Technical Report to NRCS-IDAHO

Development Report on:

Site Index Conversion
Mixed Specie Cubic-Foot Yield Curves
Douglas-fir cubic-foot Yield Curves
Mixed Specie MAI Curves and Table
Douglas-fir MAI Curves and Table

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1.1. PROJECT OVERVIEW

The current collection and dissemination of ESI forest plot information regarding *Psuedotsuga menziesii* var. *glauca* in north Idaho relies entirely on a method developed by P. H. Cochran. The incorporation of the Cochran method was introduced to NRCS Idaho from NRCS Oregon with Technical Note 190-VI.

Development of yield and site index curves by Cochran was based entirely on forest stands located on the east slopes of the Cascade Range and Blue Mountains of eastern Oregon / southeast Washington. Cochran's proposed site index and yield curves were well developed and suited for the forested landscapes used in his modeling efforts.

However, forest stands of north Idaho and northwestern Montana are often dissimilar to their counterparts of the Cascades and Blue Mountains. This dissimilarity will inherently create significant predicted site index and yield error when using the Cochran method in north Idaho. Furthermore, there were very few Cochran research plots established on cedar/hemlock habitat types. Consequently, volume and site index estimates generated by the Cochran method will not reflect north Idaho productivity on these more climax habitat types.

Several USDA-USFS research projects specifically developed site index and yield curves for north Idaho. Research papers INT-347 (R.A. Monserud, 1985) and INT-394 (A. Stage et al., 1988) address these topics. Forest stands used to develop these models were located north from Grangeville to Porthill, Idaho and east to Libby, Montana.

Most private and state forest management entities of north Idaho utilize the Stage and Monserud models for reporting yield and site index. This creates a communication breakdown between the NRCS and other forest management entities. Standardization of yield and site index reports by the NRCS is needed not only to prevent this from occurring, but also to improve rotation estimates, carbon sequestration estimates, and other natural resource interpretations. Bringing the data up to consistent and accurate standards would improve the usability and acceptance of the NRCS Idaho soil survey product.

1.2 OBJECTIVES

The objectives of this project were fourfold:

1) correlate Cochran site index values with Monserud to obtain a conversion algorithm,
2) develop predictive yield curves and algorithms suitable for north Idaho,
3) derive mean annual increment curves, and
4) create culmination of mean annual increment tables.

1.3 METHODS

1.3.1 Site Index Conversion

Site index calculations for inland Northwest Douglas-fir utilize the Monserud equation as given in Appendix 1. The equation is as follows:

$$S = [38.787 - 2.805 * (\ln A)^2 + 0.0216 * A * \ln A + (0.4948 * Z_1 + 0.4305 * Z_2 + 0.3964 * Z_3) * H + (25.315 * Z_1 + 28.415 * Z_2 + 30.008 * Z_3 * H / A];$$

where,

Z_1 = 1 if habitat type is in the DF series, or
0 otherwise;
Z_2 = 1 if habitat type is in the GF or WRC series, or
1 if have no habitat type information;
0 otherwise;
Z_3 = 1 if habitat type is in the WH or SAF series, or
0 otherwise.
H = total height – 4.5'.
S = site index – 4.5'.
A = age at breast height.
$\ln X$ = the natural logarithm of argument X.

A Cochran to Monserud conversion calculation was created using raw data from local ESI data forms. Tree growth data and habitat type were entered into a spreadsheet, from which Monserud site index values were calculated using the above equation. A least-squares regression fit was applied to the estimated Monserud and Cochran site index values. A simple, linear regression formula was determined and is as follows:

Monserud Site Index = 0.9557 * Cochran Site Index – 5.6644

1.3.2 Yield Curves

Data from Tables 1 and 2 in Appendix 2 were used as the base data for creating yield curves for two differing scenarios. Scenario one addresses volume yield based on total stand volume for naturally regenerated, unmanaged Douglas-fir, grand fir, and western white pine. Scenario two addresses volume yield based on Douglas-fir growth only in an unmanaged plantation with initial stocking density of 500 trees/ac. Both sets of data were analyzed by the PROC NLIN procedure in SAS 8.1®. A modified Richard's growth equation was used in conjunction with an iterative SAS Newton method to obtain predicted non-linear volume curves. The developed equation is as follows:

$$\textbf{Total Volume (ft}^3\textbf{)} = ((a_2*S)-a_1)*(1-\exp(-k*(A-t_0)))\wedge(1/(1-((m_2*S)+m_1)));$$

where,

a_1 & a_2 = linear slope and intercept values of an estimated volume asymptote,
S = site index (total height – 4.5'),
A = breast height age,
$-k$ = growth rate function,
m_1 & m_2 = linear slope and intercept values for the biological system exponent, and
t_0 = 6; estimated base age at which volume begins to accumulate.

Base data for site index values 60 and 70 in Table 1 were not included during model development. These data created anomalies during the model process and did not allow the equation to converge. Original data is suspect; therefore, curves were fit exclusive of these data.

Table 2 in Appendix 2 only presents base volume data for site index values of 50, 70, and 90. Consequently, only predicted curves are shown for site indexes of 40, 60, 80, and 100.

A linear fit equation was created for volume asymptote and biological exponent data using the cubic foot volume data from Tables 1 and 2 in Appendix 2. This allowed for the calculation of a volume yield estimate at a site index value outside the decadal increments given in these tables.

1.3.3 Current Mean Annual Increment Curves

Mean annual increment curves were created using both the base data and modeled data to determine the point of culmination. Mean annual increment was calculated using the following formula:

MAI = Total volume / Breast Height Age

Culmination of MAI occurs at that breast height age where incremental volume is maximized.

1.4 RESULTS

1.4.1 Site Index Conversion

Figure 1 depicts site index trends dependent on formula method and habitat type. Climax habitat types such as western red cedar and western hemlock show the greatest discrepancy between the two alternative site index calculations. These differences are significant at $\alpha = 0.1$. This wide variation is primarily attributable to the lack of THPL and TSHE site plots in the Cochran study. The declining trend in site index values shown in the climax habitat types can also be observed in more seral habitat type phases. However, these differences are not significantly different at any desirable α level. It could be stated that the differences in site index at the drier range in data is well within the measurement error, thus any differences in site index values are not entirely applicable to a change in calculation method.

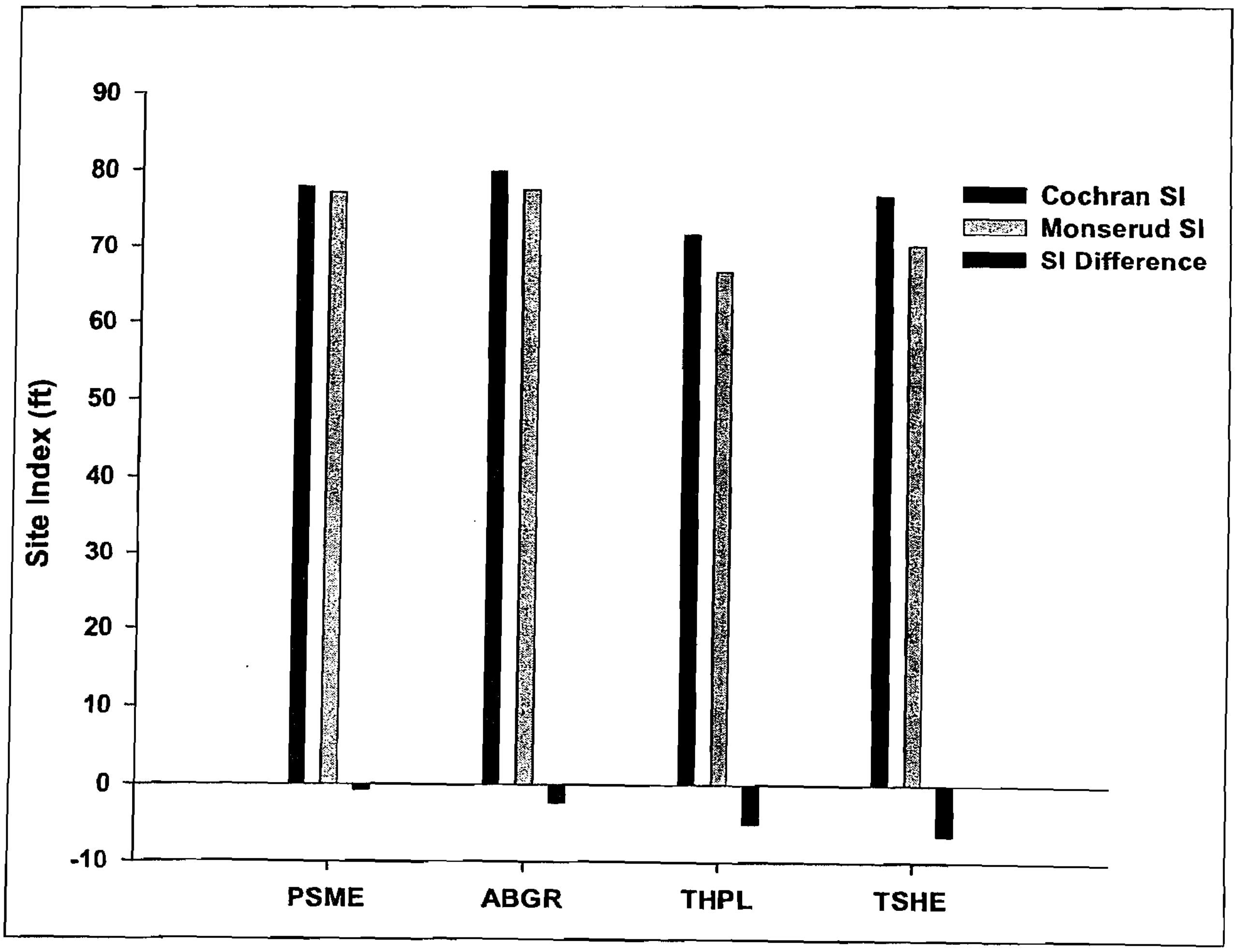

Figure 1. Site index as a function of method and vegetation series. THPL and TSHE Monserud SI values are significantly different than Cochran SI at $\alpha = 0.1$.

Least squares fit analysis showed a significant correlative difference between Cochran and Monserud site index values ($R^2 = 0.92$) (Figure 2). Statistical paired t-tests indicated significance at $\alpha = 0.01$.

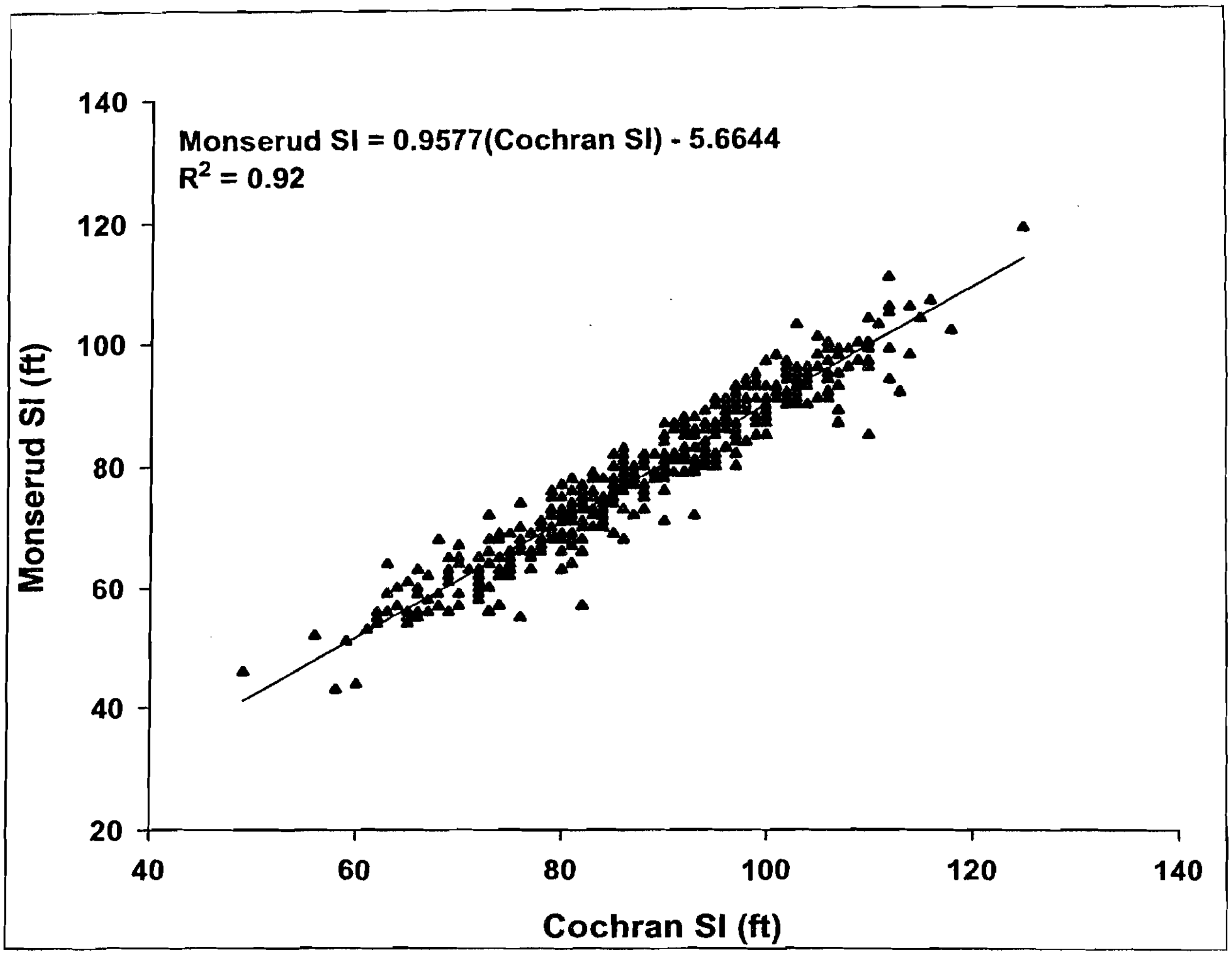

Figure 2. Least squares fit of Cochran and Monserud Douglas-fir site index data. Monserud site index is significantly different than Cochran site index at $\alpha = 0.01$.

1.4.2 Yield Curves

The modified Richard Growth equation yielded two sets of parameters for the base data used. For the naturally regenerated, unmanaged forest in a grand fir-cedar-hemlock ecosystem, the set of parameters are as follows:

a_1	a_2	$-k$	m_1	m_2	t_0
-11049.2	360.5	0.018913	0.928762	-0.00329	6

The set of parameters generated for an unmanaged plantation of Douglas-fir are as follows:

a_1	a_2	$-k$	m_1	m_2	t_0
-3219.9	189.3	0.0233	1.1377	-0.00719	6

Yield curves generated utilizing these parameters for their respective forest management regimes are presented in Figures 3 and 4.

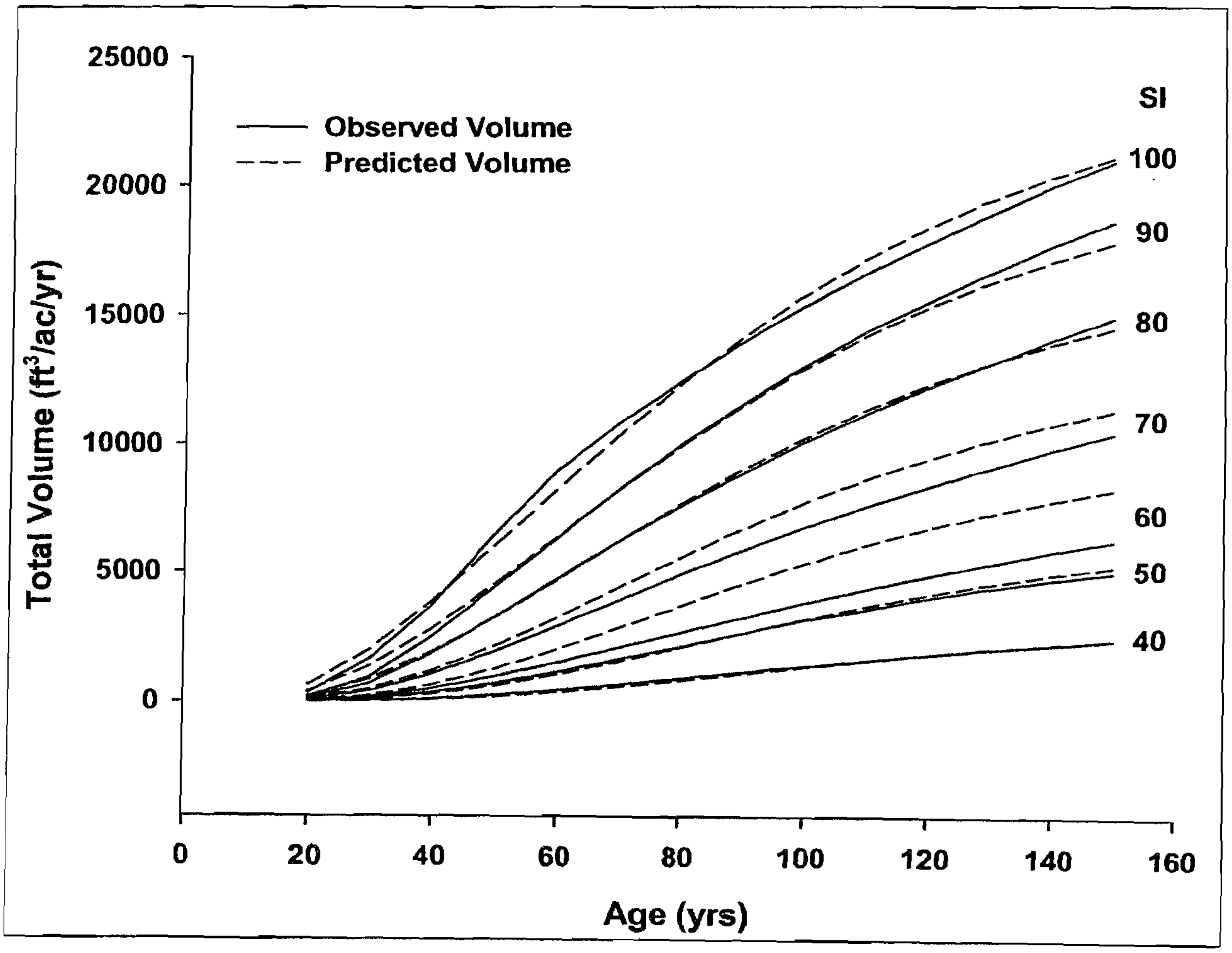

Figure 3. Total cubic-foot volume as a function of tree age and site index. Base data is derived from naturally regenerated forest stands (without management) in the grand fir-cedar-hemlock ecosystems.

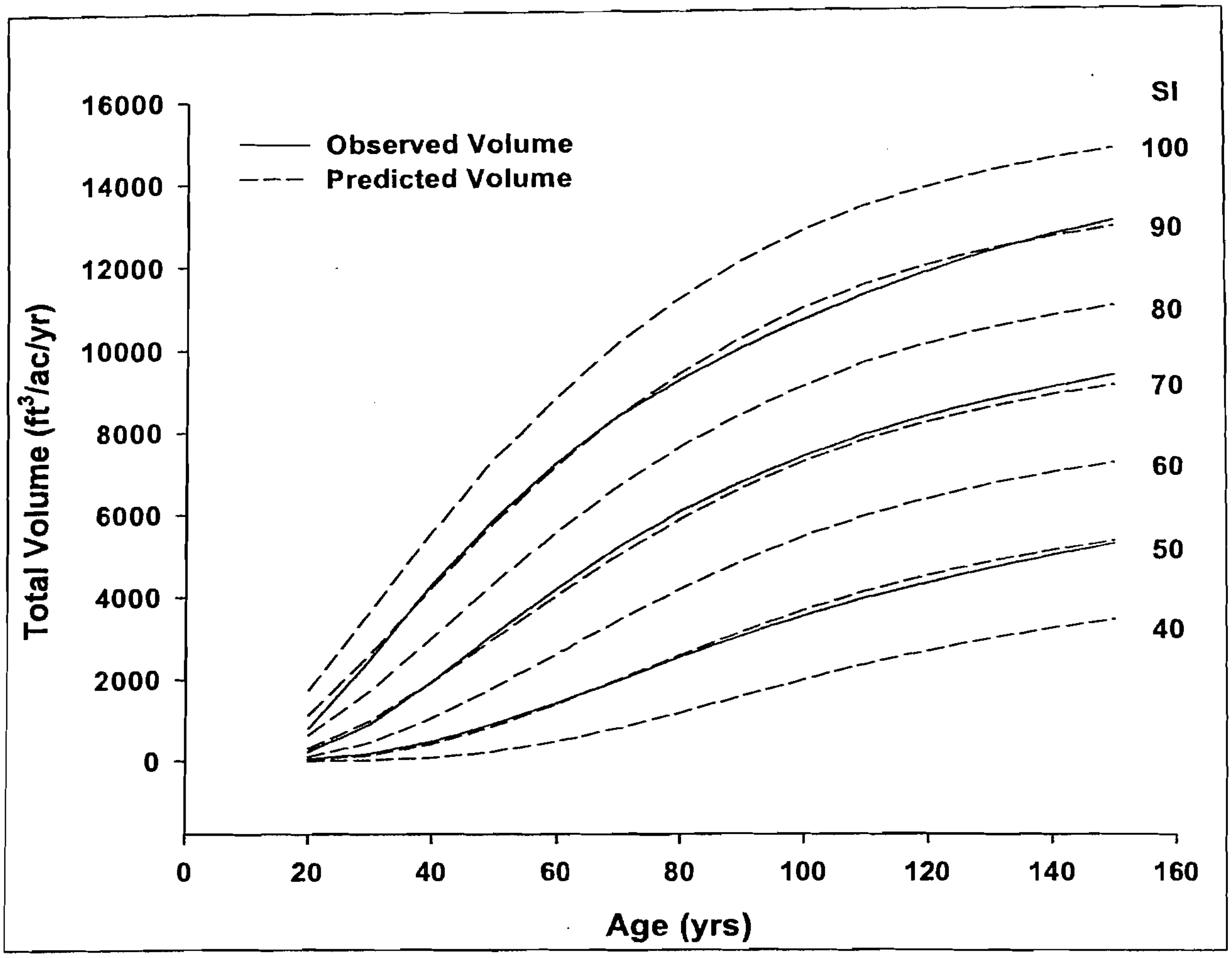

Figure 4. Douglas-fir cubic-foot volume as a function of tree age and site index. Base data is derived from DF plantations with initial stocking densities of 500 trees/ac.

Figure 3 shows a wide discrepancy between predicted and base data for site index values of 60 and 70. The potential answer to this wide difference may be in the base data. Research scientists near the INT-394 project state that there were potential anomalies in the data collected for those site indexes. Therefore, this data was removed during model creation. Volume estimates within these site index values should not be construed as widely inaccurate, as all other data was used to build the equation.

No such discrepancies existed for the Douglas-fir plantation data. The only limitation during model development for this set of data was in the limit of site index values listed. Data only existed for site index values of 50, 70, and 90. Therefore, estimated volume curves as shown in Figure 4, have no observed corollary for site index values of 40, 60, 80, and 100. However, the curves generated for 50, 70, and 90 show extremely tight fits to the original base data, thus the curves for 40, 60, 80, and 100 can be assumed as acceptable estimates.

1.4.3 Current Mean Annual Increment Curves

Mean annual increment curves for naturally regenerated and plantation forests were generated using both predicted and base data (Figures 5 and 6). Predicted MAI curves show a trend of underestimating culmination of mean annual increment (CMAI) at high site index values and overestimating at lower site index values in naturally regenerated stands. For Douglas-fir plantations, there is little discrepancy between predicted MAI and base data MAI, thus CMAI is nearly equivalent in both age and yield estimates.

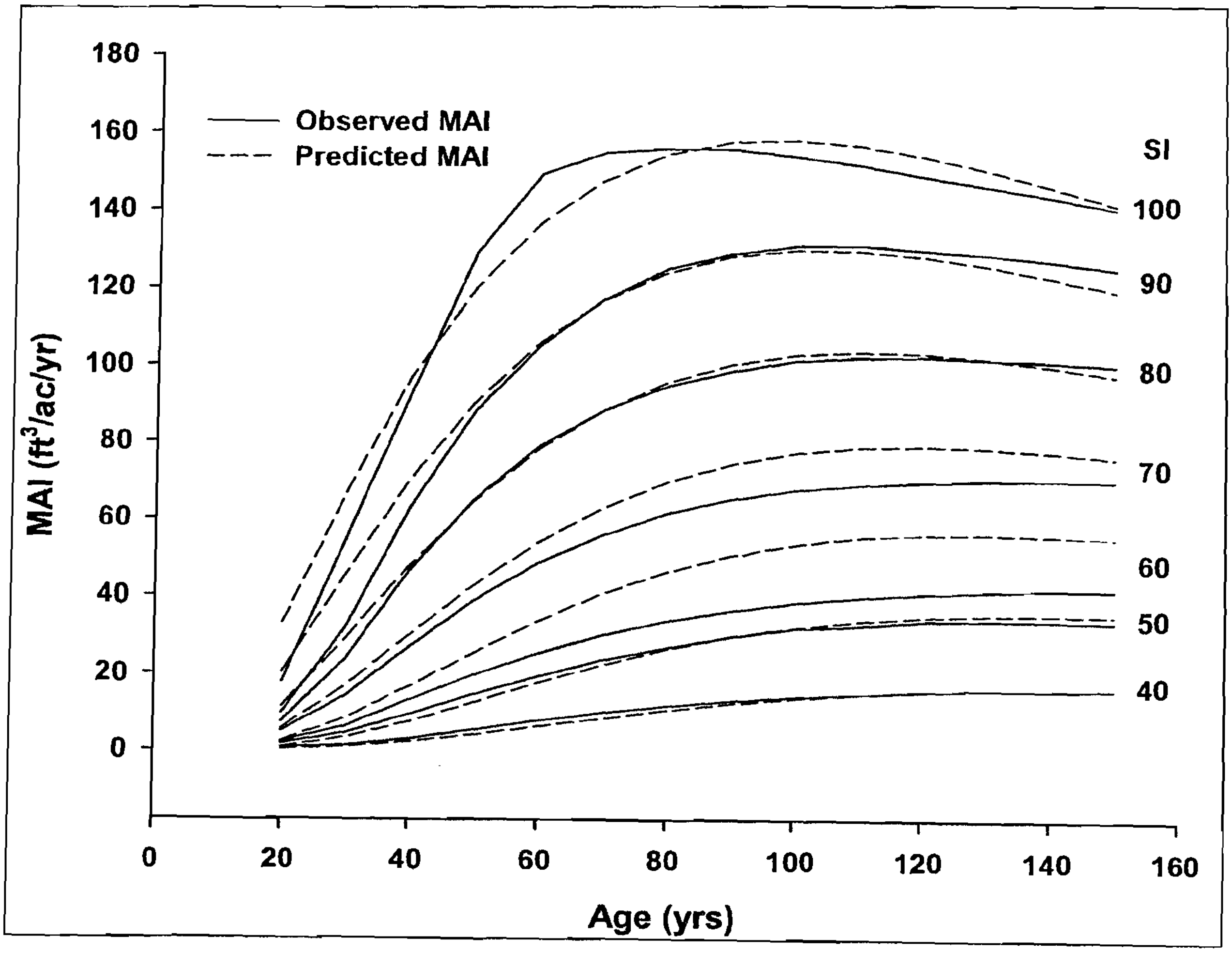

Figure 5. Mean annual increment cubic-foot volume as a function of tree age and site index. Base data is derived from naturally regenerated forest stands (without management) in the grand fir-cedar-hemlock ecosystems.

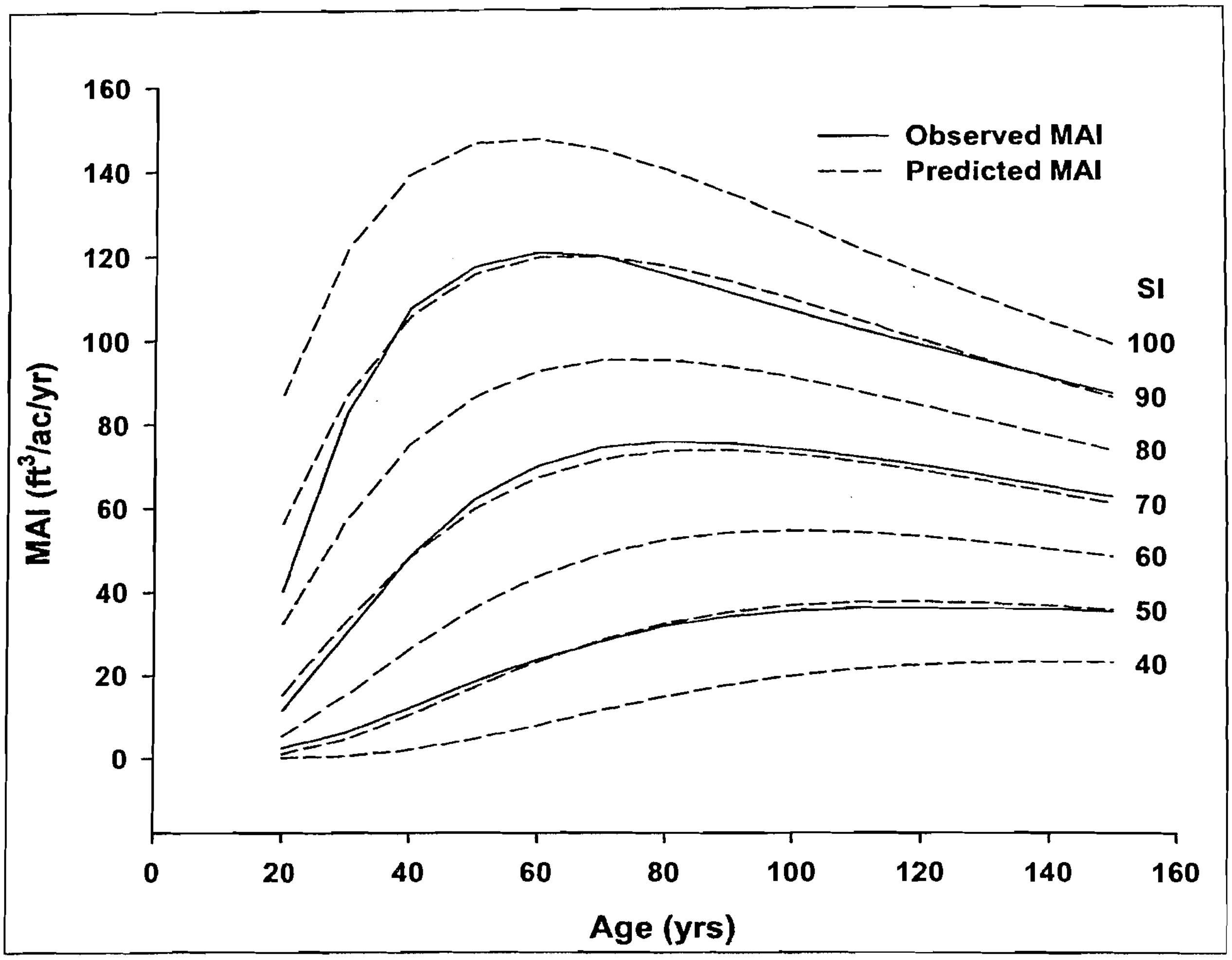

Figure 6. Douglas-fir mean annual increment cubic-foot volume as a function of tree age and site index. Base data is derived from DF plantations with initial stocking densities of 500 trees/ac.

1.4.4 Current Mean Annual Increment Tables

Using the modified Richard's growth equation as presented in 1.3.2, a matrix of CMAI values were created for both management regimes (Tables 1 and 2). Predicted CMAI values are presented in both annual cubic feet per acre and annual cubic meters per hectare. Metric values are simple conversions from the English units. The metric conversion used is as follows:

$$M^3 = Ft^3 * 0.02831685$$

These tables indicate that naturally regenerated stands on poorer quality sites take longer to accumulate less biomass than their plantation counterparts. At higher quality sites, naturally regenerated stands can sustain a larger tree biomass than pure Douglas-fir plantations; however, it may take an additional 40 years to achieve this increase. These differences are attributable to the higher volume production during the early and middle ages of plantation establishment because height growth is fastest at the early ages.

Cochran CMAI tables (Technical Note 190-VI) exhibit significant differences to those CMAI tables generated using Idaho and Montana data. Culmination age is significantly different between Cochran and regional data. Cochran underestimates CMAI when compared with regional, naturally regenerated, unmanaged forest stands and overestimates when compared with regional, unmanaged Douglas-fir plantations.

Culmination volume as generated by Cochran tends to underestimate the volume attainable on regional forestlands regardless of site quality. This volume reduction could be partially attributable to the lack of climax habitat types in Cochran's study. As stated in the site index discussion, the sites used in Cochran's study were drier and tended toward the seral habitat types. Consequently, his model would fail to account for increased productivity on the wetter climax habitat types.

Table 1. CMAI (50-yr.) as a function of site index and total age for naturally regenerated forest stands in the grand fir-cedar-hemlock ecosystems.

Site Index	CMAI		Total Age	Site Index	CMAI		Total Age
ft	ft^3/ac /yr	m^3/ha /yr	yrs	ft	ft^3/ac /yr	m^3/ha /yr	yrs
40	16	1.1	149	71	81	5.7	118
41	18	1.3	147	72	83	5.8	117
42	20	1.4	146	73	86	6.0	116
43	22	1.5	145	74	88	6.2	116
44	23	1.6	144	75	91	6.3	115
45	25	1.8	143	76	93	6.5	114
46	27	1.9	142	77	96	6.7	113
47	29	2.0	141	78	98	6.9	112
48	31	2.2	140	79	101	7.0	112
49	33	2.3	139	80	103	7.2	111
50	35	2.5	138	81	106	7.4	110
51	37	2.6	136	82	108	7.6	109
52	39	2.7	135	83	111	7.8	109
53	41	2.9	134	84	113	7.9	108
54	43	3.0	133	85	116	8.1	107
55	45	3.2	132	86	119	8.3	106
56	47	3.3	131	87	121	8.5	106
57	50	3.5	130	88	124	8.7	105
58	52	3.6	129	89	127	8.9	104
59	54	3.8	129	90	129	9.1	104
60	56	3.9	128	91	132	9.2	103
61	58	4.1	127	92	135	9.4	102
62	60	4.2	126	93	138	9.6	102
63	63	4.4	125	94	140	9.8	101
64	65	4.5	124	95	143	10.0	100
65	67	4.7	123	96	146	10.2	100
66	69	4.9	122	97	149	10.4	99
67	72	5.0	121	98	152	10.6	98
68	74	5.2	121	99	155	10.8	98
69	76	5.3	120	100	158	11.0	97
70	79	5.5	119				

Table 2. CMAI (50-yr.) as a function of site index and total age for Douglas-Fir var. *glauca*. Base data is derived from DF plantations with initial stocking densities of 500 trees/ac.

Site Index	CMAI		Total Age	Site Index	CMAI		Total Age
ft	ft^3/ac /yr	m^3/ha /yr	yrs	ft	ft^3/ac /yr	m^3/ha /yr	yrs
40	23	1.6	140	71	76	5.3	85
41	24	1.7	137	72	78	5.4	84
42	26	1.8	135	73	80	5.6	83
43	27	1.9	132	74	82	5.7	82
44	29	2.0	130	75	84	5.9	80
45	30	2.1	127	76	86	6.0	79
46	31	2.2	125	77	89	6.2	78
47	33	2.3	123	78	91	6.4	77
48	34	2.4	121	79	93	6.5	76
49	36	2.5	119	80	95	6.7	75
50	38	2.6	117	81	98	6.8	74
51	39	2.7	115	82	100	7.0	73
52	41	2.8	113	83	102	7.2	72
53	42	3.0	111	84	105	7.3	71
54	44	3.1	110	85	107	7.5	70
55	46	3.2	108	86	110	7.7	69
56	47	3.3	106	87	112	7.9	68
57	49	3.4	105	88	115	8.0	67
58	51	3.6	103	89	117	8.2	66
59	53	3.7	101	90	120	8.4	65
60	54	3.8	100	91	123	8.6	64
61	56	3.9	98	92	125	8.8	64
62	58	4.1	97	93	128	8.9	63
63	60	4.2	96	94	131	9.1	62
64	62	4.3	94	95	133	9.3	61
65	64	4.5	93	96	136	9.5	60
66	66	4.6	91	97	139	9.7	59
67	68	4.7	90	98	142	9.9	59
68	70	4.9	89	99	145	10.1	58
69	72	5.0	88	100	147	10.3	57
70	74	5.1	86				

1.5 ACKNOWLEDGEMENTS

Dr. William Wykoff, emeritus research forester for the USDA-USFS Rocky Mountain Research Station, contributed much appreciated assistance during the yield model development phase. Without his expertise in non-linear programming and his knowledge of the base data used, this project would have been exponentially more difficult. The support of Frank Gariglio, David Hoover, Lyn Townsend, and other NRCS foresters, is greatly appreciated. Without their support, this project would not have been feasible.