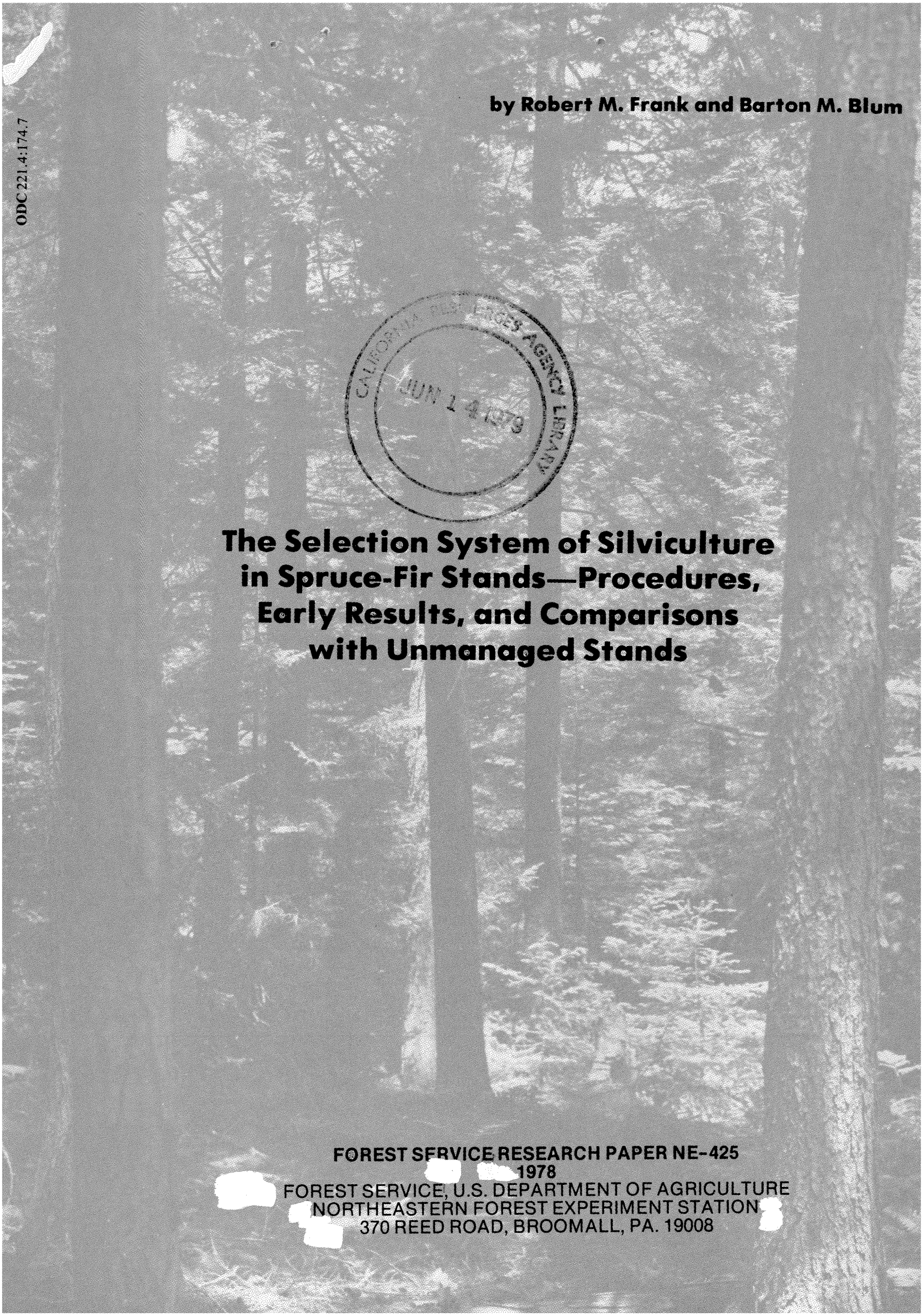


by Robert M. Frank and Barton M. Blum

The Selection System of Silviculture in Spruce-Fir Stands—Procedures, Early Results, and Comparisons with Unmanaged Stands

FOREST SERVICE RESEARCH PAPER NE-425
1978
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
370 REED ROAD, BROOMALL, PA. 19008

The Authors

ROBERT M. FRANK, research forester, received a bachelor of science degree in forestry from the Pennsylvania State University in 1954 and a master of forestry degree in forest products from the same university in 1956. He joined the USDA Forest Service in 1957 and has served in economics research, forest survey, and mine-spoil revegetation projects at the Northeastern Forest Experiment Station. Since 1963, he has been on the staff of the Station's spruce-fir silviculture project at Orono, Maine.

BARTON M. BLUM joined the Northeastern Forest Experiment Station in February 1957, shortly after earning his Master's degree in forestry from Yale University. He had earned his Bachelor's degree at Rutgers University in 1954 and has since gained a Ph.D. from the State University of New York at Syracuse in 1971. Dr. Blum is presently Project Leader of the Northeastern Forest Experiment Station's Orono, Maine work unit.

MANUSCRIPT RECEIVED FOR PUBLICATION 13 APRIL 1978

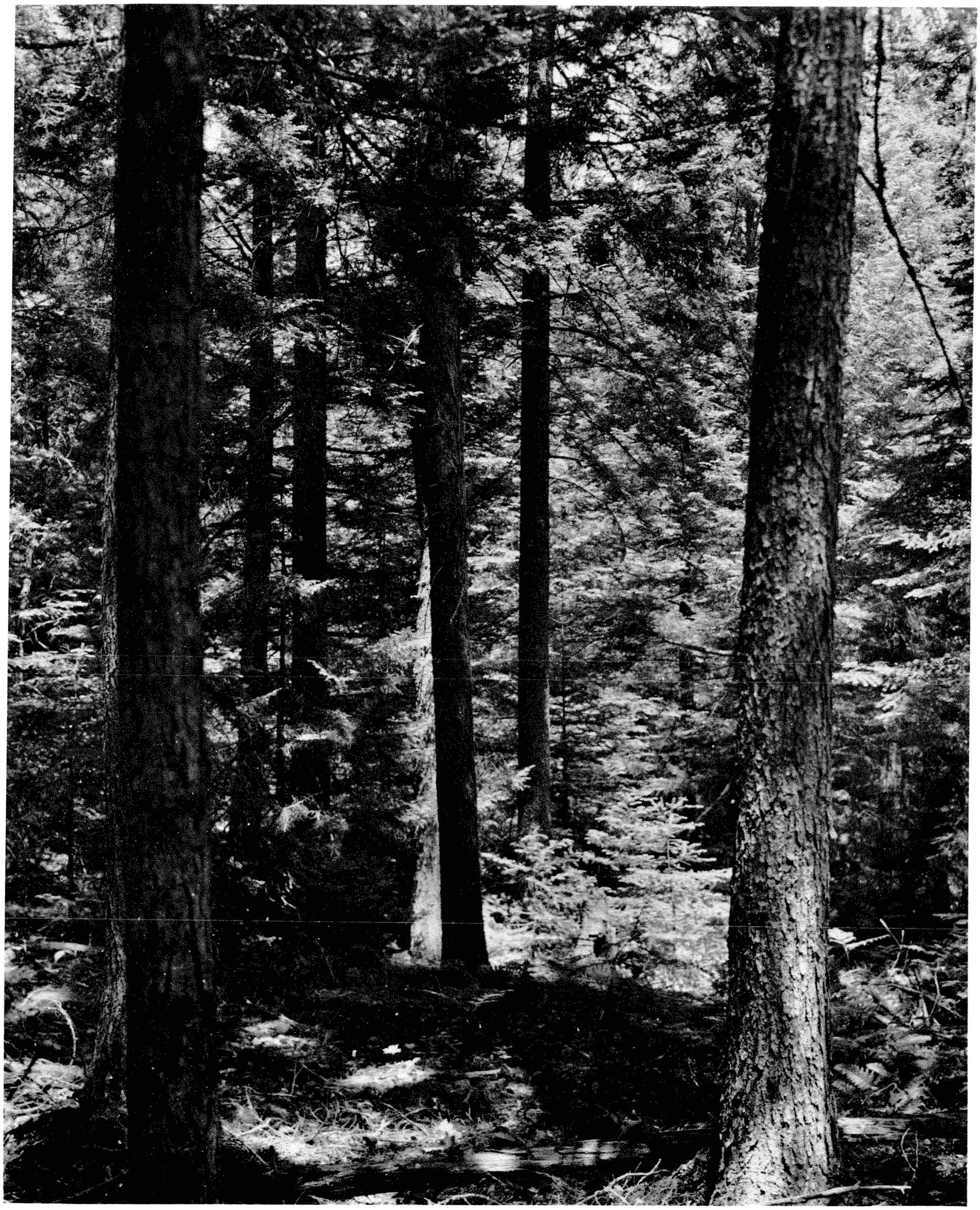
The Selection System of Silviculture in Spruce-Fir Stands—Procedures, Early Results, and Comparisons with Unmanaged Stands

by Robert M. Frank and Barton M. Blum

Abstract

Early results after 20 years of record keeping indicate that spruce-fir stands will respond to the selection system of silviculture. Stand quality is improved, species composition can be altered, diameter-class distribution approaches a stated goal, stand density is controlled, and yields are increased. Selection silviculture in spruce-fir can now be compared to early results from unregulated harvesting (commercial clearcutting) and no management for wood products (woodland preserve or wilderness). Lack of direct comparisons between selection silvicultural management and no management in spruce-fir stands has been partly responsible for the limited acceptance of the method.

Figure 1. A managed stand resulting from selection system silviculture.

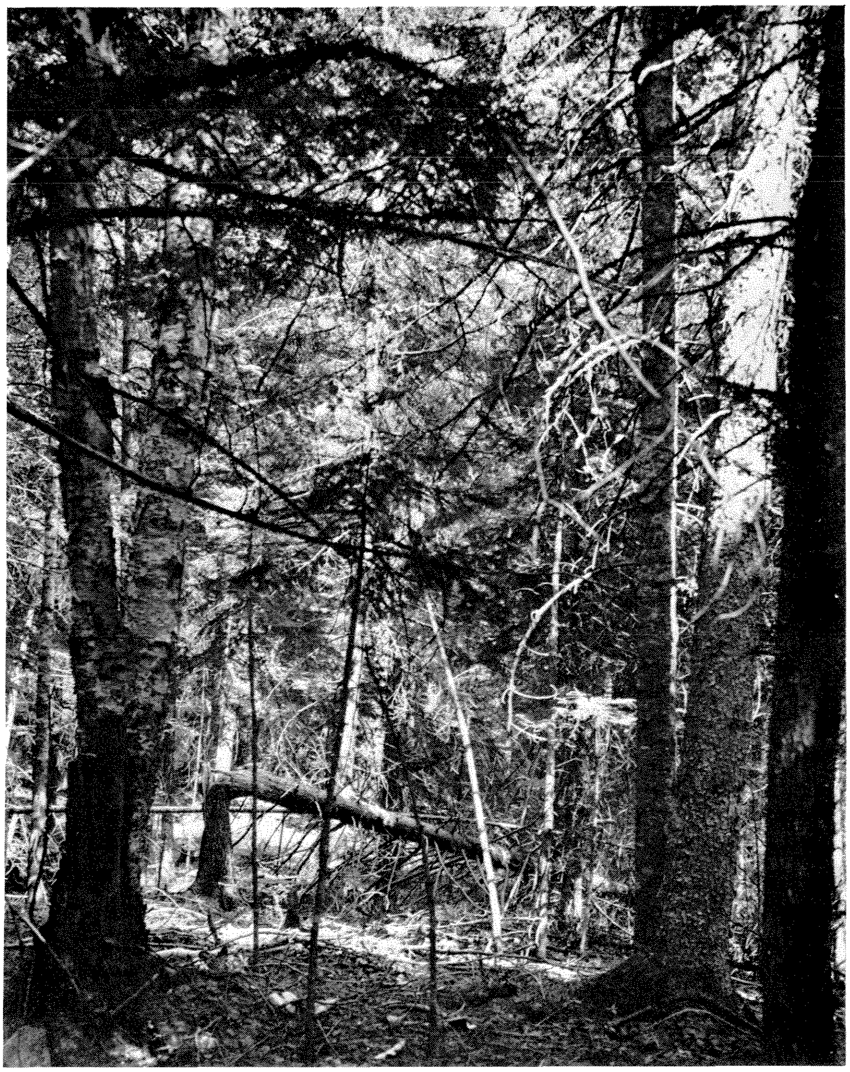


INTRODUCTION

THE SELECTION SYSTEM of silviculture, or uneven-age silviculture, is the periodic marking and harvesting of single trees or small groups of trees by diameter groups to provide a steady flow of forest products. This system requires the periodic removal of defective, slow-growing, or otherwise unwanted trees as part of the logging operation, and creates and maintains an uneven-aged stand of trees with a specific diameter distribution. Other long-term goals of the selection system are improvement of species composition, stand density, and stand quality. The system encourages the continuous establishment of natural reproduction and is particularly suitable for tolerant species such as the spruces and balsam fir. When aesthetics are important, it has the advantage of maintaining a continuous forest cover on the land.

In this paper we present the silvicultural procedures needed to apply the selection system in spruce-fir stands, and include comparative data from 20 years of experience in managing spruce and fir under the selection system, commercial clearcutting, and no management in a woodland preserve. The study is being conducted on the Penobscot Experimental Forest near Bangor, Maine (Figs. 1 and 2).

Figure 2. An unmanaged stand.



HOW TO BEGIN THE SELECTION SYSTEM OF SILVICULTURE

An inventory of the forest stand sets the stage for the initiation of any silvicultural system. The first step is to delineate each stand to be treated. Stands should be small enough to be reasonably uniform in characteristics such as species composition and diameter distribution, yet large enough to permit efficient harvesting. Utilizing streams and roads as boundaries minimizes the cost of administering boundaries.

A series of sample plots may be used to inventory stand characteristics. Or, for the smaller ownerships, the owner may desire to make 100-percent inventories. The sampling procedure can be random or systematic. For the smaller ownerships, a minimum of 10 sample plots should be taken or at least 1 per acre. In stands with uniform characteristics, this intensity of sampling should provide reliable estimates of numbers of trees, volume, basal area, species composition, diameter distribution and quality, on a per-acre basis. These can then be used to describe stand characteristics. If growth rates are desired, they can also be obtained from increment cores taken from a random selection of trees.

The inventory results, when compared with stand characteristic goals, form the blueprint for the work that must be accomplished during the initial operations. Later inventories will also serve as major tools for keeping the management program in line with the stated goals.

THE STAND CHARACTERISTICS GOALS

The primary timber management goal should be the perpetual flow of quality products from each stand in the forest ownership. This goal is attained with selection silviculture when each stand contains quality trees of desirable species in a balanced diameter-class distribution. How quickly this goal is realized depends not only on the original condition of the stand, but also on how often the stand is entered—the operating interval or cutting cycle.

Not all stands of trees are suited for the immediate application of the selection system of silviculture. Those highgraded in the past, where the best trees were removed and the poorest trees remain, are often depleted and deteriorating. Such areas have a high percentage of their growing-stock volume in cull trees, over-mature trees, or non-merchantable species and might better be regenerated by the clearcut or shelterwood systems than managed by the selection system. The conversion of even-aged stands to the selection system is also of doubtful practical value.

Nevertheless, these marginal stands can be cultured into operable selection stands if the owner is willing to accept the additional costs and time needed to condition them.

The selection of an appropriate operating interval depends on the degree of silvicultural management desired and the economics of the operation. A short interval gives a smaller periodic harvest and leaves more residual growing stock. With short operating intervals, loss of wood due to mortality may be reduced to near zero because diseased and other poor-risk trees are removed before they die. Because the general health of the stand is maintained damage is minimized from epidemics caused by insects or disease. A short operating interval means that the forest can be looked after more closely and higher production is likely.

However, if periodic production is low, a short operating interval may not be economical. Also, short intervals with frequent stand entries may result in relatively more logging damage to the residual stand, including regeneration.

Short operating intervals, less than 15 years, should result in fairly rapid attainment of initial stand characteristic goals. These goals should approximate the following:

a. *Stand quality.* Gross volume in cull trees (less than 50 percent merchantable), should be reduced to less than 5 percent of total stand volume. Defects in merchantable trees should be kept at a minimum.

b. *Species composition.* Listed below is a species composition goal suitable for a wide range of spruce-fir types. This goal is attainable on sites with impeded drainage and few hardwoods. These sites have the potential to produce cover types containing at least 50 percent spruce- fir.

Species	*Basal area (percent)*
Spruces - red, white, black *Picea rubens* Sarg., *P. glauca* (Moench) Voss, *P. mariana* (Mill.) B.S.P.	35 - 65
Balsam fir *Abies balsamea* (L.) Mill.	15 - 30*
Eastern white pine *Pinus strobus* L.	5 - 10
Paper birch *Betula papyrifera* Marsh.	5 - 10
Eastern hemlock *Tsuga canadensis* (L.) Carr.	15 - 25
Northern white cedar *Thuja occidentalis* L.	5 - 10
Other	5 - 10

* Where widespread spruce budworm *Choristoneura fumiferana* (Clem.) infestation is present this is probably too high as a goal, but nevertheless realistic in terms of the effort required to achieve a much lower fir representation in the stand.

c. *Diameter-class distribution.* A balanced diameter class distribution is essential to the selection system. A stand that has or is approaching a balanced diameter distribution is a stand in which age classes cannot be readily recognized (Meyer et al. 1952). In balanced stands, each periodic harvest will include a greater volume in large, mature trees than in small, young trees. In selection forests, DeLiocourt (1898) observed that the numbers of trees in successive diameter classes form a geometric progression. When these are plotted on graph paper, they form an inverse J-shaped curve. If they are plotted on semilogarithmic paper, the plot should approximate a straight line.

With either method, the closer the actual data fit the ideal curve or line, the better the diameter distribution is balanced. The quotient "q", or ratio of the number of trees in a diameter class divided into the number of trees in the next smaller diameter class, should be about 1.3 or 1.4 for stands being managed for several products. Balanced distributions by 1-inch classes having a "q" of 1.4 for three operating intervals and for stands being managed for integrated products are given in Table 1.[1]

On many sites that support spruce-fir types, the maximum diameter of the largest trees at the end of an operating interval should not exceed 20 inches dbh. In selecting a maximum tree size both product objective and the potential of the site to produce large trees in a reasonable time must be considered.

d. *Stand density.* The average stand density (stand density midway through the operating interval) necessary for sustained yield of all products should be between 100 and 120 square feet of basal area per acre for trees in all diameter classes, depending on the length of the operating interval. At the start of an operating interval (immediately after a harvest) this ranges between 80 and 115 square feet of basal area per acre (Table 1).

[1] Traditionally, "q" is based on 2-inch diameter classes, especially when the largest trees being managed for exceed 30 inches dbh. A "q" of 1.4 by 1-inch classes equals a "q" of 1.96 by 2-inch classes.

STAND TREATMENTS UNDER THE SELECTION SYSTEM

The initial operations under the selection system are stand conditioning operations. These operations are designed to groom formerly neglected stands by removing poor-risk and poor-quality trees. These trees may comprise the bulk of the material removed initially, with the windfirmness of the residual stand the only constraint.

Windfirmness of a stand after harvest should be given priorty over all other stand characteristics. To minimize the danger of wind damage, limit timber stand improvement and harvest operations to 10 to 40 percent of total basal area on primary softwood sites—the poorly drained areas and the thin soils of upper slopes. Similar precautions are required on secondary softwood sites—the better drained deep soil areas—where 30 to 50 percent of basal area may be removed at any one time. The amount to remove in any operation will depend on specific site conditions (Frank and Bjorkbom 1973) and should be based on experience in a given area. When possible, maintain a basal area near the goals stated in Table 1.

Once the volume of poor-risk poor-quality trees is reduced to an acceptable level, stricter compliance with selection-system criteria is called for, and the controlling factor is the stand-density goal.

The proportion of the net periodic volume growth removed during an operation is governed by the amount of total basal area in the stand at the time of the harvest. If the postharvest stand-density goal cannot be met because of inadequate stocking, less than the total periodic growth should be removed. For a rapid buildup of growing stock in a stand, only one-half the net periodic growth should be removed in each operation until the density goal can be met. If the postharvest stand-density goal can be met initially, 100 percent or more of the periodic volume growth is harvested.

Once the amount of growing stock to be removed is determined, the harvest is distributed among size classes and species in order to meet the

Table 1.—Balanced diameter-class distributions ("q" = 1.4): theoretical stand stocking goals at the start of 5-, 10-, and 20-year operating intervals (expressed as number of trees per acre and square feet of basal area per acre).

Dbh Class	5-year Operating interval		10-year Operating interval		20-year Operating interval	
	Trees	Basal area	Trees	Basal area	Trees	Basal area
in.	*no.*	ft^2	*no.*	ft^2	*no.*	ft^2
5	78	10.6	68	9.4	57	7.7
6	56	10.9	49	9.6	40	8.0
7	40	10.6	35	9.3	29	7.7
8	28	9.9	25	8.7	21	7.2
9	20	9.0	18	7.9	15	6.5
10	15	7.9	13	7.0	11	5.8
11	10	6.8	9	6.0	7	5.0
12	7	5.8	6	5.1	5	4.2
13	5	4.9	5	4.3	4	3.6
14	4	4.0	3	3.6	3	2.9
15	3	3.3	2	2.9	2	2.4
16	2	2.7	2	2.4	1	2.0
17	1	2.2	1	1.9	—	—
18	1	1.7	1	1.5	—	—
19	1	1.4	—	—	—	—
Total	271	91.7	237	79.6	195	63.0
1-4	774	23.3	683	20.5	565	17.0
Grand total	1045	115.0	920	100.0	760	80.0

treatment goals for these as closely as possible. Harvesting is a process of removing excesses to achieve the desired species composition and balanced diameter distribution.

In attempting to reach these treatment goals, thought must be given to (1) the proper distribution of residual trees, especially those being groomed as selected crop trees, (2) the environmental conditions necessary for the establishment of reproduction, and (3) the windfirmness of the residual stand.

Optimum growing space is essential for the rapid development of crop trees. For pole-sized white spruce, optimum growing space is created by releasing trees from their competitors on at least three sides (Frank 1973). In spruce-fir it is probably best to release trees when they are in the 4-inch dbh to 8-inch dbh classes. And under intensive management, even smaller trees should be released.

For the continuing development and establishment of new seedlings, openings larger than those created by the removal of individual trees may be required. The area around developing crop trees should be enlarged in successive operations.

Two of the more important steps are marking the stand to be harvested and seeing to it that loggers comply with the marking as closely as possible. In the early operations not all goals will be met simultaneously, and considerable judgment is required to achieve a balance among them. The reader is encouraged to review A Silvicultural Guide for Spruce-Fir in the Northeast (Frank and Bjorkbom 1973) for guidance in selecting and marking trees, developing tally sheets, and for additional information related to uneven-age silviculture.

THE TREATMENTS IN PRACTICE

On the Penobscot Experimental Forest we have been practicing various degrees of selection system silviculture and management using the basic profiles just outlined. Three intensities of the selection system, after 20 years under management, reached a point where early comparisons between intensities are possible. We also have data on an unregulated harvesting area and a woodland preserve for comparison.

Treatments are replicated twice, except for the woodland preserve, which is not replicated. All data are derived from 155 circular plots of 1/5-acre each, located either systematically or randomly. Treated areas average about 25 acres each.

Trees 4.5 inches dbh and larger are measured on the 1/5-acre plots; trees smaller than 4.5 inches dbh but at least 0.5 inch dbh are measured on circumscribed 1/20-acre plots; and trees smaller than 0.5 inch dbh are measured on three circular milacre plots systematically located on the circumference of each 1/20-acre plot. Sampling intensities are 13.0 percent, 3.3 percent, and 0.2 percent, respectively.

The selection system treatments

The intensity of the selection treatments we are applying is characterized by the frequency of stand entry, the minimum size-class of trees being treated, and the residual growing stock goals. We have both a 5-year operating interval and a 10-year operating interval under intensive management, and a 20-year operating interval under extensive management.

Under our intensive selection goals we mark trees down to the 1-inch diamter class for harvest or timber stand improvement. Our extensive selection treatment calls for marking trees in the 5-inch diameter class and larger only.

A more rapid buildup of growing stock is expected with the intensive treatments than with the extensive ones. In the former, up to 50 percent of net periodic growth is left to be added to the growing stock at each harvest until the desired stocking level is reached; in the latter, a maximum of 25 percent of net periodic growth is left.

Unregulated harvesting

Our unregulated harvesting area provides no control over harvesting practices. The loggers take the best and leave the rest. This treatment results in a heavy felling of merchantable trees and sometimes can approach a true clearcut. When all but a few trees are removed, the next stand entry may be delayed 40 to 65 or more years.

Woodland preserve

Our woodland preserve area is set aside to allow natural processes to control the development of the forest ecosystem. No harvesting operations or other treatments take place in this area.

RESULTS AND COMPARISONS

Results and treatment comparisons based on 20 years of observations (only 17 years in one treatment) must be read in the proper context. We emphasize that in most forest stands this is less than half of the time needed to produce either pulpwood-sized or sawlog-sized trees.

With these words of caution, we present the following results and comparisons for:

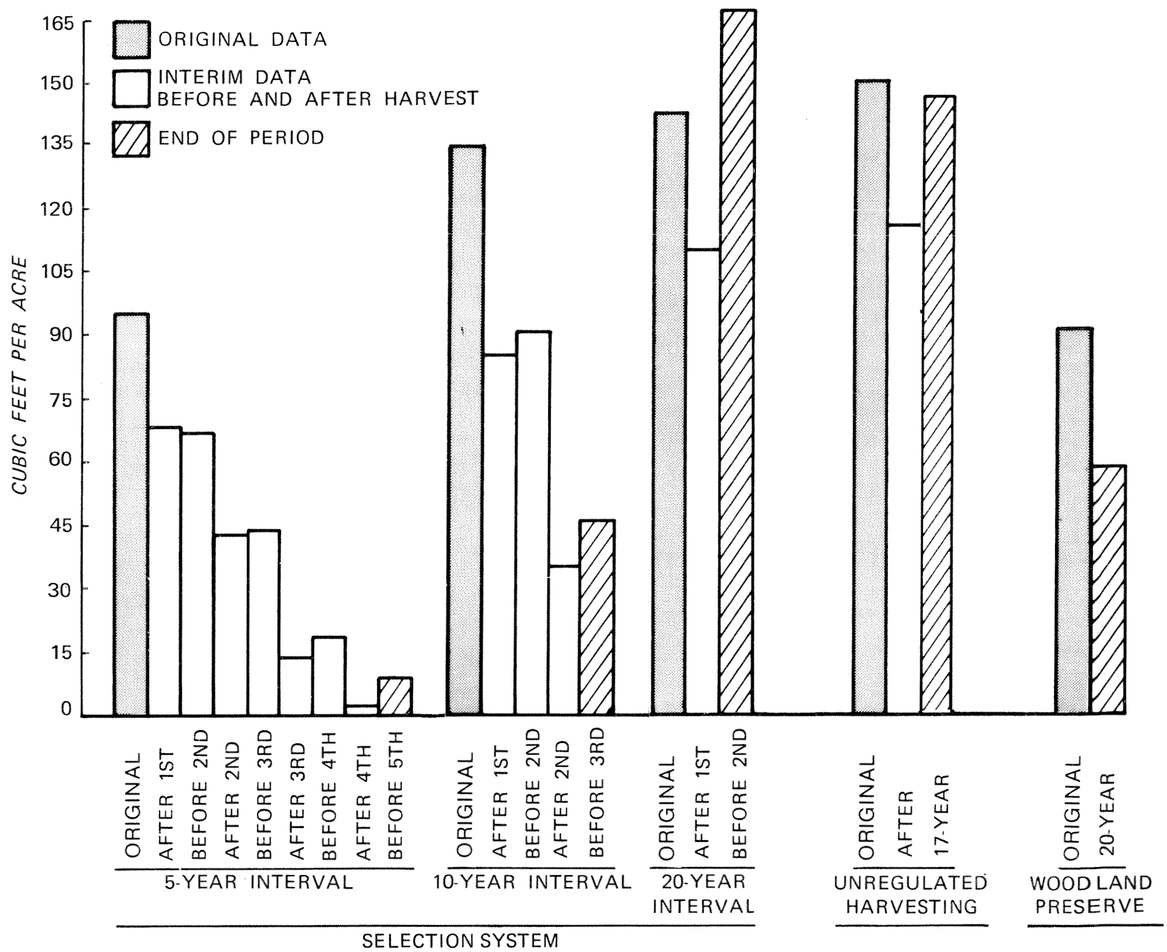
a. Stand quality
b. Species composition
c. Diameter-class distribution
d. Stand density
e. Growth

Stand quality

One measure of stand quality is the percentage of stand volume in cull trees. Our definition of a cull tree is a tree that contains less than 50 percent usable material. The cull and otherwise nonusable portions of merchantable trees are not included in the measure of stand quality. A major reduction of cull-tree volume occurred in the two intensive selection treatments; a moderate increase in the extensive selection treatments; practically no change for the unregulated method; and a moderate reduction due to natural mortality in the woodland preserve (Fig. 3).

We measured a 90 percent reduction in cull-tree volume in the intensive treatment with the 5-year operating interval. In this stand, subjected to four

Figure 3. Volume in cull trees by treatment and time period.



harvest and timber stand improvement operations, stand entries are twice and four time as frequent as those under the 10-year intensive selection treatment and the 20-year extensive selection treatment.

Cull-tree volume was reduced 65 percent under the intensive selection treatment with a 10-year operating interval; it increased 17 percent under extensive selection with a 20-year interval.

Cull-tree volume fluctuates with time in stands being managed by the selection system. Reductions in cull volume observed after each operation were usually followed by increases during the interval between stand entries (Fig. 3). Both the periodic rate of cull-tree volume accumulation and the periodic change are related to the length of the operating interval. More lengthy operating intervals tend to increase the rates of cull- tree volume accumulation between stand entries, because cull trees are allowed to accrue more volume.

These relationships for the initial 20 years of selection treatment are shown below (in cubic feet per acre):

Interval	*Annual cull-tree volume accumulation rate*	*Periodic cull-tree volume increase or decrease*
5-year	0.6	−87
10-year	0.9	−89
20-year	2.8	+24

At the end of the treatment period, cull-tree volumes in the selection system treatments were 0.6 percent, 2.5 percent, and 6.2 percent of growing stock for the 5-, 10-, and 20- year interval treatments, respectively.

With unregulated harvesting, cull-tree volume increased modestly from 8.1 percent to 10.6 percent of growing stock. Cull-tree volume accumulation was at an annual rate of 1.9 cubic feet per acre. The cull-tree volume at the end of the treatment period was 10.6 percent of growing stock, 3.4 times the average for the selection systems.

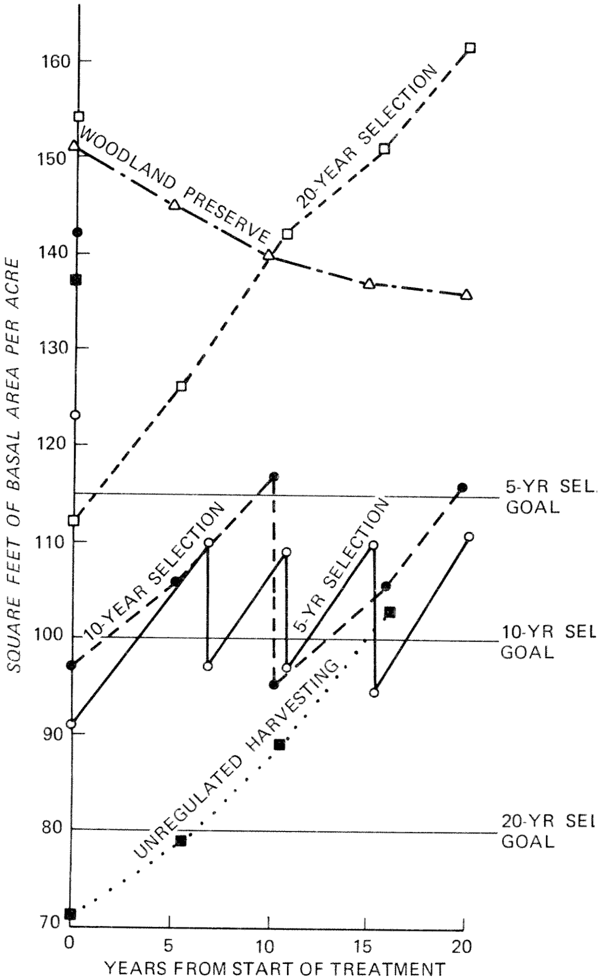
Surprisingly, cull-tree volume decreased from 4.0 to 2.4 percent of growing stock in the woodland preserve, apparently because of the high mortality rate of 52 cubic feet per acre per year—almost 6 times that observed in the selection areas and almost 3.5 times that observed in the unregulated area. Evidently cull trees were not persisting. Two-thirds of the mortality was in balsam fir.

Stand density

Densities of the selection system treatments were designed to be different at the start of an operating interval which is immediately after each harvest (Fig. 4). Theoretically they should be approximately equal at the end of each interval which is immediately before each harvest.

The density goal of the 20-year interval treatment was lowest; the goal for the 5-year interval the highest. However, these goals were not met because of variations in original basal areas, fear of excessive wind damage after logging, and continued removal of poor-risk trees to condition stands. Inconsistencies in controlling basal area

Figure 4. Actual and theoretical basal area densities by treatment at various times.



densities are being reduced and variations from goals will shortly be minimized (Fig. 4). And as more knowledge becomes available, the goals themselves may be changed. For instance, if adequate numbers of saplings fail to reach pole size, this may indicate overstocking and density goals might be reduced.

Species composition

The species composition goals given earlier are based primarily on the adaptability of the various species to environmental conditions fostered by the selection system and their ability to grow on a range of spruce-fir sites. On most spruce-fir sites, shade-tolerant species such as red spruce, balsam fir, and hemlock will increase in numbers in the understory soon after selection silviculture is initiated. Less shade-tolerant species, including paper birch and white pine, will decline in numbers. In fact, an early increase in regeneration of preferred species in the understory is no guarantee that they will be successfully established unless the necessary cultural practices are carried out periodically. It will take a long time to change the representation of species in the overstory.

How close we are to meeting these goals now and in the near future is reflected in the present composition of the sapling, pole, and sawtimber classes. How well we will fare over the long term, however, is indicated by trends in species composition, growth, and regeneration from which crop trees will eventually be chosen.

Species composition of regeneration. The tolerant spruces, primarily red and white spruce, increased in both numbers per acre (Table 2) and percent stocking (Table 3) under all treatments; in the woodland preserve, there was a decrease in percent stocking of spruce less than 6 inches tall. Percent stocking as a measure of the number of stocked milacres is an indicator of the distribution of regeneration throughout the area being sampled.

The largest increase in spruce seedlings taller than 6 inches occurred in the stands managed by the selection system. Spruces made up 11.1 percent of all seedlings at 19 years, compared with 7.4 percent at 9 to 10 years (Table 2). Perhaps of greater importance to future stand composition than number of seedlings is the increase in percent stocking of this size class. In the selection system stands, spruce stocking increased from an average of 16 percent 9 to 10 years after treatment to 42 percent after 19 years (Table 3).

Balsam fir is increasing in large numbers except where management is most intense—the 5-year interval selection treatment. This treatment registered the smallest gain, only 1,000 seedlings per acre during the past 10 years. Balsam fir had the highest stocking of any species.

Hemlock is responding in a manner very similar to spruce, but numerical increases are much larger. More prolific seeding habits, greater seed source, and greater shade tolerance account for these increases. Hemlock, though not as highly

Table 2. Status of regeneration: number of stems per acre 6 inches in height to 0.5 dbh by treatment at two periods of time after initial treatment.

Species	Treatment and number of years since initial treatment									
	Selection system						Unregulated (commercial clearcutting)		Woodland preserve	
	Intensive 5-yr interval		Intensive 10-yr interval		Extensive 20-yr interval					
	10 years	19 years	10 years	19 years	9 years	19 years	9 years	19 years	10 years	19 years
Spruce	430	1160	770	2500	160	730	370	640	150	1040
Balsam fir	2990	3990	4390	9290	900	2730	4600	6700	4150	12110
Hemlock	1770	5030	1070	5510	760	3830	1210	2190	150	340
Red maple	1300	1070	1070	1030	220	300	1310	1550	220	480
Paper birch	350	490	630	290	590	100	1790	360	70	740
Other species	400	780	420	460	230	200	1910	1030	560	810
Total	7240	12520	8350	19080	2860	7890	11190	12470	5300	15520

Table 3. Status of regeneration: percent stocking by treatment, by species, and by size class at two periods of time after initial treatment.

Species and size class	Treatment and number of years since initial treatment									
	Selection systems						Unregulated (commercial clearcutting)		Woodland preserve	
	Intensive 5-yr. interval		Intensive 10-yr interval		Extensive 20-yr interval					
	10 years	19 years	10 years	19 years	9 years	19 years	9 years	19 years	10 years	19 years
Spruce										
<6.0 in	59	65	64	79	66	86	32	36	63	59
>6.0 in	21	45	20	49	8	32	20	33	7	33
All	64	77	66	88	68	89	43	52	63	67
Balsam fir										
<6.0 in	85	81	97	90	94	93	89	86	100	100
>6.0 in	59	71	65	74	38	41	70	86	70	70
All	89	94	98	98	95	94	96	98	100	100
Hemlock										
<6.0 in	95	88	55	63	87	91	49	54	22	37
>6.0 in	49	62	25	46	12	47	31	36	15	22
All	95	93	57	72	87	91	54	61	33	48
Red maple										
<6.0 in	79	77	85	39	77	50	54	77	96	93
>6.0 in	26	30	30	33	9	14	39	41	7	26
All	83	82	87	58	77	59	65	84	96	100
Paper birch										
<6.0 in	27	23	30	16	24	6	27	17	37	59
>6.0 in	13	14	21	14	14	9	35	16	7	7
All	30	28	38	23	30	12	44	28	44	59
Other species										
<6.0 in	34	24	42	37	26	13	50	41	44	63
>6.0 in	18	26	16	20	5	10	32	36	22	33
All	40	38	49	49	27	21	61	57	44	74
All species										
<6.0 in	100	96	99	94	98	98	98	93	100	100
>6.0 in	81	85	81	82	53	61	85	90	70	78
All	100	99	100	99	98	98	100	99	100	100

favored as the spruces, is a species well adapted to our stand conditions.

Red maple (*Acer rubrum* L.), usually an unwanted species because of its poor quality and restricted markets, is being reduced numerically under selection silviculture. Our aim is not to eliminate it completely but to encourage only selected specimens. It should not be a future problem in our selection stands but is increasing in both the unregulated stands and the woodland preserve.

Other species present are cedar, white pine, aspen (*Populus tremuloides* Michx., and *P. grandidentata* Michx.), paper birch and gray birch (*Betula populifolia* Marsh). They will not be major components of selection stands. As seed-source trees of these species are removed from the overstory, the opportunity for establishing new regeneration is diminished. Also, the ability of these less tolerant species to grow into a dominant position is limited because of the continuous overstory present. The more open crown canopy of the unregulated stands enhances the persistence of intolerant species. Their retention and propagation in the woodland preserve is dependent upon a seed source in the overstory and upon conditions favorable for regeneration and ultimate establishment brought about by high mortality. White pine is and has been a very important component of the growing stock in the woodland preserve. Cedar is also represented in moderate numbers.

None of our treatments has resulted in a shortage of established regeneration (Table 2 and 3). For instance, after 19 years of management, the lowest percent stocking by species is restricted to the two treatments supporting the most basal area:

Spruce — 32 percent stocking, 20-year interval selection

Balsam fir — 41 percent stocking, 20-year interval selection

Hemlock — 22 percent stocking, woodland preserve

Red maple — 14 percent stocking, 20-year interval selection

Paper birch — 7 percent stocking, woodland preserve

Other species — 10 percent stocking, 20-year interval selection

Any species — 61 percent stocking, 20-year interval selection

In summary, observations of regeneration over a period of almost 20 years indicate that spruce-fir stands can be cultured to ultimately support favored species and that species composition goals can be met.

Species composition of saplings, poles, and *sawtimber.* It will be many years before the stands being managed under the selection system reach the species composition goals suggested for spruce-fir types. The time required to mold a stand to a desired species composition is related both to the intensity of management and to the differences between the composition goal and that of the original stand—the lower the intensity and the larger the deviation, the more time is required.

With the exception of the 10-year interval stands, where the goal has been reached primarily because of favorable species representation at the outset, the goals of the other selection treatments have not been reached. Both the 5-year and the 20-year interval stands supported a minor amount of spruce and fir and a large amount of hemlock (Table 4). However, if the present trend continues in these stands, the spruce-fir component will increase at the expense of all other species including hemlock. The hemlock component is expected to decrease slowly under all levels of management,

Table 4. Status of trees 0.5 inches dbh and larger: percentage of basal area by species at various times for each treatment.

Time	Species					
	Spruce	Balsam fir	Hemlock	Red maple	Paper birch	Other species[a]
			SELECTION, 5-YEAR INTERVAL			
Original stand	14	11	40	11	5	19
After 1st harvest	17	12	40	7	6	18
Before 5th harvest	22	17	44	5	4	8
Selection system goal	35-65	15-30	15-25	5-10	5-10	10-20
			SELECTION, 10-YEAR INTERVAL			
Original stand	20	36	16	8	3	17
After 1st harvest	27	36	14	7	2	14
Before 3rd harvest	34	28	16	10	3	9
Selection system goal	35-65	15-30	15-25	5-10	5-10	10-20
			SELECTION, 20-YEAR INTERVAL			
Original stand	15	16	47	3	1	18
After 1st harvest	18	17	43	2	1	19
Before 2nd harvest	20	18	45	3	1	13
Selection system goal	35-65	15-30	15-25	5-10	5-10	10-20
			UNREGULATED HARVESTING			
Original stand	17	29	19	12	4	19
After 1st harvest	7	29	15	17	4	28
17th year measurement	10	24	18	20	5	23
			WOODLAND PRESERVE			
Original stand	13	37	13	7	2	28
20th year measurement	14	18	18	14	3	33

[a] Mostly northern white cedar, eastern white pine, and other hardwoods.

both with the removal of all low quality, poor risk trees and with the entrenchment of a stronger component of intensively favored spruce.

As expected, unregulated harvesting reduced the spruce-fir component and correspondingly increased hardwoods. These results would have been more pronounced if a higher proportion of the stand had been harvested.

Except for the large reduction in balsam fir, the composition of the woodland preserve remained relatively stable. The reduction in fir was accompanied by gains in hemlock, red maple, and white pine. A further reduction in the relatively short-lived balsam fir component is expected in the future.

Diameter-class distribution

The number of years required to approach the goals shown in Table 5 depends on the original stand conditions and the length of the operating interval. Experience has demonstrated that two or three conditioning operations at the scheduled intervals are needed to achieve semblance of order in a formerly disordered stand.

Early trends in our stands under selection silviculture show a rapid reduction in numbers of trees in the 1- to 4-inch dbh class (Table 5 and Fig. 5). However, except for the two smallest classes in the 5-year interval treatment, all other diameter classes in selection treatments are close to their goals or show surpluses from which the next removals will be made. Diameter distributions are expected to remain essentially balanced after this operation is completed.

The relatively dense canopy of the woodland preserve is retarding the development of seedlings into the sapling class. This may not continue, however, because the high mortality in this treatment has created openings suitable for sapling development. Almost 60 years after the last harvest in this stand, the number of saplings is 300 per acre and the total number of trees in all size classes is only 600 per acre. No other treatment has so few trees.

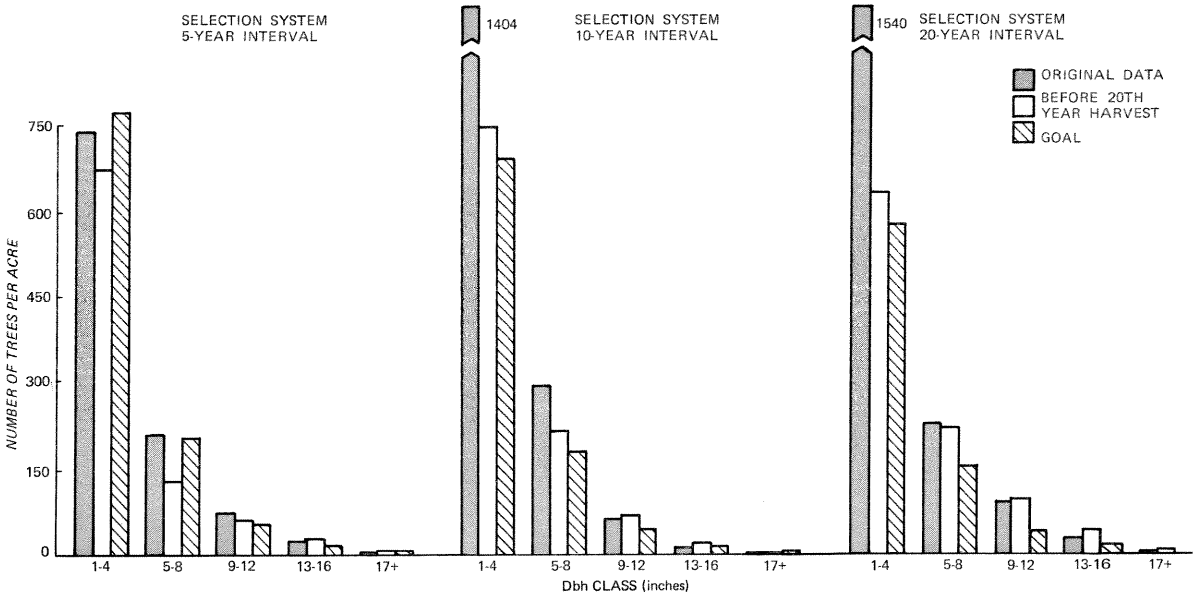
Table 5. Status of trees 0.5 inches dbh and larger: number of trees per acre by 4-inch diameter classes at various times for each treatment.

Time	Size class (dbh in inches)					Total
	Saplings (1-4)	Poles (5-8)	Small sawtimber (9-12)	Medium sawtimber (13-16)	Large sawtimber (17+)	
			SELECTION, 5-YEAR INTERVAL			
Original stand	*734*[a]	207	72	19	*2*	*1034*
After 1st harvest	*624*	*160*	56	*13*	*1*	*854*
Before 5th harvest	*668*	*126*	61	23	3	*881*
Goal after harvest	773	202	53	14	3	1045
			SELECTION, 10-YEAR INTERVAL			
Original stand	1404	285	60	*9*	*1*	1759
After 1st harvest	1016	223	*36*	*4*	[b]	1279
Before 3rd harvest	730	211	64	14	*1*	1020
Goal after harvest	683	177	46	12	2	920
			SELECTION, 20-YEAR INTERVAL			
Original stand	1540	221	88	22	2	1873
After 1st harvest	1200	193	68	11	[b]	1472
Before 2nd harvest	625	217	90	35	3	970
Goal after harvest	565	147	38	10	0	760
			UNREGULATED HARVESTING			
Original stand	999	287	60	10	2	1358
After 1st harvest	693	186	20	2	1	902
17th year measurement	1054	228	45	6	1	1334
			WOODLAND PRESERVE			
Original stand	858	310	64	16	4	1252
20th year measurement	299	200	70	23	9	601

[a] Values in italics are below goals based on $q = 1.4$

[b] Less than 0.5 trees per acre

Figure 5. Diameter-class distribution by number of trees per acre by treatment at two periods of time and by goal.



Periodic annual growth

The components of growth include net growth, mortality, ingrowth, accretion, and gross growth. These terms are:

Net growth. The net change in volume between two inventories (ingrowth + accretion − mortality). Also called net increase and production.

Mortality. Trees that died during the measurement period, excluding ingrowth trees that died.

Ingrowth. Trees that grew larger than the threshold size (4.5 inches dbh) between inventories.

Accretion. Increase in the volume of all trees present initially and still present at the end of the period (survivor growth).

Gross growth. Total volume produced by all trees during the period (net growth + mortality).

Net growth and mortality. Growth data are for all trees 4.5 inches dbh and larger. Volume in these trees is that of a bark-free bole from a 1-foot-high stump to a 4-inch-diameter top.

Periodic annual net growth varied greatly between the selection treatments and the unregulated harvesting and woodland preserve—from a low of 9 cubic feet per acre per year in the woodland preserve to a high of 53 to 60 cubic feet per acre per year in the selection treatments. The unregulated area grew at a net rate of 36 cubic feet per acre per year (Table 6 and Fig. 6).

Mortality ranged from 5 to 14 cubic feet per acre per year in the selection treatments; it was 15 cubic feet per acre per year in the unregulated treatment and 52 cubic feet per acre per year in the woodland preserve, where almost two-thirds of the mortality was balsam fir. The loss of this species resulted in an average drain from growing stock of 16.5 cubic feet per acre per year (Table 6 and Fig. 6).

Harvested volumes and number of harvests for each treatment are given below. They do not include volumes to be removed during the 20th year because these data are not yet available.

Treatment	*Number of harvests*	*Volume removed* $ft^3/acre$
Selection system		
5-yr interval	4	1 260
10-yr interval	2	1 100
20-yr interval	1	700
Unregulated	1	1 050
Woodland preserve	0	0

Table 6. Distribution of periodic annual growth by species, treatment, and growth component (in cubic feet per acre).

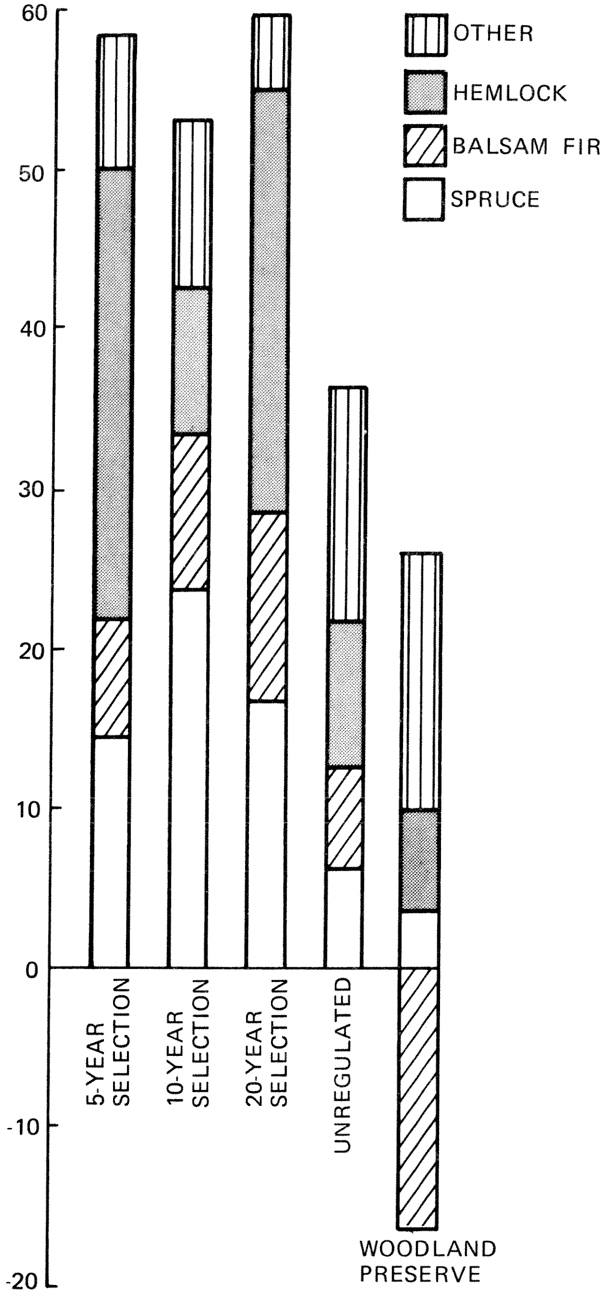
Species	Treatment	Growth Component				
		Ingrowth	Accretion	Gross growth	Mortality	Net growth
Balsam fir	Intensive selection 5-yr	4.6	4.3	8.9	1.7	7.2
	Intensive selection 10-yr	7.5	11.9	19.4	9.7	9.7
	Extensive selection 20-yr	5.6	7.6	13.2	2.1	11.1
	Unregulated	7.3	7.9	15.2	8.8	6.7
	Woodland preserve	6.5	11.0	17.5	34.0	-16.5
Spruce	Intensive selection 5-yr	0.7	14.8	15.5	1.1	14.4
	Intensive selection 10-yr	2.0	23.6	25.6	2.1	23.5
	Extensive selection 20-yr	1.1	17.0	18.1	1.0	17.1
	Unregulated	1.0	5.7	6.7	.6	6.1
	Woodland preserve	.7	8.4	9.1	5.4	3.7
Hemlock	Intensive selection 5-yr	2.0	26.9	28.9	.5	28.4
	Intensive selection 10-yr	.7	8.7	9.4	.3	9.1
	Extensive selection 20-yr	1.2	27.6	28.8	2.1	26.7
	Unregulated	1.6	8.9	10.5	1.5	9.0
	Woodland preserve	.7	5.5	6.2	.0	6.2
Other softwood	Intensive selection 5-yr	.8	3.3	4.1	1.4	2.7
	Intensive selection 10-yr	.7	3.4	4.1	.9	3.2
	Extensive selection 20-yr	.7	2.6	3.3	1.2	2.1
	Unregulated	1.0	5.3	6.3	1.5	4.8
	Woodland preserve	.1	16.8	16.9	11.2	5.7
Red maple	Intensive selection 5-yr	.7	2.7	3.4	.1	3.3
	Intensive selection 10-yr	1.7	3.8	5.5	.2	5.3
	Extensive selection 20-yr	.7	1.4	2.1	.2	1.9
	Unregulated	2.6	5.8	8.4	1.2	7.2
	Woodland preserve	2.6	5.9	8.5	.4	8.1
Paper birch	Intensive selection 5-yr	.1	1.8	1.9	.1	1.8
	Intensive selection 10-yr	.3	1.7	2.0	[a]	2.0
	Extensive selection 20-yr	.2	.7	.9	.3	.6
	Unregulated	.5	2.0	2.5	.3	2.2
	Woodland preserve	[a]	1.4	1.4	.1	1.3
Other hardwood	Intensive selection 5-yr	.3	.7	1.0	.3	.7
	Intensive selection 10-yr	.2	.5	.7	.4	.3
	Extensive selection 20-yr	.1	.1	.2	.2	.1
	Unregulated	.5	1.0	1.5	.7	.7
	Woodland preserve	.0	2.2	2.2	1.3	.9
Total	Intensive selection 5-yr	9.1	54.5	63.6	5.2	58.4
	Intensive selection 10-yr	13.2	53.7	66.9	13.6	53.3
	Extensive selection 20-yr	9.7	57.0	66.7	7.1	59.6
	Unregulated	14.4	36.7	51.1	14.7	36.4
	Woodland preserve	10.7	51.1	61.8	52.4	9.4

[a] Less than 0.05 cubic feet

The situation in the unregulated stands and woodland preserve are strikingly different. Unregulated commercial clearcutting reduced stand density to an understocked condition. Basal area in merchantable-sized trees was only 50 square feet per acre; total basal area was 71 square feet per acre. Increasing periodic annual net growth figures of 29, 36, and 42 cubic feet per acre suggest that acceptable growing stock is developing, despite the lack of silvicultural input. The stand has a current stocking of 109 square feet per acre.

The woodland preserve supported 151 square feet of basal area per acre at the start of the study. Natural attrition has reduced this to 136 square

Figure 6. Periodic average annual net growth by species and treatment.



feet per acre. Both these levels represent overstocking, as is shown in the high average annual mortality rate.

The loss of fir on the woodland preserve reduced this species to 18 percent of total stand basal area after 20 years, from 37 percent at the start of observations. The loss of fir and other species amounted to 875 cubic feet per acre over and above that lost on the selection system areas during the 20-year observation period.

Ingrowth. Ingrowth data attest to the aggressiveness and persistence of balsam fir. Regardless of treatment, balsam fir ingrowth amounted to between 50 and 60 percent of total ingrowth. No other species approached this level. Spruce ranged between 7 and 15 percent; hemlock, between 5 and 22 percent; and red maple, between 7 and 24 percent (Table 6). Ingrowth of balsam fir is expected to decline in the 5- and 10-year selection treatments because fir trees are periodically removed from the overstory, reducing seeding potential. However, fir will remain a major contributor of ingrowth in the unregulated stands because fir growing stock is continuously replenished. And for the immediate future, fir will dominate ingrowth in the woodland preserve because the openings created by fir mortality regenerate to fir.

Increases of spruce are possible in the selection system being tested as spruce overstory trees become more important in the species mix. Removals of less desirable species and cultural treatments favoring spruce make this possible.

Accretion and gross growth. Accretion is perhaps one of the best indexes of success or failure of a treatment to provide optimum growing conditions for individual trees. It is also the component of growth most significantly affected by abnormal weather patterns. For instance, an extended drought usually results in a slowdown in individual tree growth.

The stands managed by the selection system have maintained the highest annual accretion—54 to 57 cubic feet per acre. Added to relatively high ingrowth, this results in high gross growth. For the selection system at the intensities under investigation, annual gross growth had a narrow range of from 64 to 67 cubic feet per acre (Table 6).

The accretion rate in the woodland preserve was also high; 51 cubic feet per acre per year. Accretion is not expected to vary with slight increases in stand density. And average stand density in the preserve was slightly higher than in the 20-year interval selection treatment—144 square feet per acre compared to 137 square feet per acre when beginning and current basal areas are averaged. With the addition of ingrowth, gross growth averaged 62 cubic feet per acre during the period.

For the area subjected to the unregulated commercial clearcut, accretion was at an annual rate of 37 cubic feet per acre. As stand density increases and the stand again becomes fully stocked, accretion is expected to increase. Gross growth was 51 cubic feet per acre per year.

In both the unregulated stands and the woodland preserve where spruce is not being managed for, the accretion rate of fir exceeds that of spruce. In the selection treatments, spruce is favored and its accretion rate is more than twice that of balsam fir (Table 6). Hemlock, a strong contender for site occupancy, has a slightly higher accretion than spruce.

DISCUSSION AND CONCLUSIONS

Except in the most degenerate forest stands, the concepts of selection system silviculture can be put into practice in most spruce-fir types. The goals and procedures we have set forth are believed to be both attainable and practical.

We will not attempt to base a long-range forecast from our silvicultural systems on only 20 years of records. However, our initial comparisons between the selection systems, a commercial clearcut, and a woodland preserve reflect long-term trends. How predictive these trends are must be evaluated in the future.

Our findings indicate that a forest will respond to the intensification of cultural practices. Frequent and regular periodic operations, employing proper silvicultural concepts, will:

- improve stand quality by removing poor-risk trees,
- eventually change species composition to the degree made possible by the silvical characteristics of the species and the silvicultural system being used,
- result in a diameter-class distribution approaching the stated goal,
- control stand density and maintain it at the desired level, and
- increase the yield of a variety of forest products by harvesting trees that are likely to die and increasing the growth of residual trees.

LITERATURE CITED

DeLiocourt, F.
1898. **De l'amenagement des sapinieres.** Bull. Soc. for. de Franche-Comte et Belfort, Besancon.

Frank, Robert M.
1973. **The course of growth response in released white spruce—10-year results.** U.S. Dept. Agric. For. Serv. Res. Pap. NE-258.

Frank, R. M. and J. C. Bjorkbom
1973. **A silvicultural guide for spruce-fir in the Northeast.** U.S. Dept. Agric. For. Serv. Gen. Tech. Rep. NE-6.

Meyer, H.A., A.B. Recknagel, and D.D. Stevenson
1952. **Forest management.** Ronald Press, New York. 290 p.

Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories and research units are maintained at:

- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Kingston, Pennsylvania.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- University Park, Pennsylvania.
- Warren, Pennsylvania.