Management of Spruce-Fir in Even-Aged Stands in the Central Rocky Mountains

Robert R. Alexander and
Carleton B. Edminster

Research Paper RM-217
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

Abstract

Potential production of Engelmann spruce and subalpine fir in the central Rocky Mountains is simulated for various combinations of stand density, site quality, ages, and thinning schedules. Such estimates are needed to project future development of stands managed in different ways for various uses.

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USDA Forest Service
Research Paper RM-217

July 1980

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Silviculture of Spruce-Fir in the Central Rocky Mountains

Engelmann spruce (*Picea engelmannii* Parry)—subalpine-fir (*Abies lasiocarpa* (Hook) Nutt.) forests are the largest and most productive timber resource in the central Rocky Mountains (Choate 1963, Miller and Choate 1964). Spruce and fir reach maximum development above 9,000 feet elevation on north-facing slopes, and are the principal tree species above 10,500 feet on all slopes.

Limited areas of the original spruce-fir forests were logged in the late 1800's to provide fuel, lumber, and props for early mining camps, but only relatively small quantities of timber were harvested on national forests until the 1950's. Cutting has increased since then, primarily for timber products, but spruce-fir forests provide other resources that are becoming increasingly important. These forests grow on areas that yield the most water in the central Rocky Mountains. They also provide habitats for a wide variety of wildlife, forage for livestock, developed and dispersed recreation, and scenic beauty.

How these forests are managed affects all resources and uses (Alexander 1977). For example, if timber production is the primary objective, growing stock levels (GSL)[2] should be kept higher, but forage production and water yield can be substantially increased only at the lower GSL's. Low to medium GSL's are generally considered necessary to improve developed recreational opportunities and enhance foreground esthetics. Although land managers must increasingly direct their practices toward multiple uses, these practices must be based on sound silvicultural principles of the forest types involved. Moreover, land managers must understand the trade-offs between the timber resource and other physical, social, and economic considerations.

[2]Growing stock level (GSL) is defined as the residual square feet of basal area when average stand diameter is 10 inches or more. Basal area retained in a stand with an average diameter of less than 10 inches is less than the designated level (Myers 1971, Edminster 1978). Tables A-1, A-2, and A-3 give the number of trees, basal area, and square spacing for stands with average diameters after thinning of 2 to 10 inches, for GSL levels 40 to 180).

Clearcutting old-growth spruce-fir forests and allowing cutover areas to restock naturally, regardless of the time required or the stocking achieved, was common from the 1950's until recently. Today, management intensity has increased, and managers are concerned with prompt restocking of cutover areas with a new stand, increasing growth of the new stand by control of stand density, and improving yields by periodic thinning to maintain stocking control and growth rates.

Spruce-fir forests are naturally productive. In unmanaged, old-growth stands, average annual growth is 80 to 100 fbm per acre per year, even allowing for mortality normally associated with old-growth forests. Under even-aged management, annual net growth can be increased to 200 to 650 fbm per acre per year by controlling stand density (Edminster 1978).

Stand density control offers the greatest opportunity for increasing wood production by increasing growth and reducing mortality, but harvested stands must be replaced promptly to reduce time required to reach maximum yields. In the past, either long regeneration periods—up to 20 years or more—or regeneration failures have been common in spruce-fir forests because too little attention was paid to the regeneration requirements. Moreover, low stumpage values have hindered intensive management in the central Rocky Mountains. Improving stumpage values and better understanding of regeneration allows the forest manager to do the cultural work needed to increase timber production.

Establishment of Regeneration

Research has been directed toward perpetuating Engelmann spruce, the most valuable timber species of the type (Alexander 1974, Noble and Alexander 1977). Spruce-fir forests can be maintained as a vigorous, productive forest under an even-aged management system. Clearcutting, standard shelterwood, and simulated shelterwood are the cutting methods to use to convert old-growth to managed, even-aged stands. Each cutting method has its use, depending upon stand and site conditions, wind and disease problems, regeneration requirements, and management objectives. Uneven-aged management systems, which include individual tree and group selection cutting methods and their modifications, are also appropriate for use in spruce-fir stands. They are not discussed in this paper because there are no comparable growth and yield prediction tools available for an uneven-aged management system.

Many old-growth forests have an understory of advanced reproduction containing a moderate amount of spruce. These stands can be managed as even-aged by removing the overstory in a simulated shelterwood. Logging damage to established regeneration must be controlled by: (1) locating and marking skid roads on the ground at about 200-foot intervals, and confining skidding equipment to these skid roads to reduce indiscriminate travel over the cutover area; (2) felling trees in a herringbone pattern to the skid road to reduce disturbance when logs are moved onto the skid road; and (3) close coordination between felling and skidding operations, especially in stands with large volumes, where it is necessary to fell and skid one tree before another is felled (Alexander 1957, Roe et al. 1970). This type of cutting simulates the final harvest of a shelterwood method.

In stands without advanced reproduction at harvest, spruce regenerates from seed, provided there is a dependable seed supply, at least 40% of the seedbeds are exposed mineral soil, and environmental conditions are suitable (Roe et al. 1970). Shade is especially important to survival and early growth. Because solar radiation is high at elevations where spruce grows, it does not established readily in the open (Noble and Alexander 1977, Ronco 1970).

If a clearcut option is used, seed is dispersed from trees standing around the perimeter of the opening, but less than 10% of the seed is dispersed beyond 300 feet from its source (Alexander 1969, Noble and Ronco 1978). On shaded mineral soil on north slopes, the maximum clearcut opening likely to restock naturally is 400 to 500 feet in diameter; on south slopes it is only 100 to 200 feet. Adequate stocking usually requires more than one good seed year. On unprepared and unshaded seedbeds, openings 50 to 100 feet in diameter will restock on north slopes, but will require a number of good seed years. On south slopes under similar conditions, few seedlings survive in openings (Alexander 1974, Roe et al. 1970).

If a shelterwood option is used, seed for regeneration is dispersed from trees left standing on the area after the seed cut. At time of final harvest, the same care in logging suggested for management with advanced reproduction is required. A standard shelterwood cutting is more likely to result in more evenly distributed reproduction than clearcutting, but may favor fir over spruce.

Regeneration of Engelmann spruce may be slow to establish and poorly distributed regardless of cutting method or the best efforts of the manager to ensure an adequate seed supply, favorable seedbeds, and suitable environmental conditions. If stands remain unstocked or poorly stocked more than 5 years after the final harvest, the manager must take action under the regulations of the National Forest Management Act of 1976 to artificially regenerate these areas. Guidelines for planting spruce have been prepared by Ronco (1972).

With either a clearcut or shelterwood option, minimum acceptable stocking with spruce-fir is 600 trees per acre after 5 years, with at least one-half of the reproduction spruce. However, at least 850 trees per acre are preferred at age 30 years if spruce-fir stands are to be managed at the higher GSL's.

Need for Early Precommercial Thinning

Establishing a new stand is only the beginning. Trees must have room to grow to reach merchantable size in a reasonable amount of time. Where spruce and fir have regenerated successfully after cutting, stands seldom contain more than 2,000 stems per acre at age 10 years. This density can be maintained early in the life of the stand without appreciable reduction in diameter growth. Precommercial thinning is not required before age 30 years. Where many advanced spruce and fir (4,000-6,000 stems per acre) survive after a simulated shelterwood cutting (Alexander 1963, 1968), early precommercial thinning is desirable to reduce density to 800 to 900 stems per acre to attain acceptable growth rates.

Estimates of Growth Under Intensive Management

Intensive management of spruce-fir forests provides many opportunities for increasing usable wood production, but estimates of future stand development under various management regimes are needed.

The best information available on the growth of spruce and fir from sapling stage to final harvest under even-aged management with either a clearcut or shelterwood cut is provided by field and computer simulation procedures developed by Myers (1971) and Alexander et al. (1975) and refined by Edminster (1978). The procedures were developed from field data on past growth related to stand density, age, and site quality. Data were obtained from a large number of both permanent and temporary plots established in thinned and natural stands throughout the central Rocky Mountains.

The modeling concept used in these programs holds that the whole stand is the primary model unit, characterized by average values. The equations upon which the growth and yield simulations are based are given in Alexander et al. (1975). The programs project stand development by consecutive, 10-year periods and include relationships to project average stand diameter, average dominant and codominant height, and number of trees per acre. Average diameter at the end of a projection period is a function of average diameter at the beginning of the period, site index, and basal area per acre. Periodic average dominant and codominant height growth at managed stand densities is a function of age and site index. Periodic mortality is a function of average diameter and basal area per acre. Stand volume equations are used to compute total cubic feet per acre; factors are computed to convert thus to merchantable cubic feet and board feet. Prediction equations are included to estimate the effects of differing intensities of thinning from below on average diameter, average dominant and codominant height, and trees retained per acre.

Yield simulations discussed in the following paragraphs were made to the same hypothetical initial stand conditions for all growth parameters.

1. Average age at first GSL thinning is 30 years. Note that age in the yield table simulation is measured at breast height (4.5 feet). A minimum of 20 years is allowed for spruce and fir trees to regenerate and grow to 4.5 feet in height. The total age of the stand is, therefore, at least 20 years older than age measured at breast height. The age referred to hereafter in the text, and in all tables and figures, is measured at breast height.
2. Average stand diameter is 4.5 inches d.b.h.[3]
3. Stand density is 800 trees per acre.
4. Site index is 50-, 60-, 70-, 80-, 90- and 100-foot classes, at base age 100 years (Alexander 1967).
5. Projections were made for 70 years (stand age 100 years), 90 years (stand age 120 years), 110 years (stand age 140 years), and 130 years (stand age 160 years).
6. Thinnings from below were made every 20 and 30 years to GSL's of 40, 60, 80, 100, 120, 140, 160, and 180, with initial and subsequent entries made to the same GSL.
7. Clearcut and two-cut shelterwood options were used.
8. Minimum size for inclusion in board foot volume determination was 8 inches d.b.h. to a 6-inch top. Volumes were determined from tables prepared by Myers and Edminster (1972).
9. All entries were made as scheduled even though all thinnings could be precommercial.

Diameter Growth

Periodic mean annual diameter growth of spruce and fir is related to stand density and site quality, but is affected little by the cutting cycles tested. Cutting cycles do influence average stand diameter, however, because thinning from below increases average diameter at each entry. Actual basal area in a stand with an average diameter of less than 10 inches d.b.h.

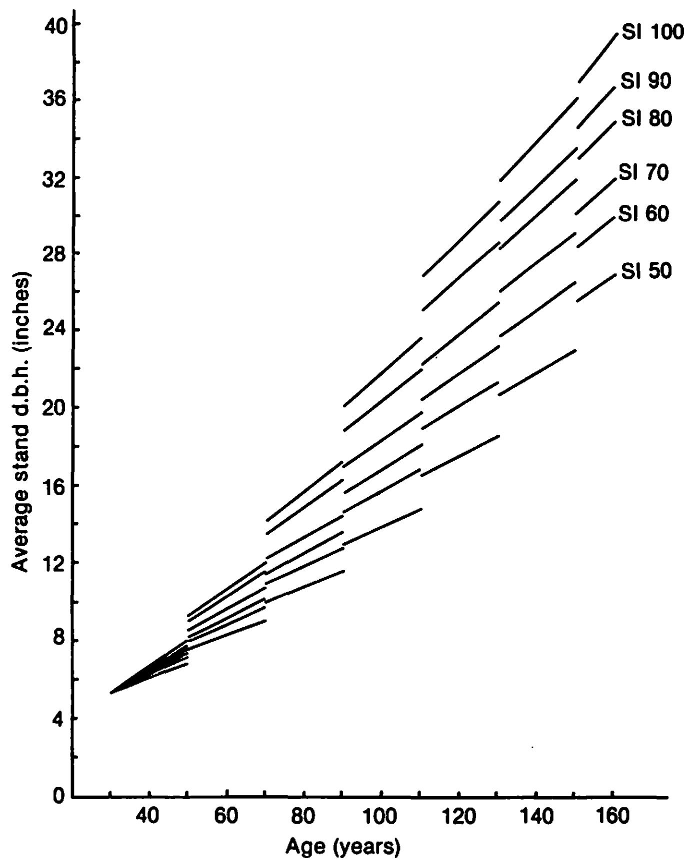

Figure 1.—Estimated average stand diameter in relation to age for different site classes at GSL 100 with a 20-year thinning schedule—clearcut option.

continues to increase, because periodic thinning does not reduce basal area to a fixed (GSL) amount until an average stand diameter of 10 inches d.b.h. is reached. Consequently, the rate of diameter growth for a given GSL is not constant over time and is essentially a negative exponential function of basal area per acre in the program. In contrast, periodic diameter growth is a linear function of site index, so that differences in diameter growth resulting from site quality are constant throughout the range of GSL's and rotations examined.

Growth rates and changes in diameter resulting from thinning frequency were examined to determine average size of trees relative to rotation age. For example, with a clearcut option, at GSL 100 with a 20-year cutting cycle, trees reach average stand diameters of 14.0 to 21.9 inches d.b.h. after 100 years; and 27.0 to 39.7 inches d.b.h. after 160 years for the range of sites tested (fig. 1). On an average site (index 70), with a 20-year cutting cycle, mean stand diameters reached 10 inches d.b.h. at 50 to 82 years of age for the range of GSL's 40 to 180 (fig. 2).

With a shelterwood option, the thinning regimes are the same until 20 years before the final harvest at rotation age, when a heavier cut is made. Since the seed cut is also made from below to reserve the larger trees

[3]*Average stand diameter is the diameter of the tree of average basal area; it is not the average of all the tree diameters.*

for seed production, the average stand diameters at rotation age are slightly larger than with a clearcut option (fig. 3). On an average site (index 70), with a 20-year cutting cycle, mean stand diameters under a shelterwood option reach 10 inches at about the same ages with the same range of GSL's as with a clearcut option.

Height Growth

Periodic mean annual height growth of spruce and fir increases with site index and decreases with age, but is influenced little by GSL's, cutting method, or the cutting cycle. However, since fewer and, therefore, taller trees are left after each thinning from below, the mean height of the dominant and codominant trees is increased slightly at each entry. The increase is positively correlated with thinning frequency and negatively correlated with GSL.

Basal Area Growth

Periodic mean annual basal area increment is related to stand density, site quality, and frequency of thinning, but is relatively unaffected by cutting method. Since actual basal area continues to increase

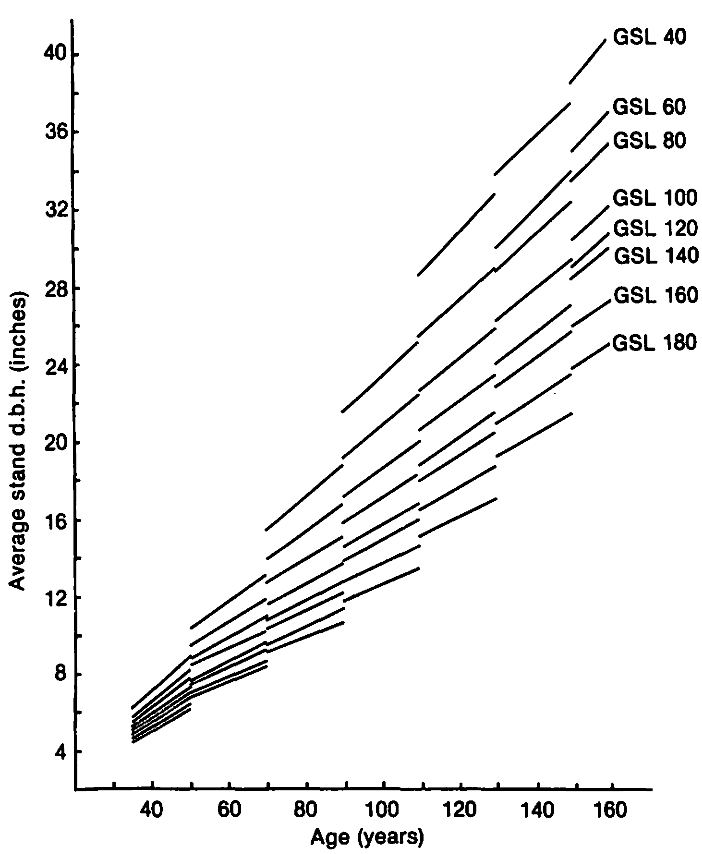

Figure 2.—Estimated average stand diameter in relation to age and growing stock level on site index 70 lands with a 20-year thinning schedule—clearcut option.

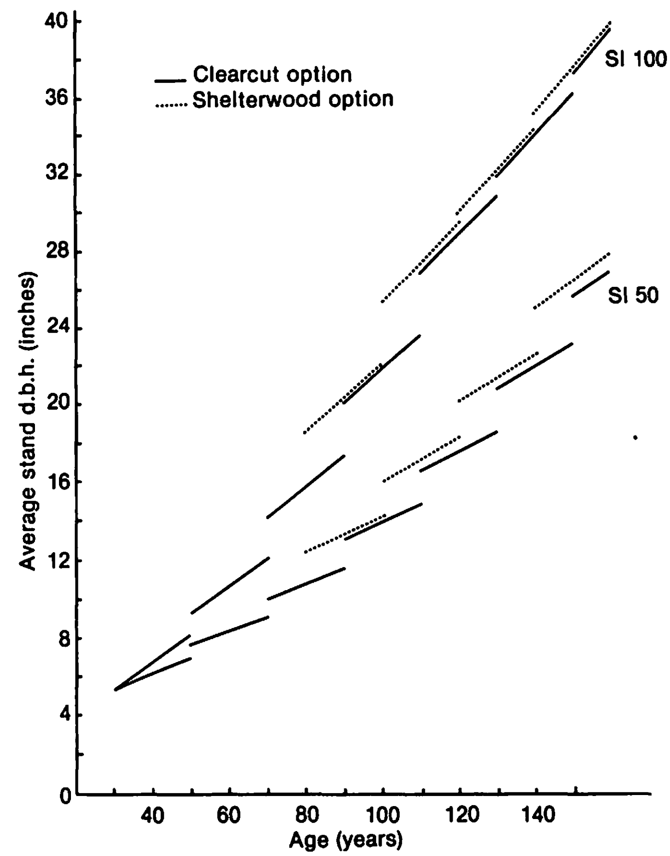

Figure 3.—Estimated average stand diameter with clearcut and shelterwood options in relation to age for site indexes 50 and 100 at GSL 100 with a 20-year schedule.

in a stand until average stand diameter reaches 10 inches d.b.h. and thinning reduces basal area to a fixed amount (GSL), the rate of basal area growth for a given GSL is not constant over time. Periodic basal area increment is greater at higher GSL's, but the rate of increase diminishes at the higher stand densities. Periodic mean basal area growth is also greater at higher site indexes. Moreover, the differences in basal area growth between site classes become progressively greater with higher GSL's. Periodic mean basal area increment is greater with a 30-year cutting cycle than with a 20-year entry at all growing stock levels examined.

Total Cubic-Foot Volume Increment

Cubic-foot volume production is related to stand density, site quality, rotation age, and frequency of thinning (table 1 and table A-4). Cutting methods, however, have little effect on cubic volume growth (fig. 4).

Although mean annual cubic volume increment increases as GSL and site index increase, the rate of increase diminishes as GSL increases, while the differences in growth between site classes becomes greater (fig. 5). Cubic volume increment will apparently continue to increase at GSL's above 180 on all but site index 50 lands.

Table 1.—Estimated total cubic-foot volume production per acre of spruce-fir in relation to growing stock level, site index, rotation age, and cutting cycle, with a clearcut option

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160	180
years		*thousand cubic feet*							
Site index 50									
100	20	2.09	2.56	3.00	3.34	3.58	3.73	3.82	3.74
120		2.42	3.10	3.74	4.22	4.60	4.91	5.04	4.87
140		2.74	3.56	4.33	4.90	5.46	5.95	6.24	6.12
160		3.06	3.98	4.86	5.65	6.37	6.98	7.41	7.36
100	30	2.19	2.71	3.09	3.35	3.52	3.63	3.70	3.58
120		2.62	3.36	3.94	4.34	4.67	4.84	4.92	4.70
140		2.95	3.85	4.54	5.17	5.61	5.96	6.09	5.99
160		3.30	4.32	5.12	5.82	6.53	7.01	7.28	7.18
Site index 60									
100	20	2.59	3.26	3.89	4.44	4.82	5.08	5.20	5.11
120		3.00	3.95	4.75	5.41	6.00	6.46	6.73	6.94
140		3.37	4.49	5.40	6.24	7.00	7.78	8.27	8.55
160		3.74	4.98	6.08	7.02	7.90	8.67	9.39	9.86
100	30	2.82	3.55	4.11	4.50	4.81	5.06	5.20	5.13
120		3.30	4.31	5.15	5.76	6.24	6.58	6.78	6.90
140		3.70	4.86	5.87	6.69	7.29	7.92	8.27	8.46
160		4.08	5.41	6.58	7.55	8.32	8.94	9.38	9.76
Site index 70									
100	20	3.30	4.18	4.89	5.55	6.17	6.66	6.99	6.90
120		3.78	4.88	5.87	6.70	7.48	8.22	8.76	9.11
140		4.20	5.49	6.61	7.69	8.65	9.58	10.25	10.82
160		4.62	6.08	7.39	8.61	9.76	10.86	11.68	12.35
100	30	3.42	4.42	5.23	5.94	6.45	6.67	6.97	7.03
120		4.07	5.24	6.38	7.34	8.23	8.76	9.07	9.23
140		4.49	5.87	7.17	8.39	9.42	10.15	10.70	10.98
160		4.93	6.50	8.02	9.42	10.56	11.44	12.06	12.51
Site index 80									
100	20	3.90	5.00	5.95	6.81	7.62	8.37	8.92	9.15
120		4.46	5.78	6.96	8.00	9.00	10.01	10.80	11.48
140		4.97	6.50	7.92	9.16	10.36	11.56	12.60	13.44
160		5.42	7.18	8.75	10.22	11.68	12.99	14.24	15.30
100	30	4.23	5.44	6.50	7.42	8.14	8.68	9.04	9.15
120		4.88	6.38	7.69	8.86	9.89	10.67	11.24	11.41
140		5.40	7.08	8.55	9.95	11.23	12.28	13.01	13.47
160		5.94	7.82	9.60	11.26	12.72	13.89	14.77	15.26
Site index 90									
100	20	4.56	5.89	7.06	8.10	9.08	9.97	10.72	11.26
120		5.16	6.77	8.32	9.55	10.79	11.88	12.92	13.76
140		5.73	7.64	9.30	10.81	12.23	13.62	14.90	15.97
160		6.26	8.32	10.30	12.03	13.73	15.23	16.70	18.03
100	30	4.98	6.40	7.74	8.97	10.00	10.70	11.20	11.52
120		5.72	7.49	9.22	10.69	11.89	12.88	13.56	14.02
140		6.31	8.30	10.22	12.04	13.66	14.91	15.95	16.38
160		6.99	9.15	11.34	13.38	15.12	16.11	17.68	18.38
Site index 100									
100	20	5.33	6.82	8.21	9.54	10.78	11.87	12.81	13.37
120		6.02	7.82	9.52	11.14	12.67	14.11	15.34	16.12
140		6.64	8.74	10.70	12.60	14.42	16.07	17.56	18.58
160		7.28	9.58	11.81	13.95	16.02	17.94	19.58	20.91
100	30	5.75	7.44	9.06	10.60	11.91	12.96	13.70	14.08
120		6.61	8.80	10.66	12.55	14.10	15.47	16.42	16.94
140		7.25	9.65	11.96	14.11	15.99	17.68	18.76	19.57
160		7.87	10.59	13.10	15.54	17.78	19.73	20.98	21.86

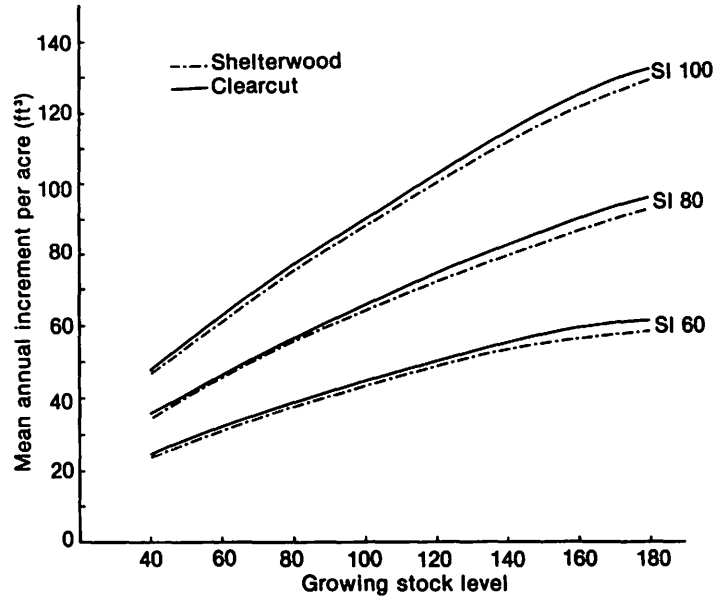

Figure 4.—Estimated mean annual total cubic-foot volume increment per acre with clearcut and shelterwood options in relation to growing stock level and site index classes 60, 80, and 100, for a 140-year rotation with a 20-year thinning schedule.

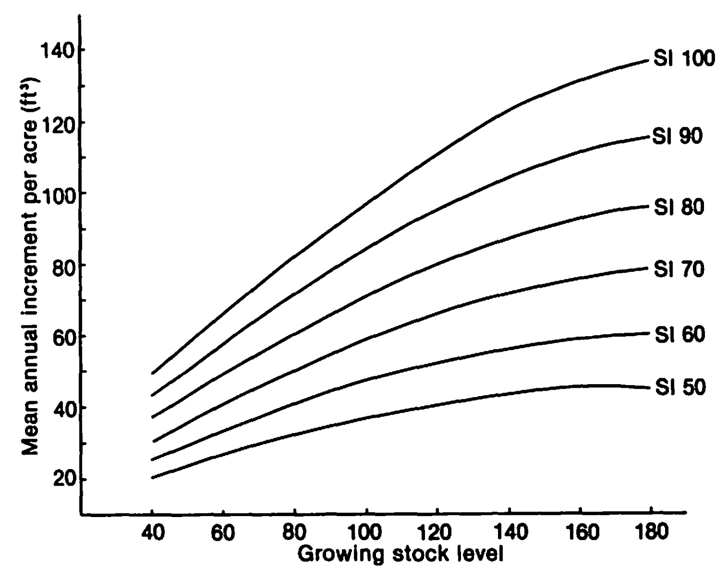

Figure 5.—Estimated mean annual total cubic-foot volume increment per acre in relation to growing stock level and site index for a 120-year rotation with a 30-year thinning schedule—clearcut option.

Average annual cubic volume increment per acre is greater on site index 80 to 100 lands at GSL's 40 to 140 on 100-year rotations. At GSL's above 140, growth is greater on a 120-year rotation. On site index 50 to 70 lands, growth is generally greater on rotations longer than 100 years at GSL's greater than 60.

Mean annual cubic volume increment is always greater with a 30-year cutting cycle for all GSL's at rotations of 120 years or longer. At GSL's greater than 160 with a 100-year rotation, there is little difference in cubic volume between a 20- and a 30-year cutting cycle.

Board-Foot Volume Increment

Board-foot volume production (table 2 and table A-5) is related to all stand parameters evaluated, but there is little difference in average annual increment between clearcut and shelterwood options (fig. 6). Mean annual sawtimber volume growth increases as stand density increases throughout the range of GSL's on site index 70 or better lands, but generally levels off or declines on site index less than or equal to 60 lands at GSL's above 160 (fig. 7).

Board-foot volume growth increases with site quality, and the differences in growth between site classes are greater as GSL increases. Throughout the range of GSL's, average annual board-foot increment per acre is always greater for all site classes on a 160-year rotation (fig. 8).

At GSL's 40 through 160 on rotations longer than 100 years, and at GSL's 40 to 140 on shorter rotations, board-foot volume growth is greater on a 30-year cutting cycle than on a 20-year cycle. At higher GSL's, growth is greater with more frequent thinnings (fig. 9).

Maximizing Board-Foot Volume Yields

What yields can be expected with intensive management of spruce-fir to maximize timber production? If the objective is to integrate timber production with other resources uses, what are the timber trade-offs? How can these objectives be attained with the fewest precommercial thinnings?

The largest volume production per acre (104,800 board feet) is attained with a clearcut option on site index 100 lands, at GSL 180, on a 160-year rotation, with a 30-year cutting cycle (table 2). These stands will contain about 38 trees per acre with an average d.b.h. of nearly 32 inches at rotation age (table 3). Volume production and tree size attained are about the same under a two-cut shelterwood (tables A-5 and A-6).

Volume production substantially declines when GSL is reduced. The decline is greater with each successive reduction. At site indexes 60 to 90, with a clearcut option, largest volume production also occurs at GSL 180 on a 160-year rotation but with a 20-year cutting cycle. On site index 50 lands, greatest production is at

Table 2.—Estimated board-foot volume production per acre of spruce-fir in relation to growing stock level, site index, rotation age and cutting cycle, with a clearcut option (trees 8 inches d.b.h. and larger to a 6 inch top)

Rotation age	Cutting cycle	Growing stock level							
		40	60	80	100	120	140	160	180
years		*thousand board feet*							
		Site index 50							
100	20	7.1	8.9	10.4	11.6	12.0	11.7	11.4	10.9
120		9.2	12.1	14.6	16.4	17.4	17.8	17.4	16.2
140		11.2	14.8	18.1	21.0	22.8	23.7	23.9	23.1
160		13.3	17.9	21.8	25.3	27.8	29.4	30.9	29.9
100	30	7.5	9.1	10.5	11.4	11.6	11.4	11.0	10.3
120		10.0	12.7	15.1	16.8	17.5	17.4	17.2	16.1
140		12.2	15.7	18.8	21.1	23.1	23.5	23.5	22.5
160		14.6	19.0	22.7	26.4	28.6	29.8	30.2	28.8
		Site index 60							
100	20	9.1	12.0	14.1	16.1	17.0	17.4	17.6	17.0
120		11.6	15.6	19.2	21.8	23.6	25.2	26.2	25.8
140		14.1	19.3	23.8	27.2	29.7	31.6	33.3	34.3
160		16.6	22.9	28.3	32.6	36.0	39.2	41.3	42.4
100	30	9.8	12.5	14.3	15.6	16.5	17.0	17.0	16.3
120		12.8	17.0	20.4	22.6	24.0	25.4	26.2	25.2
140		15.4	20.6	25.1	28.6	31.5	33.7	34.9	33.7
160		18.1	24.2	29.1	33.9	37.9	40.8	42.4	41.4
		Site index 70							
100	20	11.7	15.0	17.9	20.6	23.0	24.7	25.4	24.9
120		14.8	19.2	23.6	27.6	31.2	34.1	36.1	35.8
140		17.6	23.8	29.1	34.3	38.9	42.7	45.1	46.2
160		20.6	27.7	34.2	40.6	46.6	50.7	54.2	56.8
100	30	12.4	16.2	19.2	21.6	23.2	24.3	24.6	24.1
120		16.1	21.7	26.0	29.6	32.8	34.8	35.5	34.8
140		19.0	25.5	31.6	36.9	40.7	43.4	44.7	45.1
160		22.1	29.8	37.1	43.0	48.2	52.3	54.9	56.5
		Site index 80							
100	20	13.8	18.2	22.2	26.0	29.6	32.5	34.3	34.1
120		17.4	23.9	29.4	34.2	38.6	42.7	46.4	47.4
140		20.7	28.8	35.7	41.6	47.5	52.9	57.0	60.1
160		24.3	33.4	41.8	49.0	56.0	62.6	68.2	72.6
100	30	15.5	20.0	24.2	27.8	30.6	32.4	33.5	33.0
120		19.8	25.7	31.8	37.4	41.8	45.0	46.4	45.7
140		23.2	31.4	38.1	44.8	50.1	54.6	57.8	58.5
160		27.0	33.3	45.6	53.6	60.2	65.9	69.8	71.2
		Site index 90							
100	20	16.4	22.6	27.8	32.1	35.9	39.1	42.5	44.5
120		20.4	28.6	35.4	41.3	46.9	52.0	56.2	59.9
140		24.4	33.9	42.3	50.1	57.4	63.7	69.3	74.2
160		28.2	39.4	49.4	58.7	67.2	74.7	82.2	89.0
100	30	18.7	25.2	30.7	35.5	39.3	42.2	43.8	43.2
120		23.5	31.9	39.7	46.6	52.2	56.4	58.9	58.2
140		27.4	37.2	46.9	55.6	62.6	68.3	72.1	73.1
160		31.7	43.2	54.4	65.0	73.6	80.6	85.8	87.0
		Site index 100							
100	20	19.6	26.6	32.7	38.4	43.6	48.2	51.8	54.2
120		24.2	33.2	41.5	49.0	56.0	62.4	68.0	71.6
140		28.6	39.5	49.8	59.2	68.0	76.0	83.2	88.1
160		33.1	45.8	57.8	68.5	79.4	88.8	97.6	104.6
100	30	21.9	29.2	36.3	43.3	48.7	52.6	54.2	53.6
120		27.6	37.9	47.6	56.3	63.2	69.2	72.1	71.4
140		32.1	44.4	56.0	66.4	75.3	82.7	87.4	88.9
160		36.6	51.2	64.5	76.5	87.7	96.6	103.0	104.8

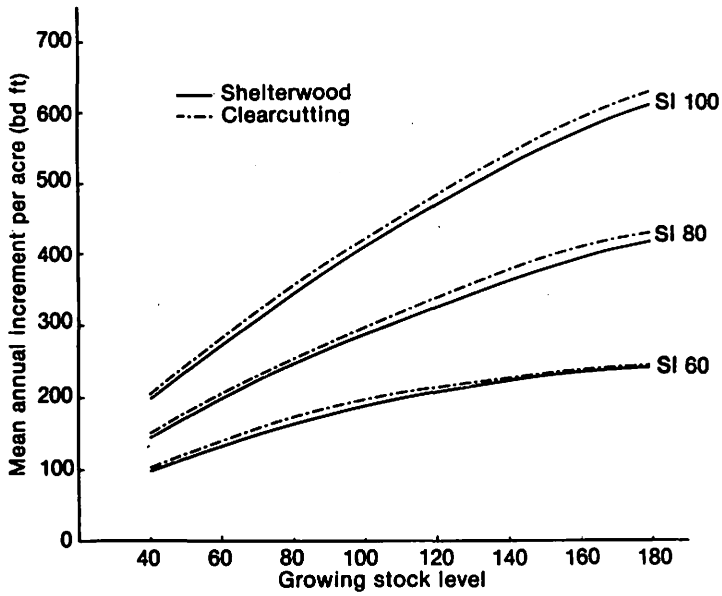

Figure 6.—Estimated mean annual board-foot volume increment per acre with clearcut and shelterwood options in relation to growing stock level for site index classes 60, 80, and 100, for a 140-year rotation with a 20-year thinning schedule.

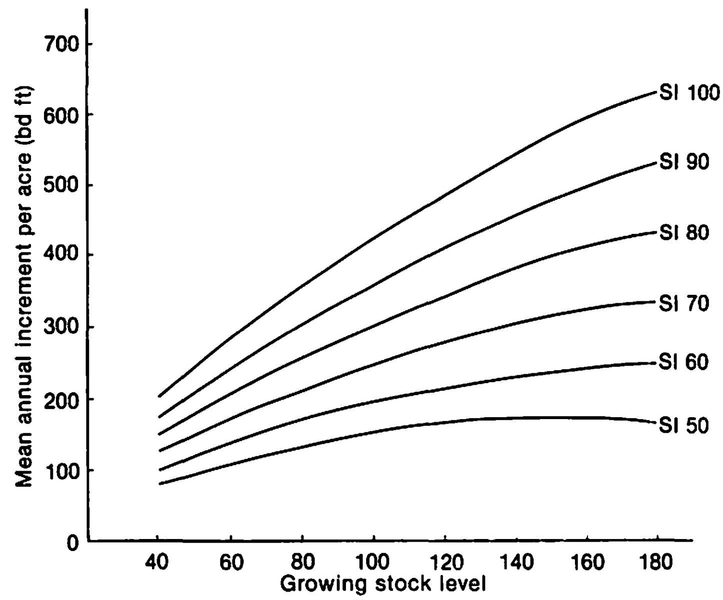

Figure 7.—Estimated mean annual board-foot volume increment per acre in relation to growing stock level and site index for a 140-year rotation with a 20-year thinning schedule—clearcut option.

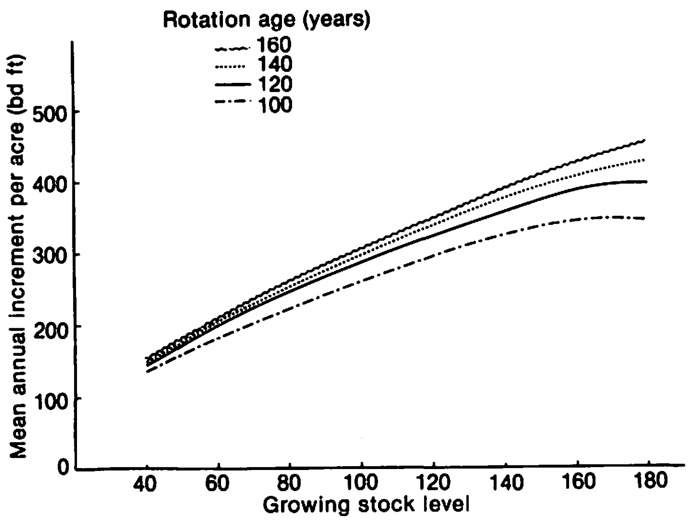

Figure 8.—Estimated mean annual board-foot volume increment per acre in relation to growing stock level and rotation age on site index 80 lands with a 30-year thinning schedule.

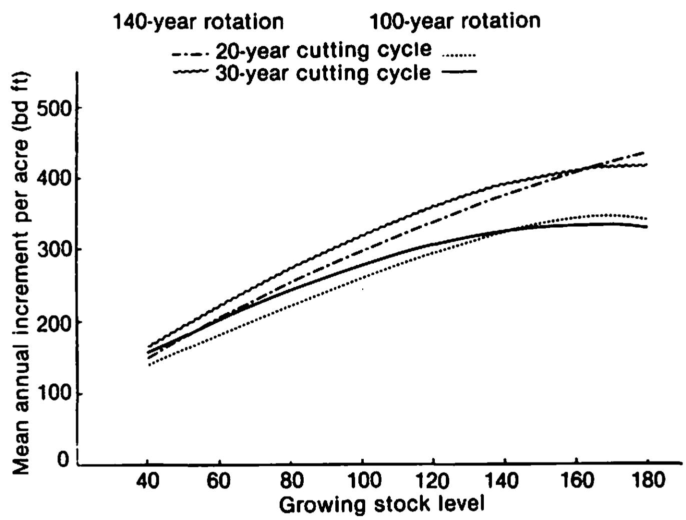

Figure 9.—Estimated mean annual board-foot volume increment per acre in relation to thinning schedules for 100- and 140-year rotations on site index 80 lands.

Table 3.—Estimated average diameter (inches) and number of trees per acre of spruce-fir at final harvest in relation to growing stock level, site index, rotation age, and cutting cycle, with a clearcut option

Rotation age	Cutting cycle	Growing stock level 40		60		80		100		120		140		160		180	
		No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter
Site index 50																	
100	20	21	20.2	44	17.1	74	15.1	107	14.0	155	12.7	233	11.2	281	10.5	371	9.6
120		13	25.7	25	22.2	45	19.3	67	17.6	97	16.0	145	14.1	200	12.8	294	11.2
140		9	30.1	16	27.9	28	24.2	42	22.0	62	19.8	93	17.5	130	15.8	192	13.8
160		7	34.8	12	32.2	18	30.0	28	27.0	42	24.1	62	21.3	89	19.1	129	16.8
100	30	24	18.9	48	16.3	79	14.6	123	13.1	172	12.1	256	10.7	303	10.1	378	9.5
120		24	21.7	48	18.6	79	16.6	123	14.8	172	13.6	256	11.9	303	11.3	353	10.5
140		12	25.8	24	24.3	40	21.6	63	19.0	90	17.4	139	15.2	182	14.1	254	12.6
160		8	33.1	12	31.4	22	27.4	36	23.8	51	21.9	77	19.2	105	17.5	153	15.4
Site index 60																	
100	20	18	21.6	36	18.8	62	16.6	85	15.8	132	13.9	170	13.2	247	11.7	305	11.1
120		11	27.7	21	24.3	37	21.4	51	20.2	80	17.7	102	16.9	148	15.0	189	14.0
140		8	32.5	13	30.7	23	27.0	32	25.3	50	22.2	64	21.1	93	18.8	121	17.4
160		6	37.6	10	35.4	17	31.5	21	30.1	33	27.3	42	25.9	61	23.1	81	21.2
100	30	20	20.6	39	18.1	68	15.9	98	14.8	143	13.3	191	12.5	251	11.6	336	10.6
120		20	23.8	39	20.8	68	18.2	98	16.8	143	15.1	191	14.1	251	13.0	312	11.9
140		10	31.3	19	27.2	33	23.9	49	21.8	73	19.6	98	18.2	132	16.7	184	15.0
160		6	36.3	12	31.6	17	30.9	27	27.7	39	25.0	54	23.1	73	21.1	104	18.8
Site index 70																	
100	20	16	23.1	30	20.7	50	18.5	74	17.0	105	15.6	135	14.9	182	13.7	241	12.6
120		9	30.6	17	27.1	29	24.1	44	21.9	62	20.1	80	19.1	109	17.5	147	16.0
140		6	36.0	12	31.8	18	30.5	27	27.7	39	25.4	50	24.1	68	22.0	90	20.2
160		6	40.6	9	36.9	13	35.2	20	32.0	25	31.6	32	29.9	44	27.2	59	24.9
100	30	18	21.9	34	19.6	53	18.0	81	16.2	114	15.0	152	14.0	207	12.8	268	12.0
120		18	25.5	34	22.6	53	20.7	81	18.6	114	17.2	152	16.0	207	14.6	266	13.5
140		8	34.0	16	29.8	25	27.2	40	24.4	56	22.5	74	21.0	103	19.1	137	17.5
160		5	39.5	10	34.6	17	31.6	21	31.2	30	28.9	40	26.7	55	24.4	76	22.1
Site index 80																	
100	20	14	25.2	27	21.9	42	20.4	63	18.4	87	17.2	113	16.3	143	15.5	192	14.2
120		9	30.4	15	28.8	23	26.9	37	23.9	50	22.4	65	21.2	83	20.1	112	18.4
140		6	36.0	11	33.9	17	31.6	23	30.3	31	28.4	40	26.9	51	25.5	68	23.4
160		6	40.8	8	39.3	12	36.7	17	35.1	23	32.9	29	31.2	33	31.6	43	29.3
100	30	16	23.6	29	21.1	47	19.2	68	17.8	95	16.5	127	15.4	161	14.6	229	13.0
120		16	27.4	29	24.5	47	22.2	68	20.6	95	19.1	127	17.8	160	16.7	227	14.8
140		9	32.8	13	32.7	22	29.3	32	27.3	45	25.2	60	23.5	79	21.9	113	19.5
160		6	38.4	9	38.0	14	34.1	20	31.9	27	29.4	32	30.2	41	28.3	60	24.9
Site index 90																	
100	20	12	26.7	23	24.0	37	21.7	51	20.5	72	19.0	94	17.9	121	16.9	155	15.8
120		8	32.2	12	32.1	21	28.6	29	2.69	41	25.0	54	23.4	68	22.2	90	20.6
140		6	38.2	9	37.7	15	33.7	21	31.7	25	31.8	33	29.8	41	28.3	54	26.3
160		4	44.6	7	43.6	11	39.2	15	36.9	18	36.8	24	34.6	31	32.8	40	30.6
100	30	14	25.2	26	22.5	41	20.6	57	19.5	77	18.4	108	16.8	136	16.0	181	14.7
120		14	29.4	26	26.3	41	24.0	57	22.7	77	21.4	108	19.5	135	18.5	179	16.8
140		8	35.2	14	31.5	19	31.8	27	30.1	36	28.4	49	26.0	63	24.5	87	22.3
160		5	41.2	9	37.1	12	37.1	17	35.1	23	33.2	31	30.4	33	31.6	46	28.6
Site index 100																	
100	20	11	28.3	20	25.8	32	23.4	45	21.9	59	21.0	81	19.4	121	18.3	132	17.2
120		7	34.3	13	31.2	18	30.9	25	28.9	33	27.7	45	25.7	68	24.3	76	22.5
140		5	40.7	9	37.0	13	36.4	18	34.1	23	32.7	32	30.4	41	31.2	45	28.2
160		5	46.3	7	43.2	9	42.2	13	39.7	17	38.1	23	35.5	31	36.2	33	33.6
100	30	11	25.6	20	24.1	31	22.3	43	21.0	57	19.8	77	18.5	99	17.5	131	16.0
120		11	31.1	20	28.3	31	26.1	43	24.6	57	23.0	77	21.5	98	20.3	128	18.4
140		6	37.3	11	33.9	17	31.5	24	32.9	26	30.5	34	28.7	45	27.0	60	24.5
160		4	43.8	7	39.8	11	37.1	15	38.3	15	35.7	21	33.5	28	31.6	38	31.7

GSL 160 on a 20-year cutting cycle, with GSL's 120 and 140 nearly as favorable.

Table 2 also shows the amount of volume given up as GSL is reduced from 180 to 40 for all combinations of stand parameters examined. Moreover, it shows that more volume can be produced over the same time span with 160-year rotations than with shorter rotations.

Whether the board foot volume production potentials can be achieved depends largely on how much money can be invested in thinning. It is assumed that once a stand reaches a minimum merchantable size of 8 inches average d.b.h. to a 6-inch top, market conditions permit intermediate thinnings to be made as scheduled. If economic constraints limit managers to only one precommercial thinning in the life of the stand, their options are severely restricted, with either a clearcut or shelterwood cut alternative. For example, on site index 50 to 60 lands, stand density must be reduced to GSL's 40 and 60, respectively, and the cutting cycle increased to 30 years (table 4). On site index 80 lands, a GSL of 120 can be maintained with a 30-year cutting cycle, and on site index 100 lands where there is considerable flexibility, a GSL of 160 can be maintained.

Thinnings to a constant GSL have been assumed up to now. However, if only one precommercial thinning is possible, managers can increase their flexibility by changing GSL's with successive re-entries. For example, on site index 70 lands with a 30-year cutting cycle, stand density is initially reduced to GSL 100. At the time of the second thinning, GSL is increased to 120, and increased to GSL 140 with the third thinning. Volume production will be less than maximum, but reasonably close to the volume available from a stand maintained at a constant GSL 140. Attempts to raise the GSL to 140 at the time of the second entry into the stand would result in a second precommercial thinning. By following this procedure, managers can increase GSL on site index 60 lands from 60 to 100.

Where economic conditions permit investment of funds in two precommercial thinnings, the manager has the opportunity to maximize timber production on site index 60 to 100 lands. On site index 50 lands, a GSL of 120 could be maintained or it could be increased to GSL 140 by changing the level with the second entry, provided that the rotation was at least 140 years.

Table 4.—Number of precommercial thinnings of spruce-fir in relation to growing stock level, site index, rotation age, and cutting cycle, with a clearcut or shelterwood option

Cutting cycle	Site index	Growing stock level							
		40	60	80	100	120	140	160	180
years									
20	50	2	2	2	3	3	4	4	[1]5
	60	2	2	2	2	3	3	3	[1]4
	70	1	2	2	2	2	2	3	3
	80	1	1	2	2	2	2	2	3
	90	1	1	2	2	2	2	2	2
	100	1	1	1	2	2	2	2	2
30	50	1	2	2	2	2	3	3	3
	60	1	1	2	2	2	2	2	3
	70	1	1	1	1	2	2	2	2
	80	1	1	1	1	1	2	2	2
	90	1	1	1	1	1	1	2	2
	100	1	1	1	1	1	1	1	2

[1]*Thinnings on a 100-year rotation would be precommercial.*

Trade-Offs to Increase Values of Other Resources

Understory vegetation in spruce-fir forests is potentially important as forage for big game, but production is lower in stands with high overstory density and closed canopies. To increase forage production, the manager must be willing to trade off timber production. For example, reduction of tree competition by clearcutting old-growth stands to bring them under management produces favorable changes in the amount and composition of understory species used as forage by deer (Regelin and Wallmo 1978, Wallmo 1969, Wallmo et al. 1972). Changes in vegetational composition and the quantities of forage available, rather than any differences in nutritive values, accounts for heavier grazing of cut areas (Regelin et al. 1974). This change in production and composition, which varies considerably with habitat type, persists 15 to 20 years before competition from new tree reproduction begins to reduce understory vegetation (Regelin and Wallmo 1978). Thinning second-growth spruce-fir stands also increases amount and composition of understory species, especially where stand density is reduced to low levels. However, data and methodology are not available to quantify changes in understory production and composition associated with the various habitat types for the range of GSL's, rotation ages, cutting cycles, and site indexes examined here for timber production.

Spruce-fir forests yield the most water in the Rocky Mountains. The proportion of water yield to precipitation is high because of the cold climate, short growing season, and the accumulation of an overwinter snowpack (Leaf 1975). Because most of the water available for streamflow comes from snowmelt, the most efficient pattern of timber harvest for water yield in old-growth stands is to clearcut about 30% to 40% of a drainage (1) in small, irregular-shaped patches about five to eight times tree height in diameter, (2) protected from the wind, and (3) interspersed with uncut patches of about the same size (Leaf 1975). Leaf and Alexander (1975) estimated water available for streamflow after clearcutting in spruce-fir stands under different management strategies using simulations generated by hydrologic and timber yield models (Alexander et al. 1975, Leaf and Brink 1973, Edminster 1978). Projected water yield increases at GSL 100, on a 30-year cutting cycle, on site index 80 lands, for a 140-year rotation are shown in figure 10. Simulation analyses also showed that estimated water yield was influenced little by any combination of initial and subsequent GSL's in managed stands that ranged from

80 to 120. More water should be available for streamflow at lower GSL's because of the reduction in consumptive use by trees, but no comparisons were made at higher or lower GSL's because of limitations in the simulation programs. One unknown factor is water use by competing understory vegetation associated with different habitat types for different GSL's.

Based on information available from research and simulation, it is clear that stand density must be substantially reduced and maintained at a low (GSL 40 to 60) stocking level to benefit water and forage resources. Other resource values may require moderate (GSL 80 to 100) stocking levels. Considerable timber volume production is given up, however, at low to moderate stand density levels. For example, on site index 100 lands, at GSL 80 with a 160-year rotation and a 30-year reentry schedule, 40,300 fewer board feet per acre are produced than with GSL 180. If the GSL is reduced to 40, the loss in volume production is 68,200 fbm per acre (table 2).

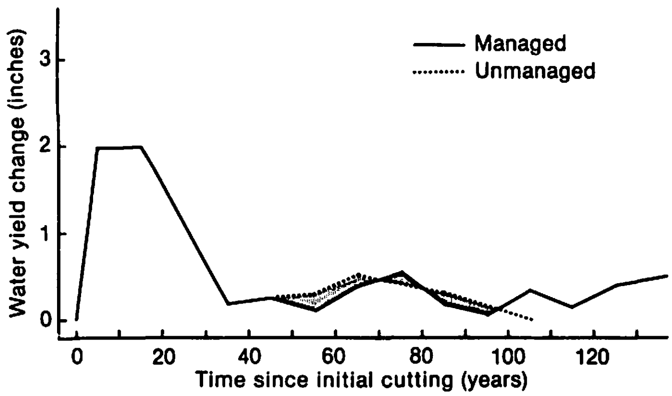

Figure 10.—Project changes in annual water yield from simulation for GSL 100 and site index 70 lands, with a 30-year cutting cycle, and a 140-year rotation (Leaf and Alexander 1975).

Management Caution

This simulation program estimates growth responses to different stand parameters that appear reasonable and consistent within the limits of current knowledge, but no spruce-fir stand has been under management for a long time and simulation extends beyond the limits of the available data base. Comparisons of estimates with actual values from plots established to provide growth information will be needed to verify simulated responses.

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Appendix

Table A-1.—Basal areas (square feet per acre) after intermediate cutting in relation to average stand diameter (inches) and growing stock level

Average stand d.b.h. after cutting	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2	6.0	7.5	9.1	10.6	12.1	13.6	15.1	16.7	18.2	21.2	24.2
3	11.8	14.8	17.7	20.6	23.6	26.6	29.5	32.4	35.4	41.5	47.4
4	17.6	22.0	26.4	30.8	35.2	39.6	44.0	48.4	52.8	61.6	70.4
5	23.4	29.2	35.0	40.9	46.7	52.5	58.4	64.2	70.0	81.9	93.6
6	28.3	35.4	42.4	49.5	56.6	63.7	70.8	77.8	84.9	99.0	113.2
7	32.7	40.9	49.1	57.3	65.5	73.7	81.9	90.1	98.2	114.4	130.8
8	36.2	45.3	54.4	63.4	72.5	81.6	90.6	99.7	108.8	126.9	145.0
9	38.8	48.4	58.1	67.8	77.5	87.2	96.9	106.6	116.2	135.6	155.0
10	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	140.0	160.0

Table A-2.—Number of trees per acre in relation to average diameter (inches) and growing stock level

Average stand d.b.h. after thinning	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2	277	345	418	488	553	626	692	767	836	968	1,107
3	241	301	360	420	481	542	601	660	721	843	964
4	202	252	302	353	403	454	504	554	605	707	808
5	172	214	257	300	342	385	428	471	513	601	687
6	144	180	216	252	288	324	361	396	432	505	577
7	122	153	184	214	245	276	306	337	367	428	489
8	104	130	156	182	208	234	260	286	312	364	415
9	88	110	132	154	175	197	219	241	263	307	351
10	73	92	110	128	147	165	183	202	220	257	293

Table A-3.—Average distance (feet) between residual trees in relation to average diameter (inches) and growing stock level

Average stand d.b.h. after thinning	Growing stock level										
	40	50	60	70	80	90	100	110	120	140	160
2	12.5	11.1	10.2	9.4	8.8	8.3	7.8	7.5	7.2	4.8	4.4
3	13.4	12.0	11.0	10.2	9.5	9.0	8.5	8.1	7.8	6.7	6.3
4	14.7	13.2	12.0	11.1	10.4	9.8	9.3	8.9	8.5	7.2	6.7
5	15.9	14.4	13.0	12.0	11.3	10.6	10.1	9.6	9.2	7.9	7.3
6	17.4	15.6	14.4	13.2	12.3	11.6	11.0	10.5	10.0	8.5	8.0
7	18.9	16.9	15.4	14.3	13.3	12.6	11.9	11.4	10.9	9.3	8.7
8	20.5	18.3	16.7	15.5	14.5	13.6	13.0	12.3	11.8	10.9	10.2
9	22.3	20.1	18.2	16.8	15.8	14.9	14.1	13.4	12.9	11.9	11.1
10	24.4	21.8	20.1	18.4	17.2	16.2	15.4	14.7	14.1	13.0	12.2

Table A-4.—Total cubic foot volume production per acre of spruce-fir in relation to growing stock level, site index, rotation age and cutting cycle with a shelterwood option

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160	180
——*years*——		——*thousand cubic feet*——							
		Site index 50							
100	20	2.00	2.44	2.87	3.23	3.54	3.74	3.80	3.63
120		2.38	2.95	3.54	4.08	4.44	4.72	4.90	4.90
140		2.70	3.42	4.13	4.76	5.33	5.85	6.06	5.92
160		2.99	3.90	4.78	5.54	6.22	6.75	7.09	7.09
100	30	2.08	2.54	2.90	3.20	3.40	3.60	3.68	3.55
120		2.48	3.14	3.71	4.10	4.40	4.60	4.68	4.68
140		2.90	3.78	4.41	5.01	5.47	5.80	5.92	5.82
160		3.22	4.16	4.98	5.74	6.30	6.74	7.09	7.09
		Site index 60							
100	20	2.51	3.16	3.73	4.25	4.61	4.88	5.07	5.26
120		2.90	3.83	4.51	5.21	5.76	6.17	6.48	6.72
140		3.30	4.34	5.31	6.10	6.83	7.49	7.88	8.19
160		3.66	4.91	6.02	7.01	7.78	8.45	9.02	9.52
100	30	2.64	3.29	3.86	4.35	4.70	4.93	5.10	5.22
120		3.14	3.97	4.76	5.40	5.84	6.18	6.48	6.66
140		3.61	4.76	5.74	6.48	7.04	7.55	7.89	8.20
160		4.02	5.36	6.42	7.34	8.22	8.86	9.36	9.49
		Site index 70							
100	20	3.13	3.96	4.64	5.34	5.91	6.40	6.71	6.90
120		3.68	4.70	5.60	6.47	7.24	7.94	8.42	8.77
140		4.14	5.32	6.43	7.50	8.53	9.32	9.97	10.53
160		4.51	5.92	7.26	8.48	9.65	10.59	11.44	12.14
100	30	3.25	4.14	4.95	5.59	6.09	6.42	6.76	7.00
120		3.84	4.98	5.94	6.82	7.52	8.04	8.44	8.76
140		4.47	5.74	6.97	7.27	9.21	9.90	10.36	10.63
160		4.86	6.37	7.86	9.20	10.30	11.17	11.78	12.16
		Site index 80							
100	20	3.75	4.78	5.68	6.46	7.20	7.90	8.55	8.95
120		4.33	5.66	6.68	7.92	8.88	9.82	10.51	10.86
140		4.87	6.38	7.80	9.06	10.09	11.20	12.18	13.05
160		5.31	7.04	8.74	10.13	11.41	12.72	13.82	14.91
100	30	4.00	5.02	5.99	6.89	7.64	8.22	8.64	8.95
120		4.64	6.00	7.25	8.45	9.36	10.04	10.56	10.92
140		5.31	6.97	8.47	9.86	11.05	12.01	12.71	13.12
160		5.87	7.68	9.30	10.85	12.29	13.46	14.37	15.07
		Site index 90							
100	20	4.42	5.67	6.79	7.78	8.61	9.43	10.23	10.82
120		5.06	6.56	8.00	9.34	10.44	11.45	12.38	13.08
140		5.60	7.41	9.09	10.56	11.98	13.24	14.46	15.65
160		6.18	8.18	10.13	11.98	13.52	14.96	16.42	17.76
100	30	4.74	6.02	7.13	8.15	9.08	9.90	10.56	11.04
120		5.58	7.14	8.78	10.13	11.21	12.20	12.98	13.58
140		6.17	8.22	10.07	11.75	13.09	14.36	15.26	15.93
160		6.61	8.94	11.14	13.04	14.64	15.94	17.10	18.06
		Site index 100							
100	20	5.17	6.55	7.91	9.17	10.20	11.10	11.90	12.70
120		5.89	7.63	9.23	10.84	12.40	13.69	14.80	15.60
140		6.55	8.54	10.51	12.33	14.03	15.67	17.05	18.17
160		7.06	9.42	11.55	13.78	15.76	17.63	19.26	20.53
100	30	5.40	7.02	8.45	9.76	10.97	11.97	12.70	13.20
120		6.34	8.24	10.14	11.98	13.44	14.66	15.60	16.26
140		7.17	9.52	11.76	13.89	15.71	17.15	18.34	19.08
160		7.76	10.34	12.83	15.25	17.36	19.14	20.53	21.50

Table A-5.—Estimated total board foot volume production per acre of spruce-fir in relation to growing stock level, site index, rotation age, and cutting cycle with a shelterwood option. (trees 8 inches d.b.h. and larger to a 6-inch top)

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160	180
——*years*——		——*thousand board feet*——							
		Site index 50							
100	20	6.3	8.5	9.7	10.7	11.4	11.7	11.5	10.1
120		8.8	11.5	13.7	15.8	16.8	17.0	16.8	16.2
140		10.9	14.4	17.5	19.9	21.8	23.2	23.0	21.8
160		13.0	17.6	21.1	24.6	26.9	28.8	29.1	28.2
100	30	7.0	8.5	9.7	10.6	11.1	11.2	11.0	10.1
120		9.2	12.0	14.0	15.4	16.1	16.3	16.1	15.6
140		11.8	15.5	18.1	20.6	22.4	22.8	22.5	21.8
160		13.9	17.9	21.8	25.4	28.2	29.8	29.4	28.0
		Site index 60							
100	20	8.5	11.4	13.5	15.3	16.4	17.1	17.7	18.0
120		11.0	15.0	18.4	20.8	22.4	23.9	24.8	25.8
140		13.6	18.5	23.0	26.5	29.3	31.4	33.0	33.9
160		16.0	22.1	27.5	31.9	34.9	37.6	39.8	41.6
100	30	8.9	11.2	13.1	14.8	16.1	16.7	17.2	16.4
120		11.9	15.2	18.2	21.0	22.6	23.6	24.2	23.6
140		14.8	20.0	24.2	27.7	30.5	32.2	33.0	32.2
160		17.6	23.7	28.6	32.6	36.3	39.8	41.1	40.3
		Site index 70							
100	20	10.7	14.3	17.3	19.9	22.0	23.5	24.3	25.0
120		14.0	19.0	23.2	26.9	29.9	32.2	34.1	35.5
140		17.2	22.8	28.4	33.2	37.4	40.5	43.1	45.1
160		20.0	27.0	33.6	39.7	45.0	49.3	53.1	55.2
100	30	11.2	14.8	17.8	20.1	21.6	22.7	27.6	28.1
120		14.8	19.8	23.8	27.1	29.6	31.8	33.1	33.7
140		18.8	24.6	30.5	35.3	39.3	42.1	44.1	44.8
160		21.4	29.0	36.2	42.1	46.9	50.4	52.6	53.6
		Site index 80							
100	20	12.9	17.2	21.1	24.5	27.6	30.0	32.2	33.5
120		16.7	22.9	28.0	32.4	36.7	40.3	43.2	45.0
140		20.2	28.3	34.3	40.0	45.6	50.7	54.9	58.1
160		23.4	32.6	40.6	47.8	54.7	60.9	66.2	70.2
100	30	14.2	18.4	22.4	25.7	28.2	30.0	31.2	31.8
120		18.4	24.2	29.8	34.9	38.5	41.3	43.0	43.8
140		22.7	30.5	37.7	44.0	49.0	53.5	56.0	57.4
160		26.1	35.4	43.7	51.7	58.4	63.5	67.2	69.0
		Site index 90							
100	20	15.7	20.8	25.9	30.3	33.9	36.9	39.8	42.0
120		19.8	26.8	33.4	39.7	44.6	49.4	53.5	57.0
140		24.1	32.6	40.7	48.2	55.3	61.5	67.2	71.7
160		24.1	38.1	48.2	57.4	65.6	72.9	80.0	86.6
100	30	17.2	22.6	27.4	31.5	34.9	37.3	39.4	40.7
120		22.0	29.8	37.2	43.0	48.2	52.2	55.0	55.9
140		26.7	36.8	45.6	53.9	61.5	65.1	69.0	70.6
160		30.4	42.1	52.8	62.6	71.8	78.2	83.2	85.0
		Site index 100							
100	20	18.5	24.6	30.7	36.1	40.3	44.0	47.4	50.5
120		23.4	31.8	39.5	47.0	54.0	60.0	64.8	68.4
140		27.9	38.2	48.4	57.7	65.9	73.5	80.5	85.7
160		31.8	44.5	56.2	66.9	77.4	87.0	95.4	101.8
100	30	19.8	26.8	33.4	39.0	43.7	46.8	49.0	50.4
120		26.0	35.0	43.8	51.8	59.0	64.1	66.8	68.2
140		31.4	43.1	54.2	64.7	73.2	79.8	84.6	86.1
160		36.5	49.4	61.8	73.9	84.8	93.8	100.0	102.6

Table A-6.—Estimated average diameter (inches) and number of trees per acre of spruce-fir of final harvest in relation to growing stock levels, site indexes, rotation age, and cutting cycle with a shelterwood option

Rotation age	Cutting cycle	Growing stock level 40		60		80		100		120		140		160		180	
		No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter
Site index 50																	
100	20	19	20.6	39	17.5	65	15.6	95	14.3	135	13.1	194	11.8	236	11.1	289	10.1
120		11	26.7	22	22.6	39	19.7	57	18.2	84	16.5	125	14.5	169	13.3	226	12.2
140		7	33.5	13	28.8	24	24.9	36	22.6	53	20.5	79	18.1	110	16.3	161	14.3
160		6	35.1	11	32.3	16	30.7	23	27.9	35	24.9	52	22.1	72	20.0	107	17.4
100	30	22	19.3	43	16.7	72	14.9	107	13.6	151	12.4	208	11.2	250	10.8	295	10.0
120		12	25.2	25	21.6	42	19.1	65	17.1	91	15.8	136	13.9	181	12.9	235	12.0
140		9	29.6	18	25.3	29	22.6	46	20.1	65	18.4	100	16.1	131	15.0	180	13.5
160		7	33.3	11	31.8	18	28.3	30	24.7	44	22.5	66	19.7	87	18.2	122	16.3
Site index 60																	
100	20	17	21.8	34	19.0	57	16.9	76	16.2	116	14.3	153	13.4	209	12.3	259	10.1
120		9	28.7	19	24.7	33	21.8	45	20.7	70	18.1	90	17.2	131	15.3	164	12.2
140		7	32.7	11	31.8	19	27.9	27	26.1	43	22.2	55	21.9	79	19.4	103	14.3
160		5	37.9	9	35.6	15	31.4	18	32.0	28	28.0	36	26.8	51	23.8	67	17.4
100	30	19	20.8	36	18.4	62	16.2	85	15.3	129	13.7	164	13.0	217	12.1	264	13.3
120		10	27.6	20	24.1	35	21.1	51	19.5	76	17.4	99	16.4	133	15.1	183	13.7
140		7	32.8	14	28.5	24	25.0	36	23.1	53	20.7	70	19.3	95	17.0	133	15.9
160		6	36.5	11	31.9	15	31.1	23	28.3	34	25.6	46	23.8	62	21.8	86	19.5
Site index 70																	
100	20	15	23.4	28	21.0	46	18.7	69	17.2	97	15.9	123	15.1	166	13.9	210	13.1
120		8	31.0	15	27.5	26	24.5	39	22.5	55	20.5	70	19.6	94	18.1	126	16.7
140		6	36.1	11	32.1	15	31.5	23	28.5	33	26.0	43	24.7	59	22.6	79	20.7
160		4	42.0	8	37.1	12	35.5	18	32.5	21	32.3	27	30.8	38	28.0	50	25.8
100	30	17	22.3	30	20.2	49	18.2	75	16.6	103	15.5	138	14.4	184	13.3	231	12.5
120		9	29.3	17	26.2	27	24.0	42	21.4	59	19.9	79	18.5	109	16.9	139	15.8
140		7	34.4	11	31.8	19	28.4	29	25.7	41	23.6	55	22.0	75	20.1	99	18.5
160		5	39.7	9	35.0	15	31.9	18	32.1	25	29.5	34	27.5	48	25.0	63	23.0
Site index 80																	
100	20	13	25.3	25	22.3	39	20.6	59	18.8	79	17.7	103	16.7	133	15.7	177	14.4
120		7	33.7	14	29.3	21	27.2	32	24.7	44	22.9	58	21.6	74	20.5	99	18.8
140		6	36.2	10	34.1	14	31.9	19	31.4	27	29.1	35	27.5	44	26.0	59	23.9
160		4	42.2	7	39.6	11	36.9	15	35.3	20	33.2	25	31.5	28	32.6	37	29.9
100	30	15	24.0	27	21.5	44	19.6	63	18.2	87	16.9	118	15.7	145	15.1	196	13.8
120		8	31.7	15	28.4	24	25.8	35	23.7	48	22.1	66	20.5	83	19.4	117	17.4
140		7	33.0	10	34.0	16	30.8	23	28.6	33	26.6	44	24.7	58	23.0	81	20.6
160		5	38.8	8	38.3	13	34.4	18	32.1	20	33.2	28	30.6	36	28.7	51	25.8
Site index 90																	
100	20	12	26.7	22	24.0	35	21.9	48	20.8	67	19.3	89	18.1	110	17.4	139	16.4
120		7	34.7	11	32.2	19	29.1	26	27.5	37	25.3	48	23.8	62	22.4	80	21.1
140		5	38.5	8	37.9	13	34.0	18	31.9	21	32.9	29	30.5	36	29.0	47	26.8
160		4	44.7	6	43.9	10	39.4	14	37.1	16	37.0	22	34.8	27	33.1	30	33.6
100	30	13	25.6	25	22.7	38	21.0	63	19.7	71	18.7	100	17.1	125	16.4	164	15.2
120		7	33.9	13	30.4	21	27.8	35	26.1	39	24.7	55	22.6	69	21.4	91	19.8
140		6	35.4	12	31.7	13	33.9	23	31.7	26	29.8	37	27.1	46	25.9	64	23.3
160		4	41.6	8	37.3	11	37.4	18	35.3	20	33.4	25	30.8	29	32.0	39	29.4
Site index 100																	
100	20	11	28.1	19	25.7	30	23.7	43	22.0	57	21.0	77	19.5	99	18.4	119	17.9
120		7	34.6	10	31.4	16	34.4	23	29.5	30	28.3	41	26.0	53	24.5	67	23.0
140		5	40.8	8	37.2	12	36.7	16	34.3	21	32.9	23	33.9	30	31.8	40	29.5
160		3	47.8	6	43.4	8	42.6	12	39.9	15	38.3	21	35.7	23	34.6	30	33.8
100	30	11	27.2	22	24.3	34	22.4	47	21.3	63	20.7	83	18.9	106	17.9	139	16.6
120		7	35.2	11	32.7	18	30.2	25	28.3	34	26.7	45	25.0	58	23.6	77	21.7
140		6	37.4	10	34.1	16	31.5	17	34.2	23	32.1	30	30.3	38	28.5	53	25.7
160		4	44.1	7	40.1	11	37.3	13	36.6	18	35.9	23	33.9	30	32.0	32	32.5

Alexander, Robert R., and Carleton B. Edminster. 1980. Management of spruce-fir in even-aged stands in the central Rocky Mountains. USDA Forest Service Research Paper RM-217, 14 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Potential production of Engelmann spruce and subalpine fir in the central Rocky Mountains is simulated for various combinations of stand density, site quality, ages, and thinning schedules. Such estimates are needed to project future development of stands managed in different ways for various uses.

Keywords: stand growth, stand yield, forest management, *Picea engelmannii, Abies lasiocarpa*

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Rocky Mountains

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