United States
Department
of Agriculture

Forest Service

**Intermountain
Research Station
Ogden, UT 84401**

General Technical
Report INT-190

October 1985

COVER: A User's Guide to the CANOPY and SHRUBS Extension of the Stand Prognosis Model

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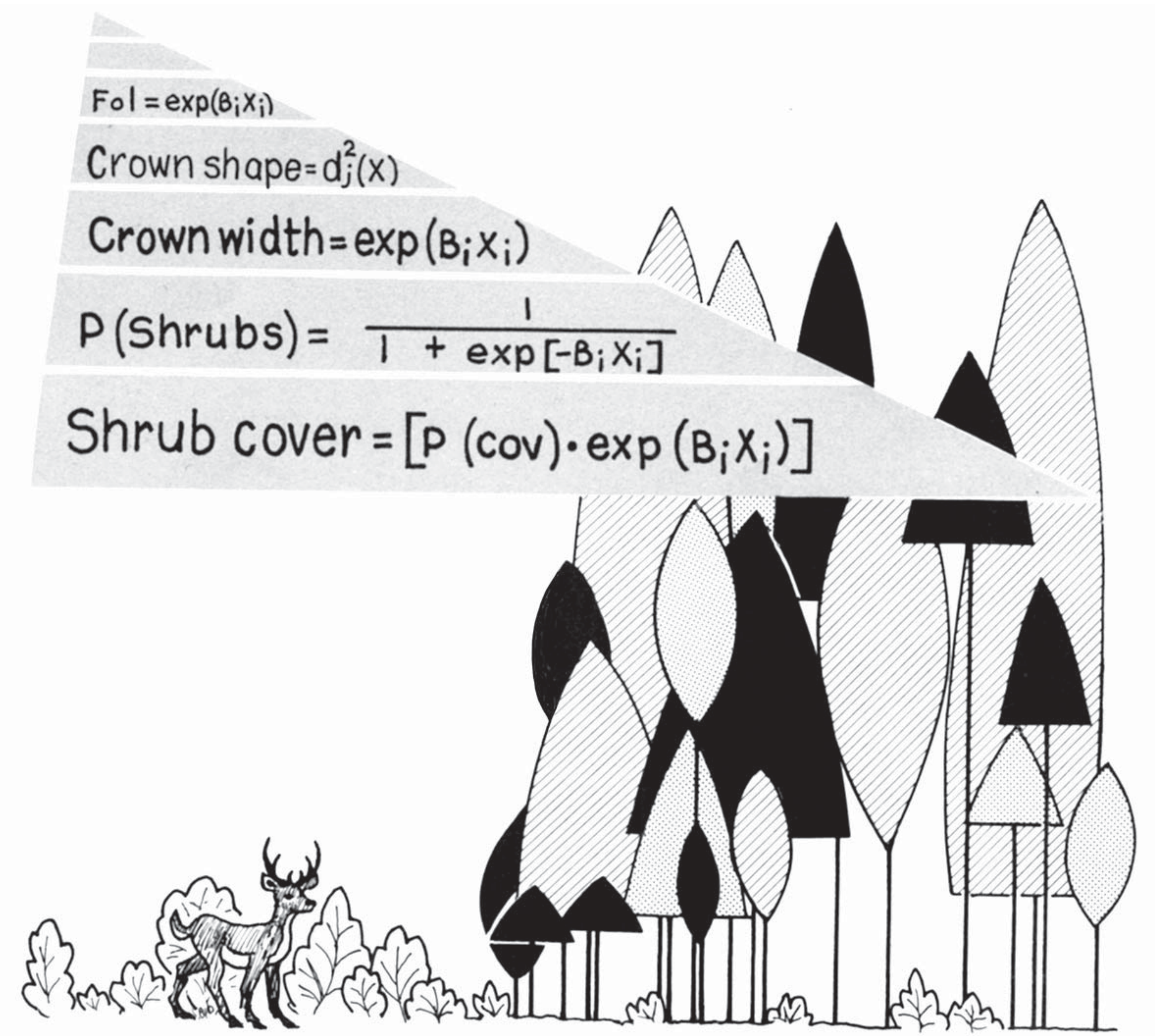

THE AUTHOR

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This publication replaces a draft user's guide distributed in 1981 (Moeur and Scharosch 1981). Enhancements to the early version of the COVER and BROWSE programs are described herein. In addition, there are changes to several of the keyword names and formats linking the COVER extension to Version 5.0 of the Prognosis Model, as reported in the Prognosis Model User's Guide (Wykoff and others 1982):

Prognosis Model User's Guide Keyword		**COVER Extension User's Guide** Keyword	
		COVER	Invoke the COVER extension (for either canopy or shrubs). field 1: Cycle to begin COVER predictions. field 2: Dataset reference number for output.
COVER	Invoke the COVER option in the shrub and cover extension. field 1: Method to be used to compute foliage biomass.	CANOPY	Compute crown cover statistics.
SHRUB	Invoke the BROWSE option of the shrub and cover extension. field 1: Number of years since stand was regenerated. field 2: Number of years shrub output will be printed. field 3: Habitat type code for processing SHRUB option.	SHRUBS	Compute shrub statistics. field 1: Number of years since stand disturbance. field 2: Habitat type code for processing SHRUBS option. field 3: Physiographic type code. field 4: Disturbance type code.

ACKNOWLEDGMENTS

Research leading to the understory development models incorporated in the COVER program resulted from cooperative studies between the Intermountain Research Station and the University of Idaho, College of Forestry, Wildlife and Range Sciences. University of Idaho cooperators who contributed to modeling of data and linkage to the Prognosis Model include Dr. Steven B. Laursen, Steve N. Scharosch, Dr. Charles R. Hatch, Dr. James A. Moore, Dr. James M. Peek, and Dr. Larry L. Irwin (now at University of Wyoming).

I am grateful to Dr. E. 0. Garton, University of Idaho, for providing the data used to fit crown shape models. Special thanks also to Nezperce National Forest personnel George Bain and Susan Wise, Salmon River Ranger District silviculturist and wildlife biologist, respectively, for supplying stand data, silvicultural prescriptions, and advice in preparing the wildlife examples.

RESEARCH SUMMARY

The COVER extension to the Stand Prognosis Model predicts tree canopy closure, crown volume, crown profile area, and foliage biomass within vertical height classes, and the probability of occurrence, height, and cover of shrubs in forest stands. The model may be used to produce a descriptive summary of a stand at the time of inventory, or to project overstory and understory characteristics through time for natural and managed stands. This paper documents use of the COVER program, an adjunct to Version 5.0 of the Prognosis Model. Preparation of input, interpretation of output, program control, and model characteristics are described. Potential applications of COVER estimates to wildlife, hydrology, and insect pest modeling are presented.

CONTENTS

COVER: A User's Guide to the CANOPY and SHRUBS Extension of the Stand Prognosis Model

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INTRODUCTION

Forest managers in the Northern Rocky Mountains have extensively used the Prognosis Model for Stand Development (Stage 1973) to summarize current stand conditions, and to predict the future path of stand growth and the likely consequences of alternative management practices on stand development. The use of stand models like Prognosis need not be restricted to timber management applications. For example, forest managers must also consider how management practices may change the suitability of a stand for wildlife habitat, the composition of the understory, or the sequence of succession. The computer model described in this paper, known as COVER, extends Prognosis by modeling the development of tree crowns and understory vegetation. COVER provides three types of information: a description of the amount of cover and foliage in the tree canopy by height class; the height and cover of shrubs, forbs, and grasses in the understory; and a summary of overstory and understory cover and biomass for the stand.

COVER offers two options that can be run separately or together: CANOPY controls predictions of values related to tree crowns; SHRUBS controls predictions of understory characteristics. Possible applications of the COVER model include examining the likely effects of silvicultural treatments on:

- forest stand characteristics important to wildlife, such as thermal cover and hiding cover, browse production, and the interactions of shrubs and trees that determine vertical and horizontal stand structure.
- dynamics of the shrub community affecting stand succession and competition with regeneration.
- vertical crown form and foliage distribution important to feeding and dispersal patterns of insect pests, such as the western spruce budworm.
- canopy cover and ground cover development which affect the hydrologic characteristics of a stand following harvest.

This manual is intended to be a companion publication to the Prognosis Model User's Guide (Wykoff and others 1982). The research described here is based on the idea that management prescriptions which affect nonvegetation ecosystem components can be compared and evaluated by examining simulated changes in the major vegetation components. Wykoff and others (1982) have summed up this philosophy, which guides our research:

> Consequences for streamflow from the forest, for wildlife populations, and for pest populations that inhabit the forest, as well as the capability of the forest to yield timber or provide recreation—all depend on how the dominant vegetation changes and is changed. Unfortunately, yield forecasts have traditionally emphasized the merchantable harvest that might be obtained, either immediately or as a sequence of yields obtainable at intervals of time into the future. Volumes of merchantable timber have been the most common units of measure because timber products have usually been the primary reason for investment. As other uses for the forest become more important, however, growth forecasts need to be stated in more fundamental descriptions of the future forest stand. Too often, evaluation of tradeoffs among conflicting activities or objectives for use of forest resources has been hampered by lack of sensitivity of the forecasts to the interactions among ecosystem components. One objective for development of the Stand Prognosis Model is to so characterize stand dynamics that the model will provide a sensitive basis for representing interactions involving the tree species.

COVER can provide a detailed picture of the vegetative structure of a single stand through time under different silvicultural prescriptions. By linking to the Parallel Processing version of Prognosis (Crookston 1985), COVER can also model long-term, large-scale changes for groups of stands arranged in time and space. As such, it may be a useful tool for enhancing forest management decisions that concern nontimber ecosystem components. This publication begins with a description of the information produced by the model and instructions for making the program run. There follows a discussion of the biological behavior of the individual submodels and a final section dealing with potential applications.

Range of Predictions

The models comprising COVER are parameterized with data collected in the Inland Northwest and Northern Rocky Mountain forests. The user should determine if the range of species and site conditions for which predictions are made are applicable to the local situation.

Submodels for the CANOPY option predict conifer crown width, crown shape, and foliage biomass. Equations for crown width and foliage biomass are derived from data on 370 trees on 14 sites in northern Idaho and western Montana (Moeur 1981; Brown 1978). Sampled stand basal area ranges from 1 to 426 ft^2/acre. Open-grown trees and trees that were obviously damaged or heavily defoliated were not sampled. Data for the crown shape models are from 9,800 trees on 12 sites in western Montana, the Blue Mountains of eastern Oregon, and the University of Idaho forest near Moscow, ID (Langelier and Garton in press a).

The understory portion of COVER includes models that predict probability of occurrence, height, and cover of individual shrub, forb, grass, and fern species (Scharosch 1984; Laursen 1984). Understory data are from over 10,000 1/300-acre plots on 500 stands in Douglas-fir, grand fir, western redcedar, west-ern hemlock, and subalpine fir habitat types. Stands were measured between 3 and 40 years following major stand disturbance. These data are from northern Idaho, northeastern Washington, and northwestern Montana (Colville, Panhandle, Kootenai, Lolo, and Clearwater National Forests), to central and southern Idaho and northwestern Wyoming (Nezperce, Boise, Payette, and Targhee National Forests) (Ferguson and others [in press]). In addition, Irwin and Peek (1979) fit models for twig production and dormant season shrub biomass on a subset of the data (grand fir, cedar, and hemlock types).

Current data sources make the COVER predictions most applicable to the Northern Region (R-l), and portions of the Intermountain (R-4) and Pacific Northwest (R-6) Regions of the Forest Service. The user should exercise caution in extending predictions outside these geographic areas.

Data Requirements

Information needed to run COVER consists of the minimum Prognosis Model input—the inventory design used to measure the stand, a list of sampled trees for which species, diameter, and plot identification have been recorded, and values for slope, aspect, elevation, habitat type, and forest location recorded on the STDINFO card (Wykoff and others 1982). If the SHRUBS option is used, time since stand disturbance, type of disturbance, and physiographic position are required.

Understory predictions are improved if field measurements of shrub height and cover are available for calibrating portions of the shrub models. These data are only supplementary, and both the CANOPY and SHRUBS options will execute without them. The keywords section discusses how to enter calibration information.

INFORMATION PRODUCED

The COVER program normally produces three displays—one describing the structure of tree crowns, another describing the composition of the understory, and a third summarizing overstory and understory cover and biomass. The user may insert keywords to turn off the printing of any of the displays.

As you proceed through this publication, the same stand used in the Prognosis Model User's Guide (Wykoff and others 1982) will be used to develop examples. The stand (S248112) is on the St. Joe National Forest. It is 57 years old at the inventory date, positioned on a northwest aspect, 30 percent midslope, at 3,400 feet of elevation, and is a *Tsuga heterophylla/Clintonia uniflora* habitat type. Values presented here result from the COVER extension combined with Version 5.0 of the Inland Empire Prognosis Model and Version 1.0 of the Regeneration Establishment Model (Ferguson and Crookston 1984). Four COVER extension keywords (COVER, CANOPY, SHRUBS, and END) inserted into the Prognosis Model runstream in figure 1 produce the example canopy and shrub displays.

Canopy Cover Statistics Display

The Canopy Cover Statistics display is the first of the three COVER displays (fig. 2). It is produced when the CANOPY option is specified. To give the user a feel for the vertical profile of the conifer component of the stand, crown cover values are partitioned by 10-foot height classes.

Trees per acre.—The number of trees per acre whose total heights fall within a given height class.

Canopy closure.—The percentage of ground area covered by the projections of individual crowns of trees whose total heights fall within a given height class (fig. 3a).

Crown profile area.—The area in square feet per acre within vertical height classes occupied by crown profiles, represented by the sum of lateral areas of crown profile sections within height classes (fig. 3b). Crown profile area may be thought of as a foliage-height profile, or the view one would have if the stand were "squashed flat" in a vertical plane.

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STDIDENT
S248112  PROGNOSIS WITH COVER EXTENSION - USER'S MANUAL EXAMPLE STAND
COMMENT
  THE PRESCRIPTION CALLS FOR IMMEDIATE REMOVAL OF EXCESS TREES,
  A COMMERCIAL THINNING AT AGE 90 TO REMOVE LODGEPOLE AND LARCH,
  A SHELTERWOOD REGENERATION TREATMENT AT AGE 120 FAVORING GRAND FIR
  AND DOUGLAS-FIR, AND AN OVERWOOD REMOVAL AT AGE 130.
END
DESIGN                                                  11.0       1.0
STDINFO         18.0     570.0      57.0       8.0       3.0      34.0
INVYEAR       1977.0
NUMCYCLE        10.0
THINPRSC      1980.0     0.999
SPECPREF      2010.0       2.0     999.0
SPECPREF      2010.0       7.0    9999.0
THINBTA       2010.0     157.0
SPECPREF      2040.0       3.0    -999.0
SPECPREF      2040.0       4.0     -99.0
THINBTA       2040.0      35.0
ESTAB         2037.0
END
COVER
CANOPY
SHRUBS          57.0     570.0        3.
END
TREEDATA         5.0
   1      248112      0101   011LP 11510   0734   00111     0  0
   2      248112      0101   031DF 001     0026   00222     0  0
   3      248112      0102   011WH 06523   0308   00111     0  0
   4      248112      0102   011L  07906   0753   00111     0  0
   5      248112      0102   016L  346            10322     0  0
   6      248112      0103   011L  08007   0633   73222     0 56
   7      248112      0103   011GF 06220   0385   00111     0  0
   8      248112      0103   011L  084       54   00111     0  0
   9      248112      0103   011LP 09511   0603   00111     0  0
  10      248112      0104   011DF 040     0203   00111    50  0
  11      248112      0104   011L  08212   0655   50111     0  0
  12      248112      0105   011DF 012     0116   00222    42  0
  13      248112      0105   011DF 019     0135   00222    47  0
  14      248112      0105   015LP 072            11322     0  0
  15      248112      0105   031GF 001     0037   00222     0  0
  16      248112      0105   011GF 05309   0277   00111     0  0
  17      248112      0106   011DF 10010   0654   00111     0  0
  18      248112      0106   011GF 06112   0388   00111     0  0
  19      248112      0106   011DF 12716   0674   00111     0  0
  20      248112      0107                          800
  21      248112      0108   011LP 09605   0603   00222     0  0
  22      248112      0108   011DF 10409   0555   74222     0 49
  23      248112      0108   011LP 085       03   00111     0  0
  24      248112      0109   011GF 10910   0657   00111     0  0
  25      248112      0109   011DF 09418   0604   00111     0  0
  26      248112      0110   011C  03206   0175   00222    32  0
  27      248112      0110   011C  001     0027   00222     0  0
  28      248112      0110   011C  05810   0287   00111     0  0
  29      248112      0110   011C  05010   0253   00111    37  0
  30      248112      0111   011GF 06614   0307   00111     0  0
  31                  -999
PROCESS
STOP
```

Figure 1.—Keyword and tree record file used to project stand S248112 using the combined Prognosis Model and COVER extension.

STAND GROWTH PROGNOSIS SYSTEM   VERSION 5.0 – INLAND EMPIRE

STAND ID: S248112   MANAGEMENT CODE: NONE   PROGNOSIS WITH COVER EXTENSION - USER'S MANUAL EXAMPLE STAND

CANOPY COVER STATISTICS

ATTRIBUTE BY 10' HEIGHT CLASS

TREES -- TREES PER ACRE
COVER -- PERCENTAGE OF CANOPY CLOSURE CONTRIBUTED BY TREES IN HEIGHT CLASS
AREA -- CROWN PROFILE AREA (SQ.FT. PER ACRE)
VOLUME -- CROWN VOLUME (CU.FT. PER ACRE X 100)
BIOMASS -- FOLIAGE BIOMASS (LBS. PER ACRE)

	STAND HEIGHT CLASS																
YEAR	0.0- 10.0'	10.1- 20.0'	20.1- 30.0'	30.1- 40.0'	40.1- 50.0'	50.1- 60.0'	60.1- 70.0'	70.1- 80.0'	80.1- 90.0'	90.1- 100.0'	100.1- 110.0'	110.1- 120.0'	120.1- 130.0'	130.1- 140.0'	140.1- 150.0'	150.1+	TOTAL
1977																	
TREES	220	131	111	39	0	41	29	17	0	0	0	0	0	0	0	0	590
COVER	22	14	26	7	0	6	7	2	0	0	0	0	0	0	0	0	84
AREA	2639	11868	5536	2070	4209	5480	2038	334	0	0	0	0	0	0	0	0	34173
VOLUME	195	788	272	123	277	347	116	13	0	0	0	0	0	0	0	0	2130
BIOMASS	593	2823	1254	338	622	886	210	16	0	0	0	0	0	0	0	0	6742
1977:POST-THIN																	
TREES	11	30	111	39	0	27	29	17	0	0	0	0	0	0	0	0	264
COVER	21	3	26	7	0	3	7	2	0	0	0	0	0	0	0	0	69
AREA	1225	9871	5536	1478	3204	4730	2038	334	0	0	0	0	0	0	0	0	28416
VOLUME	153	681	272	77	194	305	116	13	0	0	0	0	0	0	0	0	1811
BIOMASS	483	2635	1254	251	449	768	210	16	0	0	0	0	0	0	0	0	6066
1987																	
TREES	2	8	25	83	60	0	17	37	11	0	0	0	0	0	0	0	244
COVER	0	3	4	25	20	0	2	9	1	0	0	0	0	0	0	0	65
AREA	152	9462	10040	4990	1661	3928	4401	2025	239	0	0	0	0	0	0	0	36897
VOLUME	22	966	668	271	89	258	316	118	10	0	0	0	0	0	0	0	2719
BIOMASS	61	3194	2460	943	237	614	754	221	9	0	0	0	0	0	0	0	8493
1997																	
TREES	0	6	2	31	78	47	2	15	34	9	0	0	0	0	0	0	224
COVER	0	2	1	7	32	21	1	2	10	1	0	0	0	0	0	0	76
AREA	2	7105	11698	9158	5356	2069	3080	2163	1141	174	0	0	0	0	0	0	41946
VOLUME	0	978	1185	682	354	167	292	186	66	8	0	0	0	0	0	0	3917
BIOMASS	0	2408	3384	1898	966	483	802	391	80	7	0	0	0	0	0	0	10418
2007																	
TREES	0	0	6	14	30	53	42	16	5	33	5	0	0	0	0	0	204
COVER	0	0	1	3	12	26	26	5	1	10	1	0	0	0	0	0	85
AREA	2	3513	12374	11483	8574	5163	2175	2665	1642	790	43	0	0	0	0	0	48423
VOLUME	0	638	1671	1144	721	351	171	290	163	47	2	0	0	0	0	0	5198
BIOMASS	0	1155	3894	2936	1694	868	442	784	340	56	1	0	0	0	0	0	12171

Figure 2.—The canopy cover statistics display is produced when the CANOPY keyword is present in the runstream.

2007:POST-THIN																	
TREES	0	0	0	9	26	50	42	8	2	20	0	0	0	0	0	0	157
COVER	0	0	0	2	11	26	26	4	0	7	0	0	0	0	0	0	78
AREA	0	3508	12119	11212	8485	5090	1440	858	392	69	1	0	0	0	0	0	43172
VOLUME	0	638	1651	1131	718	348	129	157	71	8	0	0	0	0	0	0	4852
BIOMASS	0	1154	3831	2869	1682	852	395	560	253	27	0	0	0	0	0	0	11623
2017																	
TREES	0	0	0	0	19	16	52	32	7	9	12	0	0	0	0	0	147
COVER	0	0	0	0	5	11	33	26	5	2	6	0	0	0	0	0	87
AREA	0	1526	11392	13226	11036	8526	5393	1651	704	309	59	0	0	0	0	0	53821
VOLUME	0	339	1934	1763	1197	795	421	164	132	59	13	0	0	0	0	0	6817
BIOMASS	0	410	3515	3588	2278	1463	872	469	461	208	48	0	0	0	0	0	13312
2027																	
TREES	0	0	0	0	0	20	19	043	22	13	15	5	0	0	0	0	136
COVER	0	0	0	0	0	7	13	033	21	9	5	4	0	0	0	0	91
AREA	0	55	8324	12536	12670	10210	7725	4863	1683	455	160	22	0	0	0	0	58704
VOLUME	0	14	1682	1993	1624	1148	759	461	201	72	10	0	0	0	0	0	7965
BIOMASS	0	10	2354	3257	3032	1956	1372	1081	608	238	30	1	0	0	0	0	13973
2037																	
TREES	0	0	0	0	0	15	13	15	31	27	10	12	3	0	0	0	126
COVER	0	0	0	0	0	5	9	13	30	23	7	5	3	0	0	0	94
AREA	0	0	4645	11071	13303	11677	9643	6992	3813	1313	456	133	5	0	0	0	63051
VOLUME	0	0	1029	2020	2077	1593	1160	684	341	184	82	17	0	0	0	0	9186
BIOMASS	0	0	1028	2871	3489	2525	1781	1108	724	544	258	54	0	0	0	0	14381
2037:POST-THIN																	
TREES	0	0	0	0	0	0	1	7	5	3	5	12	3	0	0	0	35
COVER	0	0	0	0	0	0	0	1	1	2	3	5	3	0	0	0	14
AREA	0	0	153	722	976	1418	1537	1308	1187	859	407	119	5	0	0	0	8692
VOLUME	0	0	32	129	155	213	204	147	160	159	77	16	0	0	0	0	1292
BIOMASS	0	0	39	220	269	388	410	344	450	506	254	53	0	0	0	0	2933
2047																	
TREES	2192	37	0	0	0	0	0	1	5	5	2	12	6	1	0	0	2261
COVER	11	2	0	0	0	0	0	0	1	2	2	6	4	1	0	0	29
AREA	3380	45	575	972	1504	1623	1434	1492	1364	884	474	194	47	0	0	0	13991
VOLUME	51	4	117	176	251	238	181	214	239	162	84	25	2	0	0	0	1744
BIOMASS	209	11	282	475	688	677	531	796	984	667	349	109	9	0	0	0	5788
2057																	
TREES	2873	185	0	0	0	0	0	0	1	9	1	2	15	3	0	0	3090
COVER	28	9	0	0	0	0	0	0	0	2	2	2	8	4	0	0	55
AREA	11411	1347	540	967	1558	1772	1709	1535	1477	1315	827	441	162	34	0	0	25095
VOLUME	248	38	117	192	290	296	252	202	227	244	155	79	17	0	0	0	2357
BIOMASS	771	101	273	506	837	885	793	720	830	901	577	295	62	1	0	0	7551
2067																	
TREES	1696	603	91	0	0	0	0	0	0	1	9	2	12	4	3	0	2421
COVER	26	31	7	0	0	0	0	0	0	0	2	3	7	3	5	0	85
AREA	17479	8596	1260	937	1479	1883	1828	1593	1856	1606	1027	588	275	107	16	0	40530
VOLUME	484	303	153	199	292	346	295	226	320	304	181	88	26	4	0	0	3222
BIOMASS	1377	760	338	431	679	847	755	594	1095	1081	615	289	78	12	0	0	8950
2077																	
TREES	997	593	249	45	5	0	0	0	0	0	5	4	2	15	0	3	1921
COVER	23	38	22	6	1	0	0	0	0	0	1	2	3	10	1	5	111
AREA	16734	17017	6011	1500	1244	1898	1893	1793	1720	1686	1430	925	522	217	67	2	54662
VOLUME	514	722	334	220	242	385	344	289	260	287	273	166	84	21	1	0	4142
BIOMASS	1584	1703	925	425	503	842	773	681	698	862	865	530	270	63	3	0	10728

Figure 2. (Con.)

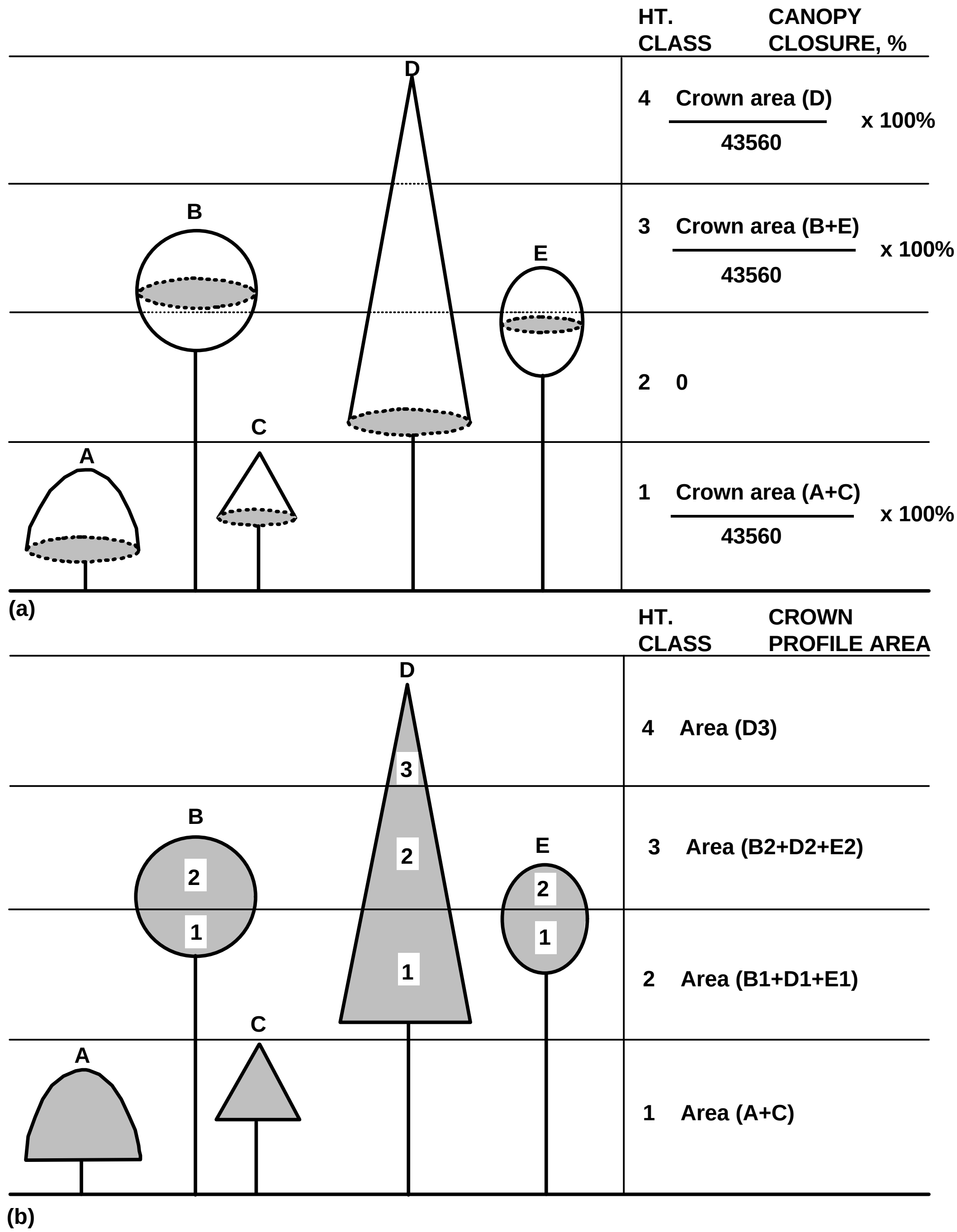

Figure 3.—Canopy structure computations in the CANOPY option of COVER: (a) canopy closure by 10-ft height class; (b) crown profile area by 10-ft height class.

Crown volume.—The volume in cubic feet per acre of tree crowns within height classes. Volume is determined using integration of standard volume formulas for conical, spherical, parabolic, elliptic, and neiloid crown forms.

Foliage biomass.—The biomass of foliage in pounds per acre in the stand, represented by the sum of foliage in individual crown sections within height classes.

Shrub Statistics Display

The second COVER display, shrub statistics by species (fig. 4) is produced when the SHRUBS keyword is present in the runstream. Predictions are made for each of 31 species or species groups listed in table 1. Nine species with the greatest predicted cover in the stand are always displayed: three each within low (less than 1.7 ft), medium (1.7–7 ft), and tall (7 ft and greater) height classes (Patterson and others 1985).

Cover.—The percentage of area covered by the canopy of an individual species projected vertically onto the ground. Species cover is weighted by probability of occurrence.

Height. —Average height of the species, in feet.

Probability of occurrence.—The proportion (expressed as a percentage) of l/300-acre plots in the described stand that contain the indicated species.

The remaining species within each height class are combined into an “other” category. For these, cover is the sum of other species cover weighted by their probabilities, height is their average height weighted by species cover, and probability is the sum of their individual probabilities. In addition, the user may specify up to six species which will always be displayed, using the SHOWSHRB keyword card and supplemental data record.

Shrub values are computed only between 3 and 40 years following stand disturbance (the lower and upper limits of the range of data used to model shrub production). In the course of a projection, if a thinning causes canopy closure to fall below 50 percent, and if the thinned volume is at least 20 percent of the volume before thinning, then time since stand disturbance is reset to 3 years and shrub computations resume. In the example simulation, time since disturbance was incremented from initial stand age of 57 years until the overstory removal in year 2037. Neither the thinning in 1977 nor the one in 2007 opened the canopy enough to trigger shrub calculations in the program. The overwood cut in 2037 reduced crown closure from 98 percent to 14 percent, causing the shrub response calculations to begin.

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                                   STAND GROWTH PROGNOSIS SYSTEM         VERSION 5.0 – INLAND EMPIRE

STAND ID:  S248112     MANAGEMENT CODE:  NONE     PROGNOSIS WITH COVER EXTENSION - USER’S MANUAL EXAMPLE STAND


------------------------------------------------------ SHRUB STATISTICS -----------------------------------

                   LOW SPECIES (0-1.7 FT)        MEDIUM SPECIES (1.7-7 FT)        TALL SPECIES (7+ FT)
                ----------------------------   --------------------------       -------------------------
                ARUV:ARCTOSTAPHYLOS UVA-URSI    LONI:LONICERA SPP.               ACGL:ACER GLABRUM
                BERB:BERBERIS SPP.              MEFE:MENZIESIA FERRUGINEA        ALSI:ALNUS SINUATA
                LIBO:LINNAEA BOREALIS           PHMA:PHYSOCARPUS MALVACEUS       AMAL:AMELANCHIER ALNIFOLIA
                PAMY:PACHISTIMA MYRSINITES      RIBE:RIBES SPP.                  CESA:CEANOTHUS SANGUINEUS
                SPBE:SPIRAEA BETULIFOLIA        ROSA:ROSA SPP.                   CEVE:CEANOTHUS VELUTINUS
                VASC:VACCINIUM SCOPARIUM        RUPA:RUBUS PARVIFLORUS           COST:CORNUS STOLONIFERA
                CARX:CAREX SPP.                 SHCA:SHEPHERDIA CANADENSIS       HODI:HOLODISCUS DISCOLOR
                                                SYMP:SYMPHORICARPOS SPP.         PREM:PRUNUS EMARGINATA
                                                VAME:VACCINIUM MEMBRANACEUM      PRVI:PRUNUS VIRGINIANA
                                                XETE:XEROPHYLLUM TENAX           SALX:SALIX SPP.
                                                FERN:FERNS                       SAMB:SAMBUCUS SPP.
                                                COMB:OTHER SHRUBS COMBINED       SORB:SORBUS SPP.

                        --------------------------------------------------------------------------------
                         ATTRIBUTES OF THE FIRST THREE SPECIES WITH GREATEST COVER IN EACH HEIGHT GROUP
                                    (ALL OTHERS WITHIN GROUP COMBINED INTO CATEGORY "OTHR")
                        --------------------------------------------------------------------------------
                                 COVER -- SPECIES COVER
                                HEIGHT -- AVERAGE SPECIES HEIGHT (FEET)
                                  PROB -- SPECIES PROBABILITY OF OCCURRENCE

YEAR                     LOW SPECIES             MEDIUM SPECIES            TALL SPECIES
----                ----------------------    ----------------------    ----------------------

1977           : TIME SINCE DISTURBANCE=  57. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

1977 POST-THIN : TIME SINCE DISTURBANCE=  57. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

1987           : TIME SINCE DISTURBANCE=  67. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

1997           : TIME SINCE DISTURBANCE=  77. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2007           : TIME SINCE DISTURBANCE=  87. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2007 POST-THIN : TIME SINCE DISTURBANCE=  87. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2017           : TIME SINCE DISTURBANCE=  97. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2027           : TIME SINCE DISTURBANCE= 107. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2037           : TIME SINCE DISTURBANCE= 117. EXCEEDS 40 YEARS.  SHRUB STATISTICS NOT COMPUTED.

2037:POST-THIN
SPECIES              LIBO  SPBE  PAMY  OTHR    VAME  FERN  RUPA  OTHR    ACGL  COST  AMAL  OTHR
 COVER                7.5   2.3   0.7   0.0    13.2   4.9   4.3  10.5    11.7   0.8   0.6   0.8
 HEIGHT               0.5   1.8   1.5   0.7     2.4   2.1   2.3   2.9     8.3   5.5   5.5   4.7
  PROB               27.7   9.6   5.1   0.0    50.3  25.2  26.9  71.7    39.0   2.2   4.2   8.9

2047
SPECIES              LIBO  PAMY  SPBE  OTHR    VAME  RUPA  LONI  OTHR    ACGL  SALX  AMAL  OTHR
 COVER                8.9   5.8   2.2   0.1     8.7   4.1   2.5   7.5     4.9   1.0   0.9   2.0
 HEIGHT               0.5   1.7   1.8   0.7     2.4   2.4   3.1   2.8     8.8   8.9   6.6   5.9
  PROB               31.3  34.2   8.6   0.4    37.9  22.6  16.4  42.8    15.5   5.2   5.9  11.2

2057
SPECIES              LIBO  PAMY  SPBE  OTHR    VAME  RUPA  LONI  OTHR    ACGL  SAL  AMAL  OTHR
 COVER                9.9   7.3   2.1   0.1     6.6   3.1   2.1   5.7     3.0   1.3   0.9   1.5
 HEIGHT               0.5   1.6   1.8   0.7     2.3   2.3   3.0   2.8     8.3   9.2   6.5   6.1
  PROB               32.9  41.4   7.9   0.6    33.9  18.3  14.5  34.6    10.9   7.7   5.8   9.3

2067
SPECIES              LIBO  PAMY  SPBE  OTHR    VAME  RUPA  LONI  OTHR    ACGL  SALX  AMAL  OTHR
 COVER               10.7   6.8   1.8   0.2     4.8   2.1   1.5   4.3     1.8   1.2   0.7   0.9
 HEIGHT               0.5   1.5   1.7   0.7     2.3   2.2   2.8   2.7     7.3   8.7   5.7   6.0
  PROB               33.4  39.2   6.9   0.8    30.3  13.7  11.8  28.8     8.1   8.0   5.0   6.7

2077
SPECIES              LIBO  PAMY  SPBE  OTHR    VAME  RUPA  ROSA  OTHR    ACGL  SALX  AMAL  OTHR
 COVER               11.5   5.7   1.5   0.2     3.4   1.2   1.1   3.1     1.0   1.0   0.5   0.5
 HEIGHT               0.5   1.4   1.6   0.7     2.2   2.0   2.8   2.5     6.3   7.7   4.8   5.9
  PROB               33.9  34.2   5.9   1.1    26.8   9.6  10.1  23.0     6.0   7.6   4.0   4.7
```

Figure 4.—The shrub statistics display is produced when the SHRUBS keyword is present in the runstream.

Table 1.—Understory species for which predictions are currently made in the SHRUBS portion of the COVER program, height class, and source of information

Code	Scientific name	Common name	Height class[1]	Source[2]
AGCL	*Acer glabrum*	Rocky Mountain maple	T	a, b
ALSI	*Alnus sinuata*	Sitka alder	T	a
AMAL	*Amelanchier alnifolia*	Serviceberry	T	a, b
ARUV	*Arctostaphylos uva-ursi*	Kinnikinnick	L	a
BERB	*Berberis* spp.	Oregon grape	L	a
CARX	*Carex* spp.	Sedge	L	a
CESA	*Ceanothus sanguineus*	Redstem ceanothus	T	a, b
CEVE	*Ceanothus velutinus*	Shinyleaf ceanothus	T	a, b
COST	*Cofnus stolonifera*	Red-osier dogwood	T	a
FERN	*Athyrium filix-femina* *Pteridium aquilinum*	Fern	M	a
HODI	*Holodiscus discolor*	Ocean-spray	T	a, b
LIBO	*Linnaea borealis*	Twinflower	L	a
LONI	*Lonicera* spp.	Honeysuckle	M	a, b
MEFE	*Menziesia ferruginea*	Menziesia	M	a
PAMY	*Pachistima myrsinites*	Pachistima	L	a, b
PHMA	*Physocarpus malvaceus*	Ninebark	M	a, b
PREM	*Prunus emarginata*	Bittercherry	T	a, b
PRVI	*Prunus virginiana*	Common chokecherry	T	a
RIBE	*Ribes* spp.	Currant	M	a, b
ROSA	*Rosa* spp.	Rose	M	a, b
RUPA	*Rubus parviflorus*	Thimbleberry	M	a, b
SALX	*Salix* spp.	Willow	T	a, b
SAMB	*Sambucus* spp.	Elderberry	T	a
SHCA	*Shepherdia canadensis*	Russett buffaloberry	M	a
SORB	*Sorbus* spp.	Mountain-ash	T	a
SPBE	*Spiraea betulifolia*	Shinyleaf spiraea	L	a, b
SYMP	*Symphoricarpos* spp.	Snowberry	M	a, b
VAME	*Vaccinium membranaceum* *Vaccinium globulare*	Big huckleberry Globe huckleberry	M	a, b
VASC	*Vaccinium scoparium*	Grouse whortleberry	L	a
XETE	*Xerophyllum tenax*	Common beargrass	M	a
COMB		Other shrubs combined	M	a
	Artemisia tridentata	*Prunus pensylvanica*		
	Clematis columbiana	*Purshia tridentata*		
	Cornus nuttallii	*Rhamnus purshiana*		
	Crataegus douglasii	*Rhododendron albiflorum*		
	Juniperus spp.	*Rhus trilobata*		
	Ledum glandulosum	*Rubus leucodermis*		
	Lonicera caerulea	*Rubus ursinus*		
	Lonicera involucrata	*Spiraea pyramidata*		
	Oplopanax horridum	*Taxus brevifolia*		
	Philadelphus lewisii	*Vaccinium caespitosum*		

[1]T = tall, M = medium, L = low (from Patterson and others 1985).
[2]a: Probability of occurrence from Scharosch (1984).
Height and percent cover from Laursen (1984).
b: Twig production and dormant season biomass (ABGR/CLUN, THPL/CLUN, TSHE/CLUN habitat types only) from Irwin and Peek (1979).

Canopy and Shrubs Summary Display

The third display is the Canopy and Shrubs Summary display (fig. 5).

Understory attributes:

Time since disturbance.—Time in years since the stand has been entered for harvest or site preparation. At the start of a projection, this value is set equal either to stand age or to the value entered on the SHRUBS keyword record, and is incremented by the length of each cycle. A thinning which reduces canopy closure below 50 percent and accounts for at least 20 percent of the prethinning volume causes time since disturbance to be reset to 3 years. See the previous section for more explanation.

Probability of shrub cover being greater than zero.—The proportion (expressed as a percentage) of l/300-acre plots in the described stand that contain any shrub cover.

Shrub cover.—Sum of individual percentage cover, weighted by probability, for all species in low (0—l.7 ft), medium (1.7—7 ft), and tall (over 7 ft) height classes, and total shrub cover.

Average shrub height.—Average height in feet of all species, weighted by predicted species cover.

Dormant shrub biomass.—Total dormant season aboveground shrub biomass in pounds per acre.

Twig production.—Current year's number of twigs per square foot. Shrub biomass and twig production are only computed for ABGR/CLUN, THPL/CLUN, and TSHE/CLUN habitat types (codes 520, 530, and 570).

Stand successional stage code.—A vegetation life form classification described by Peterson (1982), which provides a basis for relating wildlife use to the shrub and conifer structure of the stand.

Overstory attributes:

Stand age.—Overstory age in years, entered on the STDINFO card and incremented by the length of each projection cycle. The value of stand age will change during the projection if RESETAGE, a regeneration establishment model keyword (Ferguson and Crookston 1984), is used.

Top height.—Current average height in feet of the largest 40 trees per acre by d.b.h.

Canopy closure.—Total percentage canopy closure.

Crown foliage biomass.—Total foliage biomass in pounds per acre.

Sum of stem diameters.—The sum of stem diameters at breast height for all trees in the stand, in feet. This quantity may be used to compute stem area available for hiding cover by multiplying by height value of interest (for example, average shoulder height of an elk).

Number of stems.—Total number of trees per acre.

Shrub-small conifer competition:

If the SHRUBS option is in effect, a display similar in format to the Canopy Cover table is produced. It expands the resolution of the first 20 ft of the stand, and displays both shrub cover and number of trees cumulatively by height.

Shrub cover.—Total cover of shrubs whose predicted heights are greater than the current height.

Number of trees.—Total number of trees per acre whose heights are greater than the current height.

STAND GROWTH PROGNOSIS SYSTEM VERSION 5.0 – INLAND EMPIRE

STAND ID: S248112 MANAGEMENT CODE: NONE PROGNOSIS WITH COVER EXTENSION - USER’S MANUAL EXAMPLE STAND

CANOPY AND SHRUBS SUMMARY

DEFINITIONS OF SUCCESSIONAL STAGE CODES USED IN OUTPUT

1: RECENT DISTURBANCE	6: TALL SHRUB WITH MOSTLY CONIFERS
2: LOW SHRUB	7: SAPLING TIMBER
3: MEDIUM SHRUB	8: POLE TIMBER
4: TALL SHRUB WITH NO CONIFERS	9: MATURE TIMBER
5: TALL SHRUB WITH FEW CONIFERS	10: OLD-GROWTH TIMBER

	UNDERSTORY ATTRIBUTES										OVERSTORY ATTRIBUTES					
			SHRUB COVER													
DATE	TIME SINCE DISTURB. (YEARS)	PROB. (SHRUB COV>0) (%)	LOW (%)	MED (%)	TALL (%)	TOTAL (%)	AVG. SHRUB HEIGHT (FEET)	DORMANT SHRUB BIOMASS (LB/AC)	TWIGS (NO./ SQFT)	SUCC. STAGE CODE	STAND AGE (YRS)	TOP HEIGHT (FEET)	CANOPY CLOSURE (%)	FOLIAGE BIOMASS (LB/AC)	SUM OF STEM DIAMS. (FEET)	NUMBER OF STEMS
1977	57										57	63	84	6742	185	590
POST-THIN	57										57	64	69	6066	147	264
1987	67										67	68	65	8493	169	244
1997	77										77	76	76	10418	186	224
2007	87										87	78	85	12171	195	204
POST-THIN	87										87	77	78	11623	154	157
2017	97										97	84	87	13312	164	147
2027	107										107	92	91	13937	170	136
2037	117										117	98	94	14381	173	126
POST-THIN	3	78	11	33	14	57	3.5	388	2.3	6	117	100	14	2933	50	35
2047	10	78	17	23	9	48	3.0	876	3.0	6	127	89	29	5788	120	2261
2057	20	75	19	18	7	44	2.7	607	0.3	6	137	95	55	7551	207	3090
2067	30	69	19	13	5	37	2.3	272	0.0	7	147	101	85	8950	265	2421
2077	40	58	19	9	3	31	1.8	101	0.0	7	157	107	111	10728	325	1921

SHRUB-SMALL CONIFER COMPETITION

SHRUB COVER -- TOTAL COVER OF SHRUBS GREATER THAN HEIGHT
TREES/ACRE -- TOTAL NUMBER OF TREES PER ACRE GREATER THAN HEIGHT

		HEIGHT (FEET)										
YEAR		0.0	0.5	1.0	2.0	3.0	4.0	5.0	7.5	10.0	15.0	20.0
POST-THIN	SHRUB COVER	57	50	50	46	17	14	13	12	0	0	0
	TREES/ACRE	35	35	35	35	35	35	35	35	35	35	35
2047	SHRUB COVER	48	39	39	31	14	9	9	6	0	0	0
	TREES/ACRE	2261	2261	1717	838	531	297	209	100	69	32	32
2057	SHRUB COVER	44	34	34	23	11	7	7	4	0	0	0
	TREES/ACRE	3090	3090	2433	1936	1486	1191	948	381	217	74	32
2067	SHRUB COVER	37	26	26	17	6	5	4	1	0	0	0
	TREES/ACRE	2421	2421	2421	2282	1973	1647	1411	984	726	286	123
2077	SHRUB COVER	31	19	19	10	4	3	2	1	0	0	0
	TREES/ACRE	1921	1921	1921	1921	1890	1803	1633	1304	923	551	330

Figure 5.—Canopy and shrubs summary display

PROGRAM ORGANIZATION

Each projection cycle in the Prognosis Model starts with simulated thinnings if thinning activities have been scheduled for that cycle. If either the CANOPY or SHRUBS option has been selected, crown and shrub statistics are computed and displayed following the thinning. Next, diameter and height growth, change in crown ratio, and mortality rate are computed for each tree record in the inventory by the main program. The tree attributes are updated at the end of the cycle and then crown and shrub statistics are computed once again. Thus, in thinning cycles, COVER values are computed and displayed twice. In projection cycles with no thinning, there is only one call to the COVER extension at the end of the cycle.

Crown cover and shrub predictions are displayed following a thinning to show the immediate effects of treatment on cover development. Predictions and display for crowns and for shrubs are handled somewhat differently in the postthin sequence. In the CANOPY subprogram, the crown models use prethin levels of stand density statistics (trees per acre, basal area, and relative diameter) to predict crown dimensions on remaining trees. This is done because no immediate response in crown dimension or foliage on residual trees to a change in stand density would be expected. In the SHRUBS subprogram, predictions are made using postthin stand density statistics to reflect the more rapid response of understory plants that one would expect following an opening up of the canopy.

The COVER extension may be used in conjunction with ESTAB, a Prognosis Model extension that simulates regeneration and subsequent development of a regenerated stand (Ferguson and Crookston 1984). Inside the combined COVER, ESTAB, and Prognosis Models, shrub values are computed prior to the establishment of new trees. Although presently ESTAB does not include effects of shrub development on the establishment of new trees, the computation sequence has been set up in anticipation of feedback between the shrubs and regeneration systems. For now, the shrub-small conifer display in the Summary table may help the user examine effects of shrub competition on newly established trees.

Shrub statistics (probability of occurrence, height, cover, biomass, and twig production) are not computed if time since disturbance exceeds 40 years. If the COVER extension is used in conjunction with the regeneration establishment model, and stand age is reset to a value less than 40 years using the RESETAGE keyword, shrub calculations will resume. Also, as discussed previously, shrub statistics will resume beginning with the postthin predictions for a cycle in which a heavy thinning takes place. Canopy cover statistics are displayed regardless of the value for time since disturbance.

KEYWORD DESCRIPTIONS

The keyword system used in the COVER extension is similar to that used for the Prognosis Model. Presently, 13 keywords are used to invoke the CANOPY or SHRUBS options, supply needed information to the extension, or modify its output. The position of these cards in the Prognosis Model deck is unimportant except that they should be in a group beginning with the COVER keyword and ending with the END keyword. Like all other keywords, they must precede the PROCESS card. Formatting of keyword records follows the scheme used for all other Prognosis Model keywords. Columns 1 to 10 are reserved for the keyword itself, followed by seven parameter fields of 10 columns each. Numeric data should be right-justified within the parameter field, or include a decimal point. Three of the keyword records in the SHRUBS option are followed by supplemental data records. The END record signifies the end of keywords for the extension and returns control to the main program. The appendix summarizes keyword records available in the COVER option.

Calling the Extension

COVER Keyword

The COVER keyword record signifies the beginning of keywords for the extension. It has two parameter fields.

COVER field 1: Cycle number in which COVER calculations begin; default = beginning of projection. COVER calculations will be performed in all cycles subsequent to the specified one.

field 2: Dataset reference number for COVER output; default = 18.

Overstory Options

CANOPY Keyword

The CANOPY keyword invokes the crown cover options of the extension, which compute crown width, shape, and foliage biomass for each tree record, and tree cover summary statistics for the stand. It has no parameter fields associated with it.

Understory Options

SHRUBS Keyword

The SHRUBS keyword tells the program to compute shrub statistics. It has four parameter fields.

SHRUBS field 1: Time in years since stand disturbance; default = stand age. If stand age is not supplied, default = 3 years.

field 2: Habitat type code selected for processing shrub options. Table 2 lists habitat types for which shrub predictions are made; default = stand habitat type code.

field 3: Physiographic type code. 1 = bottom, 2 = lower slope, 3 = midslope, 4 = upper slope, 5 = ridge; default = 2.

field 4: Disturbance type code. 1 = none, 2 = mechanical, 3 = burn, 4 = road; default = 1.

As indicated, each of the SHRUBS keyword parameters has a default value in the event that no value is supplied by the user. The value entered for time since disturbance should be the number of years since the stand was entered for harvest or site preparation. Time since disturbance will be set to stand age entered on the STDINFO keyword record if the user fails to supply a value on the SHRUBS keyword, and will be incremented by the length of each projection cycle. Although stand age is not used by the Prognosis Model to calculate tree growth, time since disturbance is a significant predictor of shrub development. As noted previously, shrub calculations are performed only if the current value of time since disturbance is between 3 and 40 years. Three situations may occur to reset time since disturbance. First, if a value less than 3 years is entered (or if the age fields on both the SHRUBS and STDINFO keywords are left blank), initial time since disturbance will be set to 3 years. Second, if a scheduled thinning causes canopy closure to fall below 50 percent, and if the volume removed is 20 percent or more of the volume before thinning, then disturbance time is reset to 3 years. Finally, if the Regeneration Establishment Model is being used, and stand age is reset to a value less than 40 years using

Table 2.—Valid habitat type codes for the SHRUBS option (from Pfister and others 1977; Steele and others 1981)

Abbreviations	Codes	Habitat types and phases
		Pseudotsuga menziesii series
PSME/AGSP	210	*Pseudotsuga menziesii/Agropyron spicatum*
PSME/FEID	220	*Pseudotsuga menziesii/Festuca idahoensis*
PSME/PHMA	260	*Pseudotsuga menziesii/Physocarpus malvaceus*
PSME/SYAL	310	*Pseudotsuga menziesii/Symphoricarpos albus*
PSME/CARU	320	*Pseudotsuga menziesii/Calamagrostis rubescens*
PSME/CAGE	330	*Pseudotsuga menziesii/Carex geyeri*
PSME/SPBE	340	*Pseudotsuga menziesii/Spiraea betulifolia*
PSME/SYOR	380	*Pseudotsuga menziesii/Symphoricarpos oreophilus*
PSME/ACGL	390	*Pseudotsuga menziesii/Acer glabrum*
PSME/BERE	395	*Pseudotsuga menziesii/Berberis repens*
		Abies grandis series
ABGR/SPBE	505	*Abies grandis/Spiraea betulifolia*
ABGR/XETE	510	*Abies grandis/Xerophyllum tenax*
ABGR/COOC	511	*Abies grandis/Coptis occidentalis*
ABGR/VAGL	515	*Abies grandis/Vaccinium globulare*
ABGR/CLUN	520	*Abies grandis/Clintonia uniflora*
ABGR/ACGL	525	*Abies grandis/Acer glabrum*
ABGR/LIBO	590	*Abies grandis/Linnaea borealis*
		Thuja plicata series
THPL/CLUN	530	*Thuja plicata/Clintonia uniflora*
THPL/ATFI	540	*Thuja plicata/Athyrium filix-femina*
THPL/OPHO	550	*Thuja plicata/Oplopanax horridurn*
		Tsuga heterophylla series
TSHE/CLUN	570	*Tsuga heterophylla/Clintonia uniflora*
		Abies lasiocarpa series
ABLA/CLUN	620	*Abies lasiocarpa/Clintonia uniflora*
ABLA/STAM	635	*Abies Iasiocarpa/Streptopus amplexifolius*
ABLA/ACGL	645	*Abies lasiocarpa/Acer glabrum*
ABLA/CACA	650	*Abies Iasiocarpa/Calamagrostis canadensis*
ABLA/MEFE	670	*Abies lasiocarpa/Menziesia ferruginea*
ABLA/XETE	690	*Abies lasiocarpa/Xerophyllum tenax*
ABLA/SPBE	705	*Abies Iasiocarpa/Epiraea betulifolia*
TSME/XETE	710	*Tsuga mertensiana/Xerophyllum tenax*
ABLA/VAGL	720	*Abies Iasiocarpa/Vaccinium globulare*
ABLA/VAGL	721	*Abies Iasiocarpa/Vaccinium globulare, Vaccinium scoparium phase*
ABLA/VASC	730	*Abies Iasiocarpa/Vaccinium scoparium*
ABLA/CAGE	790	*Abies lasiocarpa/Carex geyeri*
ABLA/LUHI	830	*Abies lasiocarpa/Luzula hitchcockii*

the RESETAGE keyword, time since disturbance will also be reset to the same value.

Shrub statistics will be computed only if a valid habitat type code is encountered. Even if a code other than those listed in table 2 has been entered for the stand on the STDINFO record, the user may supply a separate habitat code that affects only the SHRUBS option. Thus shrub predictions may be made (at the user's discretion) by substituting a similar valid habitat type code. Allowing predictions to be made for similar habitat types assumes that, even though habitat type classification is based on unique potential climax vegetation, seral community development may not be unique and similar habitat types may respond with fairly similar shrub communities in the first 40 years following disturbance. If a substitute habitat type code is used, the program writes a cautionary message to that effect.

Shrub Calibration Options

If shrub information has been recorded in the inventory, it may be used to adjust the embedded models to reflect unique variations in site and environment. Shrub height, cover, and occurrence models may be calibrated using either of two types of data collected according to Region 1 Stand Examination Procedures (USDA 1983). The two methods are to measure the height and average cover of up to three distinct shrub layers in the stand, or alternatively to measure the height and cover of individual species. When real shrub measurements are provided to the model, the information is used to scale predictions to match observed values. The scaling factors are computed only once, at the start of the first cycle, and are applied to the predictions for all cycles until a simulated thinning occurs. Because the course of shrub development may be expected to be altered following a thinning, the original information input for calibration may no longer be appropriate. Thus, once a thinning occurs, all calibration ceases and shrub predictions are no longer multiplied by the scaling factors.

SHRBLAYR Keyword

This keyword is one of two possible methods for providing field data with which to calibrate the shrub predictions. The SHRBLAYR keyword record contains six fields of 10 columns each for recording average height and percentage of ground cover value for each distinct shrub layer (up to three layers) in the understory. There is no inherent height or percentage of cover ranking of the layers; they may be entered in any order. The information is coded according to the following format:

SHRBLAYR field 1: average height of shrub layer 1, in feet

field 2: percentage of cover of shrub layer 1

field 3: average height of shrub layer 2, in feet

field 4: percentage of cover of shrub layer 2

field 5: average height of shrub layer 3, in feet

field 6: percentage of cover of shrub layer 3

The SHRBLAYR method of calibration sorts the shrub species by uncalibrated predicted height at the beginning of the projection. Progressing down through the species list from predicted tallest to shortest, the individual uncalibrated shrub cover predictions, weighted by probability of occurrence, are summed. When the sum of cover accounts for the same proportion as entered for the tallest shrub layer on the SHRBLAYR card, the summing ceases, and those species are grouped into a class. The process is repeated for each input layer. Once the classes are delineated, average predicted height and total cover for each layer are computed and compared to the entered values for the layers. Scaling factors are computed that adjust the predicted values to match the input calibration values. The scaling factors are applied individually to the cover and height predictions of each species within delineated classes.

The calibration values entered on the SHRBLAYR card and the computed scaling factors are displayed in the Shrub Model Calibration Statistics display (fig. 6). This display is printed immediately preceding the Shrub Statistics display if calibration is specified.

```
                                        STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE
STAND ID:  S248112     MANAGEMENT CODE:  NONE     PROGNOSIS WITH COVER EXTENSION - SHRUB LAYER CALIBRATION

----------------------------------------------  SHRUB MODEL CALIBRATION STATISTICS  ---------------------------

CALIBRATION BY SHRUB LAYER (SHRBLAYR KEYWORD CARD):

          AVERAGE HEIGHT (FEET)                         AVERAGE PERCENT COVER
    -----------------------------------       -----------------------------------
    SHRUB  OBSERVED  PREDICTED  SCALING       SHRUB  OBSERVED  PREDICTED  SCALING
    LAYER  VALUES    VALUES     FACTORS       LAYER  VALUES    VALUES     FACTORS
    -----  --------  ---------  -------       -----  --------  ---------  -------

      1      6.0        5.4      1.10           1      10.0        8.2     1.21
      2      3.0        2.3      1.31           2      20.0       17.1     1.17
      3      1.0        0.9      1.11           3      20.0       17.2     1.16

                              HEIGHT        % COVER
     SHRUB    ASSIGNED        SCALING       SCALING
    SPECIES    LAYER          FACTOR        FACTOR
    -------   --------       ---------     ---------

      ARUV       3              1.11          1.16
      BERB       3              1.11          1.16
      LIBO       3              1.11          1.16
      PAMY       3              1.11          1.16
      SPBE       2              1.31          1.17
      VASC       3              1.11          1.16
      CARX       3              1.11          1.16
      LONI       2              1.31          1.17
      MEFE       1              1.10          1.21
      PHMA       1              1.10          1.21
      RIBE       1              1.10          1.21
      ROSA       2              1.31          1.17
      RUPA       2              1.31          1.17
      SHCA       1              1.10          1.21
      SYMP       2              1.31          1.17
      VAME       2              1.31          1.17
      XETE       3              1.11          1.16
      FERN       2              1.31          1.17
      COMB       1              1.10          1.21
      ACGL       1              1.10          1.21
      ALSI       1              1.10          1.21
      AMAL       1              1.10          1.21
      CESA       1              1.10          1.21
      CEVE       1              1.10          1.21
      COST       1              1.10          1.21
      HODI       1              1.10          1.21
      PREM       1              1.10          1.21
      PRVI       1              1.10          1.21
      SALX       1              1.10          1.21
      SAMB       1              1.10          1.21
      SORB       1              1.10          1.21
```

Figure 6.—Shrub model calibration by shrub layer, performed when the following keyword records are specified:

```
COVER
SHRUBS          20.0     570.0       3.0
SHRBLAYR         1.0      20.0       3.0      20.0       6.0      10.0
```

SHRUBPC and **SHRUBHT** Keywords

The SHRUBPC and SHRUBHT keywords are used to supply calibration information in instances where cover and/or average height measurements have been gathered for some or all of the individual species.

The format for the two keywords is identical, each requiring up to five cards for its input. The leading card has just the keyword entered on it. Following are up to four supplemental data records containing eight fields of 10 columns each. The first four columns of each field are used to identify the shrub species, using the abbreviations given in table 1. The remaining six columns are used to enter the corresponding percentage of cover for the SHRUBPC keyword or height in feet for the SHRUBHT keyword. For example, to enter a 50 percent cover statistic for Rocky Mountain maple, the field would appear as:

```
ACGL  50.0
----------
```

If no data were collected for a given species, there should be no entry for that species. If the species was included in the field survey but did not occur in the stand, it would be entered in the following manner:

```
ACGL   0.0
----------
```

Shrub species may be in any order on the supplemental records. Enter "–999" in the shrub code field following the last shrub entry to signify the end of the SHRUBPC (or SHRUBHT) data.

```
                                        STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE

STAND ID:  S248112     MANAGEMENT CODE:  NONE     PROGNOSIS WITH COVER EXTENSION - SHRUB LAYER CALIBRATION

----------------------------------------------  SHRUB MODEL CALIBRATION STATISTICS  ---------------------------

CALIBRATION BY INDIVIDUAL SPECIES (SHRUBHT AND/OR SHRUBPC KEYWORD CARDS):
```

	SHRUB HEIGHT (FEET)			PERCENT COVER		
SHRUB SPECIES	OBSERVED VALUE	PREDICTED VALUE	SCALING FACTOR	OBSERVED VALUE	PREDICTED VALUE	SCALING FACTOR
ARUV	0.0	0.5	0.00	0.0	0.0	0.00
BERB		0.8	1.00		0.0	1.00
LIBO	0.5	0.5	1.00	10.0	9.9	1.01
PAMY	2.0	1.6	1.24	6.0	7.9	0.76
SPBE		1.8	1.00		2.1	1.00
VASC	0.0	0.9	0.00	0.0	0.0	0.00
CARX	0.0	0.5	0.00	0.0	0.0	0.00
LONI		3.0	1.00		2.1	1.00
MEFE	5.0	4.0	1.26	1.0	1.0	0.97
PHMA		3.7	1.00		0.3	1.00
RIBE		3.2	1.00		0.5	1.00
ROSA		2.9	1.00		1.4	1.00
RUPA		2.3	1.00		3.1	1.00
SHCA		3.9	1.00		0.0	1.00
SYMP		1.7	1.00		0.8	1.00
VAME	2.0	2.3	0.86	5.0	6.2	0.80
XETE	0.0	1.5	0.00	0.0	0.0	0.00
FERN	2.0	2.1	0.96	5.0	1.6	3.06
COMB		4.1	1.00		0.2	1.00
ACGL	10.0	8.3	1.21	2.0	3.3	0.61
ALSI		3.7	1.00		0.1	1.00
AMAL		6.5	1.00		0.9	1.00
CESA		7.3	1.00		0.2	1.00
CEVE		5.2	1.00		0.2	1.00
COST		5.4	1.00		0.4	1.00
HODI		6.1	1.00		0.3	1.00
PREM	0.0	5.4	0.00	0.0	0.0	0.00
PRVI		9.3	1.00		0.2	1.00
SALX		9.2	1.00		1.3	1.00
SAMB		4.7	1.00		0.0	1.00
SORB		4.4	1.00		0.1	1.00

Figure 7.—Shrub model calibration by species, performed when the following keyword records are specified:

```
COVER
SHRUBS          20.0     570.0       3.0
SHRUBHT
ACGL  10.0MEFE   5.0VAME   2.0PAMY   2.0LIBO   0.5PREM   0.0XETE   0.0FERN   2.0
ARUV   0.0VASC   0.0CARX   0.0-999
SHRUBPC
ACGL   2.0MEFE   1.0VAME   5.0PAMY   6.0LIBO  10.0PREM   0.0XETE   0.0FERN   5.0
ARUV   0.0VASC   0.0CARX   0.0-999
```

The SHRUBPC and SHRUBHT keywords do not both have to be present in a given projection, although it is desirable. If only one of the keywords is present, only that portion of the calibration will be performed. The SHRBLAYR keyword should not be included when using the SHRUBPC and/or SHRUBHT keywords.

The data supplied on the SHRUBPC and SHRUBHT keyword cards are used to adjust probability of occurrence, height, and cover predictions for individual shrub species. Scaling factors are computed for each species as the ratio of actual to predicted height and cover at the start of the projection. Any species recorded as absent is given a zero probability of occurrence. In each cycle, these scaling factors are applied to the appropriate species and prediction. Scaling factors are ignored after the first simulated thinning.

Height and cover calibration factors by species are output in the Shrub Model Calibration Statistics Display (fig. 7).

Additional Keywords

There are seven additional keywords in the COVER extension. The first, SHOWSHRB, is used to select up to six understory species for which output will always be displayed. These are in addition to the nine species that account for the most cover. It requires one supplemental data record containing shrub species codes (table 1) in six fields of 10 columns each. The four-character codes must be right-justified within the fields.

Card 1: SHOWSHRB

Card 2: Cols. 1–10: abbreviation for first species

•

•

•

Cols. 51–60: abbreviation for last species

Three keywords are used to turn off printing of the displays:

NOCOVOUT — Suppress output of Canopy Cover Statistics display; default = table printed.

NOSHBOUT — Suppress output of the Shrub Statistics display; default = table printed.

NOSUMOUT — Suppress output of the Canopy and Shrubs Summary display; default = table printed.

The final three keywords are used to request information about the program, print intermediate debug information, and to signify the end of the COVER options:

DATELIST — Print date of last revision of COVER model subprograms and common areas.

DEBUG — Request printout of the results of most calculations for all tree and shrub records (caution: voluminous output!).
field 1: Cycle number in which debug output is to be printed; default = output printed in all cycles.

END — Signify the end of COVER keywords and return control to the main program.

The COVER keywords for the example stand are echoed in the Prognosis Model Input Summary table (fig. 8).

```
                    STAND GROWTH PROGNOSIS SYSTEM         VERSION 5.0 – INLAND EMPIRE
-------------------------------------------------------------------------------------------------------------------

                                    OPTIONS SELECTED BY INPUT

-------------------------------------------------------------------------------------------------------------------
KEYWORD   PARAMETERS:
--------  ---------------------------------------------------------------------------------------------------------
STDIDENT
          STAND ID= S248112          PROGNOSIS WITH COVER EXTENSION - USER’S MANUAL EXAMPLE STAND

DESIGN    BASAL AREA FACTOR=  40.0; INVERSE OF FIXED PLOT AREA=  300.0; BREAK DBH=    5.0
          SEE "OPTIONS SELECTED BY DEFAULT" FOR REMAINING DESIGN CARD PARAMETERS.

STDINFO   FOREST CODE= 18; HABITAT TYPE=570; AGE=   57; ASPECT CODE=  8.; SLOPE CODE=  3.
          ELEVATION(100'S FEET)= 34.0; SITE INDEX=   0.

INVYEAR   INVENTORY YEAR= 1977

NUMCYCLE  NUMBER OF CYCLES= 10

THINPRSC  DATE/CYCLE= 1980; PROPORTION OF SELECTED TREES REMOVED= 0.999

SPECPREF  DATE/CYCLE= 2010; SPECIES=  2.; THINNING SELECTION PRIORITY=  999.

SPECPREF  DATE/CYCLE= 2010; SPECIES=  7.; THINNING SELECTION PRIORITY= 9999.

THINBTA   DATE/CYCLE= 2010; RESIDUAL=  157.00; PROPORTION OF SELECTED TREES REMOVED= 0.980
          DBH OF REMOVED TREES WILL RANGE FROM   0.0 TO 999.0 INCHES

SPECPREF  DATE/CYCLE= 2040; SPECIES=  3.; THINNING SELECTION PRIORITY= -999.

SPECPREF  DATE/CYCLE= 2040; SPECIES=  4.; THINNING SELECTION PRIORITY=  -99.

THINBTA   DATE/CYCLE= 2040; RESIDUAL=   35.00; PROPORTION OF SELECTED TREES REMOVED= 0.980
          DBH OF REMOVED TREES WILL RANGE FROM   0.0 TO 999.0 INCHES

ESTAB     REGENERATION ESTABLISHMENT OPTIONS:
          DATE OF DISTURBANCE= 2037

END       REGENERATION TALLY SEQUENCE SCHEDULED FOR 2046, AND TALLY TWO FOR 2056
          END OF ESTABLISHMENT KEYWORDS

COVER     COVER OPTIONS:
          CYCLE=    1
          DATA SET REFERENCE NUMBER = 18

CANOPY    CANOPY MODEL CALCULATIONS: TREE CROWN WIDTH, CROWN SHAPE, AND FOLIAGE BIOMASS

SHRUBS    SHRUB MODEL OPTIONS:
          TIME SINCE DISTURBANCE =  57.0 YEARS
          HABITAT TYPE = 570 SELECTED FOR PROCESSING SHRUBS OPTIONS
          PHYSIOGRAPHY TYPE =   3 (MIDSLOPE)

END       END COVER OPTIONS

TREEDATA  DATA SET REFERENCE NUMBER=  5

PROCESS   PROCESS THE STAND.
-------------------------------------------------------------------------------------------------------------------
```

Figure 8.—Prognosis Model input options table showing COVER keywords.

OVERVIEW OF THE COVER SUBMODELS

Crown Width and Stand Canopy Closure.—COVER predicts crown development for the 11 conifer species listed in table 3. Logarithmic regression equations are used to predict individual tree crown width from species, d.b.h., height, and crown length for trees 3.5 inches d.b.h. and larger. For trees less than 3.5 inches d.b.h., crown width is a function of species, height, crown length, and stand basal area (Moeur 1981). Coefficient values for the crown width models for large and small trees are shown in tables 4 and 5, respectively.

Individual tree crown area is computed as the area of a circle with diameter equal to predicted crown width. Stand canopy closure is computed from the sum of the tree crown areas,

$$\text{canopy closure} = \frac{\sum \text{crown areas (ft}^2\text{/acre)}}{43{,}560 \text{ ft}^2\text{/acre}} \times 100 \text{ percent.}$$

Table 3.—Tree species recognized by COVER

Code	Common name	Scientific name
WP	Western white pine	*Pinus monticola*
L	Western larch	*Larix occidentalis*
DF	Douglas-fir	*Pseudotsuga menziesii*
GF	Grand fir	*Abies grandis*
WH	Western hemlock	*Tsuga heterophylla*
C	Western redcedar	*Thuja plicata*
LP	Lodgepole pine	*Pinus contorta*
S	Engelmann spruce	*Picea engelmannii*
AF	Subalpine fir	*Abies lasiocarpa*
PP	Ponderosa pine	*Pinus ponderosa*
Other	Whitebark pine	*Pinus albicaulis*

Table 4.—Coefficients for estimating crown width of trees 3.5 inches d.b.h. and larger (Moeur 1981):
$\ln(\text{crown width}) = b_0 + b_1\ln(D) + b_2\ln(H) + b_3\ln(CL)$

	Variable coefficients[2]	
Species[1]	Intercept b_0	ln(H) b_2
WP	4.30800	- 1.37264
L	2.31359	- .80919
DF	3.02271	- 1.00486
GF	2.20611	- .76936
WH	1.32772	- .52554
C	2.79784	- .89666
LP	1.06804	- .55987
S	3.76535	- 1.18257
AF	1.74558	- .73972
PP	1.62365	- .68098
Other	- .91984	- .07299

Variables	Variable coefficients
ln(D)	b_1 = 1.08137
ln(CL)	b_3 = .29786

[1]Species codes are given in table 3.
[2]Definition of variables:
D = diameter breast height (inches)
H = tree height (ft)
CL = crown length (ft).

Table 5.—Coefficients for estimating crown width of trees less than 3.5 inches (Moeur 1981):
$\ln(\text{crown width}) = b_1\ln(H) + b_2\ln(CL) + b_3\ln(BA)$

Species[1]	Variable coefficients[2] Intercept b_1
WP	0.37031
L	.23846
DF	.32874
GF	.38503
WH	.25622
C	.46452
LP	.26342
S	.33089
AF	.33722
PP	.36380
Other	.07049

Variables	Variable coefficients
ln(CL)	b_2 = 0.28283
ln(BA)	b_3 = .04032

[1]Species codes are given in table 3.
[2]Definition of variables:
H = tree height (ft)
CL = crown length (ft)
BA = stand basal area (ft^2/acre)

In the following discussion, model behavior is displayed in the plots of simulation results from five stands whose site characteristics are listed in table 6. In each 100-year simulation, the stand was clearcut in period 1, the site was prepared by burning, and a new tree list predicted using the Regeneration Establishment Model (Ferguson and Crookston 1984). These "bare-ground" regeneration projections were used to compare responses of the crown relationships to changes in stand structure and density through time.

Table 6.—Site characteristics of the stands used to examine crown model behavior. In each simulation, the stand was clearcut, the site was prepared by burning, and regenerated using the Regeneration Establishment Model

Code	Stand	Location	Habitat type	Aspect	Slope	Elevation
					Percent	*Feet*
E	S248112	St. Joe	570 (TSHE/CLUN)	NW	30	3,400
W	Weippe	Clearwater	530 (THPL/CLUN)	NW	20	4,000
C	Cranberry	Clearwater	530 (THPL/CLUN)	S	10	3,000
G	Grouse	Clearwater	520 (ABGR/CLUN)	N	10	3,100
S	Silver	Clearwater	520 (ABGR/CLUN)	S	20	3,000

Canopy closure follows an increasing sigmoidal pattern over time on regenerated stands (fig. 9). Cover increases fairly rapidly between 0 and 20 years, as the first and second waves of regeneration produced by the establishment model enter the tree list. Then, even though numbers of trees start to decline beyond 20 years, canopy closure increases as individual tree crown width continues to expand. In the stands where canopy closure reaches 100 percent and greater, crown cover peaks and then declines beyond about 50 years in the projection (stands E, W, and G). Canopy closure is incomplete on the stands where establishment is poor (C and S). Here, crown cover levels off about 70 years after regeneration, rather than peaking and declining.

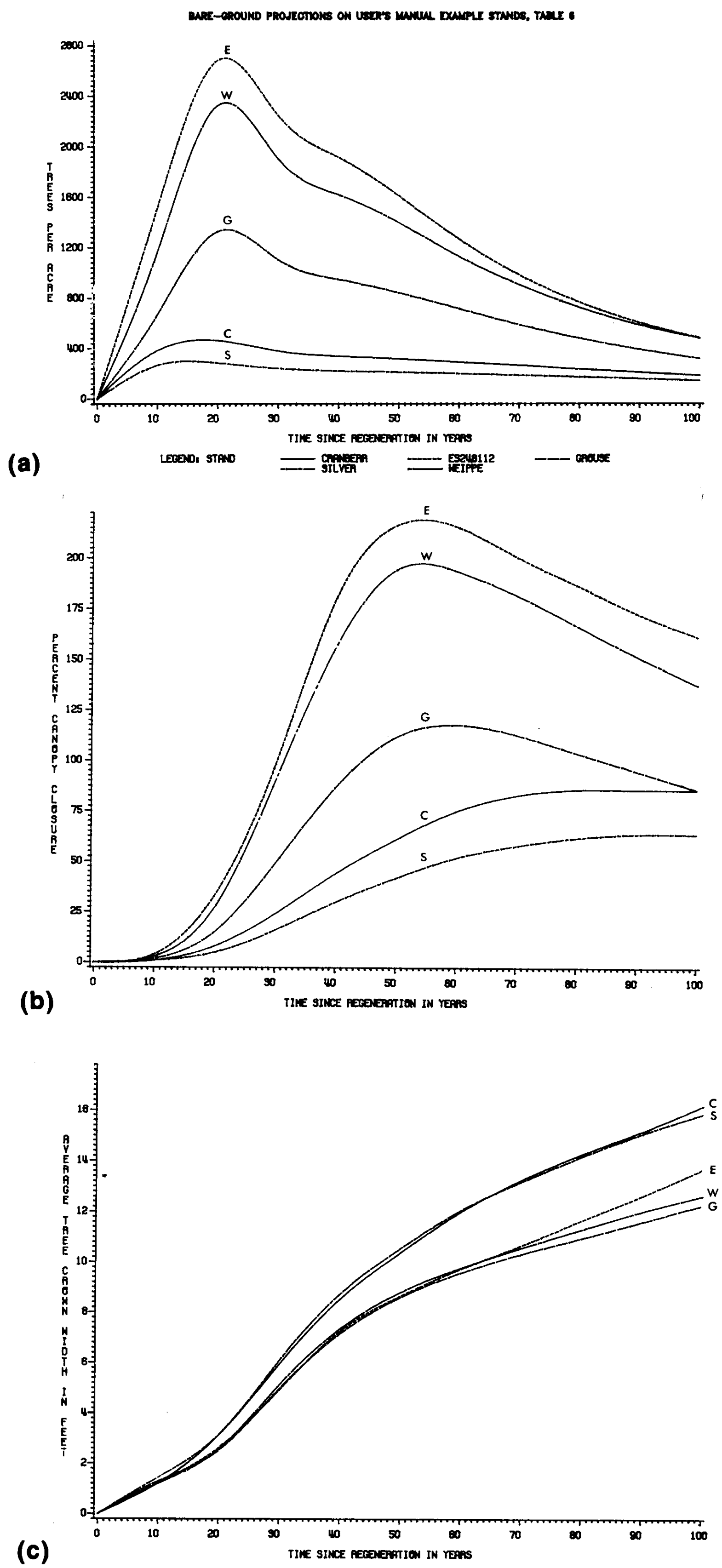
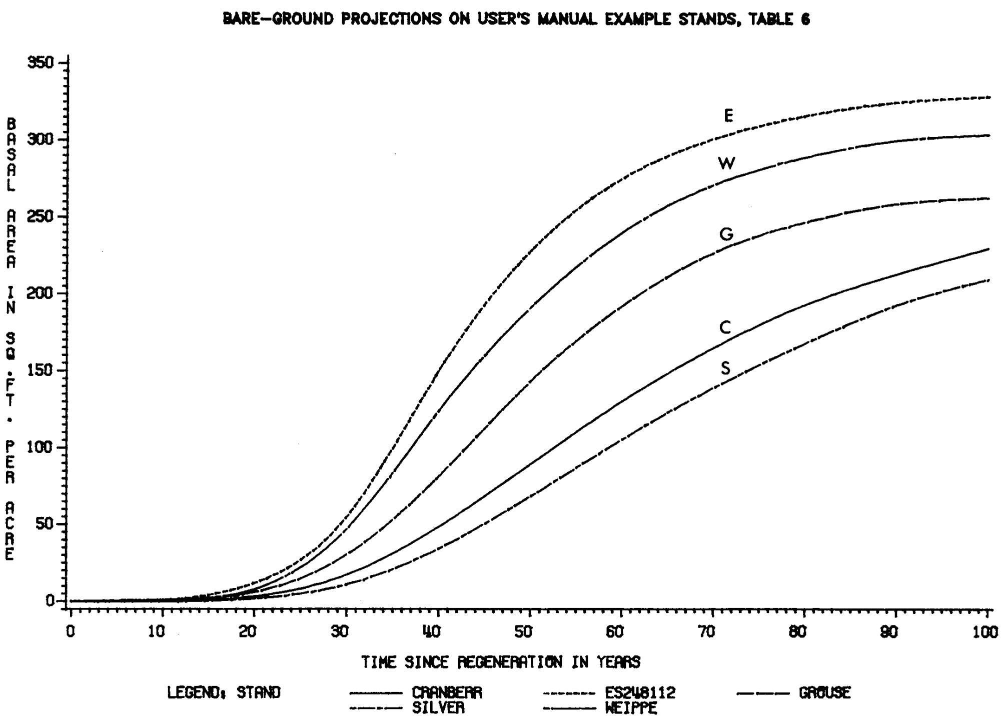


Figure 9.—Crown cover predictions for the regenerated stands in table 6: (a) predicted trees per acre versus time; (b) canopy closure versus time; (c) average tree crown width versus time.

In stands where initial densities exceed about 400 trees per acre (E, W, G), average crown width increases continually through time as the number of trees in the stand decreases. Presumably, this is related to the amount of mortality and to the types of trees that are dying. As number of trees decreases, crown width on surviving trees continues to increase through time. In addition, more of the mortality in the older stands is accounted for by suppressed trees in the understory, leaving trees with relatively more vigorous crowns. Below initial densities of 400 trees per acre, there is little relationship between individual tree crown width and number of trees, or between percentage of cover and trees. Crown width increases throughout the length of the projection in the understocked stands, even though tree numbers remain relatively constant, in-dicating that stand density is not great enough to be limiting to individual crown development. Under apparent lack of competition for space, the tree crowns in stands C and S are free to expand. In general, the model predicts that crowns will be wider in stands that start out with more open conditions.

Figure 10 shows the relationship of overstory cover to stand basal area and the effect of competition between crowns. Canopy closure is monotonically in-creasing with increasing basal area in all stands. Canopy closure attains a max-imum and then declines in the fully stocked stands, which reach maximum basal area and then level off (E, W, and G). Canopy closure levels off but does not begin to decline on stands that do not reach maximum basal area within the time frame of the projection (C and S). For a given basal area level, crown width is greater in the more open stands, this difference increasing throughout the projection.



(a)

Figure 10.—(a) Stand basal area over time; (b) predicted canopy closure versus basal area; (c) aver-age tree crown width versus basal area for the regenerated stands in table 6.

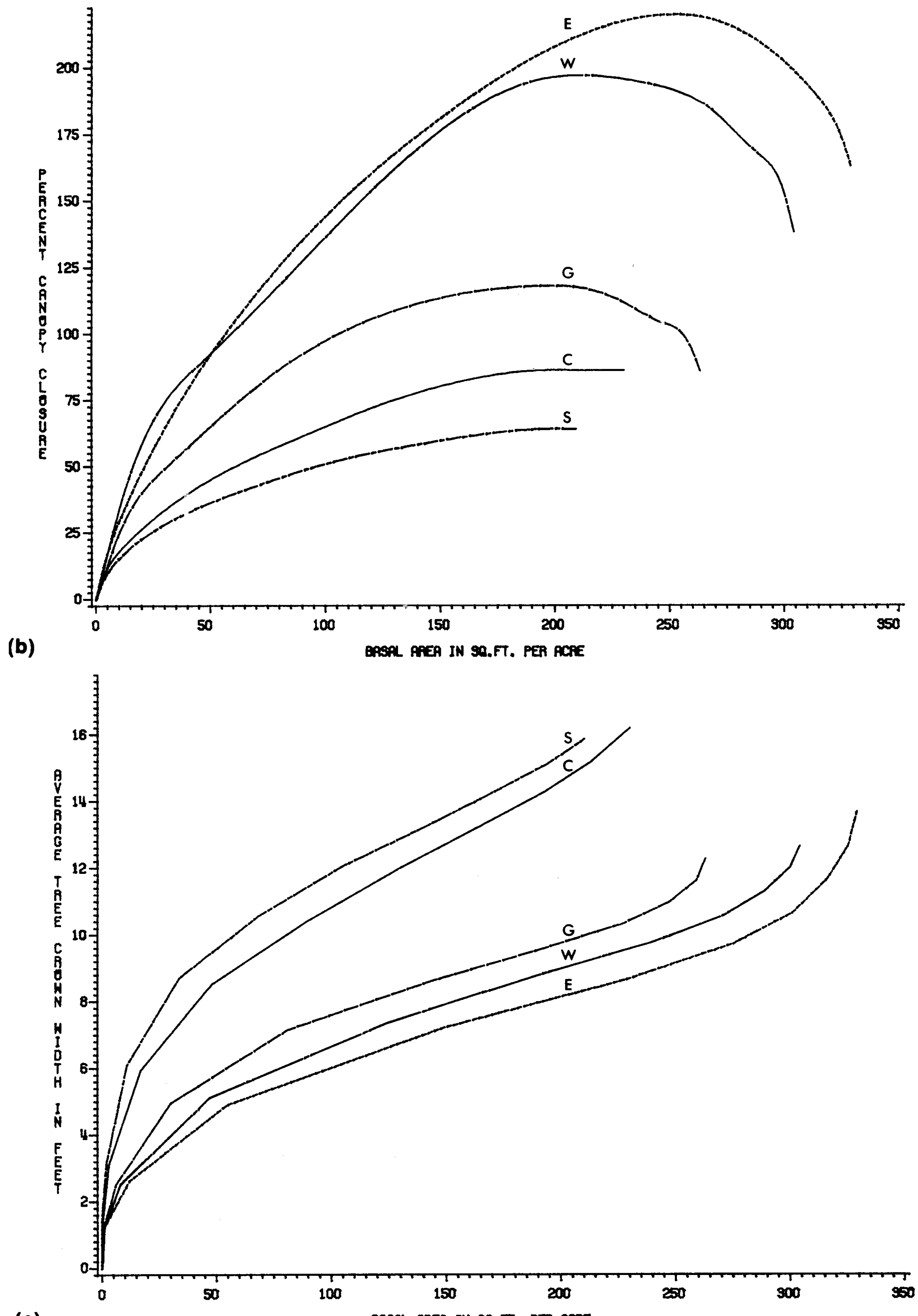

E
W
G
C
S
PERCENT CANOPY CLOSURE
0
25
50
75
100
125
150
175
200
0
50
100
150
200
250
300
350
(b)
BASAL AREA IN SQ.FT. PER ACRE
S
C
G
W
E
AVERAGE TREE CROWN WIDTH IN FEET
0
2
4
6
8
10
12
14
16
0
50
100
150
200
250
300
350
(c)
BASAL AREA IN SQ.FT. PER ACRE

Fig 10.—(Con.)

Crown Foliage Biomass.—Foliage biomass is predicted for individual trees using logarithmic linear regression equations (Moeur 1981). As in the crown width functions, there are different equation forms for trees less than 3.5 inches d.b.h. and those 3.5 inches d.b.h. and larger. The equations predict foliage biomass from species, d.b.h., change in squared diameter, height, crown length, trees per acre, and relative diameter (d.b.h./quadratic mean stand diameter) for large trees, and from species, height, crown length, and trees per acre for small trees. Coefficients for the models are listed in tables 7 and 8.

Table 7. — Coefficients for estimating foliage biomass of trees 3.5 inches and larger (Moeur 1981): ln(biomass) = $b_0 + b_1\ln(D) + b_2\ln(H) + b_3\ln(CL) + b_4\ln(DDS) + b_5\ln(TPA) + b_6\ln(DREL)$

Species[1]	Variable coefficients[2] Intercept b_0
WP	2.66607
L	1.75654
DF	2.70587
GF	3.11508
WH	2.65457
C	3.05935
S	3.30085
AF	3.06017
PP	2.45249
Other	2.62251

Variables	Variable coefficients
ln(D)	b_1 = 1.468547
ln(H)	b_2 = 1.07705
ln(CL)	b_3 = .69082
ln(DDS)	b_4 = .30885
ln(TPA)	b_5 = .14210
ln(DREL)	b_6 = .39924

[1]Species codes are given in table 3.
[2]Definition of variables:
D = diameter breast height (inches)
H = tree height (ft)
CL = crown length (ft)
DDS = change in squared diameter (in^2)
TPA = trees per acre
DREL = d.b.h./quadratic mean d.b.h.

Table 8. — Coefficients for estimating foliage biomass of trees less than 3.5 inches d.b.h. (Moeur 1981): $\ln(\text{biomass}) = b_0 + b_1\ln(H) + b_2\ln(CL) + b_3\ln(TPA)$

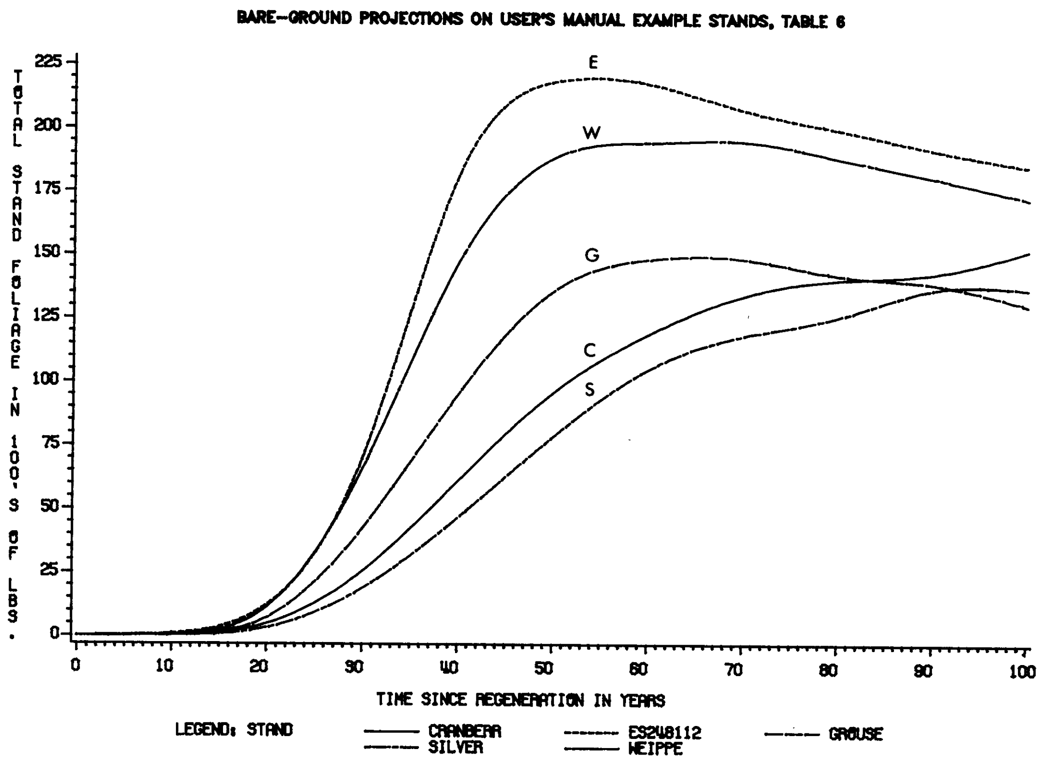
	Variable coefficients[1]	
Species[2]	**Intercept b_0**	**ln(CL) b_2**
WP	–1.94951	1.22023
L	–4.73762	1.98479
DF	–2.05828	1.25837
GF	–2.43200	1.60270
WH	–4.17456	2.00749
C	–2.24876	1.37600
LP	–3.13488	1.62368
S	–2.93508	1.96125
AF	–1.60998	1.32649
PP	–2.74410	1.58171
Other	–1.63387	1.35092

Variables	**Variable coefficients**
ln(H)	b_1 = 0.40350
ln(TPA)	b_3 = .12975

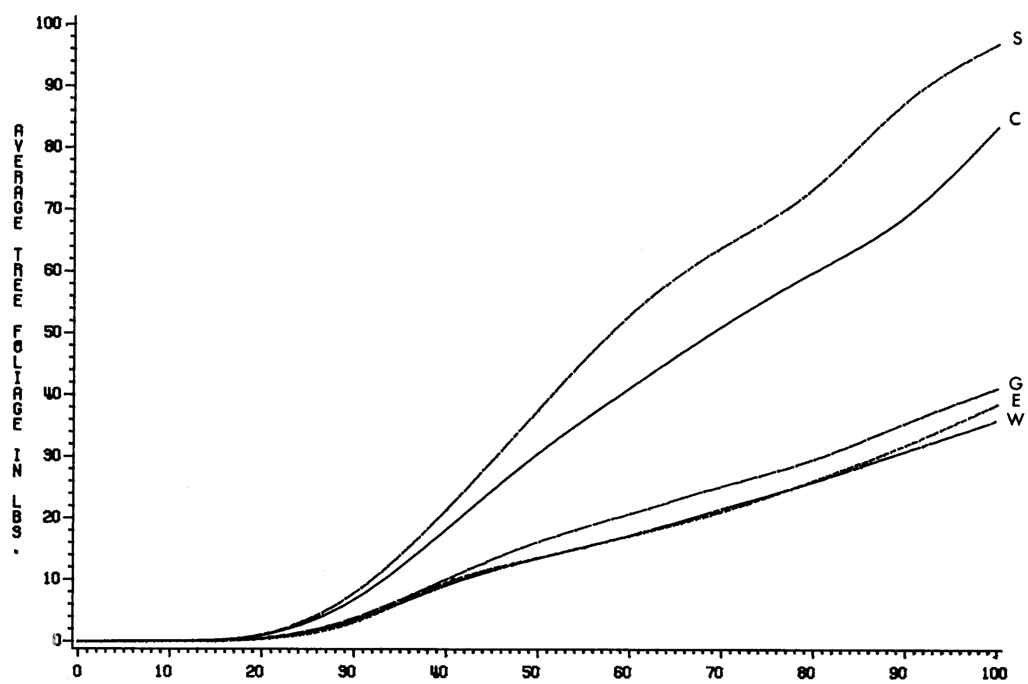
[1]Definition of variables:
H = tree height (ft)
CL = crown length (ft)
TPA = trees per acre

[2]Species codes are given in table 3.

In general, the response patterns of total stand foliage biomass to trees per acre and basal area over time are similar to those for canopy closure (fig. 11). Total foliage is greater in the stands starting out with higher initial densities, peaking at 50 to 60 years, and then declining (stands E, W, and G). Stand foliage does not decline as sharply as does percentage of canopy closure near the end of the projection. Stands with low initial densities show gradually increasing values of foliage throughout the projection (C and S). Foliage production also depends on the species composition of the mature stands. Stands W and C have higher proportions of mature trees in grand fir, cedar, and Douglas-fir. These three species have greater predicted foliage values for a given set of stand conditions. Individual tree foliage development patterns through time are quite similar to those discussed for crown width.

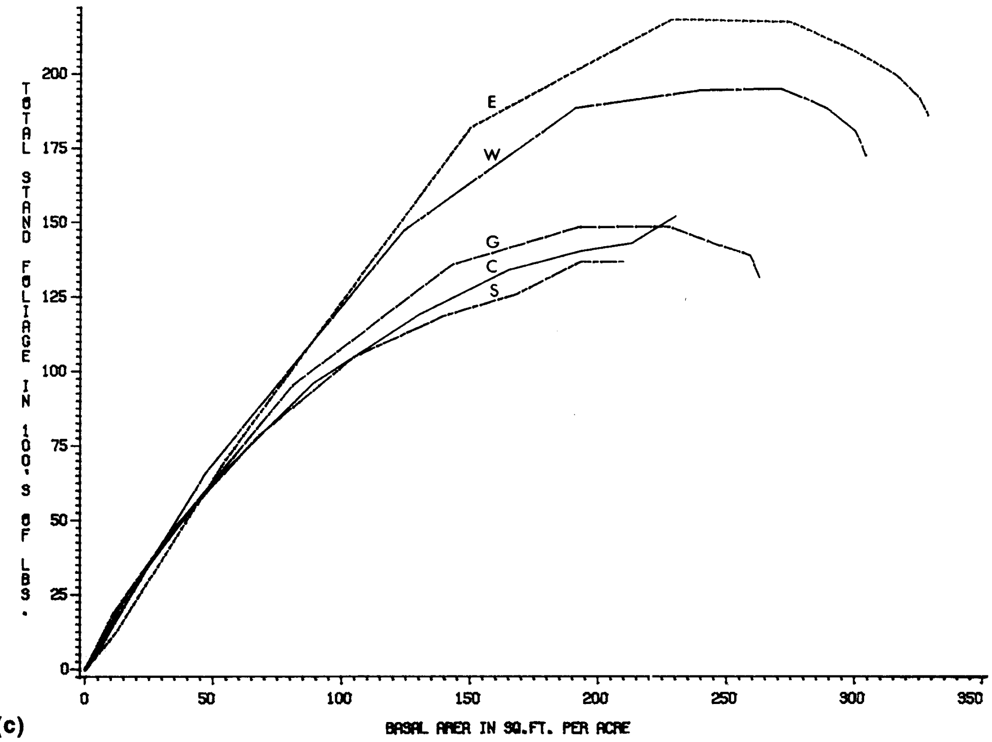


(a)

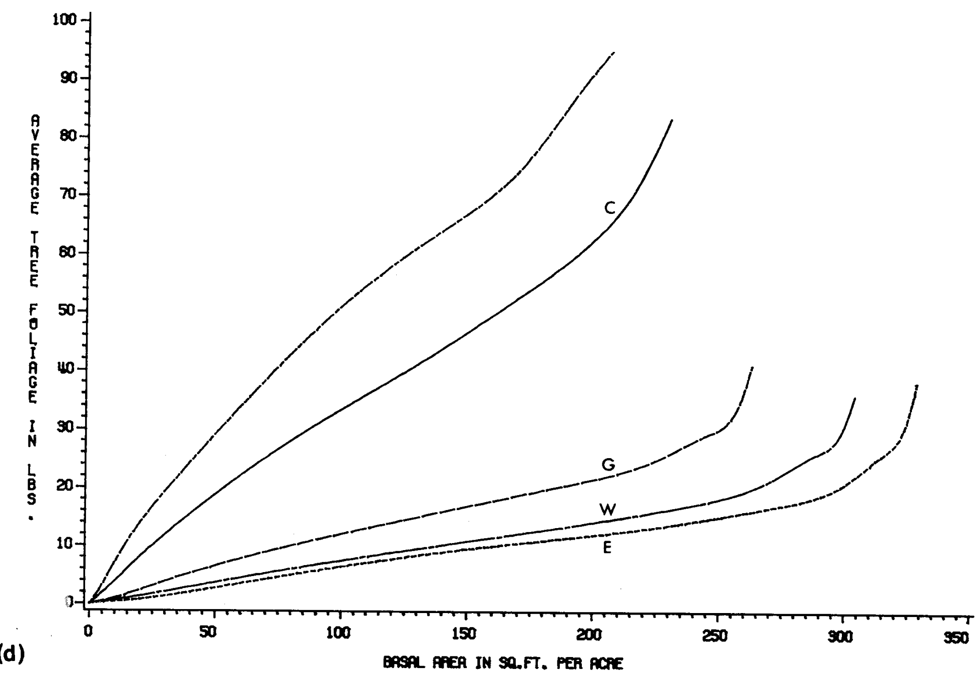


(b)

Figure 11.—(a) Predicted stand foliage and (b) tree foliage versus time; (c) stand foliage and (d) tree foliage versus stand basal area for the regenerated stands in table 6.



(c)



(d)

Figure 11.—(Con.)

Crown Shape.—Individual tree crown shape is predicted each projection cycle using a linear discriminant function (Moeur 1983). Tree crowns are classified into one of five shapes—circular, triangular, neiloid, parabolic, or elliptic—using species, height, d.b.h., crown length, crown radius, crown ratio, and trees per acre as discriminating variables. All tree crowns are assumed to have a circular bottom (fig. 12).

Crown shape is used in three places in COVER. First, crown volume within vertical height classes in the stand is computed by summing sections of individual crowns, using formulas to integrate the five different solids of revolution in figure 12. Second, crown profile area within height classes is computed by summing the lateral area of individual crown sections (fig. 3b). Finally, tree foliage biomass is distributed within height classes by the proportion of frustum volume within height classes to total crown volume. An inner senescent cone is not considered; that is, foliage is assumed to be distributed uniformly throughout the crown.

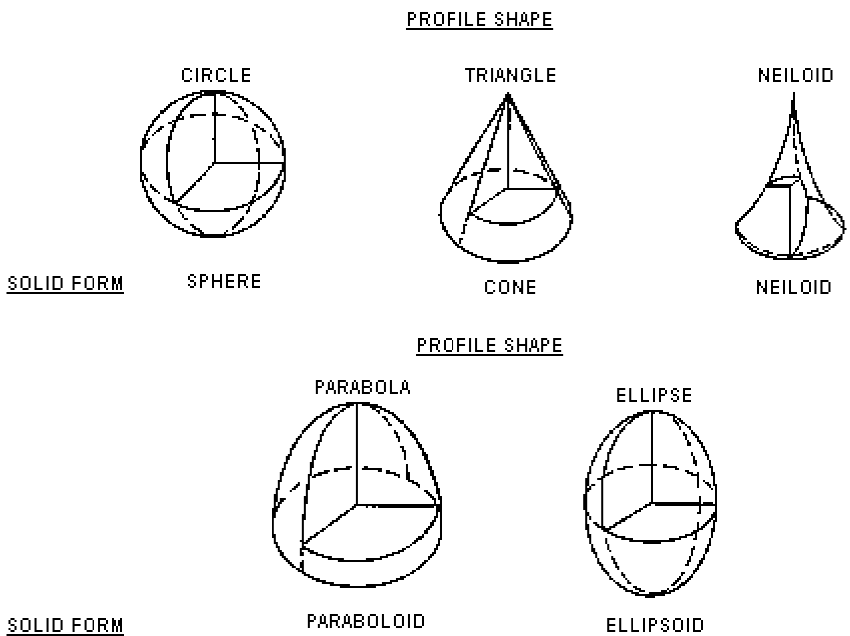


Figure 12.—Individual crowns are classified into one of five shapes in the CANOPY option (after Mawson and others 1976).

SHRUBS Submodels

The equations for predicting understory species relationships have been synthesized from the work of different people at different times. An early version of the SHRUBS extension, known as BROWSE (Scharosch 1980), incorporated studies on shrub development in grand fir, cedar, and hemlock habitat types conducted by Irwin and Peek (1979). In Prognosis 5.0, these relationships have been replaced by probability of occurrence equations for individual understory species developed by Scharosch (1984), and height and cover equations developed by Laursen (1984). Irwin and Peek's work was based on a subset (about 2,200 plots) of the data used by Laursen (1984) and Scharosch (1984). The expanded data (about 10,000 plots located in about 500 stands) include measurements from Douglas-fir and subalpine fir ecosystems as well as the original grand fir-cedar-hemlock types. Table 1 lists the species, range of habitat types, and sources of information for which predictions are currently made.

Inside the COVER program, the probability of any shrub cover on the site, and total shrub cover given that the probability is greater than zero, are predicted first. Then, probability of occurrence is calculated for each species individually using total shrub cover as a predictor. Next, heights are predicted for each species, also using total shrub cover. The species are sorted in order from tallest to shortest predicted height. Then, progressing down through the sorted list, individual species cover is calculated using predicted species height and the amount of overtopping cover. Species cover is weighted by species probability of occurrence. Finally, the cover values are summed and reported as total understory cover for the plot.

Total Shrub Cover.—Predictions for probability of any shrubs, and for total shrub cover, conditional on probability, are taken from Laursen (1984). The probability that shrub cover exists given the described stand conditions is calculated and reported in the summary display. This value expresses the proportion of 1/300-acre plots on which shrub cover is expected to be greater than zero. It is computed from a logistic regression model using slope, elevation, overstory basal area, habitat type, time since disturbance, and the interaction of time since disturbance and basal area. Next, total shrub cover is predicted using a lognormal linear regression model fit on plots in the original data where cover was actually present. Additional variables in this model are type of disturbance and the time and type of disturbance interaction. Total shrub cover predicted by Laursen's model for three hypothetical treatments is shown in figure 13.

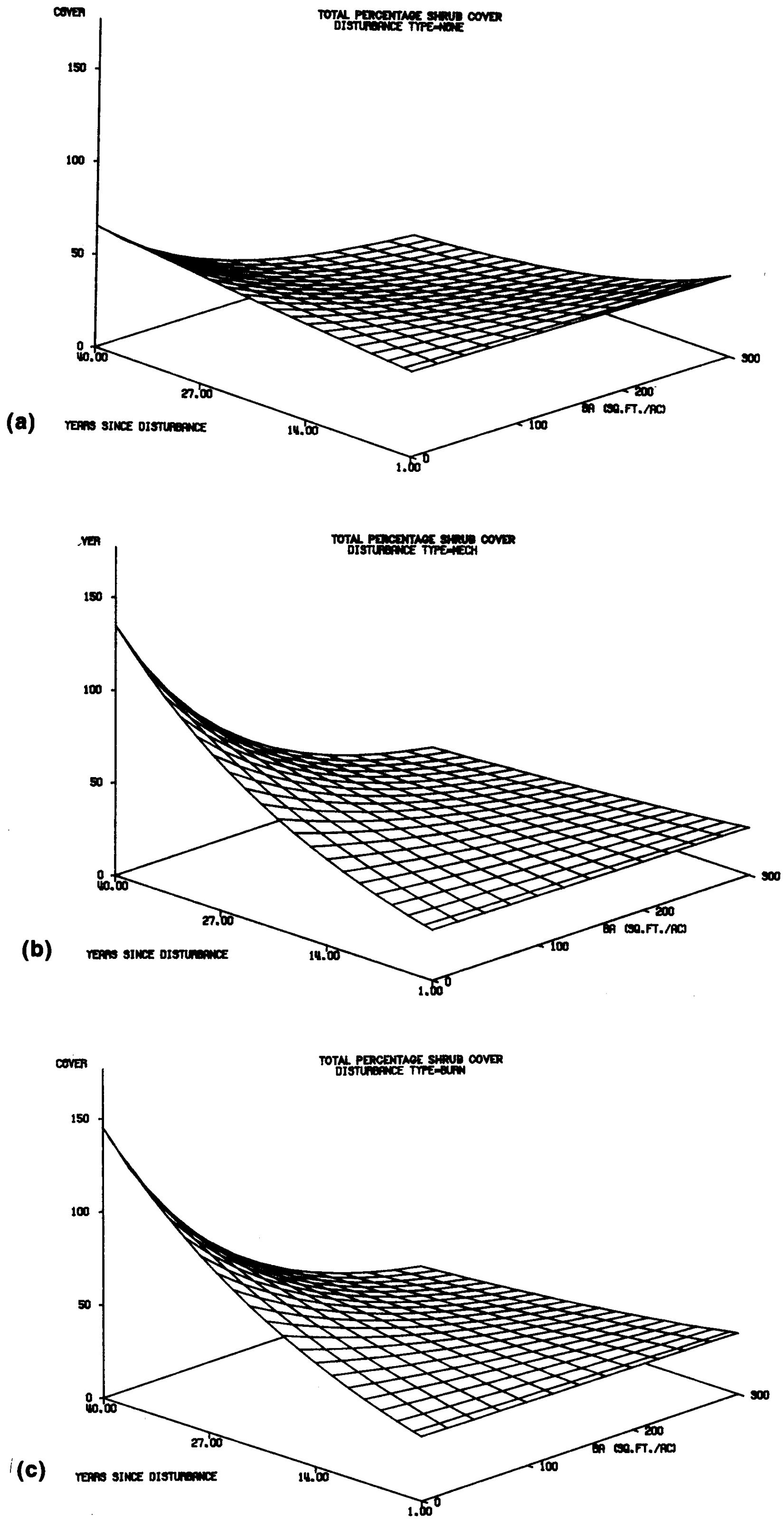


Figure 13.—Predicted total percent shrub cover relative to time since disturbance and overstory basal area following (a) no site preparation, (b) mechanical disturbance, and (c) burning. Variables held constant are slope = 0.25, elevation = 3,500 ft, habitat type = ABGR/CLUN (from Laursen 1984).

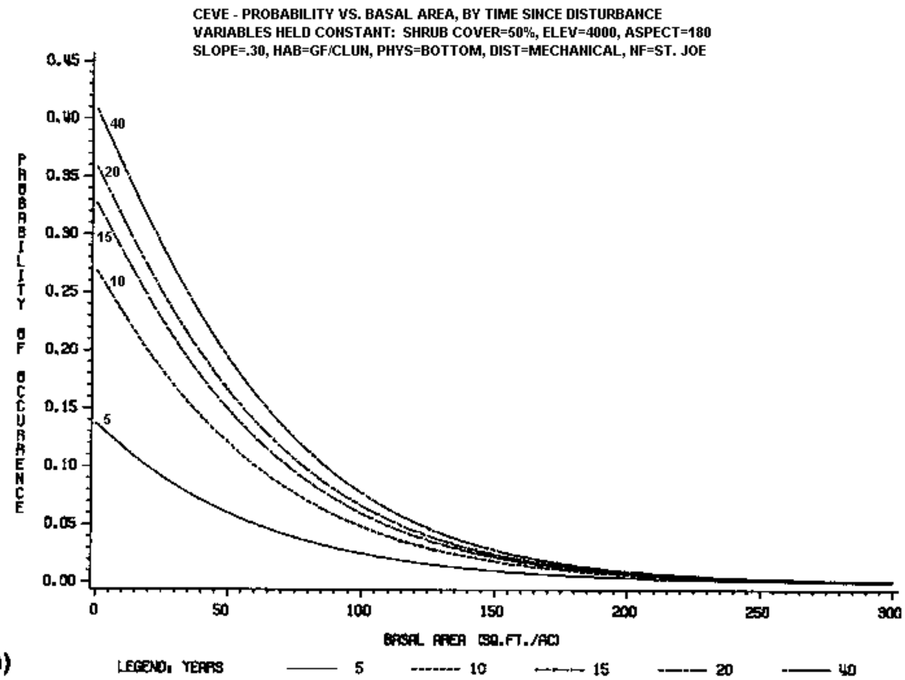
Table 9.—Variables used to predict probability of occurrence, height, and percentage of cover for the shrub species listed in table 1

Continuous variables
Overstory basal area (ft^2/acre)
Stand elevation (100's of feet)
Elevation square (10,000's of feet)
Total percent shrub cover
Slope (percent/100)
Slope x sin(aspect)
Slope x cos (aspect)
Time since site disturbance (years)
Overstory basal area x time since disturbance

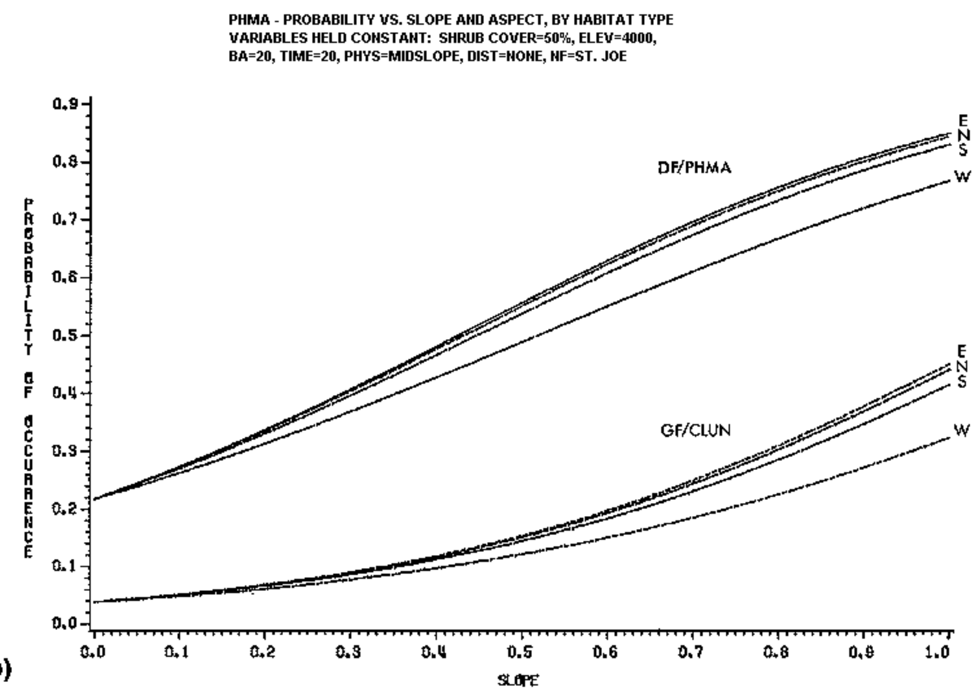
Categorical variables
Overstory climax species (includes habitat type): [1]
Douglas-fir (210, 220, 260, 310, 320, 330, 340, 380, 390, 395)
Grand fir (505, 510, 511, 515, 520, 525, 590)
Western redcedar (530, 540, 550)
Western hemlock (570)
Subalpine fir/mountain hemlock (620, 635, 645, 650, 670, 690, 705, 710, 720, 721, 730, 790, 830)
Understory climax union (includes habitat type):[1]
ABGR/CLUN, COOC, XETE, LIBO, ABLA/STAM, ABLA/LUHI (510, 511, 520, 590, 635, 690, 710, 830)
THPL series (530, 540, 550)
Tall shrub (260, 390, 515, 525, 645, 670, 720, 721, 730)
Low shrub (310, 340, 380, 395, 505, 705)
TSHE/CLUN, ABLA/CLUN (570, 620)
Grasses (210, 220, 320, 330, 650, 790)
National Forest grouping:
Boise, Payette
Nezperce
Clearwater, Coeur d'Alene, Lolo, St. Joe
Panhandle, Colville, Kaniksu, Kootenai
Physiography:
Bottom
Lower slope
Midslope
Upper slope
Ridge
Type of site disturbance:
None
Mechanical
Burn
Road
Type of disturbance x overstory basal area
Type of disturbance x time since disturbance

[1]See table 2 for habitat type code definitions.

Species Probability of Occurrence.—Predicted probability of occurrence equations for the species in table 1 are from Scharosch (1984). He uses a logistic multiple regression model to predict species occurrence from the continuous and categorical variables in table 9. The logistic model produces a sigmoidal curve with predicted values restricted to the closed interval (0,1). Representative responses of predicted probability of occurrence are plotted in figure 14.

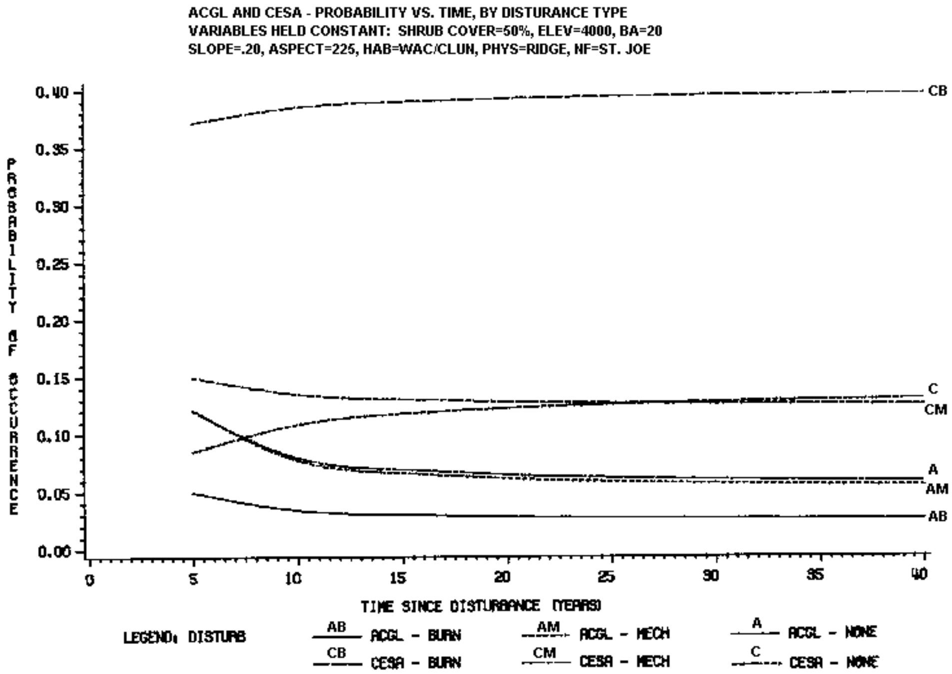


(a)



(b)

Figure 14.—(a) Predicted probability of occurrence across a range of overstory basal area and time since disturbance for Ceanothus velutinus; *(b) predicted probability of occurrence by slope and aspect for* Physocarpus malvaceus *on PSME/PHMA and ABGR/CLUN habitat types; (c) predicted probability of occurrence by disturbance type for* Ceanothus sanguineus *and* Acer glabrum *(from Scharosch 1984).*



(c)

Fig. 14.—(Con.)

Individual Species Height. —Laursen (1984) uses either linear or lognormal regression model forms to predict the average heights of individual species in the described stand. Model forms differ between species, but most contain time since disturbance, overstory basal area, and predicted total shrub cover and its residual (the difference between observed and predicted values when an observed value is supplied by the user) as independent variables. Various transformations of the independent variables in table 9 are included to represent other site and treatment effects. The equations are detailed in Laursen's paper. Representative response patterns of predicted height over time and stand basal area are plotted in figure 15.

Individual Species Cover.—Percentage of cover by species follows lognormal or logistic distributions, conditional on the presence of the species in the stand (Laursen 1984). Cover for most species is a function of predicted species height and its residual (observed minus predicted when observed values are supplied), overtopping by taller species (the percentage of predicted cover above current height), time since disturbance, type of disturbance, overstory basal area, and site conditions. Representative plots of the response of species cover to basal area over time are shown in figure 16.

Twig Production and Dormant Season Shrub Biomass.—Total current year's twig production in twigs per square foot and total dormant season aboveground shrub biomass in pounds per acre are computed only for the 16 species noted in table 1 and only on ABGR/CLUN, THPL/CLUN, and TSHE/CLUN habitat types (Irwin and Peek 1979). Twig production is a log-linear regression equation dependent on time since disturbance, overstory crown competition factor (CCF) (Krajicek and others 1961), and habitat type. Shrub biomass is also log-linear, predicted from time since disturbance and CCF.

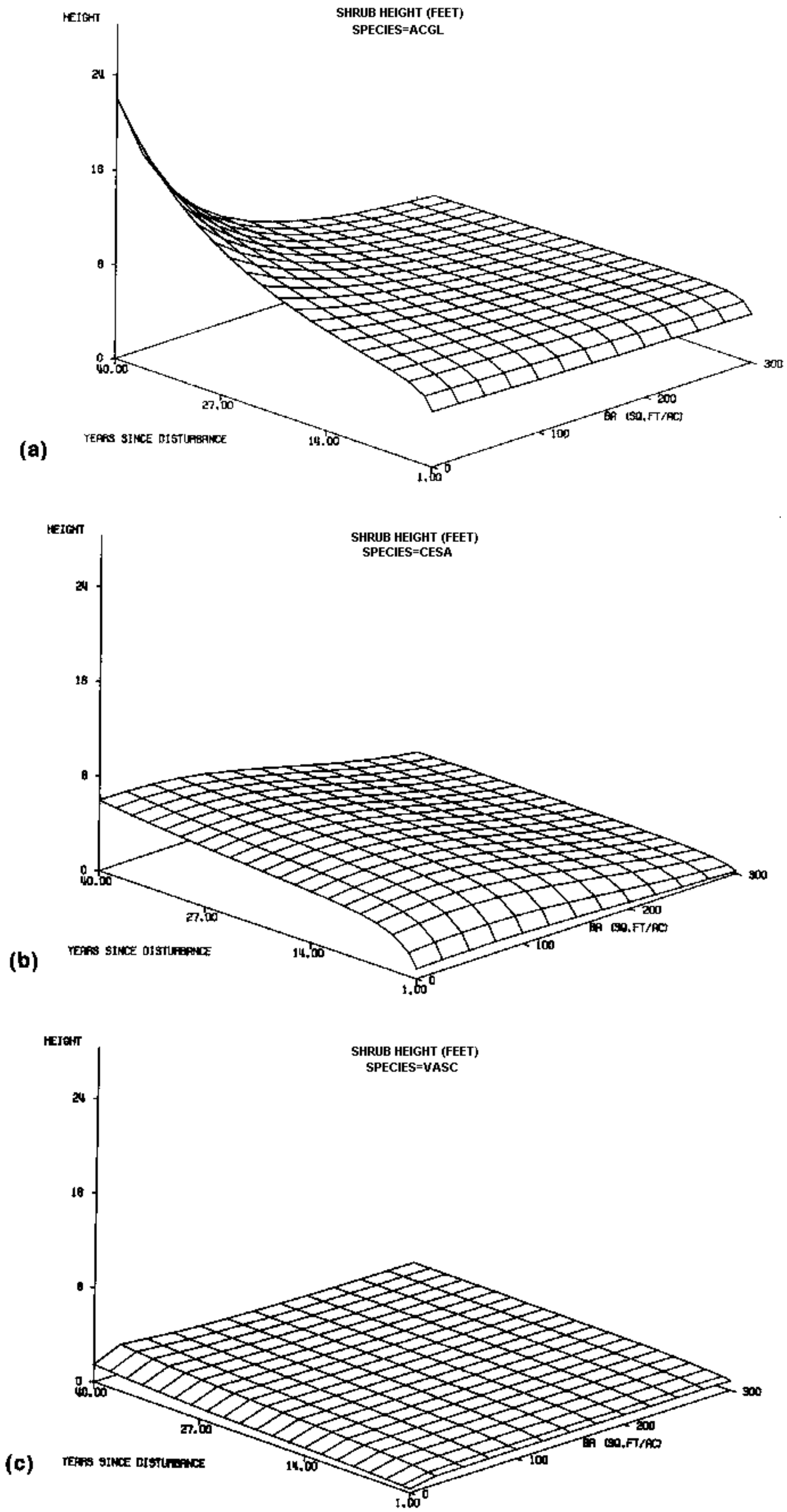


Figure 15.—Predicted shrub height relative to overstory basal area and time since disturbance for (a) Acer glabrum*, (b)* Ceanothus sanguineus*, and (c)* Vaccinium scoparium*. Variables held constant are slope =0.25, aspect = east, elevation = 3,500 ft, habitat type = ABGR/CLUN, physiography = midslope, disturbance type = burn, forest = St. Joe (from Laursen 1984).*

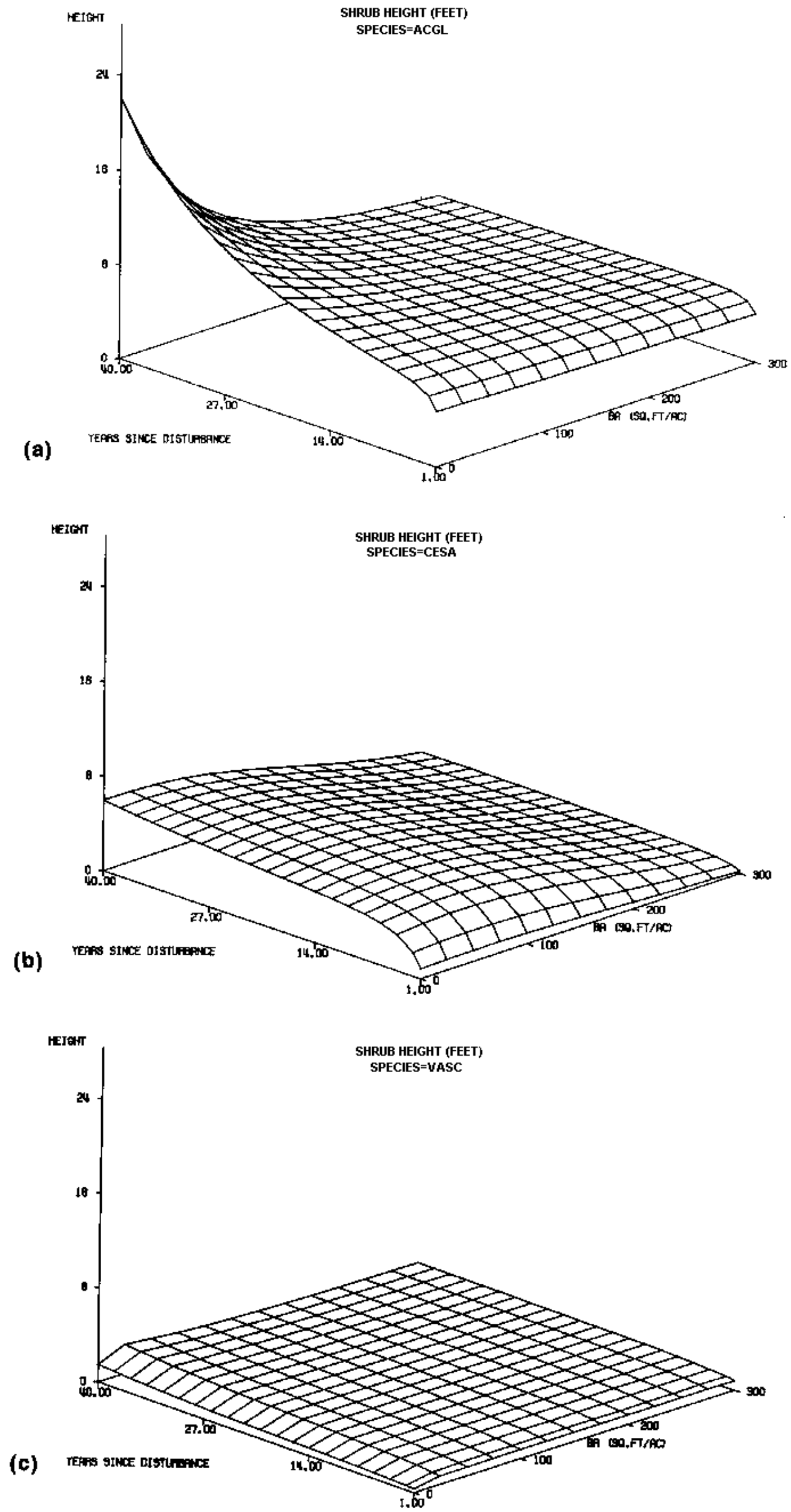


Figure 16.—Predicted shrub cover relative to overstory basal area and time since disturbance for (a) Acer glabrum*, (b*) Ceanothus sanguineus*, and (c)* Vaccinium scoparium*. Variables held constant are slope = 0.25, aspect = east, elevation = 3,500 ft, habitat type = ABGR/CLUN, physiology = midslope, disturbance type = burn, forest = St. Joe (from Laursen 1984). Values shown are for predicted cover prior to multiplication by probability of occurrence.*

Stand Successional Stage

One subprogram within the COVER extension computes and displays a "stand successional code" that is related to the vertical structure of both shrubs and trees (Peterson 1982). The purpose of the classification is to provide a basis for relating wildlife use to a particular type of stand that now exists, or that will result from management. The codes are listed in table 10.

The classification is a function of time since stand disturbance, crown competition factor (CCF), average tree height, a selectively defined "average" stand diameter, and average tall shrub height (average predicted height, weighted by predicted cover for *Acer glabrum*, *Alnus sinuata*, *Amelanchier alnifolia*, *Ceanothus sanguineus*, *Ceanothus velutinus*, *Cornus stolonifera*, *Holodiscus discolor*, *Prunus emarginata*, *Prunus virginiana*, *Salix* spp., *Sambucus* spp., and *Sorbus* spp.).

To compute average stand diameter, a series of logical tests determines whether the stand is even-aged, two-storied, or all-aged based on the distribution of trees per acre and percentage of cover by 10-ft height classes. For even-aged stands (a stand in which 90 percent of the total canopy closure is accounted for by trees within a 30-ft height range), the root mean square diameter of the stand is used as the average diameter. For two-storied stands (the two most dense 20-ft layers must be separated by 20 ft or more), the root mean square diameter for the most dense 20-ft layer only is used as the average diameter. For all-aged stands (the most dense 10-ft layer contains less than 20 percent of the total canopy closure, the three most dense 10-ft layers contain less than 50 percent, etc.), the average diameter is taken to be the root mean square diameter of the three most dense 10-ft layers. The stand is then classified according to the scheme in table 10. Note that restrictions for stages 1 to 4 are of the type "CCF less than 30 **or** average tree height less than 1 ft." For stages 5 and 6, there is a "percent shrub cover" **or** "average tall shrub height" restriction.

Table 10.—Classification scheme for assigning stand successional stage code (after Peterson 1982)

Condition	Recent disturbance (1)	Low shrub (2)	Medium shrub (3)	Tall shrub with no conifers (4)	Tall shrub with few conifers (5)	Tall shrub with mostly conifers (6)	Sapling timber (7)	Pole timber (8)	Mature timber (9)	Old-growth timber (10)
Time since stand disturbance (years)	<5									
Crown competition factor	<30 or	<30 or	<30 or	<30 or	30-50	50-100	>100	>100	>125	>100
Average tree height (ft)	<1	<1	<1	<1	<5	<5				
Percent shrub cover	<25			>70	>50 or	>30 or				
Average "tall shrub" height (ft)	<1.0	<2.5	2.5-5.0	>5.0	>5.0	>5.0				
"Average" stand diameter (inches)							<4	4-11	11-24	>24

USING THE COVER EXTENSION AS A MANAGEMENT TOOL

The general comments in this section are intended to guide the user in applying information produced by the combined Prognosis/COVER model in a broader planning context. There is little specific COVER output that directly interprets wildlife, hydrologic, or insect pest relationships. Instead, it is up to the user to interpret the information specific to his or her application. An important criterion in developing COVER was to make it broad enough in design for many applications, but primarily to link vegetation changes with nontimber resources. COVER can be a useful tool for decisionmaking when combined with knowledge of a specific resource ecology and its relation to vegetation management systems.

Wildlife Habitat Applications

Many of the shrub and tree cover development values produced by COVER can be related to wildlife habitat. An example stand projection illustrates how displays generated from COVER values can be used to compare vegetation changes and alternative treatment effects on wildlife habitat. The example presented is a stand that was inventoried in 1984 at 145 years of age. Initial stand density is 459 trees per acre, composed of an understory of Engelmann spruce beneath a sparse overstory of Douglas-fir, western larch, and grand fir. The stand is on the Nezperce National Forest, ABGR/VAGL habitat type, northeast aspect, 50 percent slope, at 5,800 ft elevation. Two silvicultural treatments were simulated and compared. In the first, the lower and upper portions of the diameter distribution were removed in cycle 1, leaving 60 Douglas-fir, larch, and spruce trees per acre, with diameters between 18 and 25 inches. At the end of the second cycle, natural regeneration was predicted to be 780 trees per acre, composed of 60 percent grand fir, 25 percent Douglas-fir, and 15 percent spruce. Twenty years after the initial thin, all trees greater than 7 inches d.b.h. were removed, and the regenerated stand was grown to age 100. This prescription is referred to as "two-step shelterwood." The second prescription, "clearcut," cut all trees in the stand in cycle 1. Natural regeneration at the end of the second 10-year cycle was 450 trees per acre, of which 65 percent were grand fir, 30 percent Douglas-fir, and 5 percent larch. This stand was then grown to age 100.

Excellent discussions of cover-forage ratios, hiding cover, and thermal cover requirements for deer and elk are presented by Thomas and others (1979a). Thermal cover is defined to be any stand of coniferous trees 40 ft or more tall, with an average canopy closure exceeding 70 percent. Figure 17 compares canopy closure and tree height for the two prescriptions. The shelterwood stand reaches a top height of 56 ft and 79 percent canopy closure at age 60. Beyond 60 years, the canopy is nearly fully closed, providing thermal cover throughout the rest of the projection. The clearcut stand supplies less adequate thermal cover, at an older age (80 years and beyond).

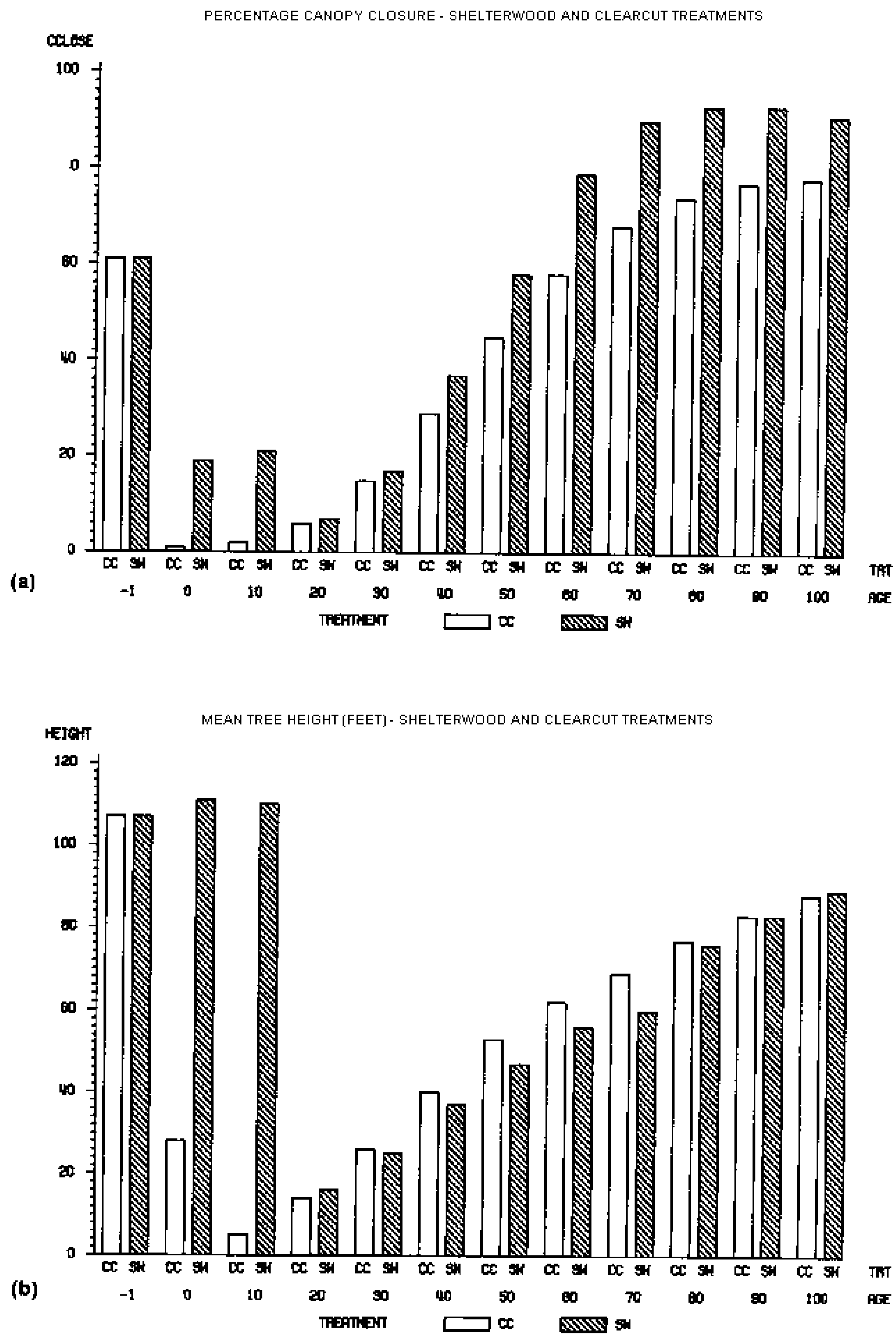


Figure 17.—Thermal cover compared for shelterwood and clearcut prescriptions for the wildlife example stand: (a) stand canopy closure versus stand age following initial thinning in 1984; (b) average tree height versus stand age.

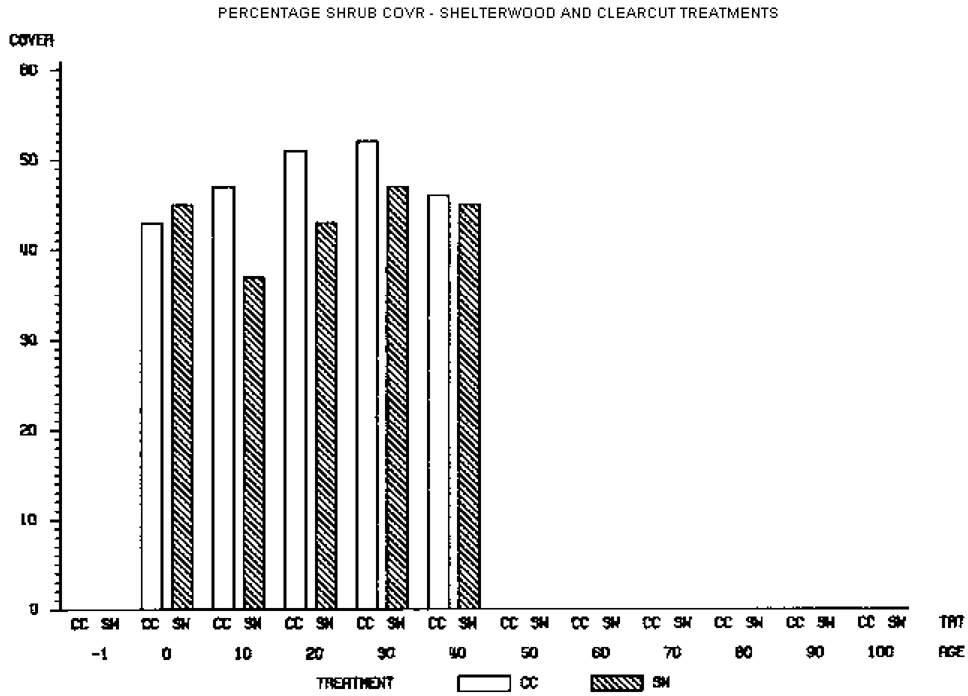
Hiding cover (defined by Thomas and others [1979b] to be vegetation capable of hiding 90 percent of a standing adult elk from view at a distance equal to or less than 200 ft) can be compared between alternative treatments by looking at shrub cover, crown profile area in the first 10 ft of height in the stand, the sum of stem diameters, and trees per acre (fig. 18). Predicted shrub cover is 44 percent for the shelterwood treatment and 43 percent for the clearcut treatment following the 1984 thinning. It increases to 52 percent at age 30 in the clearcut stand. In the shelterwood stand, shrub density decreases to 31 percent at age 20, and then the overstory removal triggers a second wave of increasing shrub cover. By age 40, shrub density is again equal in the two treatments, at about 45 percent cover.

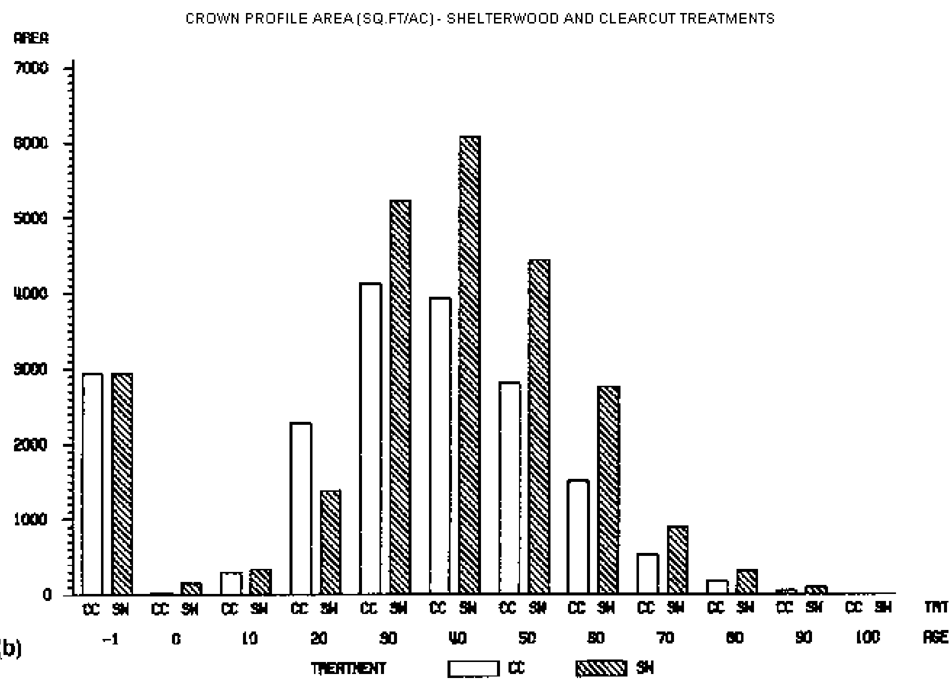
In general, hiding cover in stems and tree crowns is greater in the shelterwood treatment, primarily because regeneration is more successful. In both treatments, area in crowns in the lower 10 ft of the stand begins at nothing at stand age 0 and increases to a maximum at about 30 or 40 years. After 40 years, the lower canopy level begins to grow above the height where it can be considered effective hiding cover. Beyond 60 years, stem area contributes more to hiding cover, and crown profile area contributes less.

Figure 19 illustrates how canopy development predicted by COVER may be displayed graphically through time. The vertical distribution of crown profile area is shown for the two prescriptions immediately before thinning in 1984, and at several points in time following harvest. Similar stand profiles could be drawn to represent numbers of trees, percentage of canopy closure, crown volume, or foliage density by height. These values may be useful in relating bird habitats to the structure of vegetation (for example, see Langelier and Garton in press b; Peterson 1982) or the “life form” association with stand successional stage proposed by Thomas and others (197913).

The wildlife example presented here shows how stem area, crown profile area, and related values can be interpreted as thermal and security cover for big game. Foliage-height profiles and crown volumes by height classes are also useful statistics in analyzing bird habitat relationships. The interpretation of canopy and shrub height and density into wildlife cover is hypothetical for the example presented and, of course, depends on knowledge of actual stand conditions.

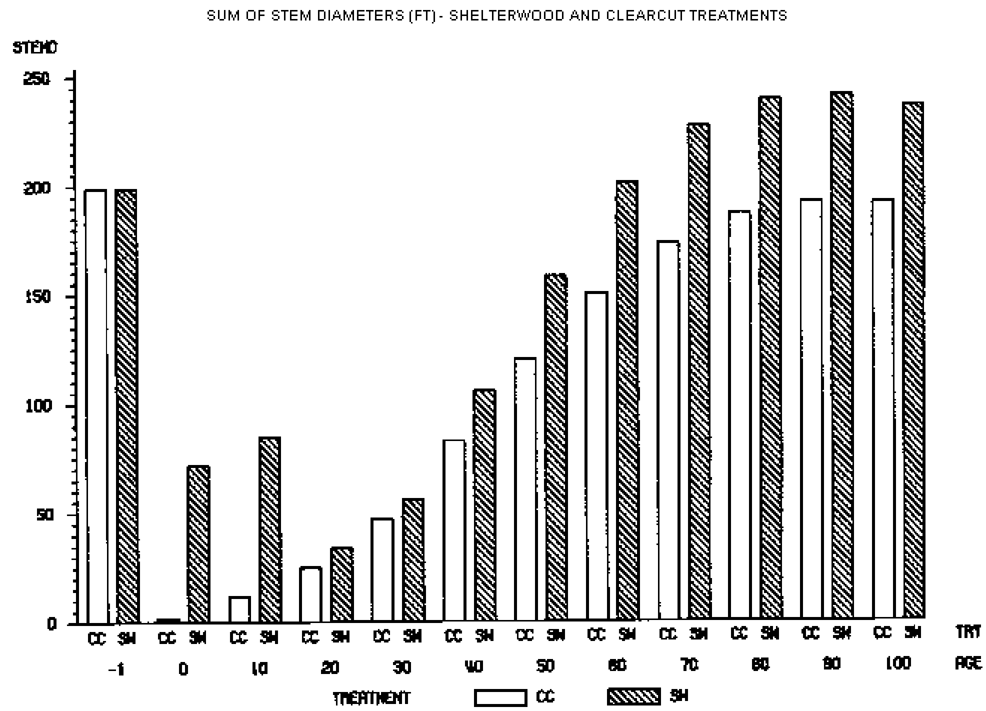
Vegetation management for wildlife use requires interdisciplinary knowledge of the interactions of vegetation, site and topographic conditions, silvicultural options, and road and harvest operations. The combined Prognosis/COVER model can provide information about the condition of the vegetation, including species composition, size, and distribution of both the overstory and under-story. Thomas (1979) points out that habitat use does not follow some arbitrary step function, but that wildlife species use vegetation despite what wildlife biologists define to be less than optimum conditions (70 percent canopy closure for thermal cover, for example). COVER values are expressed as continuous through time, rather than as threshold values, so that the user may evaluate their implications for wildlife habitat management. COVER output can be written to a disk file (by using the second parameter on the COVER keyword) for later summarization and graphical display.





(b)

Figure 18.—Hiding cover compared for shelterwood and clearcut prescriptions for the wildlife example stand: (a) percentage shrub cover versus stand age following initial thinning in 1984; (b) crown profile area in the lower 10 ft of the stand versus stand age; (c) sum of stem diameters versus stand age; (d) number of trees versus stand age.


SUM OF STEM DIAMETERS (FT) - SHELTERWOOD AND CLEARCUT TREATMENTS
STEMD
250
200
150
100
50
0
CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW TRT
-1 0 10 20 30 40 50 60 70 80 90 100 AGE
TREATMENT CC SW

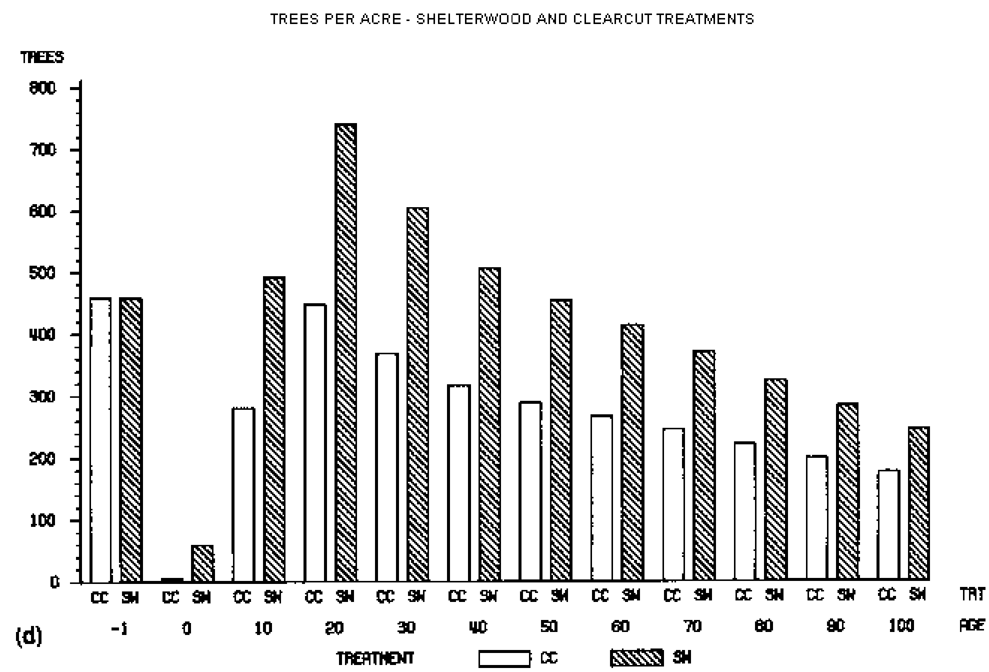

TREES PER ACRE - SHELTERWOOD AND CLEARCUT TREATMENTS
TREES
800
700
600
500
400
300
200
100
0
CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW CC SW TRT
-1 0 10 20 30 40 50 60 70 80 90 100 AGE
(d)
TREATMENT CC SW

Fig 18.—(Con.)

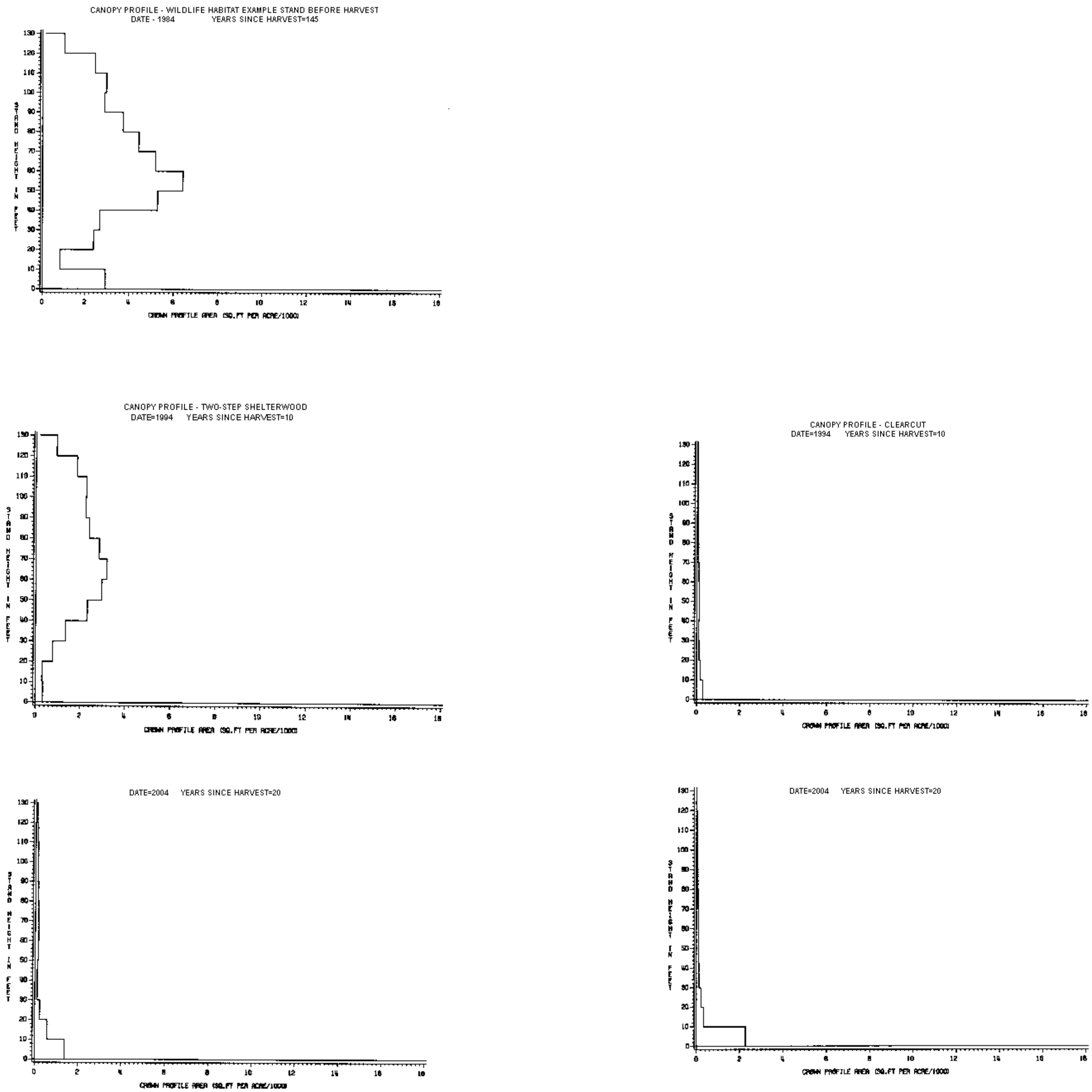


Figure 19.—The development through time of crown profile area by stand height for the wildlife habitat example.

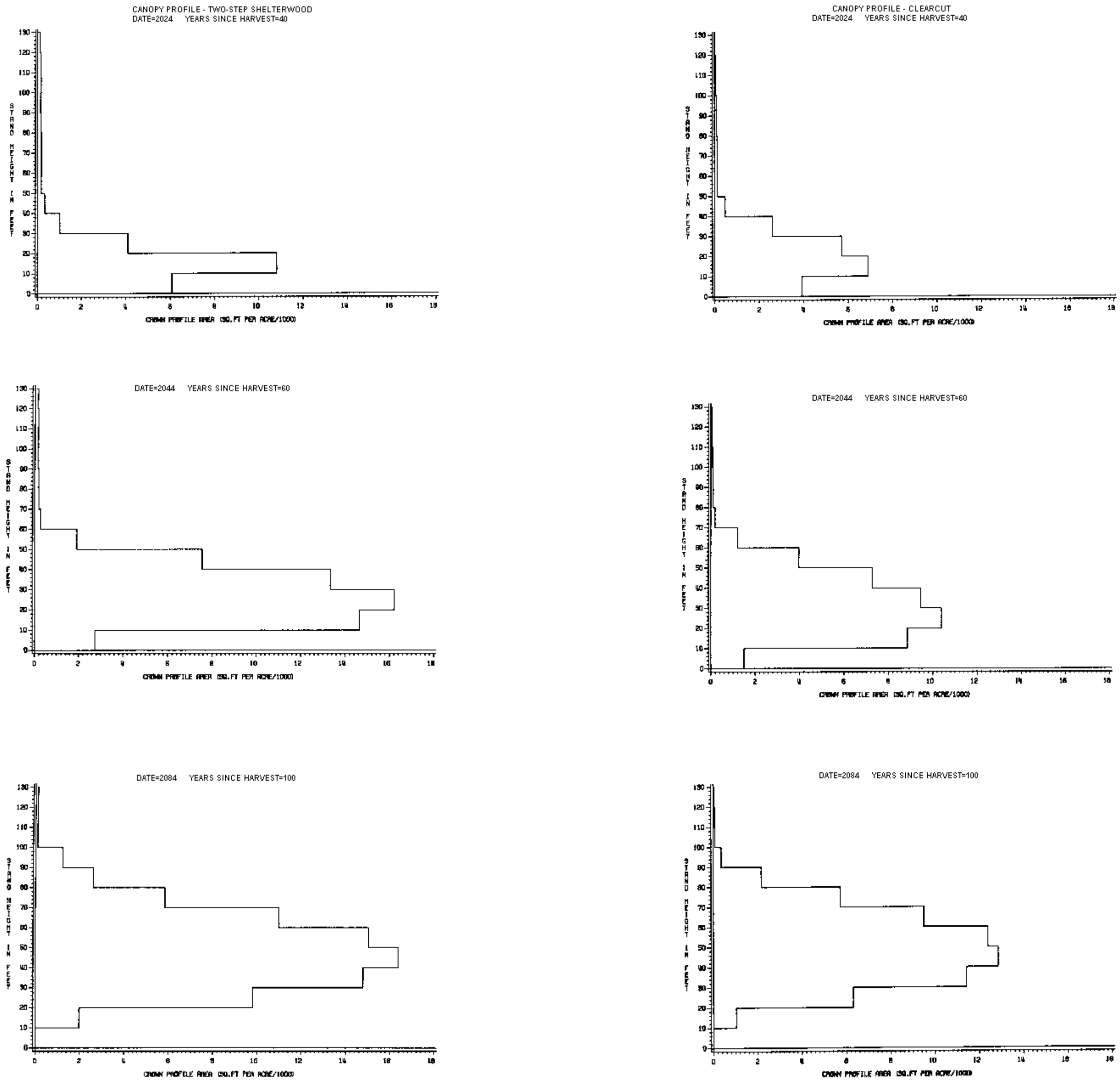


Figure 19. (Con.)

Hydrologic Applications

The COVER extension can be used to link natural or human-made vegetation changes to watershed impacts, primarily through predicted canopy closure and shrub cover values. The sum of cover conditions across stands in a watershed can be expressed as the percentage of ground exposed to precipitation and run-off following management.

Forest Insect Pest Modeling Applications

The COVER relationships for conifer foliage biomass and crown shape are currently being used in the Western Spruce Budworm Outbreak Model (Sheehan and others in preparation). The foliage equations predict total potential foliage biomass on undamaged trees. Assumptions about the partitioning of foliage by age classes within branches, the distribution of foliage within crowns, and the predicted effects of defoliation on future foliage production are all components of the western spruce budworm (WSBW) model. These relationships help predict insect damage to trees through availability of food and pattern of larvae dispersal vertically in the stand.

Succession Modeling and Planned Improvements

The combination of understory development and vertical and horizontal canopy development relationships comprising the COVER extension represents a framework for which quite detailed successional trends can be displayed through time. Planned future studies will more explicitly link the shrubs component to the regeneration system (Ferguson and others 1985) and small tree development models (Wykoff 1985) by modeling effects of shrub competition on small conifer establishment and growth rates.

A second improvement planned for COVER includes the option of making predictions on individual sample points within a stand, thus allowing a heterogeneous site to be represented in greater resolution. This will improve the prediction of shrub conditions, allow reporting of within-stand variance statistics, and provide a measure of the spatial distribution of overstory and understory cover.

Work is progressing on a graphical display link that shows the vertical and horizontal relationships of trees and shrubs through time. The display is in the form of a “lollipop” diagram in which each of several figures of a certain height and shape represent different types of tree and shrub records in the stand.

The Prognosis/COVER program incorporates models that are specific to certain species and conditions prevalent in the Northern Rocky Mountains, but it is also a general system that can be calibrated to local conditions. As shrub and crown data specific to other areas and habitat types become available, new relationships can be incorporated into the model to expand the range of predictions.

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APPENDIX: SUMMARY OF COVER KEYWORDS

Category	Keyword	Keyword use and associated parameters	Default parameter or conditions
Program control	CANOPY	Compute canopy cover statistics	None
	COVER	Invoke the COVER extension; always the first keyword record.	
		field 1: Cycle in which COVER calculations begin.	1
		field 2: Dataset reference number for COVER output.	18
	END	Last keyword record; return control to main program.	
	SHRUBS	Compute shrub statistics.	
		field 1: Number of years since stand disturbance.	Stand age (STDINFO card), or 3 years
		field 2: Habitat type code.	Stand habitat type code (STDINFO card)
		field 3: Physiographic type code.	2 (Lower slope)
		field 4: Disturbance type code.	1 (None)
Calibration	SHRBLAYR	Enter shrub calibration values by shrub layer.	No calibration
		fields 1, 3, 5: Average height (ft) of three shrub layers.	
		fields 2, 4, 6: Average cover (%) of three shrub layers.	
	SHRUBHT	Enter shrub height calibration values by species.	No calibration
		Up to four supplemental records: Species code and height (ft) in consecutive 10-column fields.	
	SHRUBPC	Enter shrub cover calibration values by species.	No calibration.
		Up to four supplemental records: Species code and cover (%) in consecutive 10-column fields.	
Output control	DATELIST	Print date of last revision for COVER model subprograms and common areas.	None
	DEBUG	Request printout of COVER calculations for tree and shrub list.	
		field 1: Cycle in which debug output is to be printed.	Print in all cycles
	NOCOVOUT	Suppress the canopy cover statistics display.	Display printed
	NOSHBOUT	Suppress the shrub statistics display.	Display printed
	NOSUMOUT	Suppress the canopy and shrubs summary display.	Display printed
	SHOWSHRB	Select additional shrub species to be displayed.	Print nine species which account for most cover.
		Supplemental record: Species codes right justified in six consecutive 10-column fields.	

Moeur, Melinda. COVER: a user's guide to the CANOPY and SHRUBS extension of the Stand Prognosis Model. General Technical Report INT-190. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Sta-tion; 1985. 49 p.

The COVER model predicts vertical and horizontal tree canopy closure, tree foliage biomass, and the probability of occurrence, height, and cover of shrubs in forest stands. This paper documents use of the COVER program, an adjunct to the Stand Prognosis Model. Preparation of input, interpretation of output, program control, model characteristics, and example applications are described.

KEYWORDS: stand structure, crown width, crown shape, canopy closure, foliage biomass, shrub cover, shrub height, shrub occurrence, stand simulation

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