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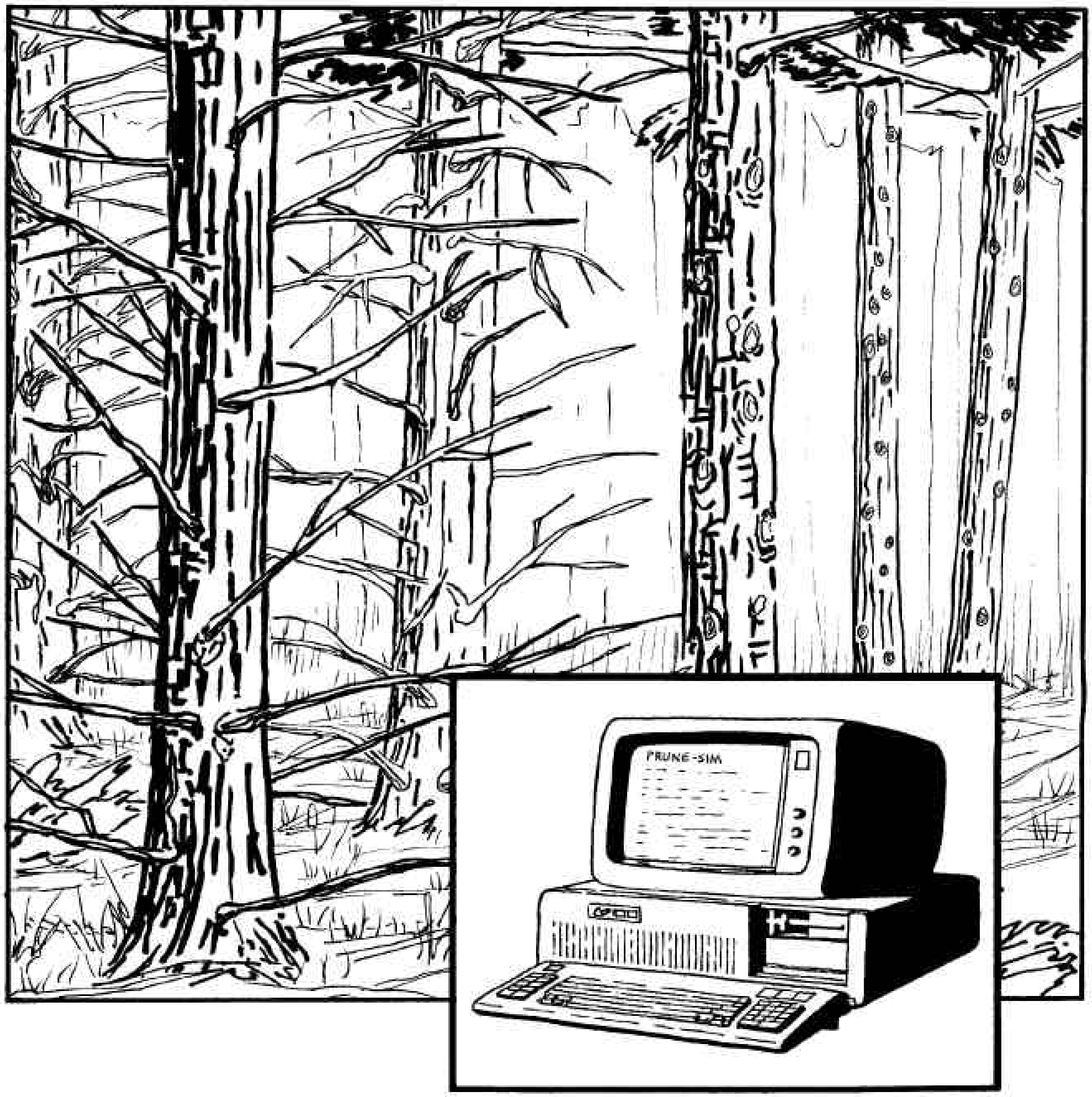
PRUNE – SIM Users Guide

Roger D. Fight, James M. Cahill, Thomas A. Snellgrove, and Thomas D. Fahey



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The Forest Resources Systems Institute
Courtview Towers, Suite 24
201 North Pine Street
Florence, Alabama 35630
(205) 767-0250

Authors

ROGER D. FIGHT is principal economist, JAMES M. CAHILL is research forester, THOMAS A. SNELLGROVE is principal research forest products technologist, and THOMAS D. FAHEY is research forester, Forestry Sciences Laboratory, P. O. Box 3890, Portland, Oregon 97208.

Abstract

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PRUNE-SIM is a spreadsheet template (program) that allows users to simulate a financial analysis of pruning coast Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii).* The program estimates the increase in product value resulting from pruning the butt 17-foot log. Product recovery information is based on actual mill experience with pruned and unpruned logs for both sawn and peeled products. Users must supply tree descriptions from sources of growth and yield information and product prices. The program calculates the difference in value for trees and stands with and without pruning. The present value of this difference represents the maximum amount that could be spent on pruning without reducing the rate of return on the investment below the specified rate. The LOTUS 1-2-3 spreadsheet program was used to develop PRUNE-SIM. The user needs a basic knowledge of spreadsheets to use this program.

Keywords: Simulation, pruning, Douglas-fir (coast), forest product value, product recovery.

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Introduction

During the last four decades in which coast Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii)* has been managed, pruning has often been suggested as a forest-management tool. The effects of pruning in young-growth stands of Douglas-fir have been documented in numerous studies (for example, Dimock and Haskell 1962, Dobie and Wright 1978, Fensom 1957, McBride 1961), and the literature supports a common theme-pruning is the only way to ensure the growth of significant volumes of clear wood in intensively managed stands. Given the short harvest cycles used in current management plans and the limb retention characteristics of Douglas-fir, the growth of clear wood in unpruned young-growth stands is minimal. What has not been well documented is the lumber and veneer grade recovery from pruned logs and the financial returns that can be expected from pruned stands. The purpose of this report is to document a computer program that can be used to analyze the financial return when pruning is applied to a wide range of management regimes.

PRUNE-SIM is a spreadsheet template (program) that can be used to simulate a financial analysis from pruning coast Douglas-fir. The program estimates the increase in product value from pruning 17-foot butt logs. It is based on lumber and veneer volume and grade recovery information reported by Cahill and others (in press). The spreadsheet requires tree descriptions from sources of growth and yield information such as DFSIM (Curtis and others 1981), TASS (Mitchell and Cameron 1985), and Technical Bulletin 201 (McArdle and others 1961). Besides the tree descriptions, users must supply prices by product grade. The spreadsheet will simulate the difference in value for trees and stands with and without pruning. The present value of this difference represents the maximum amount that could be spent on pruning under the assumed conditions without reducing the rate of return on the investment below the specified rate.

The LOTUS 1-2-3 spreadsheet program was used to develop PRUNE-SIM.

Cautions

Three cautions should be observed when this program is used:

1. Users should exercise judgment when doing analyses outside the range of the tree sizes sampled and should remember that the recovery estimates are based on pruning of the first 17-fool butt log.
2. Users should be aware that additional costs of managing pruned stands that occur after the stands are pruned are not considered in this analysis.
3. Users should recognize the uncertainties of predicting future prices of clear wood products.

The trees on which the recovery information is based came from a range of sites, but from a small geographic area. The stands sampled were of natural origin and had been repeatedly thinned but were maintained at denser stocking levels than is now considered desirable. Figure 1 shows diameters of sample trees at time of pruning and at time of harvest.

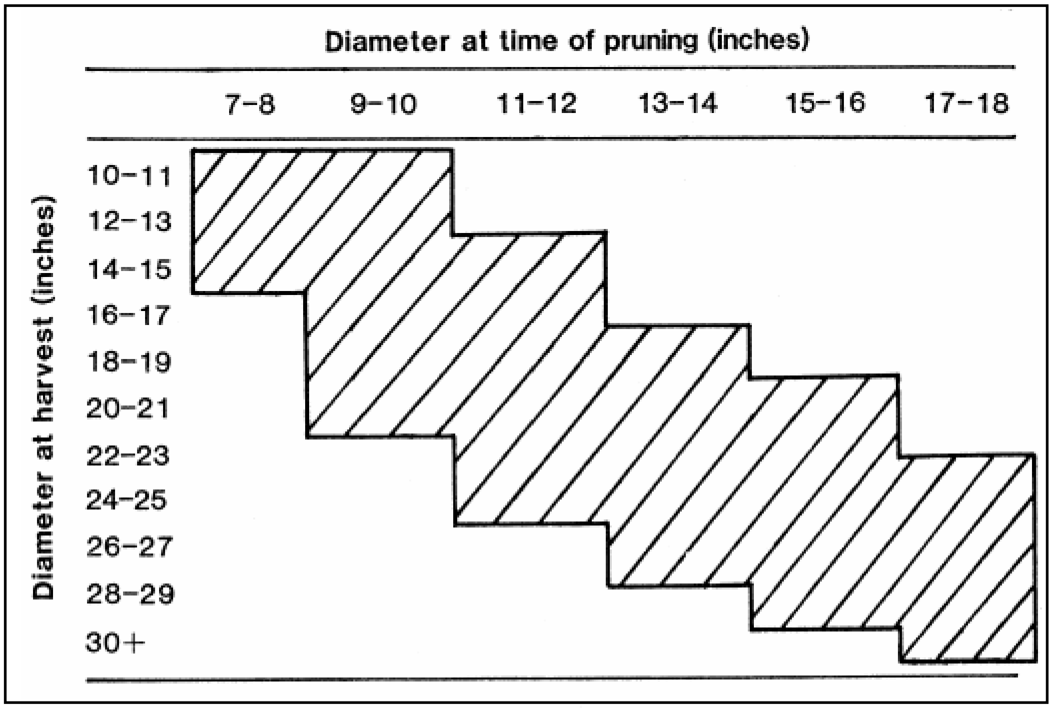

Figure 1—Distribution of sample trees by DBH when trees were pruned and DBH when trees were harvested.

We have no recent cost information on pruning; thus, PRUNE-SIM determines the maximum amount that could be spent on pruning without reducing the return below the specified rate. Additional costs, however, are ignored in these calculations; for example, additional recordkeeping will be required. In a reasonably competitive stumpage market, buyers will be willing to pay a premium for pruned logs that reflects the increase in value resulting from recovery of clear wood products. This is the rationale for using the difference in product value plus the difference in costs of harvesting and manufacturing as the basis for evaluating the returns from pruning. Convincing buyers of the quality of pruned logs may require records showing tree or stand descriptions. Even if the trees obviously were pruned, documented proof of the size of trees at time of pruning may be necessary so that the amount of clear wood can be estimated.

The characteristics of clear wood products produced from pruned young-growth Douglas-fir are different from similar products from old-growth Douglas-fir. One key difference is appearance. As long as clear wood products from old growth are available, the market is likely to be biased against clear wood from pruned young growth. Once clear wood from old growth is no longer available in sufficient quantity to meet the demand without large price increases, however, the bias against young growth should diminish.

How To Use PRUNE-SIM

Figure 2 shows the general layout of the PRUNE-SIM spreadsheet program. The spreadsheet consists of five blocks, each filling one screen width. The five blocks and a brief description are:

1. Lumber. Values for pruned saw logs are computed. This block of the spreadsheet is divided into two sections: lines 1-39 contain the input needed to run the program and the output; lines 41-66 contain the equations used to make the computations.

2. Veneer. Values for pruned veneer logs are computed. This block of the spreadsheet is similar to the one for lumber: lines 1-39 contain the input and output; lines 41-66, the equations used to make the computations.

3. Log diameters. A tree profile equation is used to estimate the diameters of the 17-foot butt log at the time ot-pruning and at the time of harvest. Total height and DBH (diameter at breast height) are independent variables in the profile equation.

4. Summary output. This block is for storing the results of PRUNE-SIM runs. Users may simulate pruning under a variety of assumptions and store the results for later analysis.

5. "Macro." This block contains a series of commands that allow users to analyze pruning under two price assumptions. Results are automatically stored in block 4.

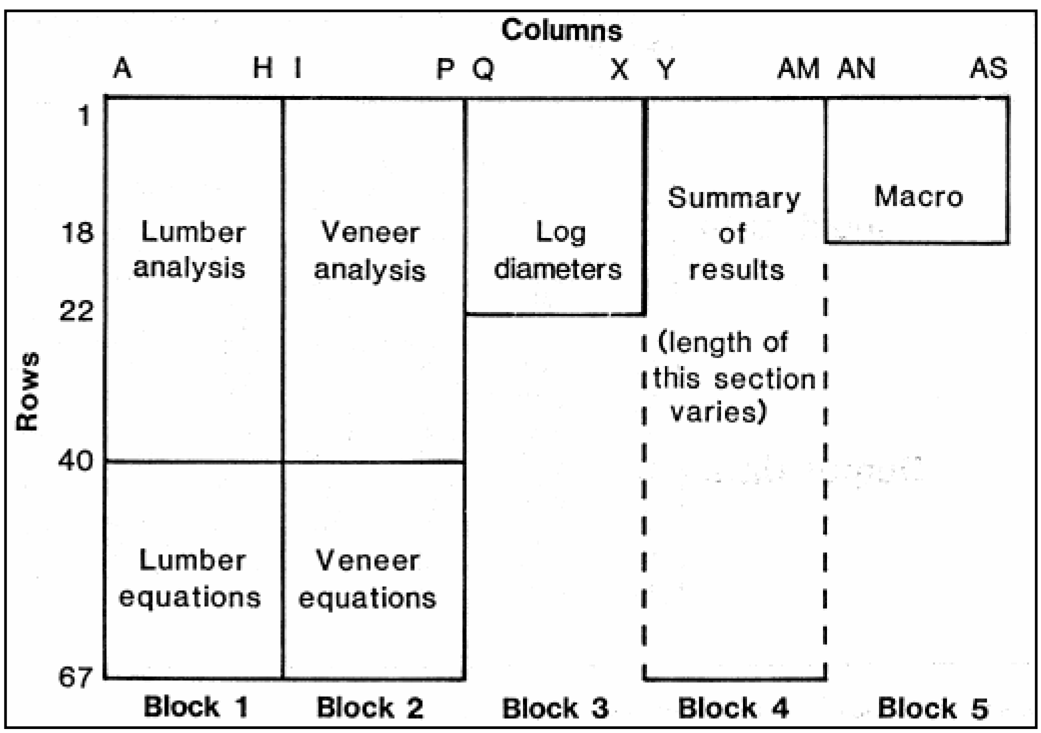

Figure 2—General layout of the PRUNE-SIM spreadsheet. Letters and numbers refer to columns and rows in the spreadsheet.

Use of PRUNE-SIM is demonstrated by the following:

Program input and program output. The general information needed to run the program and the output generated by the program will be illustrated with the lumber portion of the spreadsheet (fig. 3).

Intermediate calculations. The intermediate calculations made by the program are reviewed (fig. 4). This section provides users with a detailed view of the computations made in the PRUNE-SIM spreadsheet.

Veneer analysis. The format for the veneer portion of the spreadsheet is essentially the same as for lumber (fig. 5).

Log diameters. The tree profile equation used to estimate log diameters at the time of pruning and at the time of harvest is discussed (fig. 6).

Average diameter of pruned trees.. A technique that converts the average stand DBH to the average DBH of the pruned trees within a stand is discussed (fig. 7).

Macro feature in PRUNE-SIM. The macro feature allows users to make several PRUNE-SIM runs and store the results for further analysis (figs. 8,9, and 10).

1. Program Input and program Output

Figure 3 is an example, based on lumber, of an abbreviated spreadsheet. This figure shows only the information needed as input and the results portion of the spreadsheet. All the input is contained in rows 1-7. Five types of information are needed to run the program:

Input data

	A	B	C	D	E	F	G	H
1		PRUNING RECOVERY - LUMBER					51	05-Feb
2	LENGTH	STUMP	HEIGHT2	DBH2	HEIGHT1	DBH1	AGE1	AGE2
3	17	1	153	25.5	53	10.4	20	60
4	SD2	LD2		SD1	LD1		TREES	SUCCESS
5	20.4	26.5		7.5	12.6		60	0.95
6	PRSEL	PRSS	PRSTD	PRUE	SITE	PCT	DFSIM	TAX
7	542	250	191	111	145	300	175	1

Output data

	A	B	C	D	E	F	G	H
27		PRESENT VALUE (PVTREE and PVACRE)						
28	RATE	TREE	ACRE	LOGVOL	PCCLR	LRF	PSELU	PSELP
29	0.00	42.73	2564	45.2	75	9.2	0.20	0.53
30	0.01	28.70	1722					
31	0.02	19.35	1161	GPVU	GPVP	GPVD		
32	0.03	13.10	786	- - - - -	$/MCF	- - - - -		
33	0.04	8.90	534	2584	3579	994		
34	0.05	6.07	364					
35	0.06	4.15	249	GPVUL	GPVPL	GPVDL		
36	0.07	2.85	171	- - - - -	$/LOG	- - - - -		
37	0.08	1.97	118	116.90	161.88	44.98		
38	0.09	1.36	82					

Figure 3—An example of an abbreviated spreadsheet for saw logs. Letters and numbers refer to the columns and rows in the spreadsheet.

Tree descriptions.—The tree descriptions are contained in cells C3 to H3. Users must get this information from yield tables such as DFSIM (Curtis and others 1982). The specific information in each cell is:

C3 = HEIGHT2, height at time of harvest;
D3 = DBH2, diameter at time of harvest;
E3= HEIGHT1, height at time of pruning;
F3 = DBH1, diameter at time of pruning;
G3 = AGE1, age at time of pruning; and
H3 = AGE2, age at time of harvest.

Log-diameter computations.—Cells AS to E5 are the large and small diameters of the butt 17-foot log at time of pruning (LD1, SD1) and at time of harvest (LD2, SD2). The information entered under the tree descriptions is used by the program in computing these diameters. Cubic-foot log volumes and the percentage of clear wood are estimated from these dimensions. Details of these computations will be discussed later. The specific information in each cell is:

A5 = SD2, small-end diameter of the butt log at time of harvest;
B5 = LD2, large-end diameter of the butt log at time of harvest;
D5 = SD1, small-end diameter of the butt log at time of pruning;
E5 = LD1, large-end diameter of the butt log at time of pruning.

Number of trees and success.—An estimate of the number of trees to be pruned and the proportion surviving to age of harvest must be mad-e by the user. The specific information in the cells is:

G5 = TREES, the number of pruned trees per acre;
H5 = SUCCESS, the proportion of pruned trees assumed to be present at the time of harvest.

Lumber prices.—Users must supply the lumber prices (dollars per thousand board, feet lumber tally) for the following lumber grade groups:

A7 = PRSEL, price for D select and better;
B7 = PRSS, price for select structural;
C7 = PRSTD, price for standard and better; and,
D7 = PRUE, price for utility and economy.

Run identifier.—Cells E7, F7, and G7 contain information not used by the program but included to help identify the run:

E7 = SITE, King's (1966) 50-year site index.
F7 = PCT, the number of trees planted in an unthinned plantation or the number of trees remaining after precommercial thinning.
G7 = DFSIM, the page number in Curtis and others (1982) from which the tree descriptions used in this report are taken.

Tax information. —Cell H7 contains a tax adjustment factor. It is computed by subtracting the tax rate on income from the sale of lumber products from 1.0. This value will be used to convert an increase in gross product value resulting from pruning to an increase in gross product value that is net of income taxes. Use of 1.0 gives an analysis before taxes or when taxes are not relevant.

The financial output generated by PRUNE-SIM is shown in lines 27-38. Columns B and C show the present value per tree and per acre at the interest rate shown in column A. The equation used to calculate present value is:

$$\text{Present value} = \frac{\text{value pruned - value unpruned}}{(1 + i)^n},$$

where:
value pruned is the value of the product from a pruned log, value unpruned is the value of the product from an unpruned log, i is the interest rate, expressed as a decimal, and n is the number of years between pruning and harvest.

These values are net of income taxes if a tax multiplier other than 1.0 is input in cell H7. The other information comes from intermediate calculations and is summarized here:
D29 = LOGVOL, volume of the butt log at time of harvest;
E29 = PCCLR, percent of the log that is clear wood;
F29 = LRF (lumber-recovery factor), board feet of lumber tally per cubic foot of log;
G29 = PSELU, proportion of lumber in the select grade from the unpruned log;
H29 = PSELP, proportion of lumber in the select grade from the pruned log.
The remaining cells show the gross product value per MCF (thousand cubic feet) and per log for unpruned and pruned logs (GPVU, GPVP, GPVUL, GPVPL) and the difference in gross product value per MCF and per log that results from pruning (GPVD, GPVDL).

2. Intermediate Calculations

Figure 4 shows the unabridged form of the spreadsheet for the example shown in figure 2. It is divided into two sections; 1-7 and 1A-7A. The documentation in 1A- 7A lists the equations used for the calculations in 1-7. A detailed description of all calculations follows.

Most of section 1 is input data and was described earlier. As the documentation in section 1 A- 7 A indicates, the calculations for log diameters (SD1, LD1, SD2, and LD2) are performed in another portion of the spreadsheet and will be discussed later.

In section 2, the cubic volume of the log at harvest (LOGVOL) is calculated by Bruce's butt-log formula (Bruce 1982). The percentage of clear volume (PCCLR) is calculated as the difference between the volume of the log at harvest and the volume at the time of pruning plus 1 inch of radial growth to allow for "healover" of the pruned branches.

In section 3, the lumber-recovery factor (LRF) and the proportion of lumber from unpruned logs that falls into each of the lumber grade groups (PSELU, PSSU, PSTDU, and PUEU) are estirilatedfrom the equations shown in section 3A. The equations for the proportion of select (PSELU) and select structural (PSSU) are conditioned to be never less than zero.

Section								
	PRUNING RECOVERY - LUMBER						51	05-Feb
1	LENGTH	STUMP	HEIGHT2	DBH2	HEIGHT1	DBH1	AGE1	AGE2
	17	1	153	25.5	53	10.4	20	60
	SD2	LD2		SD1	LD1		TREES	SUCCESS
	20.4	26.5		7.5	12.6		60	0.95
	PRSEL	PRSS	PRSTD	PRUE	SITE	PCT	DFSIM	TAX
	542	250	191	111	145	300	175	1
2	LOGVOL	PERCENT CLEAR VOLUME (PCCLR)						
	45.2	75						
3		PROPORTION OF LUMBER (UNPRUNED LOGS)						
	LRF	PSELU	PSSU	PSTDU	PUEU			
	9.2	0.20	0.47	0.25	0.08			
4	LRF	PROPORTION SELECTS FROM PRUNED LOGS (PSELP)						
	9.2	0.53						
5	GROSS PRODUCT VALUE ($/MCF)							
	GPVU	GPVP	GPVD					
	2584	3579	994					
6	GROSS PRODUCT VALUE ($/LOG)							
	GPVUL	GPVPL	GPVDL					
	116.90	161.88	44.98					
7		PRESENT VALUE (PVTREE and PVACRE)						
	RATE	TREE	ACRE	LOGVOL	PCCLR	LRF	PSELU	PSELP
	0.00	42.73	2563.92	45.2	75	9.2	0.20	0.53
	0.01	28.70	1722.07					
	0.02	19.35	1161.18	GPVU	GPVP	GPVD		
	0.03	13.10	785.99	- - - - -	$/MCF	- - - - -		
	0.04	8.90	534.04	2584	3579	994		
	0.05	6.07	364.19					
	0.06	4.15	249.27	GPVUL	GPVPL	GPVDL		
	0.07	2.85	171.22	- - - - -	$/LOG	- - - - -		
	0.08	1.97	118.02	116.90	161.88	44.98		
	0.09	1.36	81.63					
	0.10	0.94	56.65					

1A
```
SD=BRUCE'S DOUGLAS-FIR PROFILE EQUATION CALCULATED AT Q1..V11
LD=BRUCE'S DOUGLAS-FIR PROFILE EQUATION CALCULATEC AT Q1..V11
```

2A
```
LOGVOL=0.005454*LENGTH*(0.75*SD2^2+0.25*LD2^2)
PCCLR=(1-(0.005454*LENGTH*(0.75*(SD1+2)^2+0.25*(LD1+2)^2)/
    LOGVOL))*100
```

3A
```
LRF=8.94-31.56/SD2+3.03*(SD2^2/(LD2)^2)
PSELU=@IF(PSELU>=0,.3599-3.3145/SD2,0)
PSSU=@IF(PSSU>=0,.6808-.0103*SD2,0)
PSTDU=.250
PUEU=1-PSELU-PSSU-PSTDU
```

4A
```
PSELP=@IF(PSELP>=0,(-2.64+0.1*PCCLR)/LRF,0)
```

5A
```
GPVU=(PSELU*PRSEL+PSSU*PRSS+PSTDU*PRSTD+PUEU*PRUE)*LRF
GPVP=(PSELP*PRSEL+((1-PSELP)/(1-PSELU))*(PSSU*PRSS+PSTDU*PRSTD+PUEU*
    PRUE))*LRF
GPVD=GPVP-GPVU
```

6A
```
GPVUL=GPVU*LOGVOL/1000
GPVPL=GPVP*LOGVOL/1000
GPVDL=GPVPL-GPVUL
```

7A
```
PVTREE=GPVDL/(1+RATE)^(AGE2-AGE1)*TAX*SUCCESS
PVACRE=PVTREE*TREES
```

Figure 4—Spreadsheet example for saw logs. Sections 1-7 contain various outputs from the program; sections 1A- 7A, the equations used to make the calculations.

In section 4, the lumber-recovery factor (LRF) is simply repeated. The lumber recovery is the same for pruned and unpruned logs. The proportion of select lumber from pruned logs (PSELP) is computed from the equation shown in section 4A. This equation is conditioned to be never less than zero.

In section 5, the gross product value per MCF of log volume is calculated for unpruned (GPVU) and pruned logs (GPVP) from the proportions of lumber grades, the lumber-recovery factor, and the prices for each grade.

The difference in value (GPVD) is the increase in value resulting from pruning. Increased volume of selects from pruned logs comes from a proportionate reduction of volume in the lower grades. The proportion of volume in the lower grades for pruned logs is calculated by use of the factor (1-PSELP)/(1-PSELU) and the proportions of lower grades for pruned logs.

In section 6, the value for pruned and unpruned logs (GPVPL and GPVUL) and the difference in value (GPVDL) is expressed in dollars per log.

In section 7, the present values per tree (PVTREE) and per acre (PVACRE) are calculated from the equations in section 7 A. The other values are repeated from previous sections of the spreadsheet.

3. Veneer Analysis

Figure 5 shows in unabridged form the portion of the spreadsheet for the analysis of pruning for veneer; it is similar to the section for lumber. The PRUNE-SIM spreadsheet is designed so that when data are entered in the lumber section, everything common to both lumber and veneer is automatically copied into the veneer input section. Users should enter all the common input data in the lumber portion of the spreadsheet even if only a veneer analysis is desired. A detailed description of the calculations that are different follows.

There are two differences in section 1. One difference is that prices for veneer grades AB and CD (PRAB and PRCD) are substituted for lumber prices. Prices are for green veneer and are quoted per thousand square feet on a finished panel size. All veneer prices used in this program should be converted to a 3/8-inch basis.

The second difference is that there is a cost saving (CSABP) that applies only to production of AB veneer from pruned logs. The basis for that cost saving is discussed later.

Section 2 is identical to section 2 for lumber.

In section 3, the veneer-recovery factor (VRF) and the proportion of AB veneer from the unpruned log (PABU) is computed from the equations shown in section 3A. Veneer recovery is based on dry trimmed veneer.

In section 4, the veneer-recovery factor is repeated. The veneer recovery is the same for pruned and unpruned logs. The proportion of AB veneer from pruned logs (PABP) is computed from the equation shown in section 4A.

```
Section
            PRUNING RECOVERY - VENEER                                    51    05-Feb
        LENGTH   STUMP  HEIGHT2    DBH2  HEIGHT1    DBH1    AGE1    AGE2
            17       1      153    25.5       53    10.4      20      60
  1        SD2     LD2              SD1      LD1           TREES  SUCCESS
          20.4    26.5              7.5     12.6              60    0.95
          PRAB    PRCD    CSABP             SITE     PCT   DFSIM     TAX
           200      90       68              145     300     175       1
------------------------------------------------------------------------------
  2     LOGVOL      PERCENT CLEAR VOLUME (PCCLR)
          45.2      75
------------------------------------------------------------------------------
                  PROPORTION OF AB VENEER (UNPRUNED LOGS)
  3        VRF    PABU
          14.3    0.06
------------------------------------------------------------------------------
  4        VRF      PROPORTION AB FROM PRUNED LOGS (PABP)
          14.3    0.54
------------------------------------------------------------------------------
        GROSS PRODUCT VALUE ($/MCF)
  5       GPVU    GPVP    GPVD
          1372    2652    1280
------------------------------------------------------------------------------
        GROSS PRODUCT VALUE ($/LOG)
  6      GPVUL   GPVPL   GPVDL
         62.06  119.96   57.90
------------------------------------------------------------------------------
                  PRESENT VALUE (PVTREE and PVACRE)
          RATE    TREE     ACRE  LOGVOL   PCCLR     VRF    PABU    PABP
          0.00   55.01  3300.56    45.2      75    14.3    0.06    0.54
          0.01   36.95  2216.83
          0.02   24.91  1494.79    GPVU    GPVP    GPVD
          0.03   16.86  1011.81  - - - - - $/MCF - - - - -
  7       0.04   11.46   687.47    1372    2652    1280
          0.05    7.81   468.83
          0.06    5.35   320.89   GPVUL   GPVPL   GPVDL
          0.07    3.67   220.41  - - - - - $/LOG - - - - -
          0.08    2.53   151.93   62.06  119.96   57.90
          0.09    1.75   105.08
          0.10    1.22    72.93
------------------------------------------------------------------------------
  1A    SD=BRUCE'S DOUGLAS-FIR PROFILE EQUATION CALCULATED AT Q1..V11
        LD=BRUCE'S DOUGLAS-FIR PROFILE EQUATION CALCULATED AT Q1..V11
------------------------------------------------------------------------------
  2A    LOGVOL=0.005454*LENGTH*(0.75*SD2^2+0.25*LD2^2)
        PCCLR=(1-(0.005454*LENGTH*(0.75*(SD1+2)^2+0.25*(LD1+2)^2)/
              LOGVOL))*100
------------------------------------------------------------------------------
  3A    VRF=(21.85-115/SD2)*0.88
        PABU=0.0562
------------------------------------------------------------------------------
  4A    PABP=(-5.77+0.193*PCCLR)*0.88/VRF
------------------------------------------------------------------------------
  5A    GPVU=(PABU*PRAB+(1-PABU)*PRCD)*VRF
        GPVP=(PABP*(PRAB+CSABP)+(1-PABP)*PRCD)*VRF
        GPVD=GPVP-GPVU
------------------------------------------------------------------------------
  6A    GPVUL=GPVU*LOGVOL/1000
        GPVPL=GPVP*LOGVOL/1000
        GPVDL=GPVPL-GPVUL
------------------------------------------------------------------------------
  7A    PVTREE=GPVDL/(1+RATE)^(AGE2-AGE1)*TAX*SUCCESS
        PVACRE=PVTREE*TREES
------------------------------------------------------------------------------
------------------------------------------------------------------------------
```

Figure 5—Spreadsheet example for veneer logs. Sections 1-7 contain various outputs from the program; sections 1A- 7A, the equations used to make the calculations.

In section 5, the gross product value per MCF of log volume is computed for unpruned (GPVU) and pruned logs (GPVP). Value is computed by use of the proportion of veneer by grade, price for each grade, the cost saving for AB veneer from pruned logs, and the veneer-recovery factor. The increase in value resulting from pruning is the difference in value between pruned and unpruned logs (GPVD).

Section 6 is comparable to section 6 for lumber.

Section 7 is comparable to section 7 for lumber except that veneer-recovery factor (VRF) replaces lumber-recovery factor (LRF) and the proportion of AB veneer (PABU and PABP) replaces the proportion of select lumber (PSELU and PSELP).

4. Log Diameters

Figure 6 shows the section of the spreadsheet that contains the equations needed to compute the diameters of the 17 -foot butt log. A tree profile equation that predicts diameters inside bark at any point on the stem was used.[1] A similar set of equations is described by Bruce (1984). The independent variables needed to make diameter predictions are DBH and total height, both at the time of pruning (cells E3 and F3 in fig. 3) and at the time of harvest (cells C3 and D3 in fig. 3). A description of how the calculations are made follows.

Line 5 shows four relative heights: (1) the small end of the butt log at harvest, (2) the large end of the butt log at harvest, (3) the small end of the butt log at time of pruning, and (4) the large end of the butt log at time of pruning. These heights are calculated from the equation in line 13 where:
xi = relative height;
H = height of the tree; and
hi = height at which relative height is being computed.

Line 7 shows the diameter inside bark at breast height for the tree at harvest and at time of pruning. These diameters are calculated from the equation in line 14, where:
dibbh = diameter inside bark at breast height, and
DBH = diameter outside bark at breast height.

Line 9 shows four relative diameters corresponding to the relative heights computed in line 5. These calculations use the equation in lines 15-17, where:
dibi = diameter inside bark at height "i,"
dibi/dibbh = relative diameter, and other variables are as defined above.

1/ Unpublished data on file with D. Bruce, mensurationist, USDA Forest Service, Forestry Sciences Laboratory, P.O. Box 3890, Portland, OR 97208.

```
          Q         R         S         T         U         V         W         X
1                 Bruce's Douglas-fir profile equation
2      LENGTH     STUMP  HEIGHT2     DBH2  HEIGHT1     DBH1
3          17         1      153     25.5       53     10.4
4   COMPUTE relative height (xi) at SD and LD (Bruce Douglas fir)
5   0.909090 1.023569 0.721649 1.072164
6   COMPUTE diameter inside bark at breast height (dibbh)
7   22.77132          9.418846
8   COMPUTE relative diameter (dibi/dibbh) at SD and LD
9   0.895412 1.077018 0.795405 1.240763
10  COMPUTE diameter inside bark at SD and LD (dibi)
11  20.38972 26.53619 7.491801 12.64486
12  ----------------------------------------------------------------------
13  xi=(H-hi)/(H-4.5)
14  dibbh=DBH*(1-(0.007144+0.00016888*DBH)^0.5)
15  dibi/dibbh=(xi^1.5+(-0.1661+5.8372/H)*(xi^1.5-xi^32)+(0.11906/DBH^2
16       -6.9988/H)*(xi^1.5-xi^2)+(xi^1.5-xi^3)*(12.2416/DBH-1017.43/H^2
17       -295.762/DBH/H))^0.5
18  dibi=dibi/dibbh*dibbh*adjust (adjust=1.082 for LD and 1.000 for SD)
19  ----------------------------------------------------------------------
20  ----------------------------------------------------------------------
```

Figure 6—Portion of the spreadsheet where log diameters are calculated. Letters and numbers refer to columns and rows in the spreadsheet.

Line 11 shows the four inside bark diameters needed by the PRUNE-SIM spreadsheet; the diameter of the small end of the butt log at harvest, the large end of the butt log at harvest, the small end of the butt log at time of pruning, and the large end of the butt log at time of pruning. These are calculated from the equation in line 18 where: "adjust" is as shown, and other variables areas defined above.

Adjust is a factor applied to the large-end diameter of the butt log. The data used by Bruce (see footnote 1) to develop the profile equation included very few measurements at 1-foot-the height of the large end of the butt log in our analysis. When we compared diameter estimates made by Bruce's equation with actual 1-foot diameters from two independent data sets, we found that the Bruce equation consistently underestimated values; an average adjustment of 1.082 was calculated with the data used to develop the recovery equations for the pruning model.

5. Average Diameter of Pruned Trees

One problem in deciding what tree descriptions are appropriate to represent pruned and unpruned trees is estimating the average DBH of the pruned trees. Dominants or codominants are the most likely candidates for pruning; thus, the average size of pruned trees will be greater than the average stand diameter given in growth and yield models. Our assumption is that pruned trees are the n largest trees in the stand, where n is the number of pruned trees. Figure 7 is a spreadsheet called STDDEV2 that is used to estimate the median diameter of the n largest trees in a stand. We have assumed that the tree diameters are normally distributed. This spreadsheet will be included with all copies of PRUNE-SIM. An example of how to use STDDEV2 follows.

THINNED NATURAL STANDS

X/2% > > > > >			10	11	12	13	14	15	16	17	18	19	20
NO.STD.DEVS. >			1.28	1.23	1.18	1.13	1.08	1.04	0.99	0.95	0.92	0.88	0.84
QD	AD	STD.D	DBH										
5.0	4.7	1.7	6.8	6.8	6.7	6.6	6.5	6.4	6.4	6.3	6.2	6.2	6.1
5.1	4.8	1.7	7.0	6.9	6.8	6.7	6.6	6.6	6.5	6.4	6.4	6.3	6.2
5.2	4.9	1.7	7.1	7.0	6.9	6.9	6.8	6.7	6.6	6.5	6.5	6.4	6.4
5.3	5.0	1.7	7.2	7.2	7.1	7.0	6.9	6.8	6.7	6.7	6.6	6.5	6.5
5.4	5.1	1.8	7.4	7.3	7.2	7.1	7.0	6.9	6.9	6.8	6.7	6.7	6.6
5.5	5.2	1.8	7.5	7.4	7.3	7.2	7.1	7.1	7.0	6.9	6.9	6.8	6.7
5.6	5.3	1.8	7.6	7.5	7.5	7.4	7.3	7.2	7.1	7.0	7.0	6.9	6.8
5.7	5.4	1.9	7.8	7.7	7.6	7.5	7.4	7.3	7.2	7.2	7.1	7.0	6.9
5.8	5.5	1.9	7.9	7.8	7.7	7.6	7.5	7.4	7.4	7.3	7.2	7.1	7.1
5.9	5.6	1.9	8.0	7.9	7.8	7.7	7.6	7.6	7.5	7.4	7.3	7.3	7.2
6.0	5.7	1.9	8.2	8.1	8.0	7.9	7.8	7.7	7.6	7.5	7.5	7.4	7.3
6.1	5.8	2.0	8.3	8.2	8.1	8.0	7.9	7.8	7.7	7.6	7.6	7.5	7.4
6.2	5.9	2.0	8.4	8.3	8.2	8.1	8.0	7.9	7.8	7.8	7.7	7.6	7.5
6.3	6.0	2.0	8.6	8.5	8.3	8.2	8.1	8.1	8.0	7.9	7.8	7.7	7.7
6.4	6.1	2.0	8.7	8.6	8.5	8.4	8.3	8.2	8.1	8.0	7.9	7.9	7.8
6.5	6.2	2.1	8.8	8.7	8.6	8.5	8.4	8.3	8.2	8.1	8.1	8.0	7.9
6.6	6.3	2.1	8.9	8.8	8.7	8.6	8.5	8.4	8.3	8.3	8.2	8.1	8.0
6.7	6.4	2.1	9.1	9.0	8.9	8.8	8.6	8.6	8.5	8.4	8.3	8.2	8.1
6.8	6.5	2.1	9.2	9.1	9.0	8.9	8.8	8.7	8.6	8.5	8.4	8.3	8.3
6.9	6.5	2.2	9.3	9.2	9.1	9.0	8.9	8.8	8.7	8.6	8.5	8.5	8.4
7.0	6.6	2.2	9.5	9.4	9.2	9.1	9.0	8.9	8.8	8.7	8.7	8.6	8.5
7.1	6.7	2.2	9.6	9.5	9.4	9.3	9.1	9.1	8.9	8.9	8.8	8.7	8.6
7.2	6.8	2.3	9.7	9.6	9.5	9.4	9.3	9.2	9.1	9.0	8.9	8.8	8.7
7.3	6.9	2.3	9.9	9.7	9.6	9.5	9.4	9.3	9.2	9.1	9.0	8.9	8.8
7.4	7.0	2.3	10.0	9.9	9.8	9.6	9.5	9.4	9.3	9.2	9.2	9.1	9.0
7.5	7.1	2.3	10.1	10.0	9.9	9.8	9.6	9.6	9.4	9.3	9.3	9.2	9.1
7.6	7.2	2.4	10.2	10.1	10.0	9.9	9.8	9.7	9.6	9.5	9.4	9.3	9.2
7.7	7.3	2.4	10.4	10.3	10.1	10.0	9.9	9.8	9.7	9.6	9.5	9.4	9.3
7.8	7.4	2.4	10.5	10.4	10.3	10.1	10.0	9.9	9.8	9.7	9.6	9.5	9.4
7.9	7.5	2.4	10.6	10.5	10.4	10.3	10.1	10.0	9.9	9.8	9.8	9.7	9.6
8.0	7.6	2.5	10.8	10.6	10.5	10.4	10.3	10.2	10.0	9.9	9.9	9.8	9.7
8.1	7.7	2.5	10.9	10.8	10.6	10.5	10.4	10.3	10.2	10.1	10.0	9.9	9.8
8.2	7.8	2.5	11.0	10.9	10.8	10.6	10.5	10.4	10.3	10.2	10.1	10.0	9.9
8.3	7.9	2.5	11.1	11.0	10.9	10.8	10.6	10.5	10.4	10.3	10.2	10.1	10.0
8.4	8.0	2.6	11.3	11.1	11.0	10.9	10.8	10.7	10.5	10.4	10.4	10.3	10.1
8.5	8.1	2.6	11.4	11.3	11.1	11.0	10.9	10.8	10.7	10.5	10.5	10.4	10.3
8.6	8.2	2.6	11.5	11.4	11.3	11.1	11.0	10.9	10.8	10.7	10.6	10.5	10.4
8.7	8.3	2.6	11.7	11.5	11.4	11.3	11.1	11.0	10.9	10.8	10.7	10.6	10.5
8.8	8.4	2.7	11.8	11.7	11.5	11.4	11.3	11.1	11.0	10.9	10.8	10.7	10.6
8.9	8.5	2.7	11.9	11.8	11.6	11.5	11.4	11.3	11.1	11.0	11.0	10.8	10.7
9.0	8.6	2.7	12.0	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	11.0	10.9
9.1	8.7	2.7	12.2	12.0	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	11.0
9.2	8.8	2.7	12.3	12.2	12.0	11.9	11.7	11.6	11.5	11.4	11.3	11.2	11.1
9.3	8.9	2.8	12.4	12.3	12.1	12.0	11.9	11.8	11.6	11.5	11.4	11.3	11.2
9.4	9.0	2.8	12.6	12.4	12.3	12.1	12.0	11.9	11.7	11.6	11.5	11.4	11.3
9.5	9.1	2.8	12.7	12.5	12.4	12.3	12.1	12.0	11.9	11.8	11.7	11.6	11.4
9.6	9.2	2.8	12.8	12.7	12.5	12.4	12.2	12.1	12.0	11.9	11.8	11.7	11.6
9.7	9.3	2.9	12.9	12.8	12.6	12.5	12.4	12.2	12.1	12.0	11.9	11.8	11.7
9.8	9.4	2.9	13.1	12.9	12.8	12.6	12.5	12.4	12.2	12.1	12.0	11.9	11.8
9.9	9.5	2.9	13.2	13.0	12.9	12.8	12.6	12.5	12.3	12.2	12.1	12.0	11.9
10.0	9.6	2.9	13.3	13.2	13.0	12.9	12.7	12.6	12.5	12.3	12.3	12.1	12.0

THINNED NATURAL STANDS

AD=0.9139*QD^1.01951

STD.D=(QD^2-AD^2)^0.5

DBH=AD+NO.STD.DEVS.*STD.D

Figure 7—Spreadsheet STDDEV2 used to calculate the median diameter of the pruned trees.

UNTHINNED PLANTATIONS

X/2% > > > > >			10	11	12	13	14	15	16	17	18	19	20
NO.STD.DEVS. >			1.28	1.23	1.18	1.13	1.08	1.04	0.99	0.95	0.92	0.88	0.84
QD	AD	STD.D	DBH										
5.0	4.7	1.7	6.8	6.8	6.7	6.6	6.5	6.4	6.4	6.3	6.2	6.2	6.1
5.1	4.8	1.7	7.0	6.9	6.8	6.7	6.6	6.6	6.5	6.4	6.4	6.3	6.2
5.2	4.9	1.7	7.1	7.0	6.9	6.8	6.8	6.7	6.6	6.5	6.5	6.4	6.3
5.3	5.0	1.7	7.2	7.1	7.0	7.0	6.9	6.8	6.7	6.6	6.6	6.5	6.5
5.4	5.1	1.7	7.3	7.3	7.2	7.1	7.0	6.9	6.8	6.8	6.7	6.6	6.6
5.5	5.2	1.8	7.5	7.4	7.3	7.2	7.1	7.0	7.0	6.9	6.8	6.8	6.7
5.6	5.3	1.8	7.6	7.5	7.4	7.3	7.2	7.2	7.1	7.0	6.9	6.9	6.8
5.7	5.4	1.8	7.7	7.6	7.5	7.4	7.4	7.3	7.2	7.1	7.1	7.0	6.9
5.8	5.5	1.8	7.8	7.7	7.7	7.6	7.5	7.4	7.3	7.2	7.2	7.1	7.0
5.9	5.6	1.8	8.0	7.9	7.8	7.7	7.6	7.5	7.4	7.4	7.3	7.2	7.2
6.0	5.7	1.9	8.1	8.0	7.9	7.8	7.7	7.6	7.5	7.5	7.4	7.3	7.3
6.1	5.8	1.9	8.2	8.1	8.0	7.9	7.8	7.8	7.7	7.6	7.5	7.5	7.4
6.2	5.9	1.9	8.3	8.2	8.1	8.0	8.0	7.9	7.8	7.7	7.6	7.6	7.5
6.3	6.0	1.9	8.5	8.4	8.3	8.2	8.1	8.0	7.9	7.8	7.8	7.7	7.6
6.4	6.1	1.9	8.6	8.5	8.4	8.3	8.2	8.1	8.0	7.9	7.9	7.8	7.7
6.5	6.2	2.0	8.7	8.6	8.5	8.4	8.3	8.2	8.1	8.1	8.0	7.9	7.8
6.6	6.3	2.0	8.8	8.7	8.6	8.5	8.4	8.3	8.3	8.2	8.1	8.0	8.0
6.7	6.4	2.0	8.9	8.8	8.7	8.6	8.5	8.5	8.4	8.3	8.2	8.1	8.1
6.8	6.5	2.0	9.1	9.0	8.9	8.8	8.7	8.6	8.5	8.4	8.3	8.3	8.2
6.9	6.6	2.0	9.2	9.1	9.0	8.9	8.8	8.7	8.6	8.5	8.5	8.4	8.3
7.0	6.7	2.0	9.3	9.2	9.1	9.0	8.9	8.8	8.7	8.6	8.6	8.5	8.4
7.1	6.8	2.1	9.4	9.3	9.2	9.1	9.0	8.9	8.8	8.7	8.7	8.6	8.5
7.2	6.9	2.1	9.5	9.4	9.3	9.2	9.1	9.0	8.9	8.9	8.8	8.7	8.6
7.3	7.0	2.1	9.7	9.6	9.5	9.4	9.2	9.2	9.1	9.0	8.9	8.8	8.7
7.4	7.1	2.1	9.8	9.7	9.6	9.5	9.4	9.3	9.2	9.1	9.0	8.9	8.9
7.5	7.2	2.1	9.9	9.8	9.7	9.6	9.5	9.4	9.3	9.2	9.1	9.1	9.0
7.6	7.3	2.1	10.0	9.9	9.8	9.7	9.6	9.5	9.4	9.3	9.3	9.2	9.1
7.7	7.4	2.1	10.1	10.0	9.9	9.8	9.7	9.6	9.5	9.4	9.4	9.3	9.2
7.8	7.5	2.2	10.3	10.1	10.0	9.9	9.8	9.7	9.6	9.5	9.5	9.4	9.3
7.9	7.6	2.2	10.4	10.3	10.2	10.0	9.9	9.9	9.7	9.7	9.6	9.5	9.4
8.0	7.7	2.2	10.5	10.4	10.3	10.2	10.1	10.0	9.9	9.8	9.7	9.6	9.5
8.1	7.8	2.2	10.6	10.5	10.4	10.3	10.2	10.1	10.0	9.9	9.8	9.7	9.6
8.2	7.9	2.2	10.7	10.6	10.5	10.4	10.3	10.2	10.1	10.0	9.9	9.8	9.8
8.3	8.0	2.2	10.8	10.7	10.6	10.5	10.4	10.3	10.2	10.1	10.0	10.0	9.9
8.4	8.1	2.2	11.0	10.8	10.7	10.6	10.5	10.4	10.3	10.2	10.2	10.1	10.0
8.5	8.2	2.2	11.1	11.0	10.8	10.7	10.6	10.5	10.4	10.3	10.3	10.2	10.1
8.6	8.3	2.3	11.2	11.1	11.0	10.9	10.7	10.6	10.5	10.4	10.4	10.3	10.2
8.7	8.4	2.3	11.3	11.2	11.1	11.0	10.9	10.8	10.6	10.6	10.5	10.4	10.3
8.8	8.5	2.3	11.4	11.3	11.2	11.1	11.0	10.9	10.8	10.7	10.6	10.5	10.4
8.9	8.6	2.3	11.5	11.4	11.3	11.2	11.1	11.0	10.9	10.8	10.7	10.6	10.5
9.0	8.7	2.3	11.6	11.5	11.4	11.3	11.2	11.1	11.0	10.9	10.8	10.7	10.6
9.1	8.8	2.3	11.8	11.6	11.5	11.4	11.3	11.2	11.1	11.0	10.9	10.8	10.7
9.2	8.9	2.3	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	11.0	10.9	10.9
9.3	9.0	2.3	12.0	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	11.1	11.0
9.4	9.1	2.3	12.1	12.0	11.9	11.8	11.6	11.5	11.4	11.3	11.3	11.2	11.1
9.5	9.2	2.4	12.2	12.1	12.0	11.9	11.7	11.6	11.5	11.4	11.4	11.3	11.2
9.6	9.3	2.4	12.3	12.2	12.1	12.0	11.9	11.8	11.6	11.5	11.5	11.4	11.3
9.7	9.4	2.4	12.4	12.3	12.2	12.1	12.0	11.9	11.8	11.7	11.6	11.5	11.4
9.8	9.5	2.4	12.6	12.4	12.3	12.2	12.1	12.0	11.9	11.8	11.7	11.6	11.5
9.9	9.6	2.4	12.7	12.5	12.4	12.3	12.2	12.1	12.0	11.9	11.8	11.7	11.6
10.0	9.7	2.4	12.8	12.7	12.5	12.4	12.3	12.2	12.1	12.0	11.9	11.8	11.7

UNTHINNED PLANTATIONS

AD=0.8826*QD^1.04143

STD.D=(QD^2-AD^2)^0.5

DBH=AD+NO.STD.DEVS.*STD.D

Figure 7—(continued)

THINNED PLANTATIONS

X/2% > > > > >			10	11	12	13	14	15	16	17	18	19	20
NO.STD.DEVS. >			1.28	1.23	1.18	1.13	1.08	1.04	0.99	0.95	0.92	0.88	0.84
QD	AD	STD.D	DBH										
5.0	4.9	1.2	6.4	6.3	6.2	6.2	6.1	6.1	6.0	6.0	5.9	5.9	5.8
5.1	5.0	1.2	6.5	6.4	6.4	6.3	6.3	6.2	6.1	6.1	6.1	6.0	6.0
5.2	5.1	1.2	6.6	6.6	6.5	6.4	6.4	6.3	6.3	6.2	6.2	6.1	6.1
5.3	5.2	1.2	6.7	6.7	6.6	6.6	6.5	6.4	6.4	6.3	6.3	6.2	6.2
5.4	5.3	1.3	6.9	6.8	6.7	6.7	6.6	6.6	6.5	6.4	6.4	6.4	6.3
5.5	5.4	1.3	7.0	6.9	6.9	6.8	6.7	6.7	6.6	6.6	6.5	6.5	6.4
5.6	5.4	1.3	7.1	7.0	7.0	6.9	6.8	6.8	6.7	6.7	6.6	6.6	6.5
5.7	5.5	1.3	7.2	7.2	7.1	7.0	7.0	6.9	6.8	6.8	6.8	6.7	6.6
5.8	5.6	1.3	7.3	7.3	7.2	7.1	7.1	7.0	7.0	6.9	6.9	6.8	6.8
5.9	5.7	1.3	7.5	7.4	7.3	7.3	7.2	7.1	7.1	7.0	7.0	6.9	6.9
6.0	5.8	1.4	7.6	7.5	7.5	7.4	7.3	7.3	7.2	7.1	7.1	7.0	7.0
6.1	5.9	1.4	7.7	7.6	7.6	7.5	7.4	7.4	7.3	7.3	7.2	7.2	7.1
6.2	6.0	1.4	7.8	7.8	7.7	7.6	7.6	7.5	7.4	7.4	7.3	7.3	7.2
6.3	6.1	1.4	8.0	7.9	7.8	7.7	7.7	7.6	7.5	7.5	7.4	7.4	7.3
6.4	6.2	1.4	8.1	8.0	7.9	7.9	7.8	7.7	7.7	7.6	7.6	7.5	7.4
6.5	6.3	1.5	8.2	8.1	8.1	8.0	7.9	7.9	7.8	7.7	7.7	7.6	7.6
6.6	6.4	1.5	8.3	8.3	8.2	8.1	8.0	8.0	7.9	7.8	7.8	7.7	7.7
6.7	6.5	1.5	8.4	8.4	8.3	8.2	8.1	8.1	8.0	8.0	7.9	7.8	7.8
6.8	6.6	1.5	8.6	8.5	8.4	8.3	8.3	8.2	8.1	8.1	8.0	8.0	7.9
6.9	6.7	1.5	8.7	8.6	8.5	8.5	8.4	8.3	8.2	8.2	8.1	8.1	8.0
7.0	6.8	1.6	8.8	8.7	8.7	8.6	8.5	8.4	8.4	8.3	8.3	8.2	8.1
7.1	6.9	1.6	8.9	8.9	8.8	8.7	8.6	8.6	8.5	8.4	8.4	8.3	8.2
7.2	7.0	1.6	9.1	9.0	8.9	8.8	8.7	8.7	8.6	8.5	8.5	8.4	8.4
7.3	7.1	1.6	9.2	9.1	9.0	8.9	8.9	8.8	8.7	8.6	8.6	8.5	8.5
7.4	7.2	1.6	9.3	9.2	9.1	9.1	9.0	8.9	8.8	8.8	8.7	8.6	8.6
7.5	7.3	1.6	9.4	9.3	9.3	9.2	9.1	9.0	8.9	8.9	8.8	8.8	8.7
7.6	7.4	1.7	9.5	9.5	9.4	-9.3	9.2	9.1	9.1	9.0	8.9	8.9	8.8
7.7	7.5	1.7	9.7	9.6	9.5	9.4	9.3	9.3	9.2	9.1	9.1	9.0	8.9
7.8	7.6	1.7	9.8	9.7	9.6	9.5	9.4	9.4	9.3	9.2	9.2	9.1	9.0
7.9	7.7	1.7	9.9	9.8	9.7	9.6	9.6	9.5	9.4	9.3	9.3	9.2	9.1
8.0	7.8	1.7	10.0	9.9	9.8	9.8	9.7	9.6	9.5	9.5	9.4	9.3	9.3
8.1	7.9	1.7	10.1	10.1	10.0	9.9	9.8	9.7	9.6	9.6	9.5	9.4	9.4
8.2	8.0	1.8	10.3	10.2	10.1	10.0	9.9	9.8	9.8	9.7	9.6	9.6	9.5
8.3	8.1	1.8	10.4	10.3	10.2	10.1	10.0	10.0	9.9	9.8	9.7	9.7	9.6
8.4	8.2	1.8	10.5	10.4	10.3	10.2	10.1	10.1	10.0	9.9	9.9	9.8	9.7
8.5	8.3	1.8	10.6	10.5	10.4	10.3	10.3	10.2	10.1	10.0	10.0	9.9	9.8
8.6	8.4	1.8	10.7	10.6	10.6	10.5	10.4	10.3	10.2	10.1	10.1	10.0	9.9
8.7	8.5	1.8	10.9	10.8	10.7	10.6	10.5	10.4	10.3	10.3	10.2	10.1	10.1
8.8	8.6	1.9	11.0	10.9	10.8	10.7	10.6	10.5	10.4	10.4	10.3	10.2	10.2
8.9	8.7	1.9	11.1	11.0	10.9	10.8	10.7	10.7	10.6	10.5	10.4	10.4	10.3
9.0	8.8	1.9	11.2	11.1	11.0	10.9	10.8	10.8	10.7	10.6	10.5	10.5	10.4
9.1	8.9	1.9	11.3	11.2	11.1	11.1	11.0	10.9	10.8	10.7	10.7	10.6	10.5
9.2	9.0	1.9	11.5	11.4	11.3	11.2	11.1	11.0	10.9	10.8	10.8	10.7	10.6
9.3	9.1	1.9	11.6	11.5	11.4	11.3	11.2	11.1	11.0	10.9	10.9	10.8	10.7
9.4	9.2	2.0	11.7	11.6	11.5	11.4	11.3	11.2	11.1	11.1	11.0	10.9	10.8
9.5	9.3	2.0	11.8	11.7	11.6	11.5	11.4	11.3	11.2	11.2	11.1	11.0	11.0
9.6	9.4	2.0	11.9	11.8	11.7	11.6	11.5	11.5	11.4	11.3	11.2	11.1	11.1
9.7	9.5	2.0	12.1	12.0	11.9	11.8	11.7	11.6	11.5	11.4	11.3	11.3	11.2
9.8	9.6	2.0	12.2	12.1	12.0	11.9	11.8	11.7	11.6	11.5	11.4	11.4	11.3
9.9	9.7	2.0	12.3	12.2	12.1	12.0	11.9	11.8	11.7	11.6	11.6	11.5	11.4
10.0	9.8	2.1	12.4	12.3	12.2	12.1	12.0	11.9	11.8	11.7	11.7	11.6	11.5

THINNED PLANTATIONS

AD=0.9561*QD^1.01015

STD.D=(QD^2-AD^2)^0.5

DBH=AD+NO.STD.DEVS.*STD.D

Figure 7—(continued)

To estimate the median diameter of pruned trees, first estimate the arithmetic mean diameter (AD) of the stand using the quadratic mean diameter (QD) given in the DFSIM output. The equations used to estimate arithmetic diameter are:

Thinned natural stands, $AD = 0.9139 * QD^{1.01951}$.
Unthinned plantations, $AD = 0.8826 * QD^{1.04143}$.
Thinned plantations, $AD = 0.9561 * QD^{1.01015}$.

These equations are based on data used to develop the DFSIM model.[2]

The next step is to estimate the standard deviation (STD.D) from the equation:

$$STD.D = (QD^2 - AD^2)^{0.5}.$$

The median diameter at breast height of the n largest trees is found by referring to a table of values for a standard normal distribution. The number of standard deviations above which n/2 percent of the population falls is the median diameter of the n largest members of the population. That number of standard deviations times the standard deviation for this stand plus the arithmetic mean diameter of this stand is the median diameter for the pruned trees. Figure 7 shows the median diameter of the pruned trees for a range of stand diameters and proportion of the stands to be pruned. For example, a precommercially thinned stand with a QD of 6.0 inches has an AD of 5.7 inches. The estimated standard deviation of that stand is 1.9. If the largest 30 percent of the trees are pruned, x/2 percent equals 15 percent. The median tree is 1.04 standard deviations above the mean: 1.04 times 1.9 is 2.0 inches above the mean of 5.7. The estimated median diameter of the pruned trees is therefore 7.7. The approach described here is not an exact solution to the problem, but it appears to be an acceptable approximation.

The DFSIM yield tables and the approach described above can now be used to provide the data needed to simulate a comparison with and without pruning. Diameter of pruned trees at the time of pruning can be determined as described above by use of the DBH (quadratic mean diameter) shown in the DFSIM yield tables. The height of the pruned trees at the time of pruning is probably best represented by "HT 40" rather than "LOREY HT." HT40 is the mean height of the 40 largest trees in the stand. LOREY HT is the height of the tree of average volume. Since we have assumed that the pruned trees will be the n largest trees in the stand, the height of the 40 largest trees in the stand is probably closer than the height of the tree of average volume. Sensitivity analysis done with differences in height at time of pruning suggests that differences of the magnitude of the difference between HT40 and LOREY HT will have a minor effect on the results. If pruning regimes are set so that most or all of the trees at final harvest

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[2] Personal communication from Robert O. Curtis, mensurationist,
USDA Forest Service, Forestry Sciences Laboratory,
3625 93rd Ave. SW, Olympia, WA 98502.

are pruned trees, no adjustment is needed to determine the diameter of the pruned trees. The quadratic mean diameter reported in the DFSIM tables can be used directly because the quadratic mean diameter and the arithmetic mean diameter are almost identical for trees of harvest size. At harvest, LOREY HT probably best represents the height of the pruned trees if almost all the trees are pruned trees.

6. Macro Feature in PRUNE-SIM

The problem in deciding the prices to use in the analysis is that the prices are needed now for a period 20 and more years from now. Future prices are not simply unknown; they are unknowable. We can look at price projections from various studies of supply and demand for timber and at historical trends, but since we cannot know what future prices will be we suggest looking at the financial return from pruning for a range of future prices. The prices used by PRUNE-SIM are the prices for lumber and veneer by product grade. The financial return from pruning depends on the difference in price between clear grades and lower grades of products. In addition to the price difference between AB and CD veneer, there is a cost saving for AB veneer produced from pruned logs. The average number of patches per sheet of AB veneer from pruned logs will be substantially less than the average number of patches per sheet of AB veneer from unpruned logs. The cost saving is added to the price in PRUNE-SIM to determine the increased return with pruning. The prices and costs used in the examples should be regarded as sample data sets and used only to verify program operation.

Many people will find this users guide more useful than any specific analysis we might publish because the number of regimes for which we can provide analyses is limited. The program allows users to do sensitivity analysis for the regimes that are most relevant to their situation; the combinations of prices, regimes, and other assumptions that may be desired in a sensitivity analysis will vary.

```
          AN        AO        AP        AQ        AR        AS        AT        AU
 1       PRSEL      PRSS     PRSTD      PRUE      PRAB      PRCD
 2         542       250       191       111       200        90
 3        1322       638       516       290       355       167
 4
 5    Alt A             LOPRICE                         PRINTSUB
 6    {loprice}         {goto}an2~/c{right 3}~a7~       /pppra1.h8~g
 7    {calc}            {right 4}~/c{right}~i7~         ra26.h40~g
 8    {printsub}                                        l------ri1.p8~g
 9    {savesub}         HIPRICE                         ri26.p40~gQ
10    {hiprice}         {goto}an3~/c{right 3}~a7~
11    {calc}            {right 4}~/c{right}~i7~
12    {printsub}
13    {savesub}         SAVESUB
14                      {goto}y1~{end}{down}{down}/ru{down}{right 14}~
15                      {goto}y3~/m{end}{down}{right 14}~{down 2}~
16                      {goto}y3~/ru{down}{right 14}~
17                      {goto}a70~/rv{down}{right 14}~y3~
18                      {goto}a1~{goto}g1~
19
20    ------------------------------------------------------------------------
```

Figure 8—Portion of the spreadsheet containing the macro commands allowing sensitivity analysis for different product price assumptions. Letters and numbers refer to columns and rows in the spreadsheet.

One area in which sensitivity analysis may be desired is price premiums for clear grades of wood products. In determining priorities for pruning, the user may wish to do sensitivity analysis on age at time of pruning, age at time of harvest, and site index. A comparison of the return from pruning fertilized stands with pruning unfertilized stands would also be useful. There are some areas where sensitivity analysis can be done only by changing the equations in the spreadsheet model. These areas include the recovery equations (currently based on one recovery study) and tree profile equations (currently based on an unpublished equation).

For ease in doing sensitivity analyses, the spreadsheet contains a macro that calculates and prints results similar to figure 3 for both lumber and veneer for two sets of specified prices. Figure 8 shows the macro and the location for the two sets of prices. Once the desired sets of prices (arbitrarily referred to as "loprice" and "hiprice") are entered into locations AN2...AS3, the macro is invoked by holding down the "Alt" key and pressing "a." Figure 9 shows what is printed when this macro is invoked; in addition to these results, an abbreviated version of the results is moved to location Y3...AM6 (fig. 10). Whatever is currently at that location is moved down to make room for the new results. This provides a way to conveniently summarize and store the results from a series of analyses. These results can be graphed to facilitate comparisons of alternative regimes or assumptions. Figure 10 shows this output with the results from the sample run shown in figure 9. Column heading abbreviations and the location in the spreadsheet from which these numbers are taken are as follows:

ID	=	run identifier number entered at G1;
Site	=	site index entered at E7;
A1	=	age at time of pruning entered at G3;
PCT	=	number of trees after precommercial thinning entered at F7;
A2	=	age at time of harvest entered at H3;
TRE	=	number of trees pruned entered at G5;
SUCC	=	proportion of pruned trees surviving to the final harvest entered at H5;
PRICE	=	the sum of the prices for each lumber or veneer grade (this variable is used to help identify runs without increasing the size of this array beyond one screen width);
TAX	=	1 minus the applicable tax rate entered at H7;
PVT 4	=	present sent value per tree at a 4-percent interest rate reported at B33 for lumber and J33 for veneer;
PVA4	=	present value per acre at a 4-percent interest rate reported at C33 for lumber and K33 for veneer;
PVT6	=	present value per tree at a 6-percent interest rate reported at B35 for lumber and J35 for veneer;
PVA6	=	present value per acre at a 6-percent interest rate reported at C35 for lumber and K35 for veneer;
PVT8	=	present value per tree at an 8-percent interest rate reported at B37 for lumber and J37 for veneer;
PVA8	=	present value per acre at an 8-percent interest rate reported at C37 for lumber and K37 for veneer.

```
            PRUNING RECOVERY - LUMBER                                51   25-Nov
  LENGTH      STUMP   HEIGHT2      DBH2   HEIGHT1      DBH1      AGE1     AGE2
      17          1       153      25.5        53      10.4        20       60
     SD2        LD2                 SD1       LD1               TREES  SUCCESS
    20.4       26.5                 7.5      12.6                  60     0.95
   PRSEL       PRSS     PRSTD      PRUE      SITE       PCT     DFSIM      TAX
     542        250       191       111       145       300       175        1
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
                 PRESENT VALUE (PVTREE and PVACRE)
    RATE       TREE      ACRE    LOGVOL     PCCLR       LRF     PSELU    PSELP
    0.00      42.73   2563.92      45.2        75       9.2      0.20     0.53
    0.01      28.70   1722.07
    0.02      19.35   1161.18      GPVU      GPVP      GPVD
    0.03      13.10    785.99   - - - - - $/MCF - - - - -
    0.04       8.90    534.04      2584      3579       994
    0.05       6.07    364.19
    0.06       4.15    249.27     GPVUL     GPVPL     GPVDL
    0.07       2.85    171.22   - - - - - $/LOG - - - - -
    0.08       1.97    118.02    116.90    161.88     44.98
    0.09       1.36     81.63
    0.10       0.94     56.65
-----------------------------------------------------------------------------


            PRUNING RECOVERY - VENEER                                51   25-Nov
  LENGTH      STUMP   HEIGHT2      DBH2   HEIGHT1      DBH1      AGE1     AGE2
      17          1       153      25.5        53      10.4        20       60
     SD2        LD2                 SD1       LD1               TREES  SUCCESS
    20.4       26.5                 7.5      12.6                  60     0.95
    PRAB       PRCD     CSABP                SITE       PCT     DFSIM      TAX
     200         90        68                 145       300       175        1
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
                 PRESENT VALUE (PVTREE and PVACRE)
    RATE       TREE      ACRE    LOGVOL     PCCLR       VRF      PABU     PABP
    0.00      55.01   3300.56      45.2        75      14.3      0.06     0.54
    0.01      36.95   2216.83
    0.02      24.91   1494.79      GPVU      GPVP      GPVD
    0.03      16.86   1011.81   - - - - - $/MCF - - - - -
    0.04      11.46    687.47      1372      2652      1280
    0.05       7.81    468.83
    0.06       5.35    320.89     GPVUL     GPVPL     GPVDL
    0.07       3.67    220.41   - - - - - $/LOG - - - - -
    0.08       2.53    151.93     62.06    119.96     57.90
    0.09       1.75    105.08
    0.10       1.22     72.93
-----------------------------------------------------------------------------
```

Figure 9—An example of the results printed when the macro is executed.

```
          PRUNING RECOVERY - LUMBER                                 51     25-Nov
 LENGTH      STUMP   HEIGHT2      DBH2   HEIGHT1        DBH1      AGE1       AGE2
     17          1       153      25.5        53        10.4        20         60
    SD2        LD2                 SD1       LD1                 TREES    SUCCESS
   20.4       26.5                 7.5      12.6                    60       0.95
  PRSEL       PRSS     PRSTD      PRUE      SITE         PCT     DFSIM        TAX
   1322        638       516       290       145         300       175          1
----------------------------------------------------------------------------------
----------------------------------------------------------------------------------
              PRESENT VALUE (PVTREE and PVACRE)
   RATE       TREE      ACRE    LOGVOL     PCCLR         LRF     PSELU      PSELP
   0.00      99.73   5984.08      45.2        75         9.2      0.20       0.53
   0.01      66.99   4019.22
   0.02      45.17   2710.13      GPVU      GPVP        GPVD
   0.03      30.57   1834.46   - - - - - $/MCF - - - - -
   0.04      20.77   1246.42      6555      8876        2321
   0.05      14.17    850.01
   0.06       9.70    581.78     GPVUL     GPVPL       GPVDL
   0.07       6.66    399.62   - - - - - $/LOG - - - - -
   0.08       4.59    275.45    296.51    401.49      104.98
   0.09       3.18    190.52
   0.10       2.20    132.22
----------------------------------------------------------------------------------
```

```
          PRUNING RECOVERY - VENEER                                 51     25-Nov
 LENGTH      STUMP   HEIGHT2      DBH2   HEIGHT1        DBH1      AGE1       AGE2
     17          1       153      25.5        53        10.4        20         60
    SD2        LD2                 SD1       LD1                 TREES    SUCCESS
   20.4       26.5                 7.5      12.6                    60       0.95
   PRAB       PRCD     CSABP                SITE         PCT     DFSIM        TAX
    355        167        68                 145         300       175          1
----------------------------------------------------------------------------------
----------------------------------------------------------------------------------
              PRESENT VALUE (PVTREE and PVACRE)
   RATE       TREE      ACRE    LOGVOL     PCCLR         VRF      PABU       PABP
   0.00      78.09   4685.28      45.2        75        14.3      0.06       0.54
   0.01      52.45   3146.88
   0.02      35.37   2121.92      GPVU      GPVP        GPVD
   0.03      23.94   1436.31   - - - - - $/MCF - - - - -
   0.04      16.26    975.89      2533      4350        1817
   0.05      11.09    665.52
   0.06       7.59    455.51     GPVUL     GPVPL       GPVDL
   0.07       5.21    312.88   - - - - - $/LOG - - - - -
   0.08       3.59    215.67    114.57    196.77       82.20
   0.09       2.49    149.17
   0.10       1.73    103.52
----------------------------------------------------------------------------------
```

Figure 9—(continued)

```
        Y    Z   AA AB  AC  AD   AE    AF    AG    AH    AI    AJ   AK   AL   AM
1      ID SITE A1 PCT  A2 TRE SUCC PRICE   TAX  PVT4 PVA4  PVT6 PVA6 PVT8 PVA8
2    ==========================================================================
3      51  145 20 300  60  60 0.95  2766     1 20.77 1246  9.70  582 4.59  275
4      51  145 20 300  60  60 0.95   522     1 16.26  976  7.59  456 3.59  216
5      51  145 20 300  60  60 0.95  1094     1  8.90  534  4.15  249 1.97  118
6      51  145 20 300  60  60 0.95   290     1 11.46  687  5.35  321 2.53  152
7    WHEN YOU USE THE MACRO THESE LINES WILL REMAIN AT THE BOTTOM.  DELETE
8    UNWANTED OUTPUT BY USING RANGE ERASE.  THEN CLOSE BLANK LINES BY MOVING
9    EVERYTHING BELOW UP.  THIS TEXT MUST BE RETAINED FOR THE MACRO TO WORK.
10   THERE MUST BE NO BLANK LINES ABOVE THIS LINE.
11
12
13
14
15
16
17
18
19
20
```

Figure 10—An example of the summary results stored in the spreadsheet when the macro is executed. Letters and numbers refer to columns and rows in the spreadsheet.

Summary

This spreadsheet template provides a means for simulating the difference between the financial returns of pruned and unpruned stands. It is accessible and easy to use for anyone who has access to a personal computer and LOTUS 1-2-3 software. This program should be widely applicable to coast Douglas-fir. There are at least two sources of conservative bias in the results that this model produces. One is that the unpruned recovery is based on stands that were grown with relatively close spacing. Unpruned trees from stands that are grown at wider spacing will likely have lower grade recovery than predicted by the model, making the increase in value after pruning larger. Another source of conservative bias is that the lumber recovery for pruned logs is based on processing that was more production oriented than grade oriented. A mill that is oriented to sawing for grade would likely get higher grade recovery from pruned logs than predicted by the model. On the other hand, the user must exercise caution in making price assumptions. Clear wood products from pruned young-growth logs have a different appearance than clear wood products from old growth. There is likely to be market resistance to clear wood products from pruned young growth. The extent of this resistance cannot be measured. Historical experience indicates, however, that as any high quality resource gets scarcer and more expensive, people become more creative in using substitutes. Clear wood products from pruned young growth should be a close substitute for clear wood products from old growth for many uses; as old growth clear wood becomes more expensive, the market resistance to young growth clear wood is likely to diminish. A final note of caution. The predicted recovery for pruned logs that fall outside the range of diameters at time of pruning and time of harvest should be regarded as suspect. Results using any such extrapolations should be scrutinized carefully.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.305 meter
1 cubic foot = 0.028 cubic meter
1 acre = 0.4047 hectare

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PRUNE-SIM is a spreadsheet template (program) that allows users to simulate a financial analysis of pruning coast Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*). The program estimates the increase in product value resulting from pruning the butt 17-foot log. Product recovery information is based on actual mill experience with pruned and unpruned logs for both sawn and peeled products. Users must supply tree descriptions from sources of growth and yield information and product prices. The program calculates the difference in value for trees and stands with and without pruning. The present value of this difference represents the maximum amount that could be spent on pruning without reducing the rate of return on the investment below the specified rate. The LOTUS 1-2-3 spreadsheet program was used to develop PRUNE-SIM. The user needs a basic knowledge of spreadsheets to use this program.

Keywords: Simulation, pruning, Douglas-fir (coast), forest product value, product recovery.

Pacific Northwest Research Station
319 S.W. Pine St.
P. O. Box 3890
Portland, Oregon 97208

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