USDA Forest Service
Research Paper RM-186

April 1977

Uneven-Aged Management of Old Growth Spruce-Fir Forests: Cutting Methods and Stand Structure Goals for the Initial Entry

Robert R. Alexander and Carleton B. Edminster[1]

[1]Chief silviculturist and associate mensurationist, respectively, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University.

Uneven-Aged Management of Old Growth Spruce-Fir Forests: Cutting Methods and Stand Structure Goals for the Initial Entry

Robert R. Alexander and Carleton B. Edminster

The Engelmann spruce-subalpine fir type occupies the largest area of commercial forest land in the subalpine zone of the central Rocky Mountains. Most of these forests are in old-growth stands, characterized by a diverse stand structure. This variability complicates the choice of silvicultural systems needed to convert old-growth forests to regulated stands for different management goals.

Some spruce-fir forests are clearly single-storied, and either broadly even-aged or composed of trees of similar sizes. Others consist of 2- and 3-storied stands, in which each story may be even-aged. These stand structures indicate that desirable spruce-fir forests can be regenerated and grown under any even-aged silvicultural system, except the seed-tree method. The latter is not applicable because of susceptibility of residual trees in old-growth stands to windthrow. Even-aged management is appropriate for high-yield timber production, increasing water yields, providing diversity of food and cover favored by many wildlife species, and creating diversity in the forest landscape to enhance amenity values[2] (Alexander 1974, Alexander et al. 1975, Leaf 1975).

Multi-storied stands that are uneven- to broad-aged are also common in spruce-fir forests (Alexander 1974, Hanley et al. 1975). Irregular stand structure may result from: (1) past disturbances such as fire, insect epidemics, or cutting, (2) gradual deterioration of old-growth stands associated with normal mortality from winds, insects, and diseases, or (3) stands that originated as uneven-aged and are successfully perpetuating this structure. Individual tree or small group selection methods appear to simulate the natural dynamics of these forests. Moreover, even-aged management is not compatible or desirable for all situations and resource needs. For example, the impact on the forest should be as light as possible in areas of steep topography and erosive soils, or where management goals in terms of both resource and social responses include maintenance of continuous high forests. Uneven-aged management is usually more appropriate for these conditions and objectives.

The purpose of this paper is to provide a working tool for practicing foresters faced with the problems of making the initial entry needed to begin conversion of old-growth forests to managed uneven-aged stands. The basis for establishing uneven-aged management involves: (1) choice of cutting method, (2) setting up goals for residual stocking, stand structure, and maximum tree diameter, and (3) marking and harvesting stands to accomplish (2).

Since there has been little cutting in spruce-fir stands under a true selection system, only limited information is available on growth and yield, stocking levels and stand structure goals to guide uneven-aged management. Consequently, many recommendations in this paper are based on work done elsewhere, especially in hardwood forests of the northeastern United States and reported by Leak and Filip (1975), Marquis (1975), Trimble and Smith (1976), and others. The principles developed for hardwood species apply elsewhere however.

Cutting Methods

Which silvicultural system to use depends upon understanding the basic differences between even- and uneven-aged management. Even-aged management involves cultural treatments, thinning and harvesting necessary for periodic regeneration of desirable species, orderly growth and development of trees to a given size in each stand, and progressive development of stands to provide sustained yield of forest products. In spruce-fir forests, the appropriate even-aged cutting systems are **clearcutting** and **shelterwood**. Managed forests are characterized by a dis-

[2]*Alexander, Robert R. A silviculturist looks at cutting methods in relation to multiple-use management of spruce-fir forests in the central Rocky Mountains. (Manuscript in preparation at Rocky Mt. For. and Range Exp. Stn.)*

tribution of even-aged stands, with each stand of sufficient acreage to be mapped, located on the ground and scheduled for treatment. Regulation is accomplished through control of the area in each size class and length of rotation.

In contrast, **uneven-aged** management includes cultural treatments, thinnings, and harvesting necessary to maintain continuous high forest cover, provide for regeneration of desirable species either continuously or at each harvest, and provide for controlled growth and development of trees through the range of size classes needed for sustained yield of forest products. Managed uneven-aged stands are characterized by trees of many sizes intermingled singly or in groups. Cutting methods do not produce stands of the same age that are large enough to be recognized as a stand. Forests are subdivided into recognizable units that can be located on the ground on the basis of timber type, site, logging requirements, etc., rather than acreage in stand-age classes. Regulation is accomplished by setting: (1) a residual stocking goal, in terms of basal area or volume, that must be maintained to provide adequate growth and yield, (2) a diameter distribution goal that will provide for regeneration, growth and development of replacement trees, and (3) a maximum tree size goal. Although individual-tree selection cutting is usually associated with uneven-aged management, group selection cutting must also be considered in spruce-fir stands.

Individual-tree selection cutting is the removal of trees in several or all diameter classes on an individual tree basis. The ultimate objective is to provide a stand with trees of different sizes and age classes intermingled on the same site (U.S. Dep. Agric. 1973). Choice of trees to be cut depends on their characteristics and relationship to stand structure goals set up to regulate the cut. This system provides maximum flexibility in choosing trees to cut or leave. Individual-tree selection cutting will favor fir over spruce, and in mixed spruce-fir-lodgepole pine stands, few intolerant pines will become established after initial cutting.

In **group selection cutting**, tree groups, ranging in size from a fraction of an acre up to about 2.0 acres are removed (U.S. Dep. Agric. 1973). Area cut is smaller than the minimum feasible for a single stand under even-aged management. Trees are marked on an individual-tree basis, but emphasis is on group characteristics, which means trees with high potential for future growth are removed along with trees with low growth potential. Loss in flexibility is partly offset by the opportunity to uniformly release established regeneration, and reduce future logging damage. When groups are composed of only a few trees, the method can be used together with individual-tree selection cutting. Group selection cutting provides a better opportunity for both spruce and lodgepole pine to become established relative to fir.

Stand Structure Goals

Under uneven-aged management, yields are regulated through control over growing stock. To establish the desired residual structure of a stand, it is necessary to control: (1) residual stocking to be left after cutting, (2) diameter of the maximum size tree to be left, and (3) diameter distribution of the residual stand.

Control of Stocking.—The first step in applying a selection cut to a spruce-fir stand is to determine residual stocking level to be retained. Since total stand growth for many species adapted to uneven-aged management does not differ greatly over the range of stocking levels likely to be management goals, stocking levels set near the lower limit, where no growth is lost, concentrate increment on fewest stems. This reduces time required to grow individual trees to a specified size, and requires a minimum investment in growing stock.

The residual stocking level with the best growth in spruce-fir stands will vary with species composition, management objectives, productivity, diameter distribution, etc. In unregulated old-growth spruce-fir stands with irregular structure, stocking usually varies from 150 to 300 ft^2 of basal area per acre in trees in the 4.0-in and larger diameter classes. This probably represents overstocking. While no guidelines are available for uneven-aged stands, residual stocking of GSL-80 to GSL-120 are suggested for managed even-aged stands, depending on site productivity, number of entries, and other management objectives (Alexander et al. 1975). These levels should be useful in estimating initial residual stocking goals in terms of ft^2 of basal area per acre for that part of the stand that will eventually be regulated under uneven-aged management.

While these general recommendations are probably adequate as a place to start, use of yield tables for **even-aged** spruce-fir stands in setting stocking goals for **uneven-aged** stands assumes there is little difference between the growing stock of the two, other than a redistribution of age classes over a smaller area (Bond 1952). This may be true when stands without a manageable understory of advanced growth are harvested by a group selection method. The end result is likely to be a series of small even-aged groups represented in the same proportion as a series of age classes in even-aged management. If advanced growth of smaller trees has become established under a canopy of larger trees, however, a different structure may develop with either individual-tree or group selection systems. Growing space occupied by each age or size class is being shared (Reynolds 1954). Assuming that damage to understory trees resulting from removal of part of the overstory trees can be minimized, advanced growth will successfully establish a series of age classes on some areas. In this situation, more trees at a larger size can be grown per acre than with a balanced even-aged growing stock (Bourne 1951, Meyer et al. 1961). Nevertheless, without better information, the residual stocking goals set for even-aged management are the best criteria available.

Maximum Tree Size.—The second item of information needed is the maximum diameter of trees to be left after cutting. In old-growth spruce-fir stands, maximum diameter usually varies from 18 to 30 in at breast height, depending on stand density, site quality, species composition, etc. Examination of yield table predictions for even-aged stands, and plot inventory information from unmanaged stands with irregular stand structure, suggests that a diameter of 24 in can be attained within the time period generally considered reasonable for even-aged, managed stand rotations under a wide range of site quality and stocking conditions. In the absence of any information on growth rates in uneven-aged stands, or rates of return for specific diameter and stocking classes, a 24-in maximum diameter seems a reasonable first approximation to set for timber production. Trees of larger diameter with a lower rate of return on investment may be appropriate for multiple-use reasons.

Control of Diameter Distribution.—Control over distribution of tree diameters is also necessary to regulate yields under uneven-aged management. This is the *most important step,* and it is accomplished by establishing the desired number of trees or basal area for each diameter class.

There are a number of ways to express diameter distributions in uneven-aged stands. When used with flexibility, the quotient q between number of trees in successive diameter classes is a widely accepted means of calculating the desired distribution (Meyer 1952). Values of q ranging between 1.3 and 2.0 (for 2-in diameter classes) have been recommended for various situations. The lower the q, the smaller the difference in number of trees between diameter classes. Stands maintained at a small q have a higher proportion of available growing stock in larger trees, for any residual stocking level, but may require periodic removal of the largest number of small trees in the diameter class where unregulated growing stock crosses the threshold into the portion of the stand to be regulated.

Consider, for example, differences in numbers of small and large trees maintained at q levels of 1.3, 1.5, 1.8, and 2.0 in stands with the same residual basal area (table 1). At all stocking levels considered appropriate for future management

Table 1.—Residual stand structures for 100 ft² of basal area and maximum tree d.b.h. of 24 in for various q values. All data on a per-acre basis

Diameter class	q = 1.3 Trees	q = 1.3 Basal area	q = 1.5 Trees	q = 1.5 Basal area	q = 1.8 Trees	q = 1.8 Basal area	q = 2.0 Trees	q = 2.0 Basal area
	No.	*Ft²*	*No.*	*Ft²*	*No.*	*Ft²*	*No.*	*Ft²*
4	38.90	3.38	79.08	6.89	156.01	13.62	210.18	18.35
6	29.90	5.87	52.72	10.34	86.68	17.01	105.09	20.63
8	23.02	8.04	35.14	12.26	48.15	16.81	52.54	18.35
10	17.96	9.65	23.43	12.78	26.75	14.59	26.27	14.33
12	13.62	10.69	15.62	12.26	14.86	11.67	13.14	10.32
14	10.47	11.20	10.41	11.12	8.26	8.83	6.57	7.02
16	8.07	11.26	6.95	9.70	4.59	6.41	3.28	4.58
18	6.21	10.97	4.63	8.18	2.55	4.50	1.64	2.90
20	4.77	10.41	3.08	6.73	1.42	3.09	0.82	1.79
22	3.67	9.68	2.06	5.42	0.79	2.08	0.41	1.08
24	2.82	8.86	1.37	4.30	0.44	1.37	0.20	0.64
Total	159.14	100.01	234.49	99.98	350.50	99.98	420.14	99.99

goals, larger numbers of small trees would have to be cut under lower q levels at the threshold diameter class (in this example the 4-in class). Fewer larger trees would be retained under higher q levels.

In the absence of any experience data or good growth and yield information, the best estimate of number of trees to leave by diameter classes is to use the lowest q value that is reasonable in terms of existing markets, stand conditions, and funds available for cultural work. Examination of plot data from a wide range of old-growth spruce-fir stands indicates that pretreatment distributions are likely to range between 1.3 and 1.8 for 2-in classes. As a general recommendation, q levels between 1.3 and 1.5 appear reasonable initial goals for the first entry into unmanaged stands.

Those readers interested only in the method for determining the residual stand structure goals, and not the mathematical manipulations required to derive the method, may skip the following material and continue reading with the section headed How to Determine Residual Stand Structure, *on page 6.*

A plot of the distribution of number of trees in successive diameter classes follows a typical inverse J-shaped curve (fig. 1), which may be described by the negative exponential function:

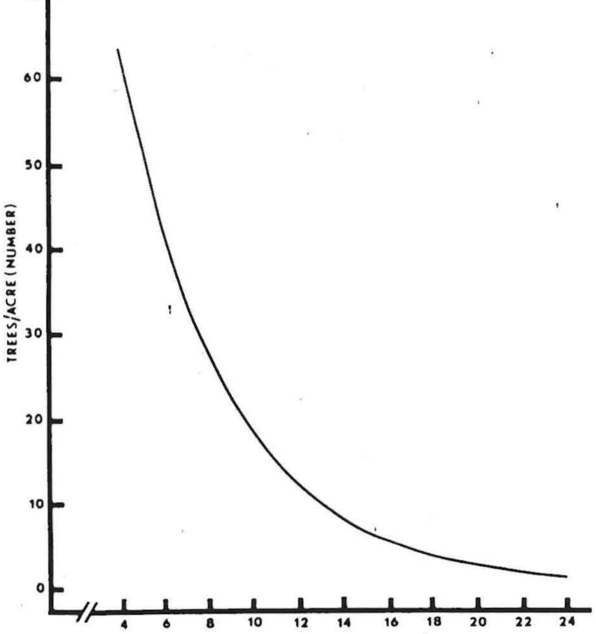

Figure 1.—Diameter distribution for a q of 1.5, maximum tree d.b.h. of 24 in, and a residual stocking of 80 ft² of basal area per acre.

$$N_i = ke^{-aD_i} \qquad (1)$$

where N_i and D_i are, respectively, number of trees per acre and midpoint of the i^{th} diameter class. Parameters a and k characterize a given distribution[3]. The constant a controls the rate at which number of trees change between successive diameter classes. The value of a is related to q by the equation:

$$a = (\ln q)/h \qquad (2)$$

where h is the width of the diameter classes. For 2-in diameter classes discussed in this paper, $h = 2$. Substituting equation (2) into equation (1) with $h = 2$ gives the following expression of the negative exponential function:

$$N_i = ke^{-D_i(\ln q)/2} \qquad (3)$$

The value of q can be estimated for a given set of stand inventory data by using the linear regression:

$$\ln N_i = b_0 + b_1 D_i$$

where b_0 and b_1 are estimates of the regression parameters. For 2-in diameter classes, $q = e^{-2b_1}$. Note the value of q for 2-in diameter classes is the square of q for 1-in classes.

The value of k in equations (1) and (3) represents a measure of density, but it is not easily related to usable measures for timber management purposes. The most useful density measures for uneven-aged spruce-fir stands are stand basal area per acre and crown competition factor (CCF) per acre (Alexander 1971). Moser (1976) presents a method for relating basal area and CCF to k which is adapted here to spruce-fir stands. Both density measures may be expressed by the formula:

$$\text{density} = c_1 \sum_i N_i + c_2 \sum_i N_i D_i + c_3 \sum_i N_i D_i^2 \qquad (4)$$

where values of coefficients c_1, c_2, and c_3 are:

	Basal area	**CCF**
c_1	0.0	0.0340
c_2	.0	.0161
c_3	.0054542	.0019

[3]*In this Paper, e^x represents the value of the exponential function at x and ln x represents the value of the natural (base e) logarithm at x.*

The Σ_i in equation (4) represents a summation over all diameter classes. After substituting equation (3) into equation (4) and performing some algebraic manipulations, the density parameter k may be expressed as:

$$k = \frac{\text{density}}{\Sigma_i (c_1 + c_2 D_i + c_3 D_i^2) e^{-D_i (\ln q)/2}} \qquad (5)$$

Thus — for a given density expressed as basal area per acre or CCF, a range of diameter classes, and a q value — the value of the density parameter k of the negative exponential function may be computed. Values of the denominator of equation (5) for a range of 2-in diameter classes and q values are presented in tables 2 and 3 to simplify computation of k. After k is computed, number of trees in each diameter class may be computed using equation (3).

Table 2.—Values for the denominator of equation (5) for different q ratios and diameter ranges using basal area as the density measure

2-in diameter classes	*q* ratio									
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
2	0.01983	0.01818	0.01678	0.01558	0.01454	0.01364	0.01283	0.01212	0.01148	0.01091
4	.09196	.07878	.06842	.06011	.05333	.04772	.04303	.03905	.03566	.03273
6	.23948	.19241	.15779	.13166	.11151	.09566	.08300	.07272	.06428	.05727
8	.47790	.36075	.28001	.22253	.18046	.14893	.12479	.10597	.09107	.07909
10	.81656	.57994	.42691	.32394	.25228	.20094	.16320	.13484	.11310	.09613
12	1.25990	.84297	.58963	.42825	.32124	.24775	.19574	.15793	.12979	.10840
14	1.80848	1.14132	.75999	.52966	.38380	.28758	.22179	.17539	.14175	.11675
16	2.45985	1.46605	.93116	.62428	.43828	.32009	.24181	.18806	.14997	.12221
18	3.20930	1.80854	1.09780	.70981	.48425	.34580	.25671	.19697	.15545	.12566
20	4.05043	2.16089	1.25606	.78523	.52209	.36565	.26753	.20308	.15901	.12779
22	4.97568	2.51618	1.40336	.85042	.55261	.38065	.27524	.20719	.16127	.12908
24	5.97669	2.86853	1.53820	.90583	.57682	.39181	.28063	.20991	.16269	.12985
26	7.04470	3.21314	1.65994	.95229	.59576	.40000	.28435	.21168	.16357	.13030
28	8.17072	3.54619	1.76854	.99077	.61041	.40593	.28689	.21282	.16410	.13056
30	9.34585	3.86479	1.86444	1.02232	.62162	.41019	.28861	.21354	.16443	.13071
32	10.56133	4.16688	1.94837	1.04797	.63012	.41322	.28975	.21400	.16462	.13079
34	11.80875	4.45107	2.02126	1.06864	.63652	.41536	.29052	.21429	.16474	.13084
36	13.08011	4.71658	2.08412	1.08520	.64131	.41685	.29102	.21447	.16480	.13087

Table 3.—Values for the denominator of equation (5) for different q ratios and diameter ranges using crown competition factor (CCF) as the density measure

2-in diameter classes	*q* ratio									
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
2	0.06709	0.06150	0.05677	0.05271	0.04920	0.04612	0.04341	0.04100	0.03884	0.03690
4	.17354	.15094	.13298	.11843	.10644	.09644	.08798	.08075	.07452	.06910
6	.32305	.26611	.22356	.19095	.16541	.14502	.12848	.11488	.10353	.09397
8	.51730	.40326	.32314	.26498	.22159	.18842	.16254	.14197	.12536	.11175
10	.75635	.55798	.42683	.33657	.27228	.22513	.18965	.16234	.14091	.12378
12	1.03904	.72570	.53058	.40308	.31625	.25498	.21040	.17707	.15155	.13161
14	1.36325	.90202	.63127	.46301	.35323	.27852	.22580	.18739	.15862	.13654
16	1.72620	1.08296	.72664	.51573	.38358	.29663	.23695	.19445	.16320	.13958
18	2.12459	1.26502	.81523	.56120	.40802	.31030	.24487	.19918	.16611	.14142
20	2.55486	1.44526	.89618	.59978	.42737	.32045	.25041	.20231	.16793	.14251
22	3.01324	1.62128	.96916	.63208	.44249	.32789	.25422	.20434	.16905	.14314
24	3.49590	1.79117	1.03417	.65879	.45417	.33327	.25682	.20565	.16974	.14351
26	3.99905	1.95352	1.09152	.68068	.46309	.33713	.25858	.20649	.17015	.14373
28	4.51897	2.10730	1.14167	.69845	.46986	.33987	.25975	.20701	.17040	.14385
30	5.05209	2.25184	1.18518	.71276	.47494	.34180	.26053	.20734	.17054	.14391
32	5.59503	2.38678	1.22267	.72422	.47874	.34315	.26104	.20755	.17063	.14395
34	6.14461	2.51199	1.25478	.73333	.48156	.34409	.26137	.20768	.17068	.14397
36	6.69785	2.62752	1.28213	.74053	.48364	.34474	.26159	.20775	.17071	.14399

Table 4.—Values of $e^{-D_i(\ln q)/2}$ in equation (3) for different q ratios

2-inch diameter classes D_i (1)	*q* ratio									
	1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)	1.6 (7)	1.7 (8)	1.8 (9)	1.9 (10)	2.0 (11)
2	0.909091	0.833333	0.769231	0.714286	0.666667	0.625000	0.588235	0.555556	0.526316	0.500000
4	.826446	.694444	.591716	.510204	.444444	.390625	.346021	.308642	.277008	.250000
6	.751315	.578704	.455166	.364431	.296296	.244141	.203542	.171468	.145794	.125000
8	.683013	.482253	.350128	.260308	.197531	.152588	.119730	.095260	.076734	.062500
10	.620921	.401878	.269329	.185934	.131687	.095367	.070430	.052922	.040386	.031250
12	.564474	.334898	.207176	.132810	.087791	.059605	.041429	.029401	.021256	.015625
14	.513158	.279082	.159366	.094865	.058528	.037253	.024370	.016334	.011187	.007813
16	.466507	.232568	.122589	.067760	.039018	.023283	.014335	.009074	.005888	.003906
18	.424098	.193807	.094300	.048400	.026012	.014552	.008433	.005041	.003099	.001953
20	.385543	.161506	.072538	.034572	.017342	.009095	.004960	.002801	.001631	.000977
22	.350494	.134588	.055799	.024694	.011561	.005684	.002918	.001556	.000858	.000488
24	.318631	.112157	.042922	.017639	.007707	.003553	.001716	.000864	.000452	.000244
26	.289664	.093464	.033017	.012599	.005138	.002220	.001010	.000480	.000238	.000122
28	.263331	.077887	.025398	.008999	.003425	.001388	.000594	.000267	.000125	.000061
30	.239392	.064905	.019537	.006428	.002284	.000867	.000349	.000148	.000066	.000031
32	.217629	.054088	.015028	.004591	.001522	.000542	.000206	.000082	.000035	.000015
34	.197845	.045073	.011560	.003280	.001015	.000339	.000121	.000046	.000018	.000008
36	.179859	.037561	.008892	.002343	.000677	.000212	.000071	.000025	.000010	.000004

Table 4 gives values of $e^{-D_i(\ln q)/2}$ to simplify computation of number of trees in 2-in diameter classes using equation (3). Table 5 is included to aid in computation of basal area or CCF by diameter classes; it gives basal area and maximum crown area (MCA) for the tree with a diameter equal to the midpoint of each diameter class. The MCA values for all trees are summed on a per acre basis to compute CCF.

Table 5.—Values of tree basal area and maximum crown area (MCA), by diameter class

2-in diameter class	Basal area	MCA
	Ft²	*% of an acre*
2	0.022	0.074
4	.087	.129
6	.196	.199
8	.349	.284
10	.545	.385
12	.785	.501
14	1.069	.632
16	1.396	.778
18	1.767	.939
20	2.182	1.116
22	2.640	1.308
24	3.142	1.515
26	3.687	1.737
28	4.276	1.974
30	4.909	2.227
32	5.585	2.495
34	6.305	2.778
36	7.069	3.076

How to Determine Residual Stand Structure

Once goals for residual stocking, maximum tree diameter, and q level have been selected, the specific structure for a stand can be calculated — providing data are available to construct a stand table.

Two existing old-growth spruce-fir stands on the San Juan National Forest in Colorado have been selected to illustrate the procedure (stands A and B). The actual inventory data for stand A are shown in cols. 1, 2, and 3 of table 6. A residual basal area of 80 ft² per acre in trees 3.0 in in diameter and larger has been chosen because: (1) it allows maximum reduction (30%) in present basal area consistent with previously developed recommendations for minimizing blowdown after partial cutting (Alexander 1973), and (2) it is the lowest basal area that appears to be a realistic timber management goal in spruce-fir stands. A maximum tree diameter of 24 in breast height was chosen because it also appears to be a realistic goals to be attained in a reasonable period of time. Lastly, a q of 1.5 was chosen because it approximates the q in the natural stand, and does not require removal of a large number of small trees. A lower q may be feasible, but it would require heavy cutting in lower diameter classes.

To determine the residual stand goal, the value of the residual density parameter k corresponding to a basal area of 80 ft² must be calculated. Values needed for this computation with a q of

Table 6.—Actual stand conditions and management goals for stand A using basal area as the density measure. All data on a per acre basis — stand goals; q = 1.5, residual basal area = 80 ft²; maximum tree d.b.h. of 24 in

Diameter class (*in*) (1)	Actual stand Trees (2)	Actual stand Basal area (3)	Residual stand goal Trees (4)	Residual stand goal Basal area (5)	Final stand Trees (6)	Final stand Basal area (7)	Cut Trees (8)	Cut Basal area (9)
	No.	*Ft²*	*No.*	*Ft²*	*No.*	*Ft²*	*No.*	*Ft²*
4	57	4.97	63.23	5.52	57.0	4.98	0	0
6	53	10.41	42.16	8.28	42	8.24	11	2.16
8	46	16.06	28.10	9.81	28	9.77	18	6.28
10	32	17.45	18.74	10.22	19	10.36	13	7.09
12	16	12.57	12.49	9.81	12.5	9.81	3.5	2.75
14	14	14.97	8.33	8.90	8.5	9.09	5.5	5.88
16	6	8.38	5.55	7.75	6	8.38	0	0
18	3	5.30	3.70	6.54	3	5.30	0	0
20	5	10.91	2.47	5.39	5	10.91	0	0
22	0	0	1.64	4.33	0	0	0	0
24	2	6.28	1.10	3.46	1	3.14	1	3.14
26	2	7.37	—	—	—	—	2	7.37
Total	236	114.67	187.51	80.01	182	79.98	54	34.67

1.5 are given in col. 6 of table 2. The value of k is computed as

$$k = \frac{80.0}{0.57682 - 0.01454} = 142.2779$$

where 80.0 is the desired basal area per acre, 0.57682 is the table value for the desired maximum tree diameter class of 24 in, and 0.01454 is the table value for the 2-in class. Note that the value for the 2-in class is subtracted from the 24-in class value, since trees below the 4-in class are not being considered in the management guidelines. Desired residual number of trees in each diameter class (col. 4 of table 6) can now be directly calculated by multiplying the proper diameter class values given in col. 6 of table 4 by the value of k computed above. The desired residual basal area in each diameter class (col. 5 of table 6) can be calculated by multiplying the residual number of trees in each diameter class by the tree basal area given in table 5.

Comparing actual and desired diameter distributions will show where deficits and surpluses occur (fig. 2). To bring this stand under management, number of trees should be allowed to increase in the diameter classes that are below the idealized stocking curve, with cutting limited to those diameter classes with surplus trees. As a guiding rule, enough trees should be left above the curve in surplus diameter classes to balance the deficit in trees in diameter classes below the curve. In this example, all surplus trees will be cut in the 6- to 14-in diameter classes, and in the 24- and 26-in classes, while no trees will be cut in

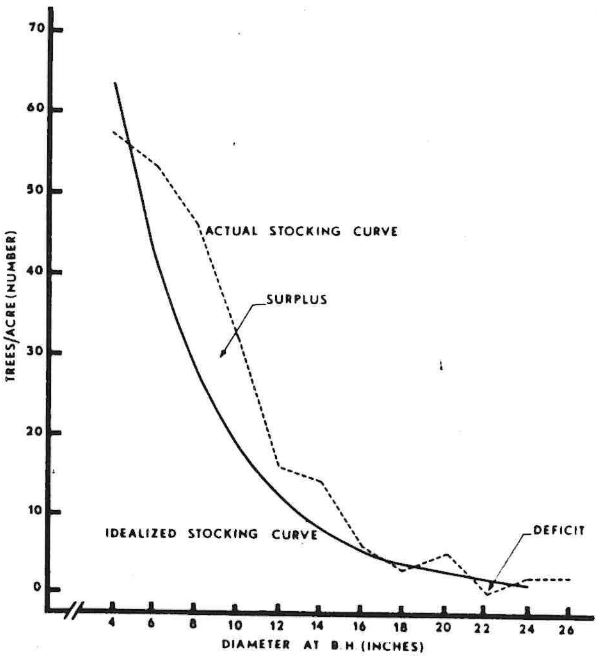

Figure 2.—Actual stocking curve of stand A from inventory data, and the idealized stocking curve based on stand structure goals.

the other classes. The final stand structure is shown in fig. 3 and cols. 6 and 7 of table 6. Cols. 8 and 9 show the trees and basal area removed.

Similar goals can be calculated using CCF as the density measure. Actual stand inventory data are again shown in cols. 1, 2, and 3 of table 7. Again assuming a 30% reduction in stand density, the residual CCF should be 55.8. Data from col. 6 of table 3 provides the following value of k:

$$k = \frac{55.8}{0.45417 - 0.04920} = 137.7880$$

The value of k is then used to compute the residual number of trees and MCA values (cols. 4 and 5, table 7). Computations are similar to the previous method using basal area, except that a slightly different k value, and tree MCA values are used. The final stand structure and trees to be cut are shown in cols. 6 through 9 in table 7.

It is not likely that unregulated stands will be brought under control with one cut or even a series of cuts. More likely, limitations imposed by stand conditions, windfall, and insect susceptibility will result in either over- or undercutting spruce-fir stands, at least at the first entry. Another example will illustrate this, using information from another stand on the San Juan National Forest (stand B). Actual stand inventory data are shown in cols. 1, 2, and 3 in table 8. A residual basal area of 120 ft² per acre in trees 3.0 in in diameter and larger would be a desirable stocking level based on previous assumptions.

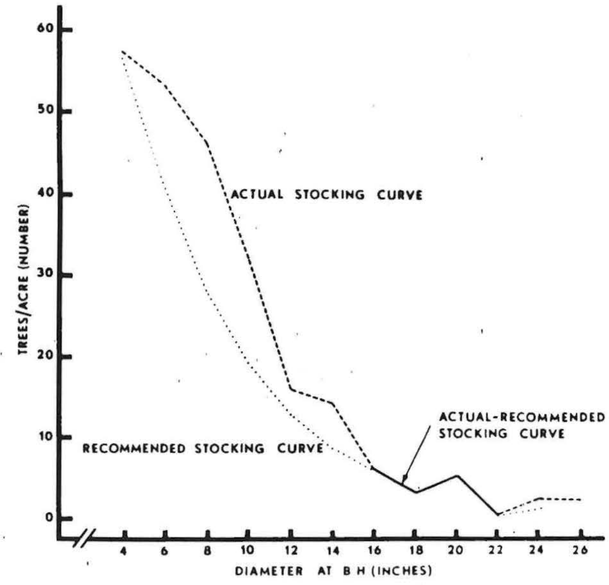

Figure 3.—Actual stocking curve of stand A, and recommended stocking curve based on stand structure goals, actual stand structure, and management and silvicultural constraints.

This would be too heavy a cut however, because it would open up the stand to possible damage from wind and subsequent loss to spruce beetles. With 223 ft² of basal area per acre in the stand, an initial reduction to 150 ft² per acre in trees 3.0 in in diameter and larger would be appropriate. A q of 1.5 and a maximum tree diameter of 24 in were

Table 7.—Actual stand conditions and management goals for stand A using crown competition factor (CCF) as the density measure. All data on a per acre basis

Diameter class (*in*) (1)	Actual stand Trees (2)	Actual stand Total MCA (3)	Residual stand goal Trees (4)	Residual stand goal Total MCA (5)	Final stand Trees (6)	Final stand Total MCA (7)	Cut Trees (8)	Cut Total MCA (9)
	No.	*CCF*	*No.*	*CCF*	*No.*	*CCF*	*No.*	*CCF*
4	57	7.35	61.24	7.90	57	7.35	0	0
6	53	10.55	40.83	8.13	41	8.16	12	2.39
8	46	13.06	27.22	7.73	27	7.67	19	5.39
10	32	12.32	18.14	6.98	18	6.93	14	5.39
12	16	8.02	12.10	6.06	12	6.01	4	2.01
14	14	8.85	8.06	5.09	8	5.09	6	3.76
16	6	4.67	5.38	4.19	6	4.67	0	0
18	3	2.82	3.58	3.36	3	2.82	0	0
20	5	5.58	2.39	2.67	5	5.58	0	0
22	0	0	1.59	2.08	0	0	0	0
24	2	3.30	1.06	1.61	1	1.52	1	1.51
26	2	3.47	—	—	—	—	2	3.47
Total	236	79.72	181.59	55.80	178	55.80	54	23.92

Table 8.—Actual stand conditions and management goals for stand B using basal area as the density measure[1]. All data on a per acre basis — stand goals: q = 1.5, residual basal area = 150 ft^2, maximum tree d.b.h. of 24 in

Diameter class (*in*) (1)	Actual stand Trees (2)	Actual stand Basal area (3)	Residual stand goal Trees[2] (4)	Residual stand goal Basal area (5)	Final stand Trees (6)	Final stand Basal area (7)	Cut Trees (8)	Cut Basal area (9)
	No.	*Ft^2*	*No.*	*Ft^2*	*No.*	*Ft^2*	*No.*	*Ft^2*
4	109	9.52	118.56	10.35	109	9.52	0	0
6	49	9.62	79.04	15.52	49	9.62	0	0
8	54	18.85	52.70	18.40	54	18.85	0	0
10	31	16.91	35.13	19.16	31	16.91	0	0
12	24	18.85	23.42	18.39	23	18.06	1	0.79
14	29	31.00	15.61	16.69	17	18.17	12	12.83
16	26	36.30	10.41	14.54	13	18.15	13	18.15
18	13	22.97	6.94	12.26	8	14.14	5	8.83
20	10	21.82	4.63	10.10	5	10.91	5	10.91
22	10	26.40	3.08	8.13	5	13.20	5	13.20
24	1	3.14	2.06	6.47	1	3.14	0	0
26	2	7.37	—	—	—	—	2	7.37
Total	358	222.75	351.58	150.01	315	150.67	43	72.18

[1]*Residual density parameter* k *for this example is computed as*

$$k = \frac{150.0}{0.57682-0.01454} = 266.77$$

Numbers of residual trees in each diameter class (col. 4) are computed by multiplying values in col. 6, table 4 by k.

again selected for the same reasons as in the first example. Procedures used to obtain cols. 4 and 5 in table 8 are also the same as before (table 6). A comparison of curves of actual and desired diameter distributions shows where deficits and surpluses occur (fig. 4). In this example, the bulk of trees removed will come from the 14- to 20-in diameter classes, but no more than half of the trees would be removed in the largest diameter classes. Few or no trees would be cut in the smaller diameter classes. The final stand structure is shown in fig. 5 and cols. 6 and 7 in table 8.

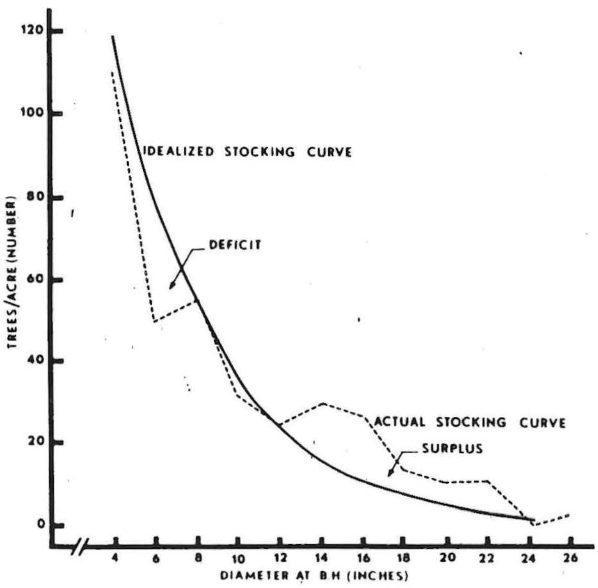

Figure 4.—Actual stocking curve of stand B from inventory data, and the idealized stocking curve based on stand structure goals.

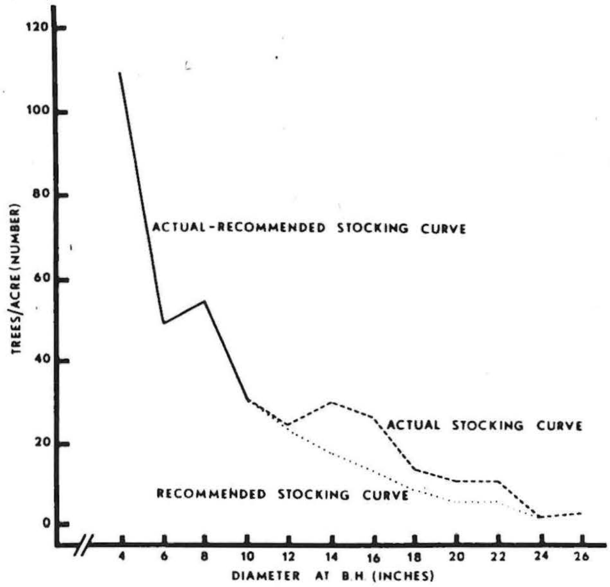

Figure 5.—Actual stocking curve of stand B, and the recommended stocking curve based on stand structure goals, actual stand structure, and management and silvicultural constraints.

Unmerchantable Trees — Regulated or Unregulated?

In the examples above, calculations were made down to the 4-in diameter class by 2-in classes because there are usually a large number of small trees in spruce-fir stands that are below minimum merchantable diameter. They compete with larger stems for growing space, and we need to know what is happening in this part of the stand. More importantly, these trees provide ingrowth into merchantable size classes needed to practice individual-tree selection silviculture.

Although small trees should not be ignored in inventory and record keeping, it may be neither desirable nor possible to regulate their numbers. In spruce-fir forests in the central Rocky Mountains, minimum merchantable diameter is usually 7 to 8 in. Regulation of the number of trees below this size requires an investment in cultural work that may not be recaptured under current market conditions. On the other hand, if trees below minimum merchantable size are left unregulated, cutting must always be heavy in the threshold diameter classes to bring ingrowth trees down to the desired number. It also means that more growing space is required for small trees than the idealized stand structure calls for. Moreover, the higher the threshold diameter class, the greater the proportion of the stand that is unregulated. More growing space is occupied by trees of low value that will be cut as soon as they cross the threshold diameter.

Marking the Trees in the Field

After residual stocking goals have been calculated and a decision made on how to handle small trees, it is time to mark the stand in the field. Marking is difficult in spruce-fir stands because the marker must designate cut or leave trees, usually with one pass through the stand, based on limited inventory data. At the same time, the marker must apply good silviculture and be aware of economic limitations. As a general rule, good silvicultural prescriptions are more important than strict adherence to structural goals, especially in unregulated stands being cut for the first time. However, marking without a structural goal — or prescribing structural goals that cannot be attained or applied — defeats the objective of regulation.

Marking for individual tree selection is more complex than for other systems, and some formal control procedure is necessary. Often, only an estimate of the initial stand and the desired residual diameter distribution is needed. With these estimates, basal areas and number of trees to be removed by diameter classes per acre can be determined. Control is maintained by a process of successive checks of residual vs the goal. For example, the markers should systematically make prism estimates of the residual stand after marking, recording trees by 2-in classes on a standard cumulative tally sheet[4]. Periodically, they should convert the prism tally to trees per acre, and compare their average prism estimate to the structural goal. Markers must then adjust to any serious deviation from the structural goal, such as too heavy marking in some diameter classes and too light in others. Their next check will determine if progress is being made or if further changes are needed. By this process, the average residual stand should come fairly close to the structural goal.

Cutting Cycles

Procedures described here are for initial entry into unregulated old-growth spruce-fir stands that are to be converted to managed uneven-aged stands. Without specific information on growth in uneven-aged stands, volumes available for cutting at some specified future time cannot be determined. However, a cutting cycle of 10 to 20 yrs seems reasonable as a first approximation for stands with all diameter classes represented, based upon the interval of reentry suggested for managed even-aged stands. If some diameter classes are not completely represented, volumes available for cutting may not warrant this frequency of cutting until a controlled diameter distribution is attained.

Harvesting the Timber

The most important problems associated with uneven-aged management in spruce-fir forests — after the stands are marked for cutting — are building and maintaining an adequate road system, developing proper logging equipment, and protecting the residual stand.

[4]It may be desirable to combine 2-in diameter classes into 4-in classes for purpose of marking control. This will simplify the marking procedure by reducing the number of diameter classes that must be handled.

Road System.—Because uneven-aged management requires frequent access by truck, the only realistic approach is to develop a permanent road system to service all areas in the management unit. In spruce-fir forests, harvesting timber usually means new road construction because large acreages are in undeveloped areas. Roads are therefore a costly front-end investment required at the time of initial entry. Furthermore, road costs usually exceed the value of stumpage removed in the initial entry, because there is no opportunity to spread the costs over the entire merchantable volume on a cutting area. Once the transportation system has been constructed, however, road costs should be independent of cutting method.

The number and location of truck roads depend upon maximum skidding distance, which in spruce-fir forests varies with skidding equipment, topography, management objectives, etc.

Protecting the Residual Stand.—Protection of the residual stand is of primary concern with any partial cutting system, but it is especially critical with individual-tree selection cutting because of frequent entries into the stand once a controlled diameter distribution is attained. Damage can result from felling, skidding, and slash disposal.

Felling damage can be reduced by using group selection and dropping trees into the openings, or marking a small clump of trees where felling one large tree will damage several adjacent trees. Skidding damage can be minimized by careful location and layout of skid roads. Skid roads should be about 200 ft apart — depending upon topography — and marked on the ground in advance of logging. These skid roads should be located so that they can be used to move logs out of the woods at each cut. Trees should be felled in a herringbone pattern to permit logs to be pulled into the skid roads with a minimum of disturbance to the residual stand. When it is necessary to deviate from a herringbone pattern to avoid felling damage, logs should be bucked into short lengths to reduce skidding damage. Skid roads should be laid out without sharp turns, because turning causes much of the skidding damage. All major skid roads should be wide enough to reduce border tree damage, but trees damaged in skidding should not be removed if they are still windfirm. Close supervision is necessary to restrict travel of skidding equipment to the skid roads, and to minimize felling damage.

Some slash disposal is usually needed after each entry, but most equipment available for slash disposal is not readily adaptable to working stands with residual trees. Burning slash will cause additional damage to the residual stand. About the only available means of treating slash are to: (1) pile and burn concentrations along landings, (2) chip, hand pile, or scatter slash along roads to reduce visual impact, and (3) lop the tops close to the ground elsewhere. In group selection cutting where there are no residual trees left in openings, small crawler tractors equipped with brush blades might be used to concentrate slash for burning. Piles must be kept small to reduce the amount of heat generated.

Summary

Conversion of old-growth spruce-fir stands with irregular structure to managed uneven-aged stands, involves three primary concerns: (1) cutting methods, (2) stand structure goals, and (3) harvesting and removal of trees. Furthermore, if regulation is to be achieved, all elements of the uneven-aged system must be accomplished on schedule and to specifications for each reentry.

Although individual-tree selection cutting is usually associated with uneven-aged management, group selection cutting must also be considered in spruce-fir stands.

Under uneven-aged management, yields are regulated through control over growing stock. To establish desired residual stand structure, it is necessary to control: (1) residual stocking left after cutting, (2) maximum tree size to be left, and (3) diameter distribution of the residual stand, defined here in terms of q, the average quotient between numbers of trees in successive diameter classes.

Stand structure goals chosen should provide for a reasonable cut of merchantable volume, an adequate residual volume for future cuts, and a predetermined level of cultural work in diameter classes below the merchantable limit.

To meet chosen structural goals, marking in the field must be controlled. This is accomplished by establishing procedures that provide for repeated estimates of residual stand volume, periodic checks of residual vs the goal, and subsequent adjustments in marking practice. Allowable harvest projections are relatively simple and straightforward in concept, but difficult to accomplish in uneven-aged spruce-fir forests because of lack of growth data. Without specific growth information, volumes available for cutting at some specified future time cannot be determined.

A permanent truck road system should be developed to service all stands under management.

Number and spacing of roads depend on maximum skidding distance, which varies with skidding equipment, topography, etc. Main skid roads should be laid out in advance of logging, without sharp turns, and wide enough to reduce damage to border trees. Felling damage can be reduced by using group selection and dropping trees into openings, or marking a small clump of trees. Some slash treatment is usually needed, but except for landings, along roads and in group openings, the only practical means is to lop the tops so they lie close to the ground.

Literature Cited

Alexander, Robert R. 1971. Crown competition factor (CCF) for Engelmann spruce in the central Rocky Mountains. USDA For. Serv. Res. Note RM-188, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Alexander, Robert R. 1973. Partial cutting in old-growth spruce-fir. USDA For. Serv. Res. Pap. RM-110, 16 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Alexander, Robert R. 1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Alexander, Robert R., Wayne D. Shepperd, and Carleton B. Edminster. 1975. Yield tables for managed stands of spruce-fir in the central Rocky Mountains. USDA For. Serv. Res. Pap. RM-134, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Bond, E. W. 1952. Growing stock differences in even-aged and all-aged forests. J. For. 50:691-693.

Bourne, R. 1951. A fallacy in the theory of growing stock. Forestry 24:6-18.

Hanley, David P., Wyman C. Schmidt, and George M. Blake. 1975. Stand succession and successional status of two spruce-fir forests in southern Utah. USDA For. Serv. Res. Pap. INT-176, 16 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Leaf, Charles F. 1975. Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge. USDA For. Serv. Res. Pap. RM-137, 31 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Leak, William D., and Stanley M. Filip. 1975. Uneven-aged management of northern hardwoods in New England. USDA For. Serv. Res. Pap. NE-332, 15 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Marquis, David A. 1975. Application of uneven-aged silviculture and management on public and private lands. p. 26-62. *In* Uneven-aged silviculture and management in the eastern United States. Proc. of an In-Service Workshop, [Morgantown,W. Va., July 15-17, 1975], 155 p. USDA For. Serv., Washington, D.C.

Meyer, H. A. 1952. Structure, growth and drain in balanced uneven-aged forests. J. For. 50:85-92.

Meyer, H. A., A. D. Recknagel, D. D. Stevenson, and R. A. Bartoo. 1961. Forest Management. 282 p. The Roland Press Co., New York, N.Y.

Moser, John W. 1976. Specification of density for the inverse J-shaped diameter distribution. For. Sci. 22:177-180.

Reynolds, R. R. 1954. Growing stock in all-aged forests. J. For. 52:744-747.

Trimble, George R., and H. Clay Smith. 1976. Stand structure and stocking control in Appalachian mixed hardwoods. USDA For. Serv. Res. Pap. NE-340, 10 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

U.S. Department of Agriculture. 1973. Silvicultural systems for the major forest types of the United States. USDA For. Serv. Agric. Handbk. 445, 114 p.

Agriculture—CSU, Fort Collins