United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Note
PNW-RN-513
April 1994

Suggested Stocking Levels for Forest Stands in Northeastern Oregon and Southeastern Washington[1]

P.H. Cochran, J.M. Geist, D.L Clemens, Rodrick R. Clausnitzer, and David C. Powell

Abstract

Catastrophes and manipulation of stocking levels are important determinants of stand development and the appearance of future forest landscapes. Managers need stocking level guides, particularly for sites incapable of supporting stocking levels presented in normal yield tables. Growth basal area (GBA) has been used by some managers in attempts to assess inherent differences in site occupancy but rarely has been related to Gingrich-type stocking guides. To take advantage of information currently available, we used some assumptions to relate GBA to stand density index (SDI) and then created stocking level curves for use in northeastern Oregon and southeastern Washington. Use of these curves cannot be expected to eliminate all insect and disease problems. Impacts of diseases, except dwarf mistletoe (*Arceuthobium campylopodum* Engelm.), and of insects, except mountain pine beetle (*Dendroctonusponderosea* Hopkins) and perhaps western pine beetle (*Dendroctonus brevicomis* LeConte), may be independent of density. Stands with mixed tree species should be managed by using the stocking level curves for the single species prescribing the fewest number of trees per acre.

Keywords: Forest health, growth basal area, mountain pine beetle, stand density index, stressed sites, Oregon—northeast, Washington—southeast.

Introduction

Concerns about forest health east of the crest of the Cascade Range in Oregon and Washington have highlighted the need for site-specific information for a range of management practices, including stocking level control. Unfortunately, several insect pests and disease problems in northeastern Oregon and southwestern Washington cannot be prevented or controlled by density management. For example, spruce beetle (*Dendroctonus rufipennis* Kirby), western spruce budworm (*Choristoneura occidentalis* Freeman), Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough), and laminated root rot *(Phellinus weirii* (Murr) Gilbert son) attack trees regardless of stand density. Thinning, however, is a

---

[1] Contribution of the Stressed Sites Cooperative in northeastern Oregon, an informal team formed to implement existing science and stimulate applied research.

P.H. COCHRAN is a research soil scientist, Pacific Northwest Research Station, Silviculture Laboratory, 1027 NW Trenton Avenue, Bend, OR 97701; J.M. GEIST is a research soil scientist, Pacific Northwest Research Station, Forestry and Range Sciences Laboratory, 1401 Gekeler Lane, La Grande, OR 97850; D.L. CLEMENS is a silviculturist, Pine Ranger District, Wallowa-Whitman National Forest, Halfway, OR 97834; RODRICK R. CLAUSNITZER is an assistant area ecologist, Malheur, Umatilla, and Wallowa-Whitman National Forests, Box 907, Baker City, OR 97814; and DAVID C. POWELL is a forest silviculturist, Umatilla National Forest, 2517 SW Hailey Avenue, Pendleton, OR 97801.

practical means of lowering the probability of serious mortality from mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and perhaps western pine beetle *(Dendroctonus brevicomis* LeConte). Thinning can prevent dwarf mistletoe *(Arceuthobium campylopodum* Engelm.) from being a serious problem in even-aged ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stands on medium and higher sites (Barrett and Roth 1985). Also thinning is often necessary to prevent stagnation or excessive mortality due to suppression and to create vigorous trees and stands in the absence of insects and disease. Thinning increases the growth of leave trees and may be used to accelerate the development of stands designated to eventually have old-growth characteristics.

Managers need stocking level curves or other density management tools to use for sites incapable of supporting the stocking levels presented in normal yield tables. The existence of sites with limited stocking capacity has long been recognized (MacLean and Bolsinger 1973), although yield tables seldom have accounted for their reduced yields. Sites with low stocking limitations often support site trees producing average or above average site index values, but these sites have been purposely excluded during construction of many normal yield tables. For example, Meyer (1961) excluded all sample plots having a stand density index of 250 or less during development of normal yield tables for ponderosa pine. Even if such plots were not excluded, normal yield tables still would be difficult to use for sites with limited stockability.

Hall (1973) recognized sites with inherently low stocking capacities when he developed a vegetation classification for the Blue Mountains. He identified six ponderosa pine plant associations representing sites with low stockabilities, and he developed discounting factors that could be used accordingly to reduce the yield and growth information from normal yield tables.

Using existing information, we devised a method for estimating the upper stocking limits for managed stands of various species and species mixes in different plant associations. We present applications of this method for the Blue and Ochoco Mountains and the Wallowa-Snake Province of northeastern Oregon and southeastern Washington.

Proposed Method

Growing space available to individual frees in stands is an important factor governing tree and stand vigor. Basal area, one of the most frequently used measures of stand density, does not by itself provide the most useful index for growing space because basal area for normally stocked even-aged stands differs with age and site index. Basal area alone therefore says little about growing space in even-aged stands, unless the basal area of a "normally stocked" stand of the same site index and age, or average diameter, is known. In contrast, stand density index (SDI) is relatively independent of site quality and age. Stand density index is the number of trees per acre that a stand would have at a quadratic mean diameter of 10 inches. We used SDI as a measure of stand density. Values for SDIs at full stocking are not available for each species in each plant association for the Wallowa-Snake and Blue Mountain Provinces, but values for growth basal area (GBA) (Hall 1987,1989) are given in plant association guides (Johnson and Clausnitzer 1992, Johnson and Simon 1987). We used some assumptions to relate GBA to SDI at full stocking and then created stocking level curves based on SDI values .

Table 1—Coefficients for the equation $\log_e(T/A) = a - b(\log_e Dq)$ for 7 different species In northeastern Oregon and southwestern Washington and the resulting SDI_n values obtained when Dq = 10 Inches

Species	a	b	SDI_n	Source
Ponderosa pine	9.97	1.77	365	DeMars and Barrett 1987[a]
Lodgepole pine	9.63	1.74	277	File data[b]
Western larch	10.00	1.73	410	Cochran 1985
Douglas-fir	9.42	1.51	380	Seidel and Cochran 1981
White or grand fir	10.31	1.73	560	Cochran 1983
Subalpine fir	10.01	1.73	416	Estimated[c]
Engelmann spruce	10.13	1.73	469	Estimated[c]

[a] Coefficients derived from Meyer's (1961) original data.
[b] Coefficients derived from data on file at the Silviculture Laboratory and used to develop gross and net yield tables for lodgepole pine (Dahms 1964).
[c] Coefficients were estimated from GBA data of Hall (1987) and the crown competition factors of Wykoff and others (1982) as explained in the text.

Stand Density Index

Reineke (1933) expressed the relation between trees per acre (T/A) and quadratic mean diameter (Dq) for well-stocked, even-aged stands (stands with bell-shaped diameter distributions) as,

$$\log_e(T/A) = a - b(\log_e Dq). \quad (1)$$

He further proposed that the slope factor (b) was 1.605 for all species, but that the intercept value (a) differed with species. Evidence now suggests that slope, as well as intercept, differs with species (Puettmann and others 1993) and that the intercept value may differ with plant association, geographic location, and perhaps other factors (DeBell and others 1989). Differences in intercept values between plant associations for a given species indicate that the density equivalent to “normal” or “full” stocking changes with site conditions. Intercept and slope values for “normal” or “fully stocked” stands and SDIs for normal stands (SDI_ns) calculated from data collected across a number of plant communities give some idea of the variation among species (table 1).

Reineke (1933) apparently plotted data (trees per acre versus Dq on log-log paper) for “normally stocked” even-aged stands and drew a freehand line skimming the highest data points. The values in table 1, except for Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), come from a least squares fit of equation (1) using data collected from stands, across a range of ages, sites, and tree sizes, that appeared to be normally stocked.

The SDI for “normal” or “fully stocked” stands with bell-shaped diameter distribution curves (SDIn) is the number of trees per acre defined by equation (1) when the Dq is 10 inches. For stands at all levels of density with bell-shaped diameter distribution curves,

$$SDI = (T/A)(Dq/10)^b. \quad (2)$$

Estimating Density Limits

"Normal" or "fully stocked" even-aged stands have dominant, codominant, Intermediate, and suppressed crown classes. Most of the growth in these stands is in the dominant and codominant trees. In the absence of serious insect and disease problems, most of the mortality is in suppressed and intermediate crown classes. Therefore, thinning an even-aged stand from below, thereby eliminating all the suppressed and some or all the intermediate trees, would not substantially decrease cubic volume growth per acre but should substantially reduce the probability of mortality. Managing a stand so that a suppressed class never develops would shift the potential production of the site to fewer, larger trees, thereby reducing mortality and allowing capture of more of the potential growth by trees that eventually could be used. Therefore, upper density limits or management zones (UMZs) often are determined by establishing the density level at which a suppressed class of trees begins to develop. This density level often is considered to be about 75 percent of the SDI of a "normally" stocked stand. Lower density limits or management zones (LMZs) often are set at 50 percent of normal density (that is, 67 percent of the UMZ). This lower limit or zone allows sufficient volume to be removed yet maintains enough stocking to capture a significant portion of the site resources in tree growth. Using these concepts, the upper limit for managed stand densities could be derived by multiplying the SDI_ns in table 1 by 0.75, if the corresponding intercept values were correct for all plant associations and if all mortality were confined to the suppressed trees.

A problem here is that intercept values for any given species are apparently not the same for all plant associations. Further, for ponderosa and lodgepole pine (*Pinus contorta* Dougl. ex Loud.), mortality due to mountain pine beetle is not confined to inermediate and suppressed trees (Mitchell and Preisler 1991). Mortality due to this insect often becomes a problem at stand densities well below 75 percent of SDI_n. Empirical stocking level curves for ponderosa pine have been developed from field observations (Cochran 1992). These observations suggest that tree mortality due to mountain pine beetle remains at a low level until a critical stand density is reached (Larsson and others 1983). This critical density differs by site index, and when exceeded, mortality can become serious. These critical SDIs for UMZs in managed stands can be expressed as a function of the SDIn for even-aged ponderosa pine stands and Barrett's (1978) site index values (S) by

$$UMZ = 365[-0.36 + 0.01 (S)], \qquad (3)$$

for site index values up to 110. For higher values of site index, the UMZ can be set at 74 percent of 365.

For lodgepole pine, mortality due to mountain pine beetle also seems to be insignificant until a certain density level is reached. Peterson and Hibbs (1989) concluded for the Blue Mountains that an SDI of 170 is the threshold density where mortality due to mountain pine beetle becomes serious for lodgepole pine. Other available evidence supports this conclusion. Mortality data from Mitchell and others (1983) indicate a threshold SDI of about 165. Unpublished mortality rates on file at the Silviculture Laboratory (Bend, OR) for two different levels of growing-stock studies in central Oregon indicate a threshold SDI of about 170 Not enough observations are available to deteimine if this critical level for lodgepole pine differs with site index.

For any species, the stocking level that constitutes full stocking apparently differs with plant association. We propose, therefore, that the upper limit of the management zone (defined by taking 75 percent of the SDI_n values in table 1 for firs and larch and defined by equation (3) for ponderosa pine) be adjusted downward for some plant associations. This downward adjustment is to be made by multiplying these stocking levels by an adjustment fraction (At) defined as,

$$Af = (\text{SDI for species in the plant association})/(SDI_n \text{ of table 1}). \qquad (4)$$

Values of SDIs for species-plant association combinations are estimated from GBA values.

Converting GBA to SDI

Hall (1987) defines GBA as that basal area at which dominant trees grow 1 inch in diameter per decade at age 100. Estimates of GBA are made by multiplying the current stand basal area by a conversion factor. This conversion factor is determined from the diameter growth of dominant trees as outlined by Hall (1987). There is no direct way to convert GBA to SDI; assumptions have to be made about Dq or trees per acre. Hall (1989: appendix 5) presents a series of graphs for several species that display plots of GBA values as a function of site index and linear regressions of both GBA and normal basal area at age 100, where available, as a function of site index. Normal basal area data for subalpine fir and Engelmann spruce in the Blue Mountains are not available. Site index values in Hall (1987,1989) and in the plant association guides (Johnson and Clausnitzer 1992, Johnson and Simon 1987) are determined by using curves from the Forest Service Handbook (FSH 2409.26d.61.1-9) and also appendix M in Johnson and Simon (1987). Dominant trees bored for determination of GBA are used as the site trees. Data of Hall (1989) from eastern Oregon and Washington include 129 plant associations for ponderosa pine, 106 plant associations for Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco), 75 plant associations for grand fir (*Abies grandis* (Dougl.) Lindl.) or white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), 71 plant associations for lodgepole pine, 59 plant associations for larch *(Larix occidentalis* Nutt), 42 plant associations for Engelmann spruce, and 28 plant associations for subalpine fir. Each plant association consists of 5 to 30 sample plots. The wide variation in plotted GBA values around each GBA regression line indicates the variability in stockability among sites (Hall 1989). The regression lines for GBA and normal basal area are nearly parallel, except for ponderosa pine where the data for normal basal area were taken from Meyer (1961) who excluded plots of low stocking. For cases where the GBA and normal BA lines are nearly parallel, it is assumed that average SDIs for “fully stocked” stands over all sampled plant associations are equivalent to those in table 1. Ratios of actual to predicted values for GBA (GBAa/GBAp) for any plant association are considered to be proportional to ratios of site-specific, fully stocked basal areas to predicted normal basal areas (BAa/BAp) or to ratios of site specific SDIs at full stocking to the SDIs of table 1 (SDIf/SDIn). This consideration is based on these assumptions: (1) stands of the same species at a given age with identical site index values and similar histories would have the same Dq at full stocking and the same dominant diameter growth rates, even though the basal area and trees per acre at full stocking differed among the stands; and (2) for stands of the same species, age, site index value, and disturbance history but with different stockabilities, Dqs and dominant diameter growth rates will be similar at the same fraction of the site-specific, full stocking.

Table 2—Coefficients for the equation GBA = a_1 + b_1 (site Index), converted to English units[a]

Species	a_1	b_1
Ponderosa pine[b, c]	36.05	1.48
Lodgepole pine	29.18	1.34
Western larch	3.57	1.86
Douglas-fir	−13.94	2.54
White or grand fir	116.57	1.53
Subalpine fir	116.70	1.13
Engelmann spruce	119.88	1.42

[a]Equation is from Hall 1989: appendix 5.
[b]Coefficients for ponderosa pine have been adjusted as described in the text so that the function GBA = a_1 + b_1 (site index) is parallel to the function normal basal area at age 100 = c + b_1(site index).
[c] The site index values (100-year base) for all species used for determining these coefficients are from curves given in Johnson and Simon 1987: appendix L.

For the special case of two even-aged stands of the same species with the same Dq but with differing densities, BA1/BA2 = SDI_1/SDI_2. If assumptions (1) and (2) above hold,

$$GBA_1/GBA_2 = (SDI_1 \text{at full stocking})/(SDI_2 \text{at full stocking}), \quad (5)$$

for two stands of the same species at the same site index value but with different stockabilities.

The regressions of Hall (1989: appendix 5) modified for ponderosa pine (table 2) were used with the site index values in the plant association guides to predict GBAs (GBA_p) for each species-plant association combination. The SDI at full stocking (SDI_f) for that species-plant association combination was then determined by employing the actual GBAs in the plant association guides (GBA_a) and an average SDI_n for that species from table 1 in a rearrangement of equation (5):

$$SDI_f = SDI_n(GBA_a/GBA_p) \ . \quad (6)$$

Values for site index and GBA_a for the Ochoco and Blue Mountains were taken from Johnson and Clausnitzer (1992: appendix D). Corresponding values for the Wailowa-Snake Province were taken from Johnson and Simon (1987: appendix E).

We estimated the SDI_n values for subalpine fir and Engelmann spruce to be 416 and 469, respectively, considering the example of Hall (1987: p. 37) for Douglas-fir and his grand fir data (Hall 1989: fig. 101). At age 100 for very low productivities, Hall estimates “maximum” basal area to be 149 percent of GBA for tolerant species and 166 percent of GBA for intolerant species. In Hall’s Douglas-fir example, normal basal area at age 100 is 124 percent of GBA. For Hall’s grand fir data, normal basal area at age 100 for the lowest site index values is 120 percent of GBA. Normal basal areas at age 100 for subalpine fir and Engelmann spruce were approximated by multiplying by 1.20 the predicted GBA values at a site index of 20 meters (65.6 feet) displayed on Hall's graphs (1989: figs. 104 and 106). A 10-inch Dq at age 100 was assumed for both species, so SDI_n is (normal basal area)/0.5454154. For ponderosa pine, a large number of stands of low stockability occur on sites with low site index values, and the lines depicting GBA and normal basal area as functions of site index are not parallel. To obtain a predictor of GBA from site index that could be used with the SDIn of 365 given in table 1, the regression line depicting normal basal area (from Meyer 1961) at age 100 as a function of site index was adjusted downward. This adjusted line passes through a basal area equivalent to 71 percent of the normal value at a site index of 50 feet as displayed on Hall's ponderosa pine graph (1989: fig. 99). This adjustment was derived from Hall's lodgepole pine graph (1989: fig. 109) where GBA is 71 percent of the normal basal area at age 100 at a site index of 50 feet. This adjusted line is presumed to approximate the relation of GBA to site index for stands within the range of densities sampled by Meyer (1961).

Stocking Levels

Values for SDI at full stocking for a given species, determined by using equation (6), differ greatly with plant associations (tables 3 and 4). The SDI values in tables 3 and 4 are not averages of the sampled stands; they are estimates of SDI values at full stocking. When these SDI values are lower than the SDIn values of table 1, the UMZs for these species-plant association combinations should be reduced. An exception is lodgepole pine (fig. 1), where a UMZ equivalent to an SDI of 170 is set in all cases for stands containing trees 9 inches in diameter at breast height (d.b.h.) to reduce the probability of serious mortality from mountain pine beetles. The LMZ for lodgepole pine is set at 67 percent of the UMZ.

Only the UMZs are given for ponderosa pine to simplify the figures (figs. 2 and 3). The first set of curves for ponderosa pine (fig. 2) displays the UMZs defined either by equation (3) or by 74 percent of 365 for site index values of Barrett (1978) of 110 feet or greater. The second set of curves (fig. 3) provides four examples of UMZs for plant associations not capable of normal stocking by Meyer's (1961) standards. These UMZs can be determined directly from equation (3) by substituting the SDIf from table 3 or 4 for 365 or by multiplying the UMZ determined from equation (3) by the ratio SDI_f/365. Consider, for example, the ponderosa pine/bluebunch wheatgrass *{Agropyron spicatum* (Pursh) Scribn. & Smith; PIPO/AGSP) plant association (table 3), which has an SDI of 133 at full stocking and a site index value (S1) of 59. To obtain the UMZ SDI, the site index value of the table (S1), which is from Meyer's (1961) system, first must be converted to the site index value (S) of Barrett's (1978) system. When Meyer's (1961) site index curves are used with the height equivalent to the average basal area of the crop trees, the S1 values of Meyer are converted to the S values of Barrett by using S = 37.74 + O.93(S1) (Cochran 1992). When Meyer's curves are used with height of dominant trees to obtain site index values, as was the case with the plant association guides, 5 is approximately 110 percent of S1. This 110-percent conversion changes the table value of 59 feet in Meyer's system to 65 feet in Barrett's system. The UMZ for a site index of 65 feet would be equivalent to an SDI of 106 (equation 3), if the SDI at full stocking was 365 for this association. The SDI at full stocking for the PIPO/AGSP association is, however, 133 (table 3). The proper UMZ value is, therefore, obtained by multiplying 106 by the fraction 133/365. This multiplication produces an SDI of 39 for the UMZ for ponderosa pine in this plant association.

Table 3—Estimated SDI values at full stocking (SDI_f) for species-plant association combinations In the

Species and values	ABLA2 series							ABGR series					
	ABLA2/ TRCA3	ABLA2/ CLUN	ABLA2/ LIBO2	ABLA2/ MEFE	ABLA2/ VAME	ABLA2/ VASC	ABLA2/ CAGE	ABGR/ GYDR	ABGR/ POMU-ASCA3	ABGR/ TRCA3	ABGR/ ACGL	ABGR/ TABR/ CLUN	ABGR/ TABR/ LIBO2
PIPO:[b]													
SI[c]	—	—	—	—	—	—	—	—	—	—	—	—	—
GBA[d]	—	—	—	—	—	—	—	—	—	—	—	—	—
SDI[e]	—	—	—	—	—	—	—	—	—	—	—	—	—
PSME:													
SI	—	—	—	—	—	73	—	—	—	—	114	—	78
GBA	—	—	—	—	—	165	—	—	—	—	175	—	239
SDI	—	—	—	—	—	366	—	—	—	—	241	—	493
LAOC:													
SI	—	104	83	—	65	66	—	—	124	110	106	—	96
GBA	—	224	181	—	116	117	—	—	200	202	172	—	134
SDI	—	466	470	—	382	380	—	—	350	398	351	—	302
PICO:													
SI	85	—	—	—	65	61	69	—	—	—	—	—	—
GBA	230	—	—	—	107	127	172	—	—	—	—	—	—
SDI	445	—	—	—	255	317	392	—	—	—	—	—	—
PIEN:													
SI	101	87	83	—	61	76	—	—	107	108	96	100	101
GBA	193	329	192	—	168	178	—	—	423	226	177	238	168
SDI	344	634	379	—	382	366	—	—	730	388	324	426	299
ABGR:													
SI	—	—	—	—	—	—	—	121	107	108	111	104	83
GBA	—	—	—	—	—	—	—	298	243	279	236	279	283
SDI	—	—	—	—	—	—	—	553	486	554	461	567	651
ABLA2:													
SI	96	84	79	89	55	66	70	—	—	—	—	—	—
GBA	207	308	166	248	114	168	175	—	—	—	—	—	—
SDI	382	605	335	475	265	365	372	—	—	—	—	—	—

[a] Based on Johnson and Clausnitzer 1992: appendix D.
[b] See appendix 1, this paper, for species code.
[c] SI=site index (base = 100 years) (Johnson and Simon 1987).
[d] GBA=growth basal area (square feet per acre).
[e] SDI=estimated values for stand density index at full stocking.

For the remaning species, two sets of stocking level curves are illustrated (figs. 4 through 13). One set of curves assumes that full stocking is equivalent to SDIs of table 1. A lower set of curves is shown for the lowest SDI at full stocking given in tables 3 or 4. To plot stocking levels for subalpine fir and Engelmann spruce (figs. 10 through 13), a slope value of -1.73 (the slope for white or grand fir; table 1) was used in equation (1). Identical slopes for all three species were used because tog-log plots of individual tree contribution to crown competition factor (CCF) as a function of the diameter (calculated from equations of Wykoff arid others [1982]) for the three species had the same slopes. Because both CCF and SDI are forms of tree:area ratios (Curtis 1970,1971), it is reasonable to assume that species having similar slopes for one form of this ratio would have similar slopes for another form of this ratio.

Blue Mountains[a,b]

ABGR series—continued									PICO series	PSME series					
ABGR/ CLUN	ABGR/ LIBO2	ABGR/ VAME	ABGR/ VASC-LIBO2	ABGR/ VASC	ABGR/ SPBE	ABGR/ CARU	ABGR/ CAGE	ABGR/ BRVU	PICO/ CARU	PSME/ PHMA	PSME/ HODI	PSME/ SYAL	PSME/ VAME	PSME/ CARU	PSME/ CAGE
—	73	76	—	86	85	77	80	—	—	88	107	83	78	75	68
—	271	119	—	77	113	130	89	—	—	125	181	119	80	106	83
—	686	292	—	172	255	316	210	—	—	274	340	273	193	263	222
87	64	71	78	78	116	80	79	—	—	88	117	89	79	81	71
247	172	177	168	133	146	178	148	—	—	124	190	138	90	133	123
453	440	404	347	274	198	357	301	—	—	225	255	247	183	264	281
117	88	75	93	77	—	93	—	81	—	97	—	98	—	—	—
247	151	162	109	109	—	132	—	167	—	115	—	93	—	—	—
458	370	464	253	304	—	307	—	444	—	256	—	205	—	—	—
—	73	67	66	71	—	74	—	—	73	—	—	—	—	—	—
—	199	102	140	133	—	142	—	—	102	—	—	—	—	—	—
—	434	238	330	296	—	307	—	—	223	—	—	—	—	—	—
104	81	88	85	—	—	—	—	60	—	—	—	—	—	—	—
282	200	178	179	—	—	—	—	258	—	—	—	—	—	—	—
494	399	341	349	—	—	—	—	590	—	—	—	—	—	—	—
101	77	71	81	75	118	87	75	80	—	—	—	—	—	—	—
308	216	183	212	152	188	198	233	260	—	—	—	—	—	—	—
636	516	455	494	368	354	444	564	609	—	—	—	—	—	—	—
—	84	79	103	—	—	—	—	—	—	—	—	—	—	—	—
—	190	204	103	—	—	—	—	—	—	—	—	—	—	—	—
—	373	412	184	—	—	—	—	—	—	—	—	—	—	—	—

The UMZs and LMZs for larch, Douglas-fir, grand or white fir, Engelmann spruce, and subalpine fir are, respectively, 75 and 50 percent of the SDI values in table 1 or tables 3 or 4. When SDI values for a particular species-plant association combination are higher than the values of table 1, the values of table 1 should be used in determining the management zones. If the SDI value for the species-plant asociation combination in table 3 or 4 is lower than the value in table 1, the SDI value in table 3 or 4 should be used. The SDI at full stocking for Douglas-fir in the grand fir/Rocky Mountain maple *(Acer glabrum* Torr.; ABGR/ACGL) plant association, for example, is 242 (table 3). The UMZ for Douglas-fir in this plant association would be 75 percent of 242, which is an SDI value of 182. The SDI for the UMZ would be 285 if the SDI at full stocking was 380 (table 1). Multiplying 285 by the fraction 242/380 also produces an SDI value of 182 for the specific UMZ.

Additional curves for different SDIs can be plotted for all species. Each SDI-mean diameter (Dq) combination can be converted to trees per acre (T/A) by rearranging equation (2). Basal areas per acre (BA/A) then can be determined by BA/A = $(T/A)(0.005454)Dq^2$. Appendix 2 provides more information on plotting stocking level curves.

Table 4—Estimated values for SDI at full stockIna (SDIO for species-plant association combinations In the

Species and values	Mountain hemlock series	Subalpine fir series						Grand fir series						
	TSME/ VASC+VAME	ABLA2/ VASC	ABLA2/ VAME	ABLA2/ CLUN	ABLA2/ LIBO2	ABLA2/ MEFE	ABLA2/ STAM	ABGR/ CLUN	ABGR/ VAME	ABGR/ LIBO2	ABGR/ ACGL	ABGR/ SPBE	ABGR/ CARU	ABGR/ PHMA
PIPO:														
SI[c]	—	—	—	118	—	—	—	98	92	—	92	103	101	—
GBA[d]	—	—	—	175	—	—	—	230	160	—	190	225	195	—
SDI[e]	—	—	—	303	—	—	—	464	339	—	403	436	384	—
PSME:														
SI	—	68	70	—	—	—	—	94	95	87	106	93	94	86
GBA	—	235	275	—	—	—	—	260	210	245	308	300	270	300
SDI	—	562	638	—	—	—	—	439	351	450	458	513	456	557
LAOC:														
SI	—	80	100	118	109	—	—	113	99	95	—	—	—	85
GBA	—	160	170	180	140	—	—	190	170	180	—	—	—	140
SDI	—	431	368	331	278	—	—	364	371	409	—	—	—	355
PICO:														
SI	65	74	80	—	95	75	72	81	72	70	—	—	—	—
GBA	95	150	150	—	150	135	130	170	120	135	—	—	—	—
SDI	226	324	305	—	266	288	287	342	265	304	—	—	—	—
PIEN:														
SI	88	90	85	110	100	95	98	104	107	—	—	—	—	—
GBA	155	240	235	290	240	200	265	290	275	—	—	—	—	—
SDI	297	454	458	493	430	368	480	508	474	—	—	—	—	—
ABGR:														
SI	—	—	—	95	—	—	—	108	96	96	115	—	—	77
GBA	—	—	—	255	—	—	—	325	270	325	375	—	—	210
SDI	—	—	—	545	—	—	—	646	574	691	718	—	—	502
ABLA2:														
SI	73	78	70	90	76	65	84	—	—	—	—	—	—	—
GBA	215	190	160	180	190	150	180	—	—	—	—	—	—	—
SDI	449	386	340	343	390	328	354	—	—	—	—	—	—	—

[a]Based on Johnson and Simon 1987: appendix E.
[b]See appendix 1, this paper, for species codes.
[c]SI=site index (base = 100 years) (Johnson and Simon 1987).
[d]GBA=growth base area (square feet per acre).
[e]SDI=estimated values for stand density index at full stocking.

Application to Mixed Species Stands

As mixed species stands develop, the more shade-intolerant species are first to diminish in crown size, experience reduced vigor, and then drop out of the stand. If maintenance of seral, intolerant trees is a stand objective, we suggest that stands with mixed species be managed by using the stocking level guide for the species in the mix that prescribes the fewest trees per acre at any stocking level.

Discussion and Conclusions

Proper silvicultural prescriptions are necessarily site specific and all conditions and problems on the site need to be considered. Stocking control can prevent suppression-related mortality, reduce the severity of dwarf mistletoe infections in some even-aged ponderosa pine stands, and lower the probability of mortality caused by mountain pine beetles, and perhaps western pine beetles, in an otherwise healthy stand. Thinning also may accelerate stands toward old-growth structure. Jhinning should not be considered a substitute for other treatments, such as species conversion in root rot pockets.

PIPO series												
PIPO/ SYAL	PIPO/ SYOR	PIPO/ CARU	PIPO/ CAGE	PIPO/ CELE/ CAGE	PIPO/ CELE/ PONE	PIPO/ CELE/ FEID-AGSP	PIPO/ PUTR/ CAGE	PIPO/ PUTR/ CARO	PIPO/ PUTR/ FEID-AGSP	PIPO/ ARTRV/ FEID-AGSP	PIPO/ FEID	PIPO/ AGSP
95	80	71	70	65	61	51	64	67	65	81	62	59
154	110	141	77	84	55	48	73	90	67	81	68	45
318	260	365	201	232	159	157	204	243	185	190	194	133
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—

Wallowa-Snake Province[a,b]

Douglas-fir series						Ponderosa pine series			
PSME/ CARU	PSME/ ACGL- PHMA	PSME/ PHMA	PSME/ SPBE	PSME/ SYAL	PSME/ SYOR	PIPO/ SYAL	PIPO/ SPBE	PIPO/ FEID	PIPO/ AGSP
85	94	87	91	94	78	78	76	77	75
160	135	105	165	160	150	100	90	85	75
361	281	232	353	333	361	241	221	207	186
72	92	73	70	66	—	—	—	—	—
195	160	140	160	170	—	—	—	—	—
439	277	310	371	420	—	—	—	—	—

Several things need to be considered when prescribing densities from information in tables 3 and 4. Hall (1987) states that GBA can be determined to only a 10-percent precision level. Also, the standard errors for GBA for many of the tree species-plant association combinations are large (Johnson and Clausnitzer 1992, Johnson and Simon 1987). A combination of sampling errors, possible errors in adjusting for the age effect, and climatic effects on diameter growth produce these large standard errors. Further, the assumptions used to convert GBA to SDI are untested. The SDIs determined from GBA values, therefore, are approximate. Field observations of normally stocked stands should be undertaken whenever possible to validate the SDIs given in tables 3 and 4.

We are not certain whether the stand densities recommended to avoid problems with mountain pine beetle for ponderosa pine stands capable of normal stocking (fig. 2) can be extrapolated to stands with low stockabilities by using adjustment factors of $SDI_f/365$. The relation between mortality caused by mountain pine beetle and stand and tree characteristics is unclear. Tree size, spacing, tree vigor, and other factors all seem to be involved (Mitchell and Preisler 1991). If tree vigor is a primary factor, our recommended adjustments seem reasonable.

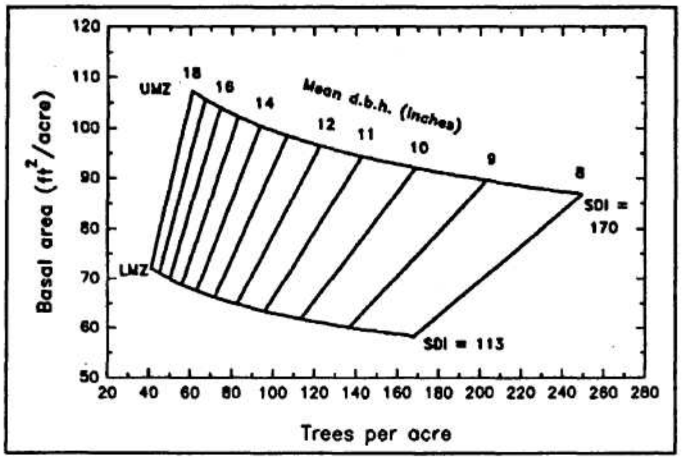

Figure 1—Stocking level curves for lodgepole pine in northeastern Oregon. The UMZ is set at an SDI of 170 to reduce the probability of serious mortality from mountain pine beetle.

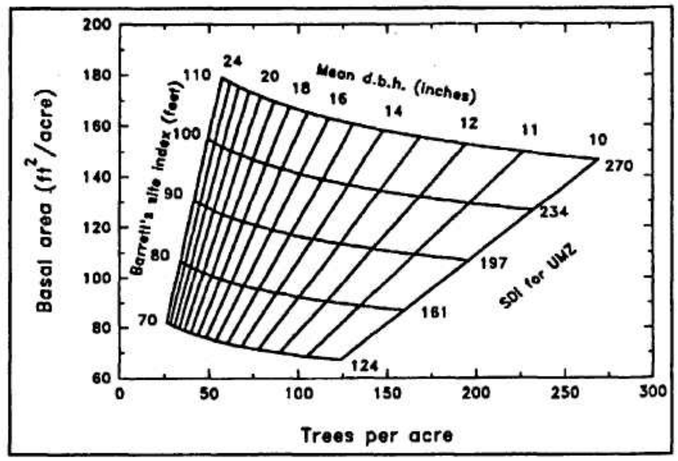

Figure 2—Upper management zones for ponderosa pine sites capable of supporting stand densities equivalent to an SDI of 365 or greater at full stocking. These UMZs represent densities where serious mortality from mountain pine beetle can begin to occur.

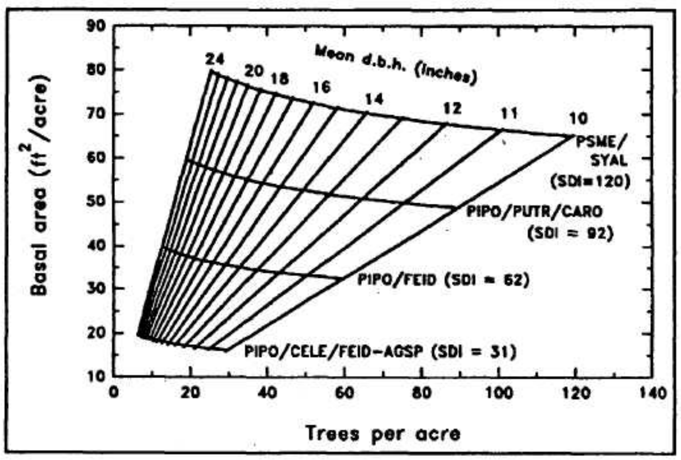

Figure 3—Examples of upper management zones for some ponderosa pine sites with low stockabilities (ponderosa pine series, tables 3 and 4). These UMZs are estimates of threshold densities where serious mortality to mountain pine beetle can occur.

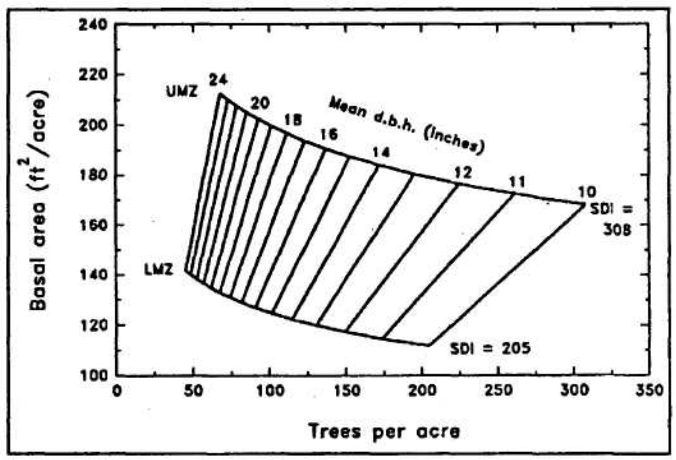

Figure 4—Stocking level curves for larch sites capable of supporting stand densities equivalent to SDIs of 410 or greater at full stocking,

We do not recommend using higher UMZs than can be derived from the SDIs in table 1, even though some sites appear capable of supporting much higher densities. Most stands can respond to new growing space within 5 years after thinning, and response in diameter growth is usually immediate. Once stands adjust to additional growing space, total cubic volume growth is fairly similar over a fairly wide range of densities (Cochran and Barrett 1993, Cochran and Oliver 1988). For this reason it may be better to err by prescribing thinnings with leave-tree, densities that are too low, rather than too high. Much of the stand growth takes place on the biggest and best trees (Cochran 1983, Cochran and Barrett 1993); hence, thinning from below is recommended

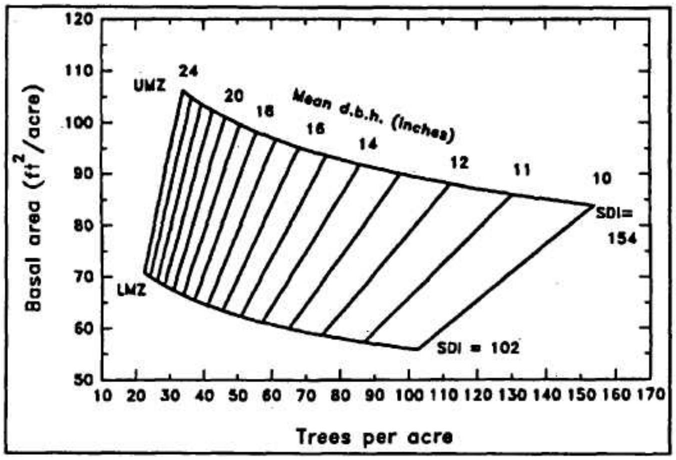

Figure 5—Stocking level curves for larch growing in the PSME/SYAL plant association (table 3) capable of supporting an SDI of 205 at full stocking.

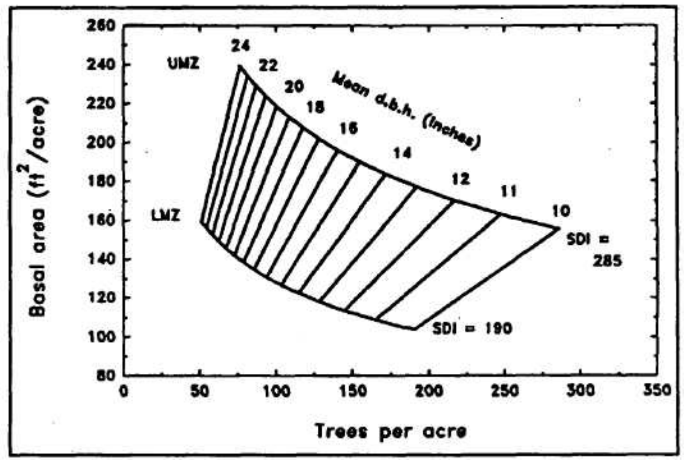

Figure 6—Stocking level curves for Douglas-fir sites capable of supporting stand densities equivalent to an SDI of 380 or greater at full stocking.

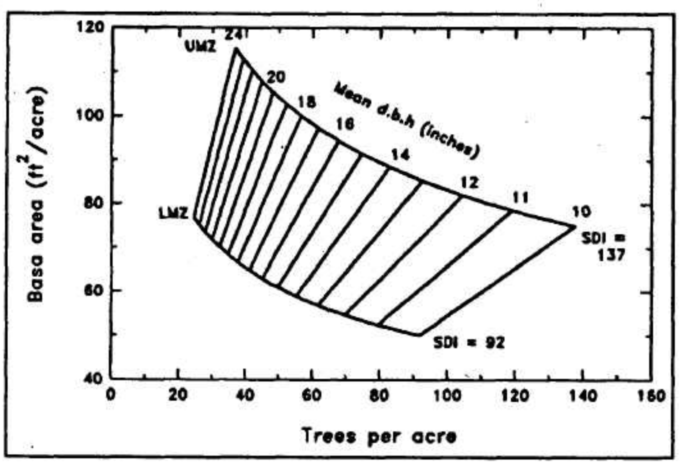

Figure 7—Stocking level curves for Douglas-fir growing in the PSME/VAME plant association (table 3) capable of supporting an SDI of 183 at full stocking.

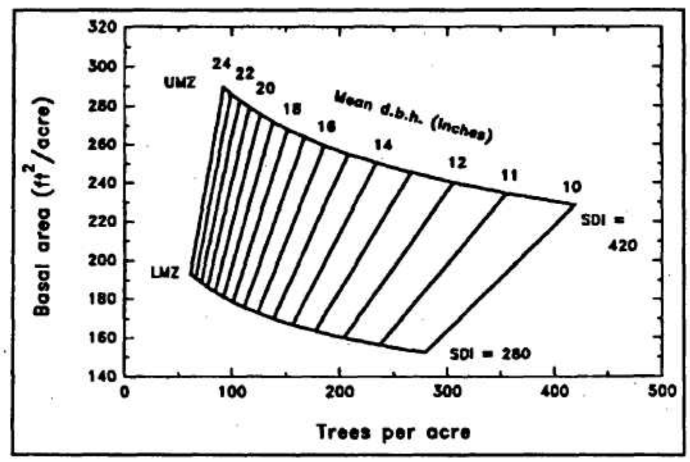

Figure 8—Stocking level curves for grand or white fir sites capable-of supporting stand densities equivalent to an SDI of 560 or greater at full stocking.

Stand development is an important factor in all aspects of forest management. Catastrophes and manipulation of stocking levels are important factors determining development of stands and the appearance of future forest landscapes. Management strategies that prevent overstocking increase the probability of producing healthy stands and pleasing landscapes.

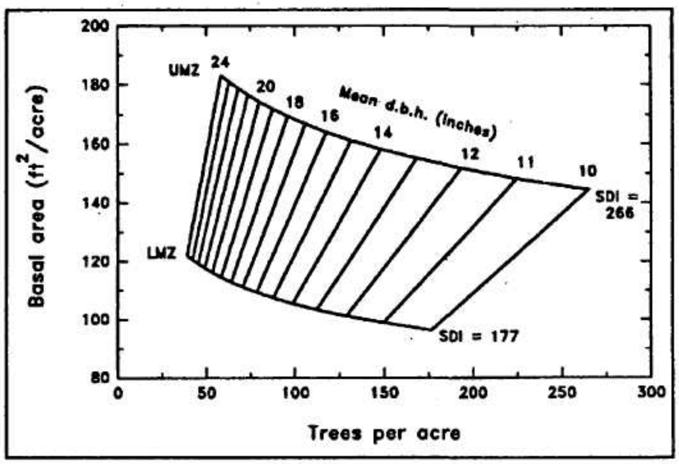

Figure 9—Stocking level curves for grand or white fir growing in the ABGR/SPBE plant association (table 3) capable of supporting an SDI of 354 at full stocking.

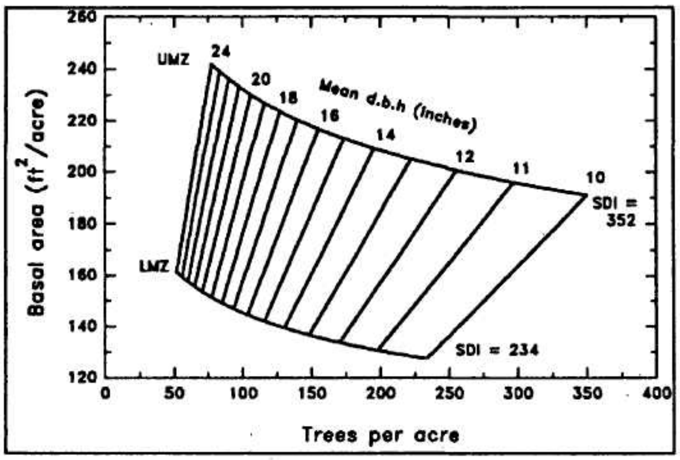

Figure 10—Stocking level curves for Engelmann spruce sites capable of supporting stand densities equivalent to an SAI of 469 or greater at full stocking.

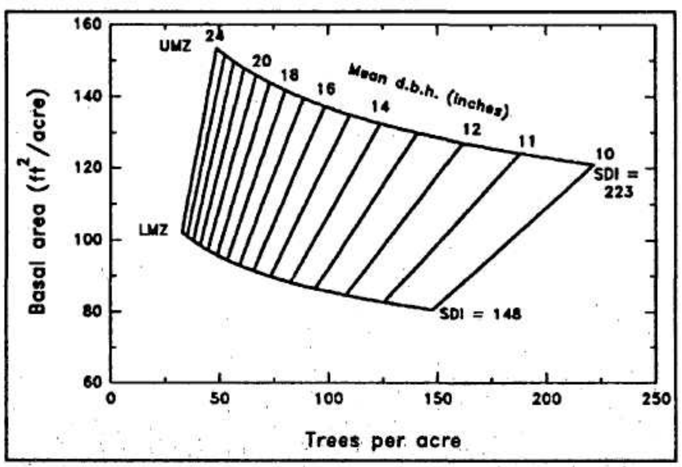

Figure 11-Stocking level curves for Engelmann spruce growing in the TSME/Vasc+Vame plant community (table 4)capable of attaining an SDI of 297 at full stocking.

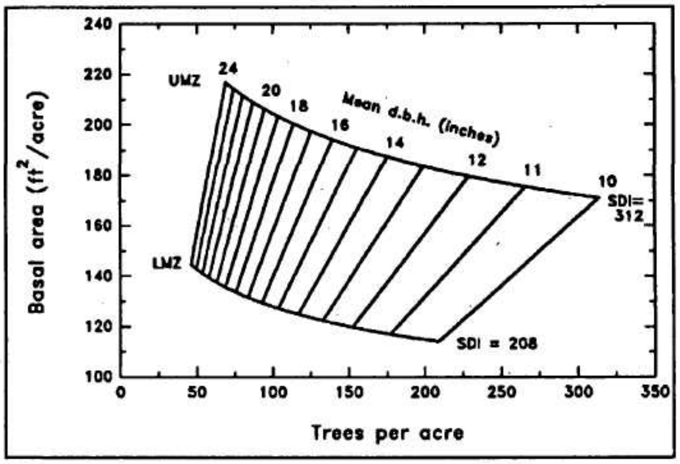

Figure 12—Stocking level curves for subalpine fir sites capable of supporting stand densities equivalent to an SDI of 416 or greater at full stocking.

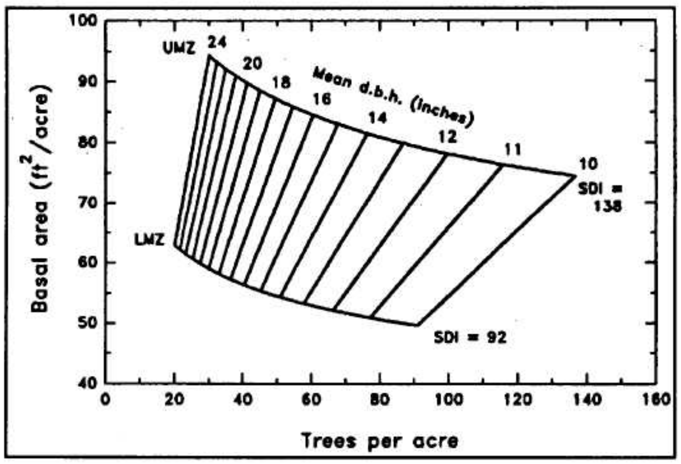

Figure 13—Stocking level curves for subalpine fir in the ABGR/VASC-LIBO2 plant community (table 3) capable of attaining an SDI of 184 at full stocking.

Literature Cited

Barrett, James W. 1978. Height growth and site index curves for managed even-aged stands of ponderosa pine in the Pacific Northwest. Res. Pap. PNW-232. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

Barrett, James W.; Roth, Lewis F. 1985. Response of dwarf mistletoe to thinning: 1. Sapling growth. Res. Pap. PNW-330. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 15 p.

Cochran, P.H. 1983. Stocking levels for east-side white or grand fir. In: Oliver, Chadwick Dealing; Kenaday, Reid M., eds. Biology and management of true fir in the Pacific Northwest: Proceedings of a symposium; 1981 February 24-26; Seattle, WA. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 186-189.

Cochran, P.H. 1985. Site index, height growth, normal yields, and stocking levels for larch in Oregon and Washington. Res. Note PNW-424. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 24 p.

Cochran, P.H. 1992. Stocking levels and underlying assumptions for uneven-aged ponderosa pine stands. Res. Note PNW-RN-509. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 10 p.

Cochran, P.H.; Barrett, James W. 1993. Long-term response of planted ponderosa pine to thinning in Oregon's Blue Mountains. Western Journal of Applied Forestry. 8(4): 126-132.

Cochran, P.H.; Oliver, William W. 1988. Growth rates for managed stands of white fir. In: Schmidt, Wyman C., comp. Future forest of the mountain west: proceedings of a stand culture symposium; 1986 September 29-October3; Missoula, MT. Gen. Tech. Rep. INT-243. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 197-200.

Curtis, Robert 0.1970. Stand density measures: an interpretation. Forest Science. **16(4): 403-414.**

Curtis, Robert 0.1971. A tree area power function and related stand density measures for Douglas-fir. Forest Science. 17(2): 146-159.

Dahms, Walter G. 1964. Gross and net yield tables for lodgepole pine. Res. Pap. PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

DeBell, Dean S.; Harms, William R.; Whitesell, Craig D. 1989. Stockability: a major factor in productivity differences between *Pinus taeda* plantations in Hawaii and the southeastern United States. Forest Science. 35(3): 708-719.

DeMars, D.J.; Barrett, J.W. 1987. Ponderosa pine managed-yield simulator: PPSIM users guide. Gen. Tech. Rep. PNW-GTR-203. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 36 p.

Hall, Frederick C. 1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. R6 Area Guide 3-1. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 62 p.

Hall, Frederick C. 1987. Growth basal area handbook. R6-ECOL-181b-1984. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 84 p.

Hall, Frederick C. 1989. The concept and application of growth basal area: a forestland stockability index. R6-ECOL Tech. Pap. 007-89. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 86 p.

Johnson, Charles Grier, Jr.; Clausnltzer, Rodrlck R. 1992. Plant associations of the Blue and Ochoco Mountains. R6-ERW-TP-036-92. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 205 p.

Johnson, Charles Grler, Jr.; Simon, Steven A, 1987. Plant associations of the Wallowa-Snake province Wallowa-Whitman National Forest. R6-ECOL-TP-255A-86. Portland, OR: U.S. Department of Agriculture,,Forest Service, Pacific Northwest Region. 400 p.

Larsson, S.; Oren, R.; Waring, R.H.; Barrett, *J.W,* 1903. Attacks of mountain beetle as related to tree vigor of ponderosa pine; Forest Science. 29(2): 395-402.

MacLean, Colln D.; Bolslnger, Charles L. 1973. Estimating productivity on sites with low stocking capacity. Res. Pap. PNW-152. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 59 p.

Meyer, Walter H. 1961. Yield of even-aged stands of ponderosa pine. Tech. Bull. 630. Revised. Washington DC: U.S. Department of Agriculture, Forest Service. 59 p.

Mitchell, R.G.; Waring, R.H.; Pitman, G.B. 1983. Thinning lodgepole pine increases tree vigor and resistance to mountain pine beetle. Forest Science. 29(1): 204-211.

Mitchell, Russel G.; Prelsler, Halganoush K. 1991. Analysis of spatial patterns of lodgepole pine attacked by outbreak populations of mountain pine beetle. Forest Science. 37(5): 1390-1408.

Peterson, William C; Hlbbs, David E. 1989. Adjusting stand density management guides for sites with low stocking potential. Western Journal of Applied Forestry. 4(2): 62-65.

Puettmann, Klaus J.; Hann, David W.; Hlbbs David E. 1993. Evaluation of the size-density relationships for pure red alder and Douglas-fir stands. Forest Science. 39(1): 1-27.

Seldel, K.W.; Cochran, P.H. 1981. Silviculture of mixed conifer forests in eastern Oregon and Washington. Gen. Tech. Rep. PNW-121. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 70 p.

Reineke, L.H. 1933. Perfecting a stand density index for even-aged forests. Journal of Agricultural Research. 46(7): 627-638.

Wykoff, William R.; Crookston, Nicholas L.; Stage, Albeit R. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.

Appendix 1

Plant species and codes used in tables 3 and 4 from Johnson and Clausnitzer (1992) and Johnson and Simon (1987).

Code	Scientific name	Common name
Trees:		
ABGR	*Abies grandis*	Grand or white fir
ABLA2	*Abies Tasiocarpa*	Subalpine fir
LAOC	*Larix occidentalis*	Western larch or tamarack
PIEN	*Picea engelmannii*	Engelmann spruce
PICO	*Pinus contorta*	Lodgepole pine
PIPO	*Pinus ponderosa*	Ponderosa pine
PSME	*Pseudotsuga menziesii*	Douglas-fir
Shrubs:		
ACGL	*Acerglabrum*	Rocky Mountain maple
ARTRV	*Artemisia tridentata vaseyana*	Mountain big sagebrush
CELE	*Cercocarpus ledifolius*	Curlleaf mountain-mahogany
HODI	*Holodiscus discolor*	Creambush ocean-spray
LIBO2	*Linnaea borealis*	Twinf lower
MEFE	*Menziesia ferruginea*	Fool's huckleberry
PHMA	*Physocarpus malvaceus*	Mallow ninebark
PUTR	*Purshia tridentata*	Bitterbrush
SPBE	*Spiraea betulifolia*	Birchleaf spirea
SYAL	*symphoricarpos albus*	Common snowberry
SYOR	*symphoricarpos oreophilus*	Mountain snowberry
TABR	*taxus brevifolia*	Pacific yew
VAME	*Vaccinium membranaceum*	Big huckleberry
VASC	*Vaccinium scoparium*	Grouse huckleberry or whortleberry
Grasses and grasslike:		
AGSP	*Agropyron spicatum*	Bluebunch wheatgrass
BRVU	*Bromus vulgaris*	Columbia brome
CARU	*Calamagrostis rubescens*	Pinegrass
CAGE	*Carexgeyeri*	Elk sedge
CARO	*Carex rossii*	Ross sedge
FEID	*Festuca idahoensis*	Idaho fescue
PONE	*Poa nervosa*	Wheeler's bluegrass
Forbs:		
ASCA3	*Asarum caudatum*	Wild ginger
CLUN	*Clintonia uniflora*	Queencup beadlily
GYDR	*Gymnocarpium dryopteris*	Oakfern
POMU	*Polystichum munitum*	Sword fern
STAM	*Streptopus amplexifolius*	Clasping leaved twisted stalk
TRCA3	*Trautvetteria caroliniensis*	False bugbane

Appendix 2
Plotting stocking level curves

Stocking level curves can be plotted with several spreadsheet programs that allow creation of columns and then plotting one column as a function of another on a defined set of axes. Some of the general steps tor plotting stocking level curves are as follows.

1. Create a column (column 1) of mean diameters (Dq) ranging from the smallest to the largest diameter of interest. Use small diameter-increments for smooth curves; for example, 10.0,10.1.....25.0.

2. Create a column (column 2) of trees per acre at full stocking (TPA1) by using the equation,

$$TPA1 = \{EXP[a - b(\log_e Dq)]\}(SDI_f/SDI_n) .$$

Obtain values of a, b, and SDI_n from table 1 and SDI_f from table 3 or table 4, or define your own SDI_f. An example for white or grand fir with an SDI of 330 at full stocking would be,

$$TPA1 = \{EXP[10.31 - 1.73(\log_e Dq)]\}(330/560).$$

3. Create a column (column 3) for trees per acre (T/A) for each diameter for the UMZ by multiplying TPA1 by the appropriate percentage (usually 75 percent).

4. Create a column (column 4) for T/A for the LMZ by multiplying TPA1 by the appropriate percentage (usually 50 percent).

5. Create a column (column 5) for basal area per acre (BA) for the UMZ,

$$BA = T/A * 0.005454154 * Dq^2 .$$

6. Create a column (column 6) for basal area per acre (BA) for the LMZ.

7. Plotting column 5 as a function of column 3 will display the UMZ curve, and plotting column 6 as a function of column 4 will display the LMZ curve.

The following additional steps are needed to create lines for each Dq.

1. Create a column (column 7) for a series of stocking levels (SL) over the range of interest. Only two values are needed; for example, 0.50, 0.75.

2. For each Dq of interest create a column giving the T/A for these stocking levels by using,

$$T/A = (SL)\{EXP[a - b(\log_e Dq)]\}(SDI_f/SDI_n)$$

For the white fir example with a 10-inch Dq, this equation would be,

$$T/A = (SL)\{EXP[10.31 - 1.73(\log_e 10)]\}(330/560) .$$

3. Next create columns giving the basal areas for each Dq over the range in stocking levels,

$$BA = T/A *.005454154 * Dq^2 .$$

4. Plotting the column of BA as a function of the column giving T/A for each Dq will produce a series of straight lines for each Dq connecting the LMZ with UMZ.

Working copies of stocking level curves may be plotted by using the following program written in QuickBASIC. A diskette with this program and instructions for use may be requested from the senior author (see page 1 for address.)

```
graphtitle$ = "Stocking Level Curves-"
ytitle$ = "BA-ft^2/Acre"
chart$ = "Dq range"
yaxis$ •=> "###--"              'defines how y axis values are printed'
xtitle$ = "Trees per Acre"
CLS
SCREEN 2
species$ = "white/grand fir"   'specifies species'
highy.= 320                     'maximum basal area on graph in ft^2/acre'
lowy = 120                      'minimum basal area on graph in ft^2/acre'
highx = 460                     'maximum, trees per acre on x axis'
lowx = 0                        'minimum tree per acre on x axis'
highDq = 25                     'maximum mean diameter-inches'
lowDq = 10                      'minimum mean diameter-inches'
al = 10.31   'intercept value for normal stocking- ln(T/A)=al-bl(ln(Dq))'
bl = 1.73                       'absolute slope value for above function'
hpns = 75             'highest stocking level on graph (percent of normal)'
lpns = 50              'lowest stocking level on graph (percent of normal)'
slip = 25                       'interval between curves on graph (percent)'
af = 560 / 560                  'specific stand SDI/regional average SDI'
yint = (highy - lowy) / 10      'interval between tics on y axis'
rpns = hpns - lpns
LOCATE 4, 25: PRINT chart$; lowDq; "-"; highDq; "in."  'these 4 lines'
LOCATE 23, 20: PRINT xtitle$; "("; lowx; "-"; highx; ")" 'print statements'
LOCATE 1, 25: PRINT graphtitle$; species$                'on graph'
LOCATE 1, l: PRINT ytitle$
ynum = highy
FOR i = 1 TO 10
  PRINT USING yaxis$; ynum; PRINT   'prints numbers on y axis'
  ynum = ynum - yint                 'defines y axis intervals'
NEXT
PRINT USING yaxis$; ynum
VIEW (30, 11)-(500, 171)             'defines portion of screen for graph'
WINDOW (lowx, lowy)-(highx, highy)    'defines coordinates of graph'
LINE (lowx, lowy)-(highx, highy), , B  'draws box around graph'
FOR n = (lowx + 20) TO highx STEP 20    'defines positioning of x axis tics"
tic = lowy + 2                           'defines length of x axis tics'
  LINE (n, lowy)-(n, tic)                'draws x axis tics'
NEXT
FOR n = lowx + 100 TO highx STEP 100                              'numbers'
  LOCATE 21, (20 + n - lowx) / ((highx - lowx) / 57.5); PRINT n    'x axis'
NEXT
FOR f = lpns TO hpns STEP slip                 'sets levels of normal density'
  TPA = EXP(al - bl * LOG(lowDg)) * (f / 100) * af     'TPA = trees per acre'
  BA = lowDg ^ 2 * .005454154# * TPA                 'BA = basal area per acre'
```

```
  PSET (TPA, BA)                                    'sets pen to begin drawing'
FOR Dq = lowDq TO highDq STEP .2              'these 3 lines define basal area'
 TPA = EXP(al - bl * LOG(Dq)) * (f / 100) * af  'as a function of trees per'
 BA = Dq ^ 2 * .005454154# * TPA                'acre for each mean diam. (Dq)'
 LINE -(TPA, BA)                                      'draws BA vs. TPA lines'
NEXT Dq
NEXT f                                          'f is percent of normal density'
FOR Dq = lowDq TO highDq
  f = lpns                                    'lowest percent of normal density'
  TPA = EXP(al - bl * LOG(Dq)) * (f / 100) * af            'displayed on graph'
  BA = Dq ^ 2 * .005454154 #.* TPA
  PSET (TPA, BA)                                    'sets pen to begin drawing'
FOR f = lpns TO hpns STEP rpns                 'sets levels of normal density'
  TPA = EXP(al - bl * LOG(Dq)) * (f / 100) * af
  BA.=Dq ^ 2 * .005454154# * TPA
  LINE -(TPA, BA)                                     'draws lines for each Dq'
NEXT f                                                'between lower and upper'
NEXT Dq                                                       'stocking levels'
END
```

Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890

U.S. Department of Agriculture
Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, OR 97208

* U.S. GOVERNMENT PRINTING OFFICE 1995-692-912