieces.

B. VARIABLE DEFINTION

The data collection involved all aspects of the yarding operation. The purpose behind the collection method was to obtain information which would provide production and damage estimates based on variables available to Forest Service personnel prior to sale appraisal and advertisement.

Damage information recorded was the gross damage to the stem. The goal of this paper is to predict the percentage of stems which will sustain damage rather than to determine the type of injury the stem will incur.

1. DEPENDENT VARIABLES

Regression equations were developed for the three dependent variables defined below:

DAMAGE - Percent of residual stems sustaining damage.

DAMA - Percent of residual stems sustaining damage to less than one quarter the circumference of the tree.

DAMB - Percent of residual stems sustaining damage to more than one quarter the circumference of the tree.

A stem which received damage can only be counted for inclusion in one of the two measured categories of damage -- DAMA or DAMB. The other possibility is that a stem could have no damage. Because of this, the dependent variable DAMAGE is a computed variable obtained by summing the values for DAMA and DAMB.

Regressions were run on each of these dependent variables because it may be useful to resource managers to obtain predictions for the

LANDAR -- The landing area, in square feet, as calculated below:

LDGLENG x LDGWID

BRUSH --- A dummy variable reflecting the brush conditions at the site:

B1 = B2 = 0	Nonexistent brush
B1 = 1	Medium brush
B2 = 1	Heavy brush

GROUND -- A dummy variable reflecting the ground conditions at the site:

G1 = G2 = 0	Firm and easy footing
G1 = 1	Slippery and moderate footing
G2 = 1	Hazardous and difficult footing

C. DAMAGE DATA SUMMARY

The average damage data has been summarized for the partial cut areas according to yarding direction and percent removal (Table 4). This table includes data for the number of turns, the number of 16.4' logs per thousand board feet, and the number of logs per turn.

The mean, maximum, and minimum values for the uphill partial cut corridors was calculated for the dependent variables (Table 5). This calculation was done for the following categories: skyline system, number of 16.4' logs per MBF, and percent removal.

The mean, maximum value, and minimum value for the independent variables CHORD, SPAN, EYD, TTHT, MAXLYD, DEFLECT, AREA, LDGLENG, LDGWID, LANDAR, CUT, LEAVE, VOLACRE, LOGSM, B1, B2, and G1 were also tabulated. Table 6 contains those values according to the type of skyline system and the number of 16.4' logs per MBF. The values tabulated according to the percent removal are shown in Table 7.

Table 4. Average damage, number of turns, number of 16.4' logs, and number of logs per turn by percent removal.

Percent Removal	UPHILL				DOWNHILL			
	# Turns	# Logs	Logs/Turn	Ave Damage [b]	# Turns	# Logs	Logs/Turn	Ave Damage
0-95	103	351	3.41	74.01 (7)[a]	283	1589	5.61	60.8 (2)
30-49	947	3658	3.86	64.58 (10)	222	950	4.28	15.0 (5)
50-59	885	4123	4.66	28.45 (8)				
60-69	340	3467	10.20	52.33 (11)				
70-79	2367	12570	5.31	54.4 (30)				
80-89	263	1705	6.48	68.37 (6)	161	650	4.04	75.0 (5)
90-99	658	3495	5.31	30.90 (6)	273	1749	6.41	37.5 (1)
Totals	5563	29369	5.28	53.81 (78)	939	4938	5.26	46.9 (13)

a) The number of corridors with a particular percent removal.

b) The percent of residual stems damaged.

Table 5. continued

Variable {min, mean, max}	DAMAGE	DAMA	DAMB
70 - 79 % Removal (Uphill)	0 54.4 100.0	0 40.2 90.0	0 14.2 75.0
80 - 89 % Removal (Uphill)	43.7 68.4 99.9	0 11.2 31.2	12.5 21.8 99.9
90 - 99 % Removal (Uphill)	0 30.9 78.8	0 19.9 57.8	0 11.0 38.4
30 - 99 % Removal (Uphill)	0 51.8 100.0	0 32.9 99.9	0 15.9 99.9

a) Indicates type of cut or direction of yarding.

The category for 30 - 99 % removal is utilized as the comparison category. This excludes the data for 0 - 9 % removal which was a special case situation.

The downhill data was not analyzed due to the small number of cases. There were only thirteen downhill cases and these were judged insufficient to perform analysis.

Table 6. continued

Variable {min, mean, max}	LIVE SKYLINE	STANDING SKYLINE	RUNNING SKYLINE	# LOGS PER MBF < 10	10≤#LOGS PER MBF ≤15	15 < # LOGS PER MBF
CUT	23.8 73.5 91.8	18.7 43.9 104.2	36.7 57.8 93.2	18.7 47.1 65.8	23.8 60.3 104.2	18.8 73.8 91.8
LEAVE	3.7 28.3 55.0	12.8 22.4 39.0	1.3 35.3 95.4	3.7 26.1 88.0	1.3 23.9 95.4	10.6 37.7 54.1
VOLACRE	3.8 12.4 21.0	7.4 14.6 21.3	11.8 19.7 38.0	10.6 19.2 38.0	3.8 15.4 28.7	7.4 11.1 13.3
LOGSM	5.1 14.8 18.8	7.5 11.2 23.9	8.3 10.6 14.2	5.1 8.0 9.8	10.0 11.9 15.0	16.6 18.8 23.9
B1	0 0.52 1.0	0 0.74 1.0	0 0.72 1.0	0 0.81 1.0	0 0.65 1.0	0 0.37 1.0
B2	0 0.48 1.0	0 0.05 1.0	0 0.2 1.0	0 0.04 1.0	0 0.27 1.0	0 0.63 1.0
G1	0 0.12 1.0	0 0.26 1.0	0 0.08 1.0	0 0.23 1.0	0 0.15 1.0	0 0.11 1.0
SILV	48.6 74.6 94.7	33.9 63.9 89.1	40.1 64.4 96.9	40.1 66.7 94.7	45.0 73.7 96.9	33.9 64.9 86.5
Number of Observations	25	19	27	26	26	19

Number of obsevations = number of corridors yarded

Table 7. continued

Variable min mean max	30 - 49% REMOVAL	50-59% REMOVAL	60-69% REMOVAL	70-79% REMOVAL	80-89% REMOVAL	90-99% REMOVAL	30-99% REMOVAL
CUT	18.7 37.3 78.0	36.7 42.1 63.0	57.7 82.7 91.8	45.4 61.6 93.2	53.2 64.1 104.2	40.3 57.3 65.8	18.7 59.1 104.2
LEAVE	25.1 54.0 95.4	27.9 34.1 55.0	34.0 45.8 54.1	15.0 20.4 33.3	10.6 11.9 12.8	1.3 2.9 3.7	1.3 28.4 95.4
VOLACRE	3.8 19.8 38.0	7.4 12.9 15.9	11.0 12.7 14.6	11.1 16.2 20.6	9.2 11.5 21.3	14.8 18.9 21.0	3.8 15.6 38.0
LOGSM	7.5 10.8 18.0	8.5 13.2 23.9	11.8 17.3 18.8	8.0 11.7 18.0	10.0 12.2 16.6	5.1 7.9 13.6	5.1 12.3 23.9
B1	0 0.9 1.0	1.0 1.0 1.0	0 0.27 1.0	0 0.5 1.0	1.0 1.0 1.0	0 0.67 1.0	0 0.63 1.0
B2	0 0.1 1.0	0 0.0 0.0	0 0.73 1.0	0 0.3 1.0	0 0.0 0.0	0 0.3 1.0	0 0.28 1.0
G1	0 0.2 1.0	0 0.38 1.0	0 0.1 1.0	0 0.13 1.0	0 0.0 0.0	0 0.3 1.0	0 0.17 1.0
SILV	33.9 40.4 48.7	53.4 55.6 56.8	61.2 64.4 69.0	72.1 75.1 77.7	81.6 83.7 89.1	94.7 95.4 96.9	33.9 68.8 96.9
Number of Observation	10	8	11	30	6	6	71

Number of observations = number of corridors yarded

VI. RESIDUAL STAND DAMAGE ANALYSIS

A. REGRESSION ANALYSIS

Regression analysis was used to quantify the relationships between the dependent variables (DAMAGE, DAMA, DAMB) and the independent variables measured. The variables were entered into the general linear regression model:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_{p-1} + \epsilon$$

using a true stepwise selection procedure.

The REGRESSION procedure of the Statistical Package for Social Sciences (SPSS), (Nie, etal, 1975) was used to generate the regression equations. The system was run on the Control Data Corporation (CDC) 3300 computer (Cyber operating system), located in Milne Computer Center, Oregon State University, Corvallis, Oregon.

The acceptance or rejection of the independent variables in each of the regression equations were based on the three selection criteria described below:

--The first criteria was the significance level of the coefficients. Given the other variables in the model, each coefficient was tested under the hypothesis:

$$H_0 : \beta_i = 0 \quad \text{vs} \quad H_a : \beta_i \neq 0$$

Using the F* test statistic:

$$F^* = \frac{MSR(X_i | X_j)}{MSE(X_i | X_j)} \quad .$$

In the regression summaries which follow,

- *** indicates that the regression coefficient associated with an independent variable was found to be significantly different than zero at the 0.01 probability level;

- ** indicates that the regression coefficient was significantly different from zero at the 0.05 probability level, but not at the 0.01 probability level;

- * indicates that the regression coefficient was significantly different from zero at the 0.10 probability level, but not at the 0.05 probability level;

- $\bar{R}^2$ is the adjusted coefficient of determination as defined earlier;

- n is the number of observations (number of corridors) used to develop the model.

B. DEVELOPMENT OF MODELS

Data from the production study was available for 143 completely yarded skyline corridors. The silvicultural prescription for 52 of these corridors was clearcut. Damage data was recorded for some of these clearcut corridors; however, because the intent of the prescription was complete removal, these cases were not included in the damage data analysis.

Downhill yarding was used for 13 of the remaining 91 corridors. The other 78 corridors used uphill yarding. Due to the relatively small percentage of corridors utilizing downhill yarding, the decision was made to analyze the damage data for uphill yarded corridors separate from the damage data for downhill yarded corridors.

The data for uphill yarding damage was analyzed in several different

As stated earlier, those variables which influence damage were unknown before the regression analysis was completed. A case can be made for each of the variables as to the possibility of its inclusion in the model. For this reason, all of the independent variables were examined by the stepwise procedure.

The final equations developed for the dependent variables are:

DAMAGE =	45.76			n = 71
	+ 0.42 (LDGLENG)	***		$\bar{R}^2$ = .48
	+ 0.49 (LDGWID)	***		
	- 1.31 (LOGSM)	**		
	- 0.022 (B1)(SPAN)	***		
	- 0.023 (B2)(SPAN)	***		
DAMA =	-10.95			n = 71
	+ 0.46 (LDGLENG)	***		$\bar{R}^2$ = .51
	+ 0.37 (LDGWID)	***		
	+ 1.47 (VOLACRE)	***		
	- 0.51 (CUT)	***		
	+ 2.11 (DEFLECT)	***		
DAMB =	41.44			
	- 0.018 (SPAN)	***		n = 71
	- 1.33 (DEFLECT)	***		$\bar{R}^2$ = .12

The models were initially developed by using the stepwise procedure with all independent variables except the dummy variables and those variables created through interaction terms with the dummy variables. Once the initial and the decision are contained in Table 8. A 95 percent probability level was used.

Table 8. Testing the coefficient of determination for the overall models

ITEM	MODEL		
	DAMAGE	DAMA	DAMB
n	71	71	71
q	5	5	2
R^2	.514	.540	.141
F calculated	13.76	15.28	5.57
F critical	2.38	2.38	3.16
DECISION	REJECT NULL	REJECT NULL	REJECT NULL

For all three models, the decision was to reject the null hypothesis and that the models explained a significant amount of variation.

3. MODELS BASED ON SILVICULTURAL PRESCRIPTION

These models were developed to determine if the variation could be best explained by various different categories of percent removal of the stand. The categories of percent removal, the code which will be used to refer to each, and the number of cases for each category are listed in Table 9. Examination of the categories demonstrates that there are numerous combinations of models which could be developed to compare to the overall model. An example of one combination is (45)(6)(789) where a regression equation would be developed for each category in the parentheses.

Regression equations were developed for each of the categories shown in Table 9. There are 31 possible combinations of these categories which could be compared to the overall model.

The independent variables which entered the various equations were not restricted to those variables which entered the overall model. All independent variables were considered during the stepwise procedure. As a result, it was possible for each category to have a different group of independent variables used to explain the variation. This was done due to the lack of prior knowledge as to which independent variables should affect damage. The use of this technique eliminated the possibility of comparing the various full models with the reduced model through the use of an F test to determine whether the n regression lines have the same slope and the same intercept.

A three step procedure was utilized to compare the different models in order to arrive at the "best" models to use based on percent removal. The first step in comparing the different models was to test the equations to determine if the amount of variation they explained was significant. The test used was the F test described in the overall model section. This test determined whether the models should continue to be considered.

If the model explained a significant amount of variation, the variables in the model were examined. It was felt that should variables other than those in the overall model enter the category model, the equations were different.

The third test in determining the "best" models was the size of the adjusted coefficient of determination. If the $\bar{R}^2$ values were higher than that for the overall model, the category models were considered to be

Table 10. Statistical values for DAMAGE equations by percent removal categories.

CATEGORY	n	q	R^2	Fcalc	Fcrit[b]	DEC[a]	VARIABLES	$\bar{R}^2$
(1)	7	3	.99	83.08	4.35	R	SPAN, B2, B1TTHT	.98
(4)	10	1	.54	9.28	4.96	R	EYD	.48
(5)	8	0	--	---	---	-		-
(6)	11	1	.47	8.02	4.86	R	MAXLYD	.41
(7)	30	3	.82	38.29	2.92	R	LDGLENG, LANDAR, B2TTHT	.79
(8)	6	1	.59	5.74	5.99	NR	MAXLYD	.49
(9)	6	1	.97	115.28	5.99	R	LANDAR	.96
(45)	18	2	.60	11.11	3.57	R	B1MAXLYD, SPAN	.54
(56)	19	1	.45	13.73	4.39	R	LDGLENG	.41
(67)	41	4	.66	17.55	2.63	R	LDGLENG, LOGSM, SPAN LDGWID	.62
(78)	36	3	.70	25.09	2.89	R	LOGSM, LEAVE, LDGLENG	.67
(89)	12	2	.74	13.05	3.89	R	LOGSM, LDGLENG	.69
(456)	29	1	.37	15.78	4.19	R	MAXLYD	.35
(567)	49	4	.63	18.89	2.59	R	LDGLENG, LOGSM, SPAN LDGWID	.60
(678)	47	3	.57	18.66	2.83	R	SPAN, LANDAR, LOGSM	.54
(789)	42	3	.68	26.85	2.86	R	LDGLENG, LANDAR, SPAN	.65
(4567)	59	4	.58	18.76	2.54	R	LDGLENG, LOGSM, LDGWID SPAN	.55
(5678)	55	4	.61	19.35	2.56	R	LDGLENG, LOGSM, SPAN LDGWID	.58
(6789)	53	4	.59	17.38	2.57	R	LDGLENG,CUT,LDGWID,SPAN	.56
(45678)	65	4	.56	19.07	2.52	R	LDGLENG, LOGSM, SPAN LDGWID	.53
(56789)	61	4	.58	19.56	2.53	R	LDGLENG,CUT,LDGWID,SPAN	.55

a) R = reject null hypothesis NR = accept null hypothesis

b) 95% probability level

Table 12. Statistical values for DAMB equations by percent removal categories.

CATEGORY	n	q	R^2	Fcalc	Fcrit[b]	DEC[a]	VARIABLES	$\bar{R}^2$
(1)	7	-	-	---	---	-		-
(4)	10	1	.43	6.04	4.96	R	LEAVE	.36
(5)	8	-	-	---	---	-		-
(6)	11	-	-	---	---	-		-
(7)	30	1	.30	4.21	4.17	R	LOGSM	.10
(8)	6	1	.67	8.04	5.99	R	MAXLYD	.58
(9)	6	2	.97	50.84	5.14	R	CHORD, MAXLYD	.95
(45)	18	2	.43	5.73	3.57	R	B1VOLACRE, SPAN	.36
(56)	19	-	-	---	---	-		-
(67)	41	-	-	---	---	-		-
(78)	36	2	.35	8.87	3.29	R	DEFLECT, LEAVE	.31
(89)	12	1	.43	7.65	4.75	R	LEAVE	.38
(456)	29	-	-	---	---	-		-
(567)	49	-	-	---	---	-		-
(678)	47	3	.36	8.05	2.83	R	VOLACRE, SPAN, DEFLECT	.31
(789)	42	3	.45	10.44	2.86	R	VOLACRE, DEFLECT, SPAN	.41
(4567)	59	-	-	---	---	-		-
(5678)	55	4	.38	7.72	2.79	R	SPAN, DEFLECT, VOLACRE, TTHT	.33
(6789)	53	3	.35	8.83	2.80	R	VOLACRE, SPAN, DEFLECT	.31
(45678)	65	2	.15	5.41	3.99	R	SPAN, DEFLECT	.12
(56789)	61	4	.36	7.69	2.53	R	VOLACRE, SPAN, DEFLECT, TTHT	.31

a) R = reject null hypothesis Nr = accept null hypothesis

b) 95% probability level

The following equations are those selected ot predict DAMA based on the silvicultural prescription for the area.

30 - 49 % REMOVAL

$$\text{DAMA} = -1.22 + 0.068\ (\text{SPAN})^{**} \qquad n = 10,\quad \bar{R}^2 = .35$$

50 - 69 % REMOVAL

$$\text{DAMA} = 2.17 + 2.34\ (\text{DEFLECT})^{***} + 0.0064\ (\text{LANDAR})^{**} \qquad n = 19,\quad \bar{R}^2 = .50$$

70 - 79 % REMOVAL

$$\text{DAMA} = -21.37 + 0.011\ (\text{LANDAR})^{***} + 0.72\ (\text{LDGLENG})^{***} \qquad n = 30,\quad \bar{R}^2 = .63$$

80 - 99 % REMOVAL

$$\text{DAMA} = 7.15 + 4.04\ (\text{TTHT})^{***} \qquad n = 12,\quad \bar{R}^2 = .68$$

The percent of variation which each variable explains is diagrammed for each equation (Figure 8).

Discussion of the variables which entered each equation and the influence of those variables will be done in the section for discussion of the regression results. At that time, the variables which entered all of the various models will be examined to determine if particular variables are more important than other variables.

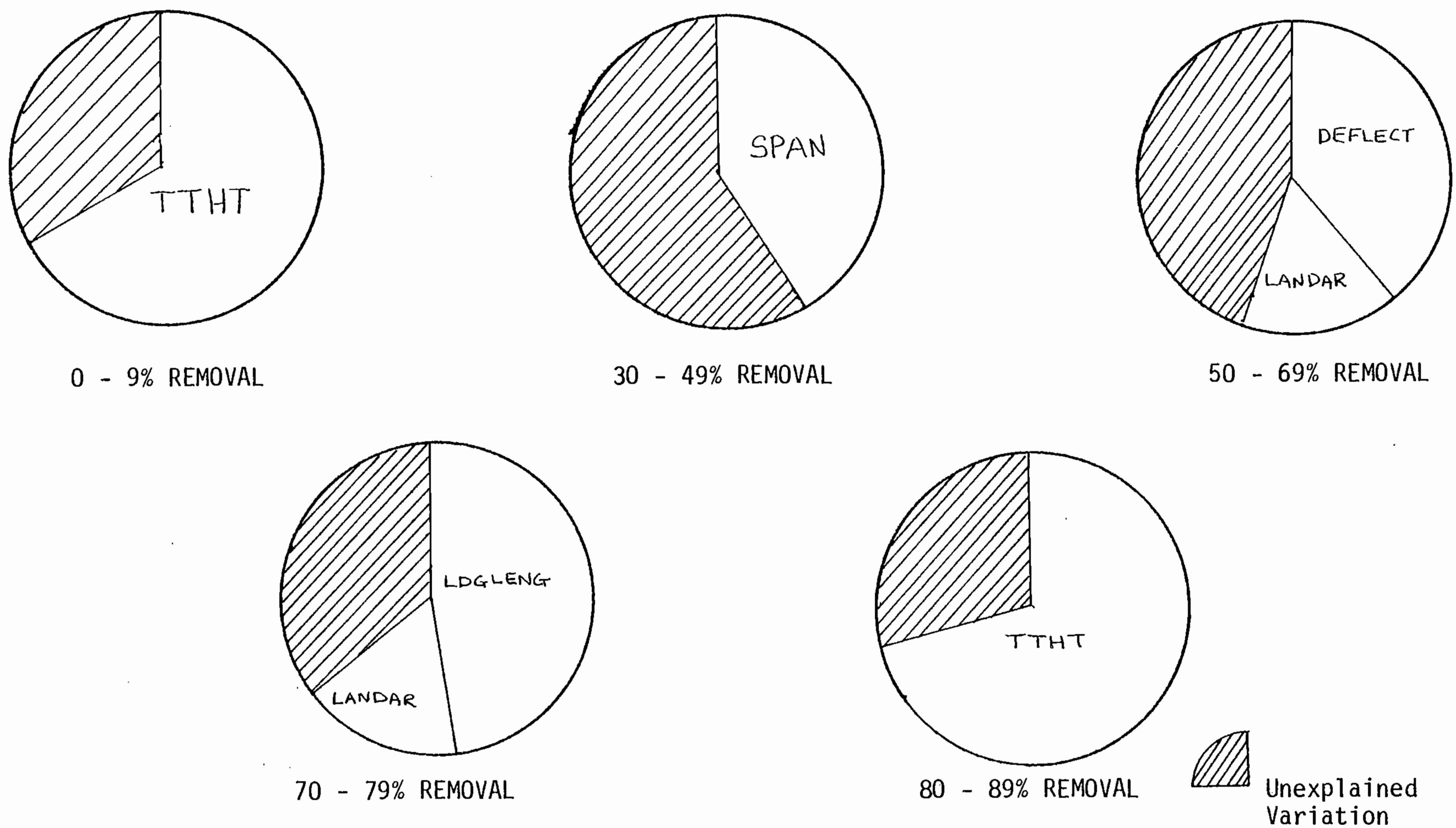


Figure 8. Variation explained for each variable in DAMA equations by silivicultural prescription.

4. MODELS BASED ON NUMBER OF 16.4' LOGS PER MBF

These models were developed in the same manner as those models based on silvicultural prescription. Any of the independent variables were allowed to enter. Those which did were subsequently tested with dummy variables and interaction terms. The values used to determine the significance of the equation, the variables which entered the equation, and the adjusted coefficient of determination are listed for each model in Tables 13, 14, and 15.

Following are the models chosen to predict DAMAGE based on the number of 16.4' logs per MBF.

<u>10 $<$ #LOGS PER MBF</u>

DAMAGE = -68.17 $n = 26$

+ 0.95 (LDGLENG)   *** $\bar{R}^2 = .75$

+ 8.61 (LOGSM)   ***

+ 0.28 (LEAVE)

<u>10 $\leq$ #LOGS/MBF $\leq$ 15</u>

DAMAGE = 31.38 $n = 26$

+ 0.17 (LANDAR)   ** $\bar{R}^2 = .18$

<u>15 $<$ #LOGS PER MBF</u>

DAMAGE = 34.75 $n = 19$

+ 0.38 (LDGLENG)   *** $\bar{R}^2 = .62$

- 0.026 (SPAN)   ***

The percent of variation which each variable explains is diagrammed for each equation (Figure 10).

Following are the models chosen to predict DAMA based on the number of 16.4' logs per MBF.

10 < #LOGS PER MBF

DAMA = -33.01 n = 26

+ 0.96 (LDGLENG) *** $\bar{R}^2$ = .67

+ 0.62 (LDGWID) ***

+ 3.60 (TTHT) *

10 ≤ #LOGS/MBF ≤ 15

DAMA = -19.03 n = 26

+ 0.49 (LDGLENG) *** $\bar{R}^2$ = .57

+ 3.84 (VOLACRE) ***

- 0.65 (CUT) **

15 < #LOGS PER MBF

DAMA = 10.37 n = 19

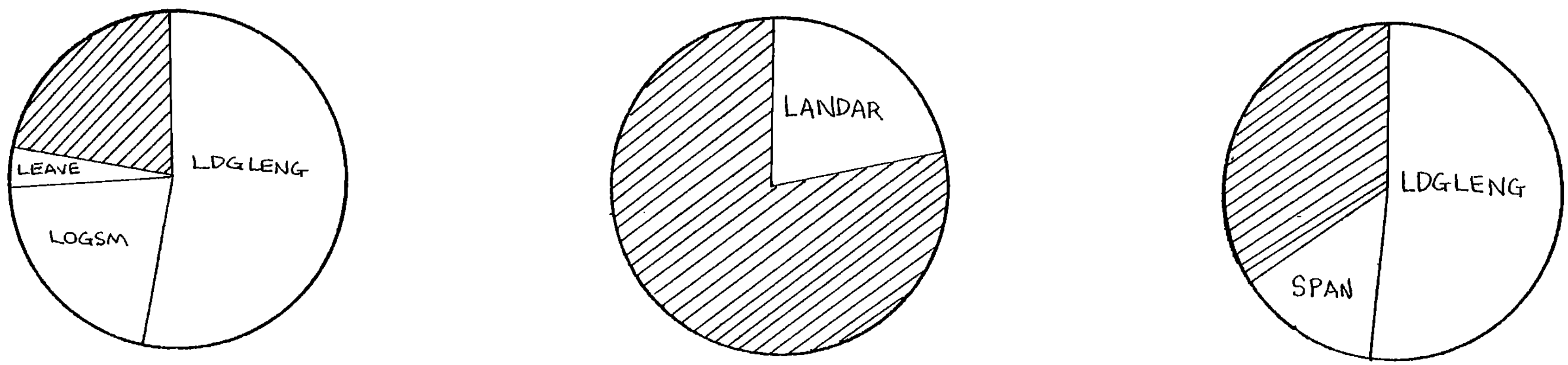
+ 7.05 (CHORD) *** $\bar{R}^2$ = .57

+ 0.26 (LDGLENG) **

- 0.53 (CUT) **

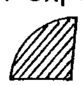
The percent of variation which each variable explains is diagrammed for each equation (Figure 11).

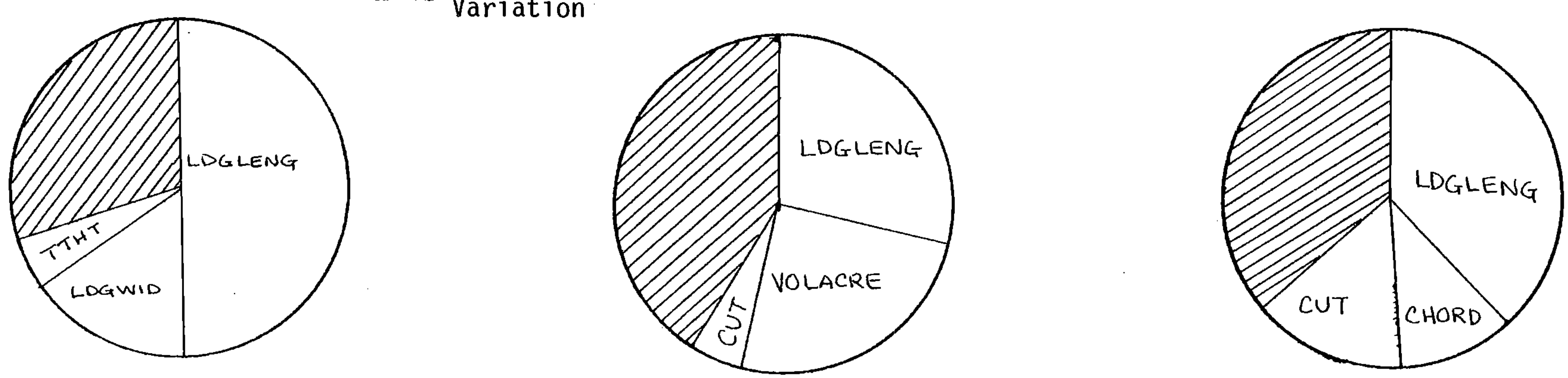
Following are the models chosen to predict DAMB based on the number of 16.4' logs per MBF.



10 < #LOGS/MBF | 10 ≤ #LOGS/MBF ≤ 15 | 15 < #LOGS/MBF

Figure 10. Variation explained by each variable in DAMAGE equations by number of logs per MBF.





10 < #LOGS/MBF | 10 ≤ #LOGS/MBF ≤ 15 | 15 < #LOGS/MBF

Figure 11. Variation explained by each variable in DAMA equations by number of logs per MBF.

Table 16. Statistical values For DAMAGE equations for LIVE SKYLINE system by silvicultural prescription category.

CATEGORY	n	q	R^2	Fcalc	Fcrit[b]	DEC[a]	VARIABLES	$\bar{R}^2$
(456789)	25	2	.53	12.45	3.33	R	SPAN, LANDAR	.49
(456)	11	1	.36	5.13	4.86	R	LOGSM	.29
(789)	14	2	.79	21.01	3.75	R	EYD, LDGLENG	.75

Table 17. Statistical values for DAMA equations for LIVE SKYLINE system by silvicultural prescription category.

CATEGORY	n	q	R^2	Fcalc	Fcrit[b]	DEC[a]	VARIABLES	$\bar{R}^2$
(456789)	25	3	.62	11.41	3.00	R	CHORD, G1TTHT, B1TTHT	.57
(456)	11	-	-	---	---	-		-
(789)	14	-	-	---	---	-		-

Table 18. Statistical values for DAMB equations for LIVE SKYLINE system by silvicultural prescription category.

CATEGORY	n	q	R^2	Fcalc	Fcrit[b]	DEC[a]	VARIABLES	$\bar{R}^2$
(456789)	25	2	.35	5.92	3.39	R	LDGWID, EYD	.29
(456)	11	-	-	---	---	-		-
(789)	14	2	.66	10.53	3.75	R	LDGLENG, CHORD	.59

a) R = reject null hypothesis NR = accept null hypothesis

b) 95% probability level

Table 22. Statistical values for DAMAGE equations for RUNNING SKYLINE system by silvicultural prescription category.

CATEGORY	n	q	R^2	Fcalc	Fcrit[b]	DEC[a]	VARIABLES	$\bar{R}^2$
(45679)	27	4	.74	15.69	2.74	R	LANDAR, CHORD, TTHT, CUT	.69
(456)	11	1	.68	19.49	4.86	R	B1LEAVE	.65
(7)	15	3	.78	12.07	3.29	R	LANDAR, CHORD, LEAVE	.72

Table 23. Statistical values for DAMA equations for RUNNING SKYLINE system by silvicultural prescription category.

CATEGORY	n	q	R^2	Fcalc	Fcrit[b]	DEC[a]	VARIABLES	$\bar{R}^2$
(45679)	27	1	.49	24.22	4.22	R	LANDAR	.47
(456)	11	1	.54	10.39	4.86	R	B1LEAVE	.48
(7)	14	1	.55	14.54	4.54	R	LANDAR	.51

Table 24. Statistical values for DAMB equations for RUNNING SKYLINE system by silvicultural prescription category.

CATEGORY	n	q	R^2	Fcalc	Fcrit[b]	DEC[a]	VARIABLES	$\bar{R}^2$
(45679)	27	1	.31	10.99	4.22	R	CHORD	.28
(456)	11	1	.54	10.54	4.86	R	B1CHORD	.49
(7)	15	2	.69	12.25	3.68	R	B1, B1VOLACRE	.63

a) R = reject null hypothesis NR = accept null hypothesis

b) 95% probability level

Following are the equations chosen to predict DAMA based on the type of skyline system used to yard the area.

LIVE SKYLINE 30 - 99% REMOVAL

$$\text{DAMA} = -20.46 + 0.76\,(\text{CHORD})^{***} - 7.04\,(\text{G1})(\text{TTHT})^{***} + 0.83\,(\text{B1})(\text{TTHT})$$

$n = 25$, $\bar{R}^2 = .57$

STANDING SKYLINE 30 - 59% REMOVAL

$$\text{DAMA} = -113.86 + 17.19\,(\text{VOLACRE})^{***}$$

$n = 7$, $\bar{R}^2 = .78$

STANDING SKYLINE 70 - 89% REMOVAL

$$\text{DAMA} = 4.04 + 7.19\,(\text{DEFLECT})^{***}$$

$n = 12$, $\bar{R}^2 = .52$

RUNNING SKYLINE 30 - 69% REMOVAL

$$\text{DAMA} = 0.40\,(\text{B1})(\text{LEAVE})^{***}$$

$n = 11$, $\bar{R}^2 = .48$

RUNNING SKYLINE 70 - 79% REMOVAL

$$\text{DAMA} = -5.34 + 0.035\,(\text{LANDAR})^{***}$$

$n = 14$, $\bar{R}^2 = .52$

The percent of variation which each variable explains is diagrammed for each equation (Figure 14).

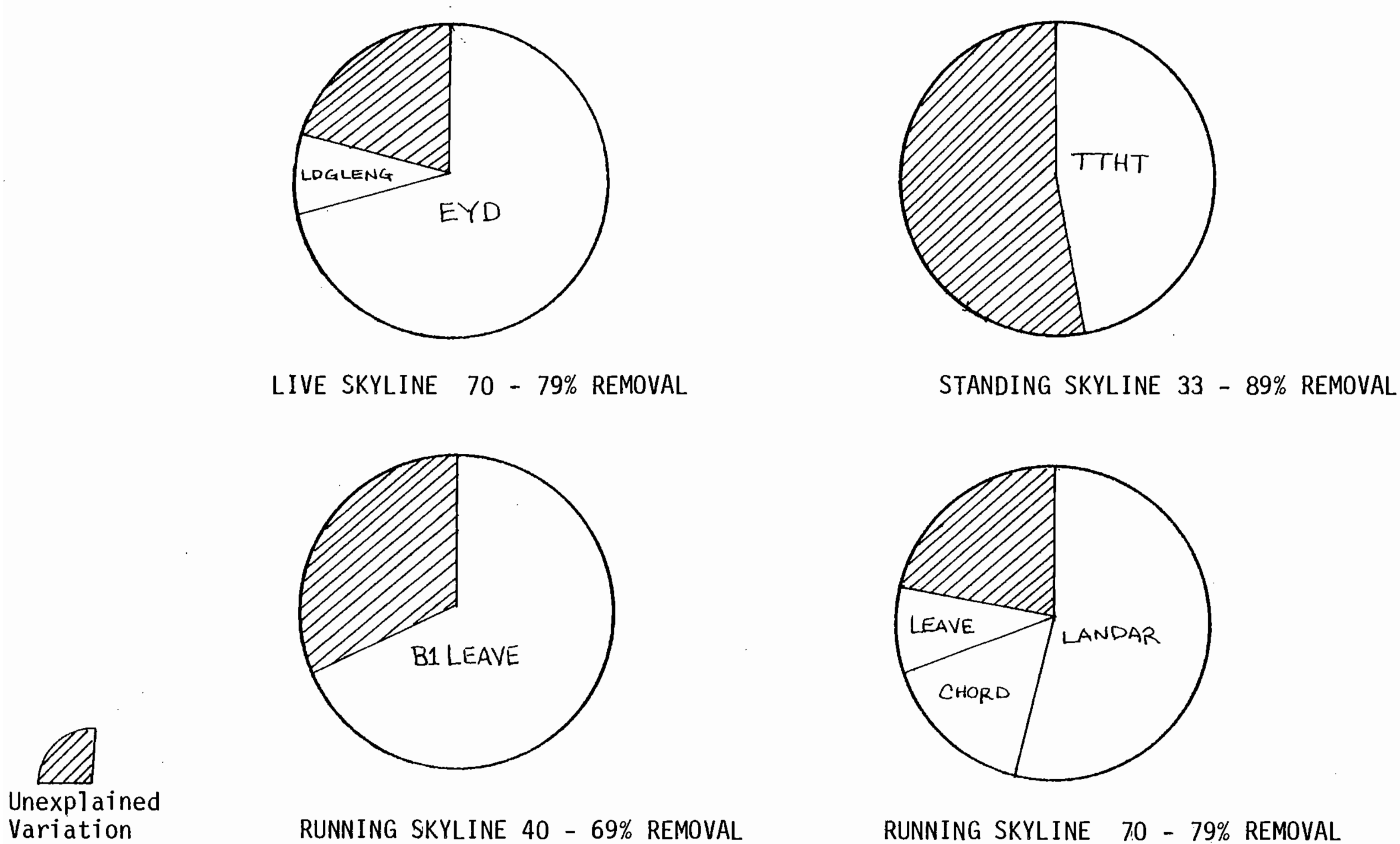


Figure 13. Variation explained by each variable in DAMAGE equations by skyline system.

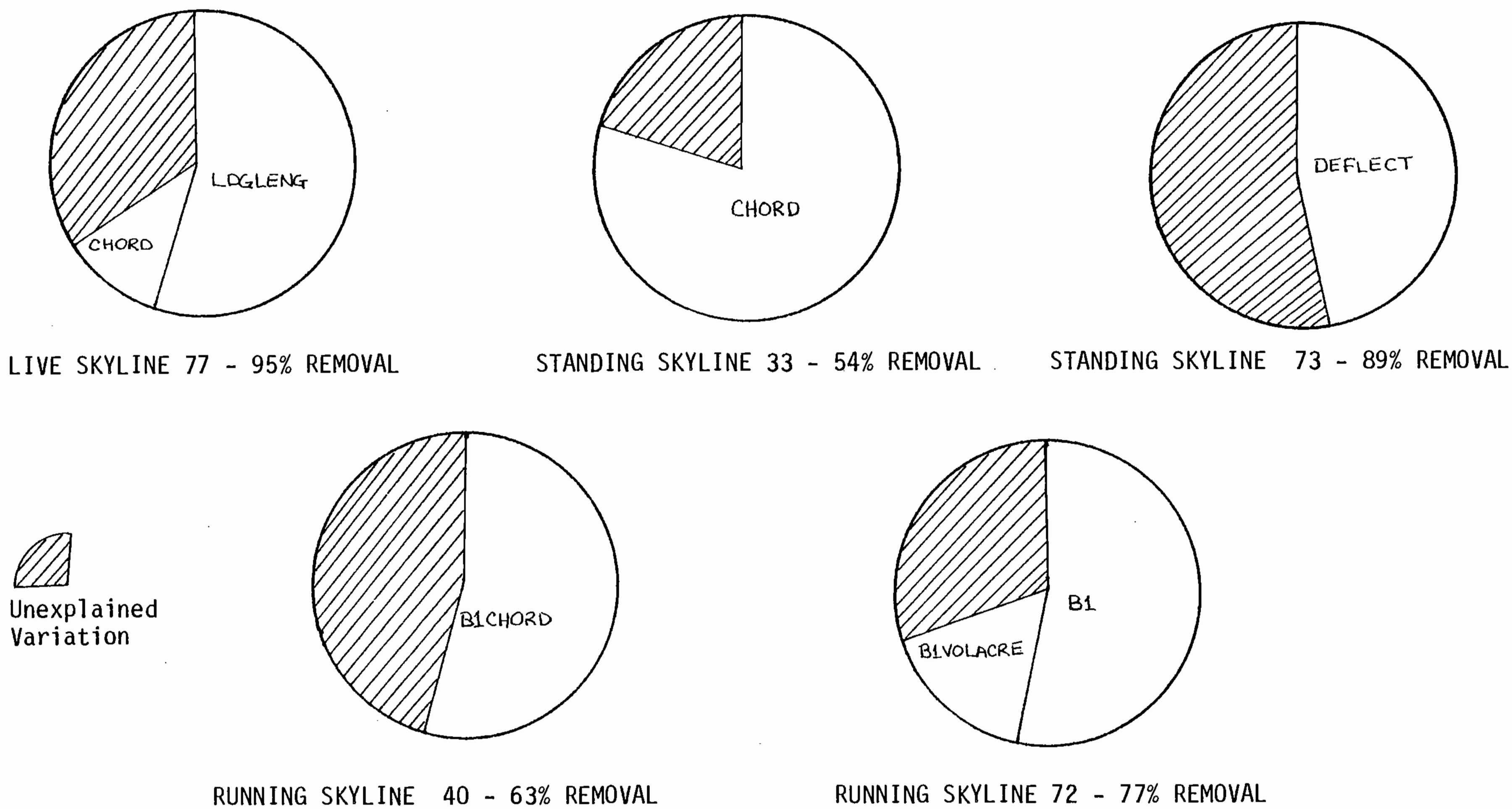


Figure 15. Variation explained by each variable in DAMB equations by skyline system.

A. DAMAGE

All of the independent variables except DEFLECT, LDGWID, AND CUT entered at least one DAMAGE model. As seen from Table 25, LDGLENG and LANDAR entered most frequently. These two variables always served to increase the percent of damage to the residual stand. One possible explanation for their entry might be the type of decking used. Decking done on the fill slope and down into the unit could cause an increase in damage. The longer the landing, the more area available to deck along the road. These two variables need to be examined more closely during future studies.

As the number of logs per thousand increased, the amount of damage increased. This is acceptable in that a higher number of logs per MBF may result in more turns being needed to yard the unit. The number of leave trees also had the effect of increasing damage. As the number of leave trees increase, the probability that a tree will be in an area of high danger increases.

The maximum lateral yarding distance decreased damage in one equation. This may be due to the fact that most of the damage in a yarding situation occurs near the corridor and a longer lateral yarding distance reduces the number of corridors needed.

Chordslope had the effect of increasing damage in one model and tail tree height decreased damage in another. These two could be somewhat related in that as tail tree height increase, chord slope will decrease. It may be possible that a flatter chordslope reduces the amount of movement of the load.

External yarding distance decreased damage in one model and horizontal span entered models with a negative sign and a positive sign. One reason

The variables which entered the DAMB equations were often interaction terms with dummy variables (B1). This indicates that a medium amount of brush may have an impact on the amount of damage incurred during yarding. It would seem that brush may serve to decrease the amount of damage as it would take up some of the yarding impacts and might surround the leave trees. However, in the DAMB equations this often had the effect of increasing the percent of the residual stand which was damaged. This also needs further study.

VIII. APPLICATION OF THE REGRESSION RESULTS

The decision remains as to which model the land manager can actually utilize. It is recommended that only those equations which explain more than 50% of the variation be applied in management decisions. It is also preferable to use those models built on a larger number of cases.

In order to compare the effectiveness of the different types of models, an example from the study data is presented below:

Running Skyline 12.3 Logs/MBF 77% Removal

% Removal	26.62 - 7.97 (B2)(TTHT) + .5 (LDGLENG) + .005 (LANDAR)
	26.62 - 7.97 (0)(5) + .5 (30) + .005 (480) = 4.17%
Logs/MBF	34.75 + .38 (LDGLENG) - 0.026(SPAN)
	34.75 + .38 (30) - 0.026 (1410) = 9.49%
System	-102.83 + .047 (LANDAR) + 1.24 (CHORD) + 2.93 (LEAVE)
	-102.83 + .047 (480) + 1.24 (3) + 2.93 (33.3) = 21.02%

The actual damage on that setting was 19.7%. In this case, the system equation would have provided the best estimate. However, during the testing of the equations in this manner, all types of models were found to provide the best estimate approximately equal number of times.

will apply to the West Side Zone and can be used to estimate the yarding production at the site rather than the yarding production of a particular setup.

Future data collection is planned to use as validation data for these regression models. Should the models be validated, this type of study is highly applicable to obtain estimates for wide usage rather than for specific machines and areas.

X. SUGGESTIONS FOR FUTURE RESEARCH

This report has provided some basic information about damage due to skyline logging. However, there are still many questions which need to be answered:

1. The manner in which the data is measured is important. This study utilized information as to the percent of residual stems sustaining damage. Other studies have looked at the size and type of wounds incurred. It would be useful to have a study which could predict the impact of the damage to the stand.
2. Questions were raised as to the variables which entered and their impact on damage. In particular, the effect of landing size on damage needs to be more fully examined. Tail tree height had differing effects based on the dependent variable being examined. It should be analyzed more fully.
3. Brush seemed to have an important effect on damage. Future studies might examine brush data more fully and develop a classification scheme for use by model users.

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