STOCKABILITY OF DOUGLAS-FIR AND IMPLICATIONS FOR MANAGEMENT

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ABSTRACT

Stockability of Douglas-fir is evaluated by use of growth basal area (GBA), the basal area at which dominant trees grow at 1 inch per decade in diameter (1 in/dec). Data from 106 plant associations in eastern Oregon and Washington were used to: (1) Relate Douglas-fir GBA to normal basal area in the appropriate site class. A range of 50-135% of normal was found. (2) Show how the combination of site index (SI) and GBA (SI/GBA) indicate different productivity levels within a SI class. Douglas-fir varied from 30-120 cf/A/YR in SI class 90 (a 400% difference). (3) Compare Douglas-fir GBA to three other species with which it grows. Douglas-fir ranged from 75-145% of ponderosa pine GBA. (4) Illustrate use of GBA for: establishing precommercial thinning guides, predicting diameter growth response to thinning, prescribing thinning for desired diameter growth rate, and appraising effects of stand density on height growth, stand volume growth, and tree suceptibility to insects and disease.

Keywords: Douglas-fir, stockability, density, growth, GBA, treatment

STOCKABILITY DEFINED

Stockability is defined as the capacity of a forest site to grow trees. It refers to the ecological ability of a site to support a certain maximum number of trees, or a certain maximum stand density. For example, a poor site at maximum stocking may be capable of supporting 150 trees per acre averaging 10 inches diameter at breast height (dbh) for a stand density of 82 square feet basal area per acre (sq.ft.BA/A). A good site at maximum stocking may be able to support 400 trees per acre, averaging 10 inches dbh, for a stand density of 218 sq.ft.BA/A. The stand densities of 82 and 218 sq.ft.BA/A represent both maximum stocking and maximum intertree competition for the two sites.

This paper uses an index for stockability called growth basal area (GBA): the basal area per acre at which dominant trees grow at the rate of 1 inch per decade (1 in/dec) in diameter. Tree diameter growth is used as a measure of competition and BA/A as an index of stand density (Hall 1987).

GBA is not a relative measure of stockability such as stand density index, relative density, tree area ratio, or crown competition factor. Rather, it is a site specific index utilizing measurements of tree diameter growth and stand basal area (Hall 1987).

The underlying assumption used with GBA is that tree diameter growth reflects competition. Slow diameter growth, such as 1 in/dec, indicates significantly greater competition than does 3 in/dec. The assumption is that a decreasing rate of diameter growth is directly related to increasing competition. Competition seems to be expressed well with stand density. Most thinning studies have shown a direct relationship between stand density and diameter growth wherein residual tree diameter growth increased with a decrease in BA/A (Dahms 1973; Harrington and Reukema 1983; Reukema and Pienaar 1973; Tappeiner *et al.* 1982; Williamson 1982).

Diameter growth is used as a point of reference for indexing stockability of forest sites in the same way that age is used in site index (SI). The diameter growth rate of 1 in/dec was selected as a reference point for indexing stockability. It is not a maximum or minimum diameter growth guide for thinning or other treatment any more than SI age is a management guide. BA/A is then used as a measure of stockability just as height is used with SI.

GBA is determined by measuring stand BA/A and diameter growth of dominant trees, relating these to a curve or equation, and determining or calculating GBA (Hall 1987). In this way, stand growth performance is used to evaluate the potential of the site for stockability. Since GBA is site specific, it is uniquely suited to appraisal of Douglas-fir stockability, particularly inland Douglas-fir with its broad distribution and wide ecological amplitude. The genetic plasticity which permits growth on a wide variety of sites should be reflected in a broad range of stockabilities. This broad range has been found for Douglas-fir in eastern Oregon and Washington.

GBA can be used for more than indexing stockability. It can be used on a stand specific basis to estimate precommercial thinning, predict diameter growth rate from thinning, or prescribe thinning to establish a desired diameter growth rate. It can also be used to refine productivity estimates of Douglas-fir when it is combined with site index (SI/GBA), and it can be used to compare stockability of Douglas-fir with its competitors.

STOCKABILITY OF DOUGLAS-FIR AND ASSOCIATED SPECIES

Table 1 illustrates GBA of Douglas-fir compared to ponderosa pine, grand fir and western larch in six plant associations of the Blue Mountains in eastern Oregon (Hall 1990). Douglas-fir GBA varied from 75-145% of that for ponderosa pine, 70-85% of grand fir, and 95-145% of western larch. Since GBA represents 1 in/dec diameter growth, 75% of ponderosa pine GBA means that Douglas-fir will grow slower in diameter than ponderosa pine in the PP/SYAL association. At 145% of ponderosa pine GBA in the DF/CAGE association, it means that Douglas-fir grows much more rapidly in diameter than ponderosa pine. These differences in species performance can be used in developing stand treatments designed to attain various management objectives.

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Table 1.—Douglas-fir (DF) growth basal area compared to ponderosa pine (PP), grand fir (GF), and western larch (WL) in six plant associations (Hall 1990). See appendix for four-letter codes.

Association	Normal* SI/BA	Growth Basal Area			
		DF	PP	GF	WL
DF/CAGE	75/150	150	105		
GF/CARU-A	75/150	190	155	225	130
PP/SYAL	85/170	90	120		
DF-SYAL	85/170	175	135		
GF/HIAL	95/190	205	190	295	220
GF/CLUN	95/190	260	230	325	190

* Cochran 1979

Douglas-fir GBA is often different than the basal area shown for a SI class. Data in a SI class are often called normal. Table 1 lists normal BA/A in each of tree SI classes for Douglas-fir in eastern Oregon and Washington (Cochran 1979). In the PP/SYAL association, Douglas-fir is about 55% of normal for SI 75, and only 75% of ponderosa pine GBA. Douglas-fir in this association is at the dry end of its ecologic amplitude. It does regenerate and grow, but not as rapidly as ponderosa pine. Ponderosa pine growth performance clearly demonstrates that it will remain dominant in climax. Douglas-fir GBA is approximately equal to normal in the DF/CAGE, and DF/SYAL associations. But it is 125% of normal in the GF/CARU-A, and 135% in the GF/CLUN associations. This variation in Douglas-fir GBA within a site index class suggests that combining GBA with site index (SI/GBA) is a way of showing different stockabilities within a SI class and thus a means for refining productivity estimates of Douglas-fir.

DOUGLAS-FIR PRODUCTIVITY

Tree physiology supports the concept of a range in productivity within a SI class (Kozlowski 1971; Zimmermann and Brown (1971). They discussed how terminal and cambial growth (height and diameter growth) differ. If they are different, there should be physiological reasons why a SI class could have more than one stockability level.

GBA combined with SI to index stand productivity includes three elements of stand growth: height growth expressed by SI, diameter growth indexed by "G" of GBA, and BA/A indexed by "BA" of GBA.

Using the combination of SI and GBA as an index of productivity is of interest only if a SI class has a range of stockabilities within it, and therefore a range of productivity. Research in Europe has clearly documented a range of productivity so broad that three levels have been established within a site index (height/site) class (Assmann 1970; Bradley *et al.* 1966).

The concept of a range in productivity within a SI class is receiving increased attention in the United States (MacLean and Bolsinger 1973). Hagglund (1981) discussed site evaluation by SI, mean annual increment, and soil/topographic characteristics, as did Carmean (1975). Curtis (1981) discussed yield tables past, present, and future and predicted multiple productivity levels per SI class. Recently, Monserud (1984) dealt directly with the problems of SI as a site indicator and discussed reasons for multiple yield classes.

Dahms (1966) showed productivities for lodgepole pine SI 78 (index age 100) of 87 and 137 cubic feet per acre per year (cf/A/YR). Later, he compared Rocky Mountain and central Oregon lodgepole pine, finding 104 versus 64 cf/A/YR for SI 80 (Dahms 1973). Most recently, Cole and Edminster (1985) showed significantly different productivity for SI 80 lodgepole pine. Their northern model estimated 71 and their central model 105 cf/A/YR. These three references imply a range from 64-137 cf/A/YR for SI 80 lodgepole pine, a variation of 215%.

Both SI and GBA are determined in the field according to stand growth performance—SI according to tree age and height, GBA according to tree diameter growth and stand BA/A. Thus, the concept of SI/GBA is a site specific system. The number of GBA classes (stockability classes) within a SI class is influenced by a species' range of stockability which often is reflected in the geographical distribution and environmental amplitude of that species.

The combination of GBA with SI does several things. First, it provides a convenient method for identifying different productivity levels. Second, it offers a means by which stand treatment can be prescribed. And third, it is a system by which the productivity classes can be identified in the field.

A SI class can have multiple GBA classes depending on how class intervals are defined and therefore multiple productivity levels. Figure 1 illustrates SI and GBA combinations for Douglas-fir in Oregon and Washington. Each point represents one of 106 plant associations. Each association is an average of 5-20 sample plots. At each plot, between 5 and 15 trees are measured for their height, age, rate of radial growth, and stand basal area in the vicinity of each tree.

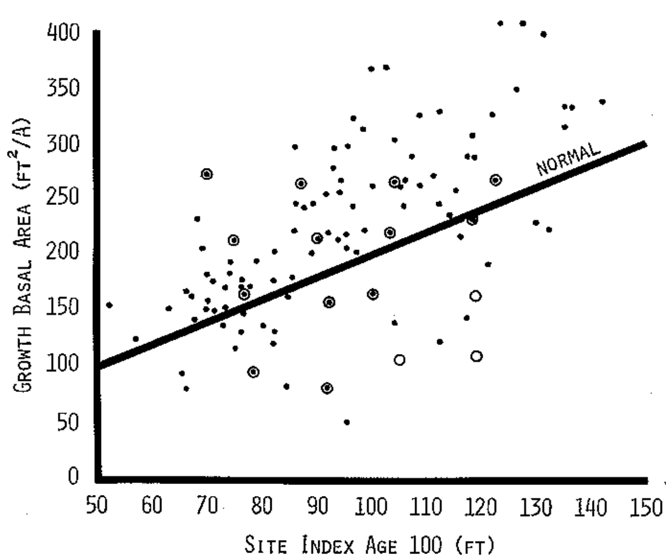

Figure 1.—Average Douglas-fir site index (SI) and growth basal area (GBA) for 106 plant associations in Oregon and Washington. Circled points identify associations representing productivity levels shown in Table 2; open circles have no representative associations.

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GBA in Figure 1 ranges from 50-425 sq.ft.BA/A. The variability of GBA within SI classes ranges from 240-400%. For SI 75, GBA varies from 80-270 sq.ft.BA/A for 330%, SI 90 varies from 75-300 sq.ft.BA/A for 400% variability, SI 105 varies from 125-370 sq.ft.BA/A for 300%, and in SI 120, it varies from 175-425 sq.ft.BA/A for 240% variability.

This change in GBA also represents difference in productivity (Table 2). Productivity in Table 2 was calculated by the equation:

$$PI = SI*GBA*K$$

where PI is the productivity index in cubic feet per acre per year, SI is site index measured in feet for age 100, GBA is sq.ft.BA/A, and K is the constant 0.0044 (n = 92, SE = 0.00015, CI(p=.05) = 0.00030 at 7% of the mean) (Hall 1987).

Using this formula, the productivity index for SI 90 in Figure 1 ranges from 30-120 cf/A/YR for 400% variation. Table 2 lists the productivity indexes of Douglas-fir in four site index classes and four GBA's, and compares them to normal (Cochran 1979). Circled points in Figure 1 represent plant associations representative of various productivities in Table 2.

Table 2.—Douglas-fir productivity index expressed as cubic feet per acre per year (cf/A/YR) for four SI classes and four GBA's compared to normal (Cochran 1979).

		SI age 100			
		75	90	105	120
Gross					
Normal	MAI	45	65	90	120
Normal	BA/A	150	180	215	240
		cf/A/YR			
	100	35	40	45	50
GBA	150	50	60	70	80
	200	65	80	95	105
	250	80	100	115	130

MANAGEMENT IMPLICATIONS OF DOUGLAS-FIR STOCKABILITY

Stockability influences stand treatment to meet various objectives such as wood production, modification of wildlife habitat, or enhancement of livestock forage. For example, low GBA's, like 50-100 sq.ft.BA/A, seldom produce good thermal cover because stockability is so low that 70% crown cover or more is difficult to attain with a stand taller than 40 feet. Simple management guidelines, such as "thin to 150 trees per acre" or "leave 125 sq.ft.BA/A", can lead to disappointing results when the wide range in Douglas-fir stockability is considered. A variation of 50-425 sq.ft.BA/A is 850% difference.

GBA can be used to prescribe thinning to attain a desired rate of diameter growth. Assume a quadratic mean (Dq) stand diameter of 10 inches dbh, dominant tree diameter growth rate of 1.5 in/dec and GBA of 150 sq.ft.BA/A. Prescribe thinning to attain 2.5 in/dec diameter growth. The slide rule in Figure 2 is entered with diameter growth converted to 20th inch radial growth, e.g., multiply in/dec by 10 (2.5 in/dec is 25/20ths).

Two steps are required using Figure 2:

1. Determine percent GBA for 25/20th's radius growth (i.e., 45%).
2. Determine BA/A to leave following thinning (i.e., about 70 sq.ft.BA/A).

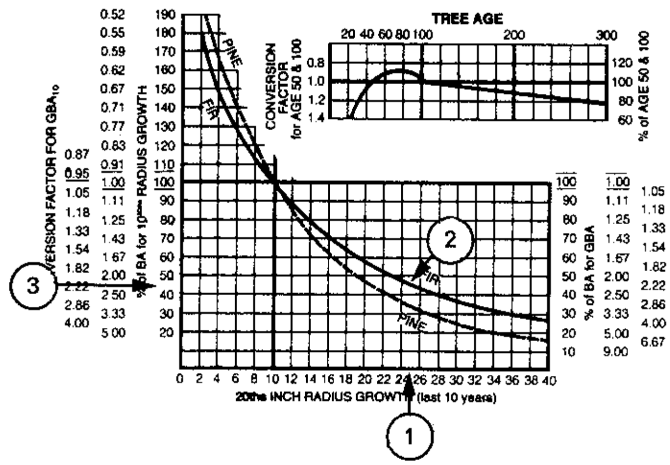

Figure 2.—Procedure for prescribing thinning to attain 25/20ths radius growth when GBA is 150 sq.ft.BA/A. First, (1) enter the graph at 25/20ths, (2) read up to the fir curve, and (3) left for 45%. Then: 0.45*150 = 67 sq.ft.BA/A. Thin to leave about 70 sq.ft.BA/A.

Dominant trees will initially average 25/20th's radius growth when thinned from below to 70 sq.ft.BA/A. Since GBA is based on diameter growth of dominants, these trees should remain after thinning. In this way, the largest, fastest growing trees in the stand continue to accumulate maximum volume. Since Douglas-fir can range in GBA from 50-425 sq.ft.BA/A due to differences in site potential, 25/20ths radius growth might be attained at leave tree BA/A ranging from 20-190 sq.ft. Livestock forage would be near maximum at 20 sq.ft.BA/A and near minimum at 190 sq.ft.BA/A.

Another situation is to predict diameter growth of dominant trees following thinning from below. For example, dominants were growing at 15/20th's radius growth at 110 sq.ft.BA/A with a GBA of 150 sq.ft.BA/A. Predict what diameter growth would be if 40 sq.ft.BA/A were removed.

1. Determine leave basal area: 110-40 = 70 sq.ft.BA/A.
2. Determine leave basal area as a percentage of growth basal area: 70/150 = 47%. This means that 70 square feet leave basal area is 47% of GBA.
3. Using Figure 2, enter the GBA graph at 47% (3), read over to the fir curve (2), and down to 25/20th's (1).

This stand when thinned to 70 sq.ft.BA/A should result in about 25/20th's radius growth (2.5 in/dec diameter) of dominant trees. This is a reverse of the procedure illustrated earlier.

GBA may be used to determine stocking after precommercial thinning. The first requirement is to specify stand conditions desired at first commercial entry, for example, a Dq stand

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diameter of 10 inches dbh, dominant tree diameter growth rate of 1.5 in/dec and GBA of 150 sq.ft.BA/A. Figure 3 illustrates how GBA may be used to establish leave tree criteria.

Two steps are required using Figure 3:

1. Determine BA/A for 15/20th's radius growth, (i.e., 112 sq.ft.BA/A).
2. Determine trees per acre for optimum stand conditions (i.e., 210 trees per acre at 10 inches dbh).

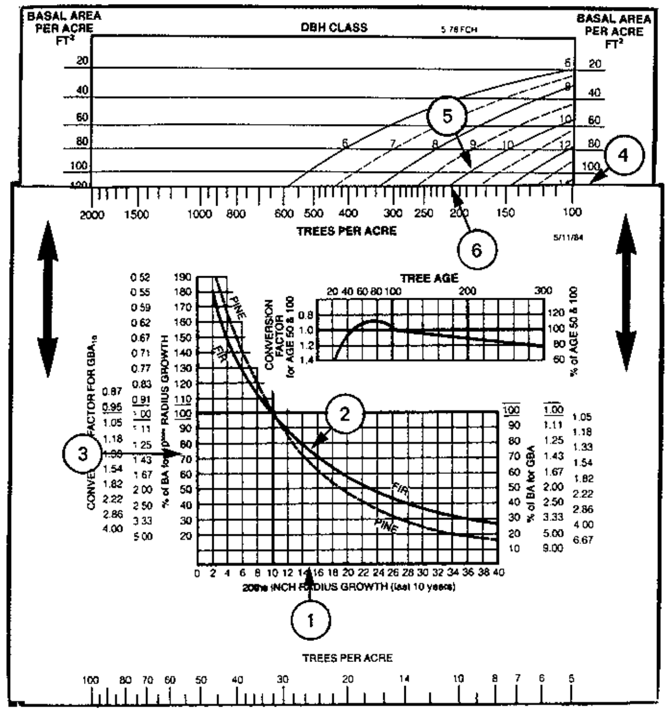

Figure 3.—Procedure for determining precommercial thinning to attain a 10-inch quadratic mean dbh stand with dominants growing at 15/20ths radius growth (1.5 in/dec in diameter) which has a GBA of 150 sq.ft.BA/A. First, (1) enter the GBA graph at 15/20ths, (2) read up the the fir curve and (3) left to 75% of GBA. Then: 0.75*150 = 112 sq.ft.BA/A. Finally, (4) set the slide at 112 sq.ft.BA/A, (5) find the 10-inch-dbh curve and (6) read 210 trees per acre. Thin to 210 trees per acre, about a 16 foot spacing.

The required stocking to leave is 210 trees per acre assuming no mortality between age of thinning and first commercial entry. Spacing for 210 trees per acre is about 16 feet. Table 3 shows leave trees for five GBA's. Table 1 indicates a range in Douglas-fir GBA of 90-260 sq.ft.BA/A corresponding to a range of 120-370 leave trees per acre for the stand conditions described above. Hiding cover for big game would be very poor at 120 leave trees per acre but would develop quickly and effectively at 370 trees per acre.

As an index of forest land stockability, GBA has other uses besides prescribing stand treatment. It indexes stand density unique to a specific site. Stand density affects rate of tree height growth and therefore SI determination. It also affects periodic and mean annual increment, tree vigor, and suceptibility of trees to insects and disease.

Table 3.—Trees to leave following precommercial thinning to attain 1.5 in/dec diameter growth of dominants in a 10 inch quadratic mean dbh stand with a GBA of 150 sq.ft.BA/AA. See Figure 3 for calculations.

	Growth Basal Area				
Leave trees	50	100	150	200	250
	70	140	210	275	350

High stand densities tend to reduce height growth. In fact, reduction can be dramatic enough to require adjustment of SI curves for lodgepole pine (Alexander 1966), ponderosa pine (Lynch 1958), and grand fir (Stage 1959). Some studies have provided enough data to relate reduction in height growth to diameter growth. Seidel (1982) and Schmidt (1978) found reduced height growth in dominant western larch trees at 1.3 in/dec diameter growth but not at 2.5 in/dec. Apparently, height growth was reduced at 60-80% of GBA.

Figure 4 illustrates the affect of stand density on Douglas-fir height growth in western Oregon. Curtis and Reukema (1970) and Reukema (1979) discussed the affects of stand density on SI determination in a Wind River, Washington plantation. Height growth of dominant trees was reduced to about 80% of maximum at 1.0 in/dec Dq diameter growth (1.5 in/dec of dominant trees and 74% of GBA). Harrington and Reukema (1983), on the other hand, found height growth reduced to about 50% of maximum at 1.0 in/dec Dq diameter growth, and about 80% of maximum at 2.0 in/dec Dq diameter growth. These Dq diameter growth rates represent 1.5 and 2.7 in/dec diameter growth of dominant trees and 74% and 41% respectively of GBA (Hall 1987). Knowing Douglas-fir GBA for a site provides the manager a means for prescribing treatment to attain a desired height growth.

Many thinning studies test the affects of stand density and thinning on production of usable wood products. The objective is to evaluate the relationship between stand treatment and tree or stand growth. In general, maximum gross cubic volume and periodic annual increment for a stand are attained with maximum stand density, (i.e., unthinned conditions or close spacing). However, maximum net stand cubic volume and growth is often produced in slightly wider spacings, or in lightly thinned stands because mortality is less. Generally, the lower the stand density, the lower the net and gross stand growth and volume produced (Assmann 1970; Curtis *et al.* 1981; Drew and Flewelling 1979; Harrington and Reukema 1983; Reukema 1979; Reukema and Pienaar 1973; Tappeiner *et al.* 1982; Wiley and Murray 1974; Williamson 1982). Maximum stand growth is attained at 90-150% of GBA (Hall 1987).

Stocking level control to influence tree vigor may be used to ameliorate affects of insects and disease. For example, indian paint fungus impacts may be reduced in grand fir and Douglas-fir by maintaining fast diameter growth (Filip *et al.* 1984). The effects of Douglas-fir beetle and fir engraver beetle

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tend to be reduced with rapid diameter growth (Johnsey 1984), and good tree vigor seems to deter spruce budworm damage (Fellin et al. 1984; Williams 1967). Diameter growth rates of 1.5-2.5 in/dec are associated with 75-45% respectively of GBA and provide reasonably good vigor. Considering the variation in Douglas-fir GBA, this suggests a range of 20-320 sq.ft.BA/A.

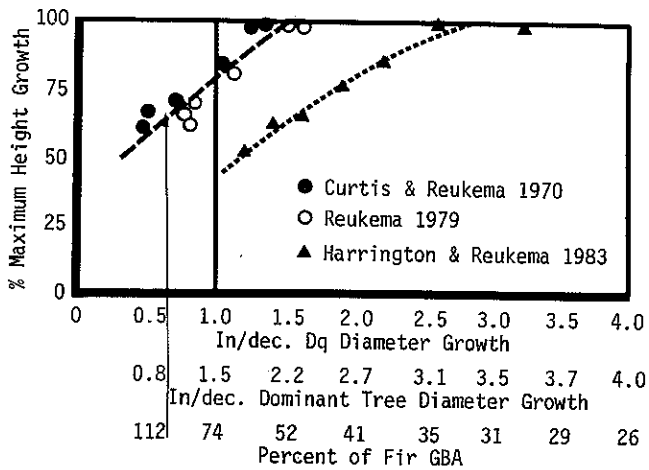

Figure 4.—Douglas-fir height growth as affected by stand density. Density is expressed as: a) in/dec diameter growth of quadratic mean (Dq) dbh trees from the author's data. b) estimated diameter growth of dominant trees using the equation Y = 1.73 - 0.19X (Hall 1987) where Y is the ratio of dominant (GBA) tree diameter growth to Dq diameter growth and X is Dq diameter growth. c) percent of GBA. The arrow approximates GBA.

SUMMARY

The land manager is confronted with several anomalies when dealing with Douglas-fir stockability. One is the range in GBA which varies from 50-425 sq.ft.BA/A. Maximum stand growth is attained at 90-150% GBA which also results in reduced tree height growth and tree vigor making Douglas-fir susceptible to insects and disease. Yet high percentages of GBA are not synonymous with high BA/A: 110% of GBA may occur between 55 and 450 sq.ft.BA/A! Tree vigor sufficient for resistance to insects and disease, 50% GBA, tends to result in near maximum height growth but only about 70% of maximum stand growth (Hall 1987). Development of big game thermal cover, 70% canopy cover in stands over 40 feet tall, is difficult to attain with GBA's less than 150 sq.ft.BA/A and maintain reasonably good tree vigor (i.e. 80% GBA). Forage production for livestock and big game is directly influenced by tree canopy cover. Maintenance of reasonable stand growth (80% GBA) will have little adverse effect on forage production for GBA's below 100 sq.ft., moderate effect from 100-150, and a major reduction from 150-200 sq.ft.BA/A. Forage would be incidental at GBA's above 200 sq.ft. Maximum tree growth might require diameter growth attained at 30-50% GBA, i.e., 2.5-3.5 in/dec diameter growth. For Douglas-fir, this means managing for 20-200 sq.ft.BA/A. The variation in site potential for Douglas-fir stockability poses interesting challenges for the land manager.

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APPENDIX

Species Codes

DF	Douglas-fir	*Pseudotsuga menziesii*
GF	Grand fir	*Abies grandis*
PP	Ponderosa pine	*Pinus ponderosa*
WL	Western larch	*Larix occidentalis*
CAGE	Elk sedge	*Carex geyeri*
CARU-A	Pinegrass, ash soil	*Calamagrostis rubescens*
CLUN	Clintonia	*Clintonia uniflora*
HIAL	White hawkweed	*Hieracium albiflorum*
SYAL	Snowberry	*Symphoricarpos albus*

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