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B758: A Biomass Study of the Thinning Potential and Productivity of Immature Forest Stands in Maine

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A BIOMASS STUDY OF THE THINNING POTENTIAL AND PRODUCTIVITY OF IMMATURE FOREST STANDS IN MAINE

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INTRODUCTION

The fundamental idea embodied in the practice of forestry ha been eloquently stated by Fernow (1913) as:

> "an art born of necessity, as opposed to arts of convenience and pleasure. Only when a reduction in the natural supplies of forest products under the demands of civilization, necessitates a husbanding of supplies or necessitates the application of art or skill of knowledge in securing reproduction, or when unfavorable conditions of soil or climate induced by forest destruction make themselves felt does the art of forestry make its appearance. Hence its beginnings occur at different times and its development proceeds at different paces."

Extensive forest management may simply be limited to the pre vention of fire. As forest management becomes increasingly intensive more intimate knowledge of the structure and physiology of the forest community and its environment becomes essential in order to take specific action. A knowledge of site productivity quickly becomes important as a guide to the effectiveness of various possible silvicultural treat ments of which thinning is often recognized as a worthwhile enterprise.

Thinning is certainly one of the best known silvicultural treatments. Smith (1962) has succintly defined thinnings as "Cuttings made in immature stands in order to stimulate the growth of the trees that remain and to increase the total yield of useful material from the stand." As early as the sixteenth century (Fernow 1913) thinnings were being made primarily for fence material and it was noted then that the thinnings improved the growth of the remaining stand. The establishmen of forest schools in Germany along with the development of practical re search in the eighteenth century encouraged the widespread practice of thinning in Europe which continues to this day.

The European colonists that came to the eastern seaboard of North America found the land covered with forests that had to be partially cleared for farms and dwellings. These enormous forest reserves have dwindled in the past 350 years as a result of commercial harvesting to meet the demands of a rapidly increasing human population. For that entire period the primary problem was the economics of harvesting and transporting the products to mills. Very little attention was given to replenishing the forests until this century. Now there is widespread recognition that intensive forest management and better utilization are vital if our forests are to be fully stocked with desired species at preferred quality levels. Thinning regimes developed for Maine species, growing conditions and markets will be a positive step towards intensive forest management to meet the demands being placed on Maine forests.

There have been some thinning studies in the United States but virtually none in Maine. Maine thinning studies are timely because the annual drain of merchantable bole material is rapidly approaching the growth of such material indicating that other means of meeting our requirements must be developed. It is highly appropriate to conduct thinning studies within the context of the Complete Forest Concept (Young 1964, 1977) because this concept considers all components of trees and shrubs (leaves or needles, branches, stem and stump-root system) of all species without the size limitations inherent in the Merchantable Bole Concept. Within the Complete Forest Concept weight, hereinafter referred to as biomass, is used as the primary quantitative measure instead of volume. It is important to bear in mind that the philosophy of the Complete Forest Concept encourage forest operations to be conducted so that the sale of all harvested material will, at the very minimum, cover all costs but preferably to provide a net income to the forest owner. Even though this may infrequently fail it is a healthier attitude than one of either ignoring silvicultural treatment entirely or demanding silvicultural treatment without regard to cost. Another aspect of the concept that must be mentioned is that there must be an immediate follow up to positive results of every study.

The first biomass studies in Maine were of individual trees in 1959 and these were extended to plots of 1970 when studies were undertaken in hardwood stands (Young 1971). These and some later investigations included in this report were made to determine the degree of confidence that could be placed into biomass estimates based on regression equations that had been prepared relating the fresh and dry weight of trees and shrubs to measurable physical dimensions of the vegetation. Once the regression equations are available it takes much less time and effort to measure the vegetation and use a computer with the equations to estimate the biomass than the time required to cut and weigh all of the above ground material (Ribe 1973).

The purpose of this study is to establish the degree of reliability that can be placed in biomass as a means of assessing thinning potential and site productivity of immature forest stands in Maine.

FIELD METHODS

The field procedures for cutting and weighing fixed plots for above ground biomass and sub-sampling methods have been described (Young 1971). In recent years these have been modified to reduce the plot area and by the addition of measurement of all standing dead trees 1.0" dbh and larger. In 1978, as an innovation, a series of three point samples at five chain intervals was used to describe the biomass of a particular species combination on a particular site. On each point sample measurements are made on all living and dead trees to which the regression equations are applied by the computer to the living trees to estimate the average stand biomass. This was a field test suggested by the results of early phases of this study.

Hardwood Stands

In the 1970 field season 67 plots, each 25 by 25 feet (1/70 acre), were located in fully stocked hardwood stands ranging from 10-46 feet in height and up to five species per plot and 17 species in total located on average or meso sites. All trees were cut about six inches above ground and weighed. In 1971 (Young 1973) 30 similar plots were located in primarily gray birch stands on wet sites and in 1972 and 1973 (Ribe 1973) 43 similar plots were located on primarily dry sites. In 1974 a total of 101 of the original 140 plots were relocated to (a) count seedling occurrence since cutting, (b) determine the amount of sprouting since cutting, and (c) to measure the stump diameter of each tree that had been previously felled.

Softwood Stands

During the 1974 field season an exploratory study was made in central and northern Maine to estimate the thinnings tonnage that chief foresters of large land owning companies would remove if (1) an economical harvesting system for thinnings existed and if (2) there was a market for the material removed in the thinning process. For this purpose 47 plots were located in fully stocked immature softwood stands. Initially 1/10 acre plots were measured but this was quickly reduced to 1/100 acre (20.9 by 20.9 feet) as the larger plot was unwieldy. For extremely dense spruce-fir thickets not exceeding 12 feet in height the plot size was reduced to 1/1000 acre (6.6 by 6.6 feet). To expedite matters the trees on each plot were measured but not cut as local weight tables were prepared from existing weight tables to estimate fresh and dry weight. On each plot all trees 1.0" dbh and larger, both living and dead, were measured and recorded separately by species. The chief forester would indicate in his judgement which trees he would "leave" and which he would cut in a thinning and the two groups were tallied separately. For administrative efficiency the "leave" trees were locate measured and painted first followed by the "cut" trees which were painte a different color.

During 1975, 66 plots, each 1/100 acre, were located, cut and weighed in northern, central and southwestern Maine on meso sites. Prio to the cutting and weighing phase thinning estimates were made based on a synthesis of the results of the chief foresters the previous summer. In addition, on each plot two trees, spruce and/or fir, were purposively selected to provide a range of size classes by species in each of the three regions. These were measured and weighed in detail to prepare separate spruce and fir weight tables for each region. Only one week was spent at each location because of the travel time and the necessity at that time of using laboratory scales in Orono to determine the fresh weight of small samples.

In 1977 two field crews obtained data on 37 more softwood sites to characterize wet and dry sites and to account, if possible, for the apparently high annual productivity of softwood stands in southwestern Maine as compared to northern and central Maine. Small, inexpensive scales accurate to 0.1 gram had been purchased so that each crew could determine the fresh weight of small samples directly on the plot making the length of the field trip independent of the distance from Orono.

Biomass Point Samples

Analysis of the data following the 1975 field season indicated that confidence could be placed in estimates of plot weights combining the regression equations and tree measurements. An opportunity to test this presented itself in 1979.

The upper quarter of the west half of Elm Stream Township, Maine is either a virgin area or very similar to one. There are no visible stumps, company records going back to 1847 do not show any cutting there, and all age classes are present from seedlings to mature trees larger than 30.0" dbh. To characterize a particular stand-site combination (wet, meso or day and softwoods or hardwoods) a random place was selected for the first point sample and the remaining two point samples were located at five chain intervals. A total of 15 combinations of stands and sites were sampled with three point samples in each. For each point all trees 1.0" dbh and larger were measured where appropriate and the dbh, height and breast height age of one of the larger trees were determined. The fresh weight equations for complete trees were used in the computer to estimate the tonnage per acre represented by each point sample. Only trees with a total age of 120 or more were used to characterize the age of each of the stands.

DATA ANALYSIS

Plot Weight Estimation and Regional Comparisons

To estimate the biomass from the 1974 plot measurements a local weight table was prepared from existing weight tables (Young et al 1964 and Young and Carpenter 1967). On a per acre basis estimates were then made for each plot in terms of (a) oven dry tons of standing dead trees, (b) oven dry tons that would be removed in a thinning, and (c) oven dry weight of living trees that would be left to continue growing. In each case the estimate was in terms of complete trees (root tips to leaf tips, inclusive). Only limited confidence can be placed in the results because the height-diameter relationships for the local weight tables were based on general experience rather than actual field data. It was for this reason that data were obtained in 1975 to prepare reliable local weight tables.

In 1975 the northern region was represented by plots located near St. Phamphile, Ashland and Telos; the central region was represented by plots near Passadumkeag Mountain, Princeton and Machias; and the southwestern region by plots near Rangeley. Separate regression equations relating fresh and dry weight of components (needles, branches and stems) and the entire above ground portion were prepared for each place within each region. Comparisons were then made between places within a region. The total data for each species was combined to prepare regression equations for each region and then comparisons were made between regions. The spruce data for all regions was combined to prepare a single set of regression equations. In the case of Balsam Fir there were no differences between the northern and southwesterly region so the data were combined to make one set of Balsam Fir equations for these two regions and the equations for the central region were used for that region. The appropriate regression equations were then used with the plot measurement data to estimate the weight per plot in order to make comparisons with the actual weight as determined by cutting all the trees and weighing them on scales in the field.

Graphical Analysis

Inasmuch as there were only a relatively few plots in both hardwood and softwood stands on wet and dry sites graphical analysis was considered to be appropriate to show the relationships between (1) height above ground and age, (2) stems per acre 1.0" dbh and larger and age, (3) oven dry tons of stems and branches per acre and age, and (4) average dry matter production of stems and branches (exclusive of needles) and age. Additional factors mitigating against regression analysis were (a) height of the stand was based on only two trees per plot and (b) annual ring counts were made in the field and are subject to human error in the estimation of total age. Consequently the results of the graphical analysis should be viewed as expressing relative differences rather than precise differences between sites and between hardwood and softwood stands.

RESULTS

Biomass Estimates Based on 1974 Local Weight Tables

Table 1 summarizes the results of the biomass estimates of the 43 plots measured in 1974 with local weight tables prepared that year. This table shows that with increased age there is a decrease in the number of living trees offset by an increase in the number of standing dead trees until about age 40 and thereafter the number of standing dead appears to be constant for the range of the data. The youngest age class had the largest tonnage which was unexpected. The drop in tonnage in the middle age class can be attributed to limited data. The local weight tables were checked in the small diameter classes and found to be high which crystallized the need to collect sufficient data in 1975 to prepare reliable spruce and fir local weight tables by regression analysis.

Regional Comparison of Weight Tables by Species

The form of the regression equation used was:

$$Ln(Y) = b_0 + b_1 Ln(D) + b_2 Ln(H)$$

where
- Y = weight in pounds
- D = diameter at breast height in inches
- H = height of tree in feet
- Ln = natural logarithm
- b_0 = equation constant
- b_1 = coefficient applied to D
- b_2 = coefficient applied to H

This equation was used to relate each component (needles, branches and stem) as well as the entire above ground portion to the physical dimensions of height and diameter for each species separately in each location of each region and then by combining all locations within a region and finally by combining data for two or more regions.

The comparison of regression equations by species for each location within a region did not show any significant differences justifying a single regression equation for each species within a region. When comparing regions there were no significant differences between the three sets of spruce equations indicating that all the data should be combined for one set of Spruce equations for all regions. For the Balsam

Fir data there were no significant differences between the regional equations for the northern and southwesterly region so they were combined but the Central Region equation was significantly different so it was used for that region. The final set of equations for the component portions are shown in Table 2.

Comparison of Plot Biomass by Weighing and by Estimating

A computer program was written to facilitate the calculation of the plot biomass using the measured plot data and the regression equations in order to make a comparison with the actual weight as determined in the field. Table 3 summarizes the results for each location within a region, for each region and for all regions combined. The maximum difference between an estimated and actual plot weight was 30.5% with the greatest variation occurring in the northern region as shown in Table 3. With at least seven plots the difference between estimated and actual weight did not exceed 6.1%. The overall difference for the 55 plots in all three regions was only 2.2%.

Site Productivity

205 plots representing meso, wet and dry sites or growing conditions were located in fully stocked immature softwood and hardwood stands in northern, central and southwestern Maine. Figures 1-8 show the relationship as determined graphically between age and (1) height, (2) stems per acre, biomass per acre oven dry of stems and branches and (3) oven dry biomass production per acre per year (without needles). To facilitate comparisons between the three sites and the two species groups the curves are expressed numerically in Table 4.

On all sites very young hardwoods grow more rapidly in height than softwoods and hardwoods on meso sites grow more rapidly than on either wet or dry sites. There are, however, fewer trees per acre on all hardwood sites than on comparable softwood sites. Wet hardwood sites have the fewest trees per acre and meso softwood sites have by far the most. On all sites advanced softwood saplings or pole size trees are about equal in numbers and this is equally true on meso and dry hardwood sites, although much lower density per acre.

By age 15 total biomass production on all softwood sites is similar, however, there is a gradual increase on meso sites after that. Meso hardwood sites at that age have produced slightly less than on meso softwoods but considerably more than the other hardwood sites. Meso hardwood sites then produce more biomass than meso softwood sites as shown in Table 4.

Point Sample Biomass

By excluding age data of six trees estimated to be less than 120 years old, the average age for the Elm Stream area was 170 years. Table 5 is a comparison of the biomass of the standing crop as calculate from the weight tables and the point sample data as compared to 35 year old stands taken from Table 4. It appears quite likely that the Elm Stream area came into equilibrium with regard to annual mortality and annual productivity many years ago. This is to be expected of an all age forest in which mortality and production each year are relatively constant. In Table 5 the approximate differences in biomass over a five fold increase in years ranges from 32.6 - 70.5 per acre. Inasmuch as all of the softwood sites produced well over one ton of biomass per year for the first 35 years the loss due to natural mortality has been staggering supporting the concept of thinning as a means of increasing the yield of useful material from the forest.

Thinning Potential

The results of the thinning trials by senior industrial foresters of six companies appear in Table 6. The foresters representing companies designated as A and B suggested less thinning than the foresters of the other four companies. The group as a whole would remove 56% of the biomass contained in 66% of the living trees 1.0" dbh and larger primarily in the smaller diameter classes. This would leave an average of 700 trees per acre. If company B, which had by far the most dense stands, were excluded there would only be about 500 trees per acre. Table 7 shows the average spacing between trees for different numbers of trees per acre.

In 1975 field crews judged the thinning potential of the plots that they measured, cut and weighed. Their guidelines were (1) that about 45% of the biomass should be removed in thinning, and (2) the thinning should be contained in about 65% of the live trees 1.0" dbh and larger as suggested by Table 6. The results of their efforts are shown in Table 7 by stand age classes. For the very dense young age class, 13-25 years old, half of the biomass would be removed by thinning half of the trees. Two stand densities were recognized in the 28-39 year old class as some were very dense and others were of similar density to the 40-75 year age class. The field crews exceeded both the biomass and density standards which can be attributed in part to inexperience in thinning and judging biomass of individual trees. Table 8 shows an

Table 1. Summary of Plot Biomass Estimates of 1974 Field Season.

Age Class	# of Plots	Number of Trees 1.0" Dbh and Larger				Oven Dry Tons/Acre/Complete Trees			
		Living Trees		Standing Dead		Living Trees		Standing Dead	
		Av.	Range	Av.	Range	Av.	Range	Av.	Range
12-20	8	23,500	18,000-36,000	375	0-2,000	96.9	72.5-141.4	0.9	0.0-5.6
24-39	9	6,300	3,100-25,000	1250	0-3,000	54.2	43.5-109.6	2.3	0.0-7.1
42-87	26	2,600	900-4,500	1100	600-2400	82.3	30.8-136.2	9.0	0.0-21.8
	43								

Table 2. Final Weight Regression Equations Based on 1975 Data

Species	Region	Moisture Content	Component	Constant b_0	Coefficient (D) b_1	Coefficient (H) b_2
Spruce	All	Fresh	Needles	0.8813	3.5377	-0.9374
			Branches	1.1351	3.6104	-1.1298
			Stem	-1.3314	1.8755	0.9166
Balsam Fir	Northern and Southwestern	Fresh	Needles	10.4684	5.8786	-4.7018
			Branches	6.7869	4.1764	-3.3420
			Stem	-1.1094	1.8836	0.8277
Balsam Fir	Central	Fresh	Needles	-2.5278	2.4205	0.4368
			Branches	-1.2446	3.3122	-0.3369
			Stem	-0.5296	2.0834	0.6065
Spruce	All	Oven Dry	Needles	-0.2325	3.4305	-0.7832
			Branches	0.4719	3.4399	-1.0223
			Stem	-2.6767	1.5490	1.2392
Balsam Fir	Northern and Southwestern	Oven Dry	Needles	9.2667	5.7484	-4.5129
			Branches	6.0523	5.0733	-3.2804
			Stem	-2.2658	1.6609	1.0085
Balsam Fir	Central	Oven Dry	Needles	-3.1003	2.4912	0.3673
			Branches	-2.0354	3.3049	-0.2707
			Stem	-0.8178	2.0332	0.4796

Table 3. Comparison of Actual Plot Biomass and Calculated Biomass on an Acre Basis Using 1974 Data

Region	Location	# of Plots	Av. Dif. Between Calculated and Actual Biomass as a Percent	Range of Difference Between Actual and Calculated Biomass for Individual Plots
Northern	St. Pamphile	7	+4.4%	(-9.7%) - (+30.5%)
	Ashland	9	+3.1%	(-4.6%) - (+6.9%)
	Telos	7	+6.1%	(-9.4%) - (+26.5%)
	All	26	+4.5%	(-9.7%) - (+30.5%)
Central	Princeton	8	-1.1%	(-18.0%) - (+18.3%)
	Machias	8	-0.1%	(-7.5%) - (10.5%)
	Passadumkeag	10	+0.1%	(-13.9%) - (+20.4%)
	All	26	-0.3%	(-18.0%) - (20.4%)
Southwestern	Rangeley	6	+2.6%	(-12.1%) - (+10.9%)
All		55	+2.2%	(-13.9%) - (+30.5%)

Table 4. Productivity of Immature Fully Stocked Young Stands in Maine from Graphical Analysis of 205 Plots

Item	Age	Site Categories					
		Hardwoods			Softwoods		
		Meso	Wet	Dry	Meso	Wet	Dry
Number of field plots		65	20	16	71	22	11
Stand Height (feet)	15	21	20	20	13	8	13
	25	32	28	28	22	16	22
	35	40	35	35	28	25	28
	45	46	39	39	32	31	31
	55	49	42	42	33	38	33
Number of living trees per acre 1.0" dbh and larger	15	3800	3100	3800	23000	5100	10800
	25	2400	1200	2400	12000	3900	6000
	35	1400	600	1400	7100	3600	4900
	45	900	400	900	4700	3600	3800
	55	800	300	800	3100	3600	2800
Above ground biomass per acre oven dry 1.0" dbh and larger exclusive of needles	15	13.5	5.5	5.5	15.5	15.5	15.5
	25	25.5	10.0	11.5	24.5	29.0	21.5
	35	40.0	15.5	19.5	36.6	36.5	27.5
	45	58.5	21.0	29.5	50.5	42.0	34.0
	55	81.0	27.5	39.5	66.5	47.0	41.0
Annual dry matter production above ground in trees 1.0" dbh and larger exclusive of the needles	15	1.20	0.56	0.40	2.04	2.04	1.62
	25	1.08	0.45	0.50	1.55	1.53	1.16
	35	1.08	0.42	0.60	1.31	1.17	0.83
	45	0.95	0.40	0.72	1.15	0.88	0.70
	55	0.92	0.39	0.82	1.05	0.69	0.63

Table 5. Comparison of the Biomass of the Standing Crop and Annual Productivity of an Immature and All Age Stands

Age of Stand	Hardwoods Meso	Hardwoods Wet	Hardwoods Dry	Softwoods Meso	Softwoods Wet	Softwoods Dry
	Aboveground biomass of trees larger than 1.0" Dbh exclusive of needles in tons per acre dry weight					
35	40.0	15.5	19.5	36.5	36.5	27.5
170	72.6 (4)	86.0 (1)	65.3 (1)	56.8 (3)	74.4 (4)	81.0 (2)
	Aboveground annual dry matter productivity for trees 1.0" dbh and larger exclusive of the needles					
35	1.08	0.42	0.60	1.31	1.17	0.83
170	0.43	0.51	0.38	0.33	0.44	0.48

Note: The numbers in parenthesis indicate the number of groups of three plots on which the average was based. 72.6 is the average of four groups of three plots taken in four separate meso sites in which hardwood trees dominated.

Table 6. Thinning Immature Softwood Stands on Meso Sites in Maine by Senior Industrial Foresters Assuming (1) the existance of efficient economical machines for thinning and (2) a market for all material thinned.

Company	Number of field plots	Av. Thinning % as aboveground biomass	Av. Thinning % of No. of live trees 1.0" dbh and larger	Av. No. of live trees left per acre	Av. No. of live trees 1.0" dbh and larger per acre before thinning on meso sites
A	6	35	54	590	1790
B	5	38	59	1400	3400
C	7	52	83	430	2600
D	4	59	58	525	2700
E	2	51	75	500	2000
F	3	70	65	450	1850
Average		56	66	700	2200

Table 7. Spacing Between Trees for Different Numbers of Trees Per Acre

Number of Trees Per Acre	Spacing in Feet Between Trees
100	20.9
200	14.8
300	12.1
400	10.4
500	9.3
600	8.5
700	7.9
800	7.4
900	7.0
1000	6.6
1100	6.3
1200	6.0
1300	5.8
1400	5.6
1500	5.4

Table 8. Thinning immature softwood stands on meso sites during 1975 field season

Age	# of Plots	Standing Dead in Tons	Av. No. of live trees 1.0" dbh and larger	Av. Thinning % in Biomass	Av. no. of trees left after thinning	Thinning % trees 1.0" dbh and larger
13-25	5	1.1	21,600	50	10,800	50
28-39						
a. very dense	3	0.3	12,800	50	6,400	50
b. normal	6	4.2	4,400	57	700	84
40-75	53	6.5	3,580	54	635	77

Table 9. Average Stand Conditions for 1975 Data to Achieve Thinning of 45% of Biomass by Removing 65% of Trees 1.0" dbh and Larger

				Oven dry Biomass in tons per acre			
Age Class	65% of trees 1.0" dbh and larger	No. of standing dead trees 1.0" dbh and larger	Total trees to be removed per acre	45% of trees 1.0" dbh and larger	Standing dead	Total	No. of trees left per acre 1.0" dbh and larger
28-39 (normal)	2900	3900	6800	26.3	4.2	30.5	1500
40-74	2400	2100	4500	30.8	6.5	37.3	1200

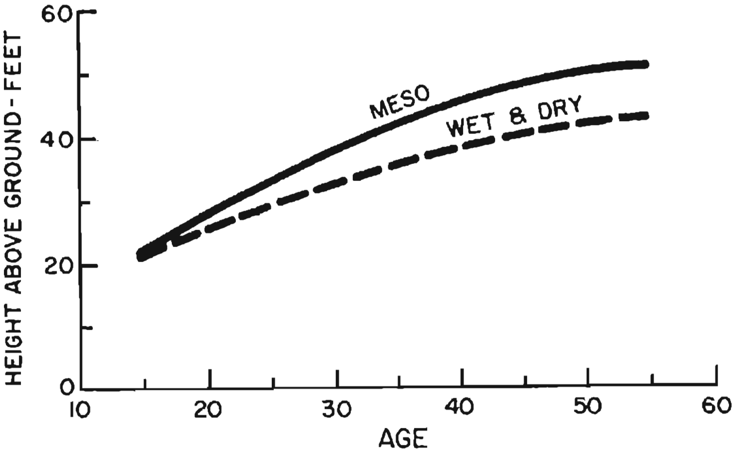

Figure 1. Height-age relationship for hardwood sites of immature fully stocked stands in Maine.

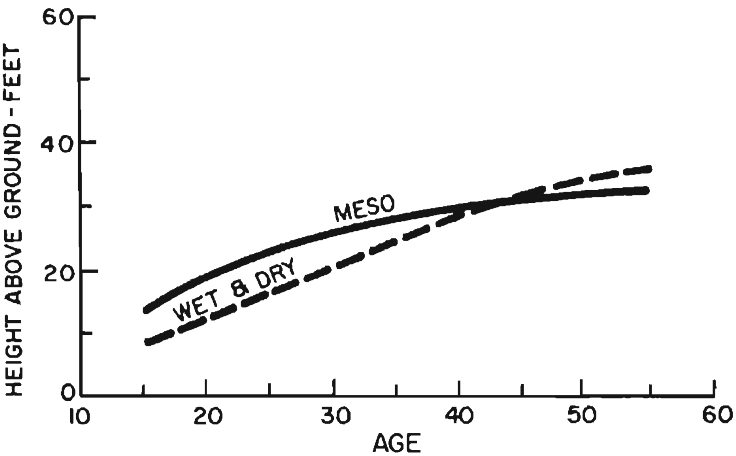

Figure 2. Height-age relationship for softwood sites of immature fully stocked stands in Maine.

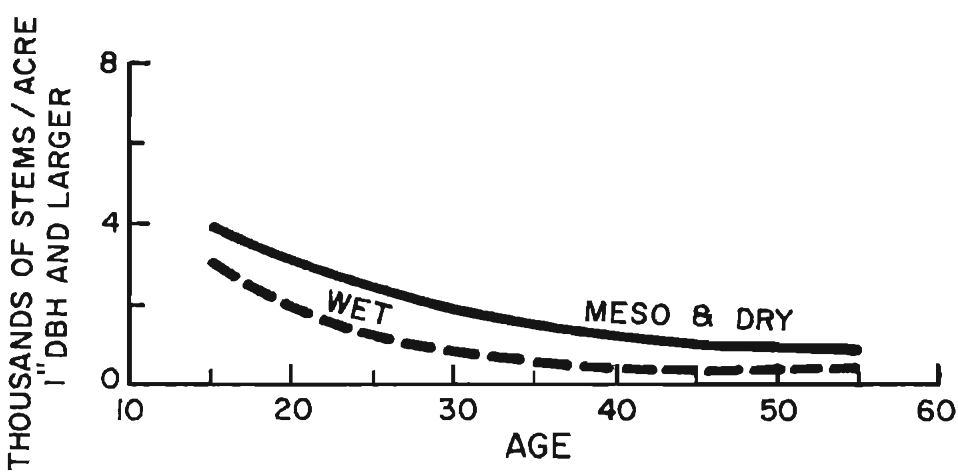

Figure 3. Number of stems per acre 1" and larger dbh-age relationship of immature fully stocked hardwood stands in Maine.

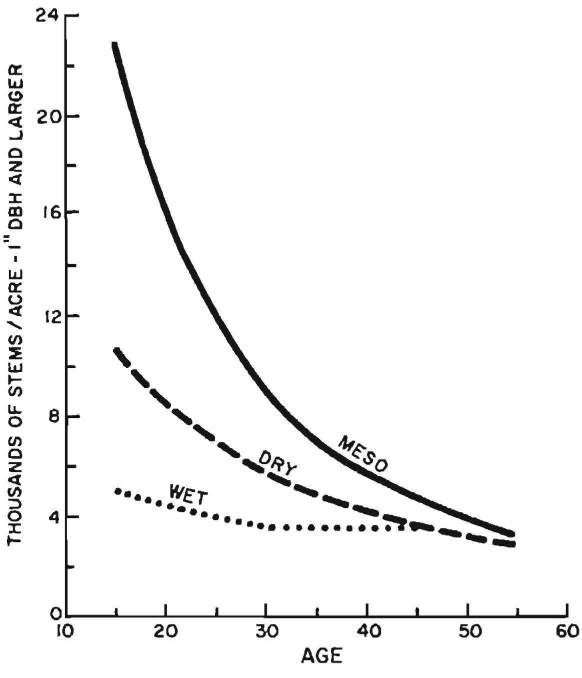

Figure 4. Number of stems per acre 1" and larger dbh-age relationship of immature fully stocked softwood stands in Maine.

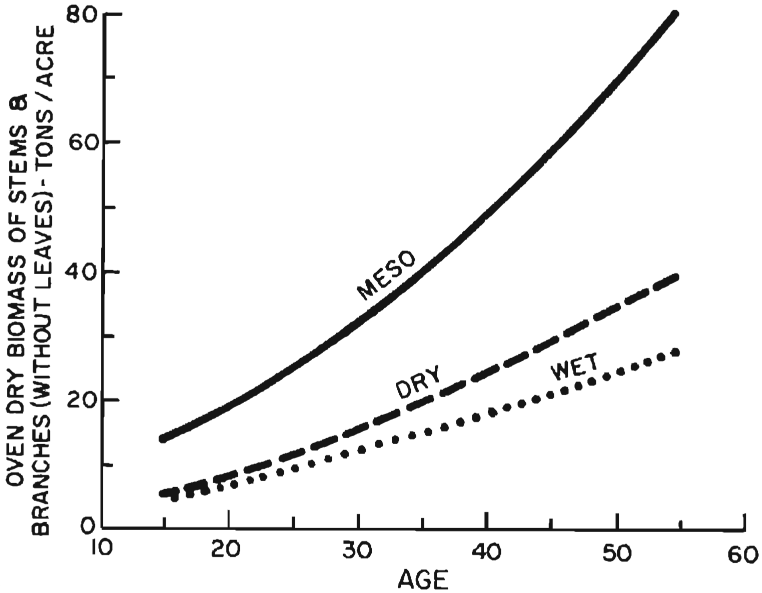

Figure 5. Oven dry biomass of stems and branches per acre-age relationship on immature fully stocked hardwood stands in Maine.

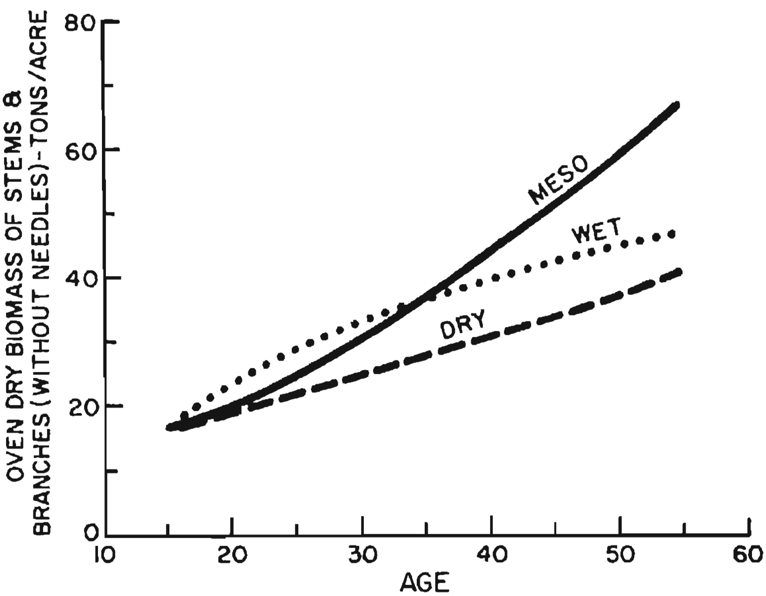

Figure 6. Oven dry biomass of stems and branches per acre-age relationship on immature fully stocked softwood stands in Maine.

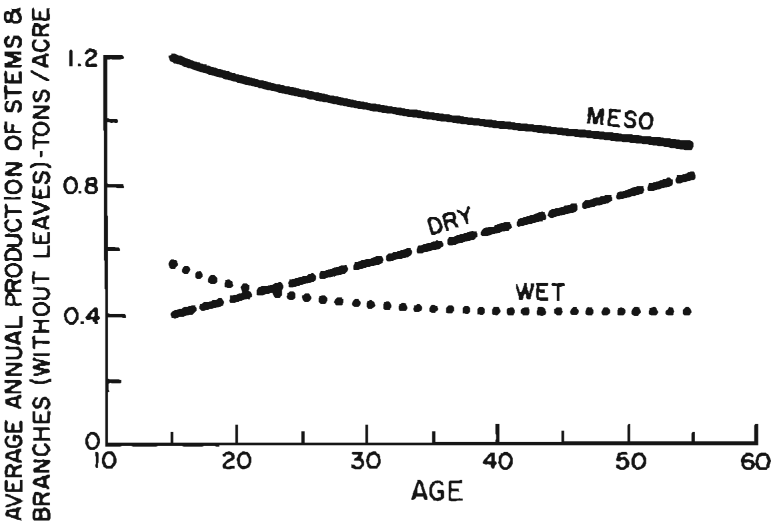

Figure 7. Dry matter production in tons of stems and branches-age relationship for hardwood sites of immature fully stocked stands in Maine.

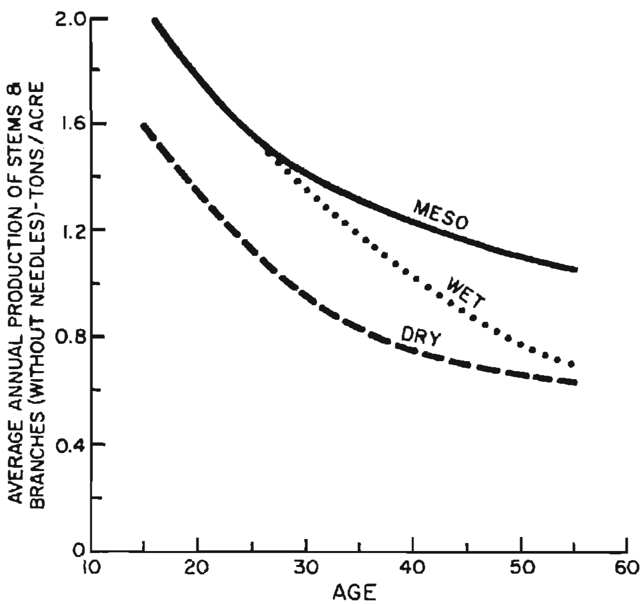

Figure 8. Dry matter production in tons of stems and branches-age relationship for softwood sites of immature fully stocked stands in Maine.

increase in the tonnage of standing dead trees which amounts to at least 10% of the weight of the living trees in the older age classes measured.

To achieve a thinning that would remove 45% of the biomass in 65% of the living trees primarily in the smaller diameter classes another analysis was made of the data. The results for two age classes are shown in Table 9 of immature softwood stands on meso sites. On the average, 6800 living and dead trees would be thinned in the 28-39 year age class with normal density and 4500 would be removed in the 40-75 year age class of similar density if there had been no previous thinning. For the 40-75 year age class, probably the most abundant in Maine, a total of 37.3 oven dry ton equivalents of the above ground portion of living and dead trees would be thinned per acre. This thinning regime would leave 1500 trees in the younger age class and 1200 in the older age class.

DISCUSSION

Plot Size Consideration

The fixed plot size of 25 by 25 feet (1/70 acre) was established for the 1970 season after taking into account practical considerations. The source is lost in the mist of the distant past but it is well known that the length of the side of a square plot for vegetational analysis should be approximately the same as the height of the vegetation to be measured. It was anticipated that the vegetation would range from 10' hgt. in alder thickets to 45' hgt. in Gray Birch-Red Maple stands. Because a variable plot size could be confusing and could cause errors in both the field and analytical work, a fixed plot of 25 by 25 feet was chosen as a compromise. If the plot had previously been located and flagged, a field crew could do all of the felling and weighing on two plots per day within a 25 mile radius of Orono. This was very important as small portable field scales were not available in 1970 and it was necessary to determine the fresh weight of all small sub-samples on the laboratory scales in Orono. In 1975 the plot size was reduced from 1/70 to 1/100 acre because there were more trees in the softwood stands than in the immature hardwood stands.

Biomass Point Samples

In the 1978 trial of biomass point samples only three point samples were measured to characterize a site-type combination in order to obtain some data on all six site-type combinations in the brief time available. Careful consideration of the comparison of actual and estimated plot weights as shown in Table 3 plus the data collected in 1978 indicates that a minimum of five point samples and preferably seven point samples should be measured to reliably estimate a site-type combination. In situations where the site-type combinations have been selected well in advance and where the soils in the selected stand have been carefully checked for uniformity, the field crew should be able to make all of the point sample measures for two site-type combinations per day.

Dead Trees

Dead trees were not measured on the hardwood plots because there were very few of them. They were so obvious and numerous in the softwood stands that they could not be ignored. In every softwood stand there are standing dead trees and reclining dead trees in various stages of decay. Because the horizontal dead trees presented many problems only the standing dead 1.0" dbh and larger were measured, recorded separately, and weighed. All of the standing dead trees were without needles and most had lost their bark. Moisture samples were taken of the standing dead trees in order to estimate oven dry weight.

The number of standing dead trees is highly correlated with age and natural competition. Fifteen year old dense softwood stands may have 27,000 living trees per acre with scarcely any dead trees at all, whereas a 55 year old softwood stand may only have 3,000 living trees but will also have as many as 1,500 standing dead trees larger than 1.0" dbh. On the average there was at least 6.0 oven dry ton equivalents of standing dead trees per acre in the above ground portion. This material has potential for pulp (Chase and Young 1976) and for energy.

Site Differentiation

The myopia of foresight as compared with the clarity of hindsight characterizes the awkward expansion of this study into site differentiation. In 1970 primary interest was centered in obtaining plot data involving a variety of species over the 15-45 foot height class range. With this in mind the plots were located in easily accessible normal or average sites.

Analysis of the 1970 data created interest in the variation that might be expected in apparently homogenous stands. Three such stands, principally gray birch, were present on wet sites. These were wet sites because Alder grew well in them as an understory and because they had been observed to be under water later in the year than normal sites.

Analysis of these data forced the senior author to become aware of site differences suggesting the desirability of locating plots in 1973 on eskers, kame, terrances, and outwash plains in Washington County, Maine that are considered to be dry. To be candid, the study had originally been conceived as a thinning study alone. Circumstances altered it into a site and thinning study. The normal sites have been referred to as meso meaning average. The wet and dry hardwood sites selected are close to the extremes of those conditions in Maine under which trees will grow. This is equally true of the wet and dry sites for the softwood stands and the meso softwood sites are the equivalent of those for the hardwood stands. To indicate the "wetness" of the wet sites for softwoods only those areas were selected where the tree species were Black Spruce.

For this study the site classification can be defined as follows:

Wet Site - A low, wet area with the water table near or at the surface weeks after the water table has been depressed on meso sites. For softwood stands this would be a Black Spruce Bog. For hardwood stands the understory would be alder, willow and other moisture tolerant species.

Dry Site - An esker, kame, kame terrance or outwash plain with a 1-2 foot overburden of soil that is quite sandy with deep sand and/or gravel underneath, or bedrock areas with no more than 2 foot soil cover.

Meso Site - Includes a range of fine and till soils that would be considered normal for Maine.

Classification of all soil in Maine simply in three categories is undoubtedly inadequate. Some larger number of categories such as 9, 11 or 13 should be tested by the biomass approach to determine the maximum number of categories for which significant differences can be determined. For example, there very well might be three categories of wet and as many of dry and the meso site might very well be expanded into five categories. These should be carefully defined in advance to insure uniformity of identification in the field.

Site Productivity

About one hundred years ago German forest scientists developed the concept of site index: height attained by the average dominant tree of a stand at an arbitrary age such as fifty years. Height and age data were to be collected over an extensive region including the entire range of sites for a particular species. Graphical analysis would then provide a family of height over age curves that never crossed and might be parallel with each curve representing a specific site index. Generally, the interval between curves would be 10 feet. In Europe and portions of the United States there has been a fairly good relation between site index and the volume of the merchantable boles per acre for intolerant species and for tolerant species that have grown in the open. Site index has not been considered a useful device by foresters in New England because most of the stands are all aged and because of the shade tolerance of the climax species which dominate.

For the site index concept to be effective there must be living trees large enough to be used in conjunction with the site index curves. About 1938 it occurred to Dr. T. S. Coile of the Duke Forestry School that it was desirable to have site index information for land where either there were no trees standing or where the trees were too small to be used with the existing site index curves. Coile developed a regression analysis procedure equating physical properties of the soil with the site index as determined from standing trees. This approach has worked well in many regions. When tried in Maine (Young 1954) it was not as sensitive, at least partially, because the difference between the best and poorest site index measured was only about 20 feet. At that time Coile observed that non-climax species such as Loblolly Pine might have a site index range of from 30-120 feet and quite likely climax species within a given region would seldom display a significant range of site index.

In a break from tradition Hoar and Young (1965) devised a simple soil classification system of (a) peat, (b) swamp, (c) fines, (d) till, (e) ledge and (f) granular with a written description of each. These were tested separately by regression analysis equating volume growth during the free growing period in terms of years of free growth. There were significant differences between the individual regression equations and several of them did cross one another in the younger periods. This study did demonstrate that a soil classification scheme could be the basis for site evaluation. Furthermore, volume growth of the bole during the free growing period for a single species, Red Spruce in this instance, can be considered as a measure of biomass as the relationship between the two must approach 1:1.

Despite the fact that there is a relationship between site index and volume of the merchantable boles per acre, there is much to be desired with site index for the following reasons:

a. It is not firmly anchored in a soil classification system.

b. It does not work well with very young stands.

c. It does not measure the complete forest as oven dry biomass of all of the vegetation.

d. It is not as sensitive to imposed treatments as oven dry biomass and, therefore, not as useful in physiological, genetic, ecological and other scientific studies. Site index was developed for professional forestry purposes rather than as a quantitative measure for forest science.

As stated earlier, site productivity was not a dominant factor when the initial hardwoods were measured and weighed in 1970 or in 1971. The 1970 plots were located in average or meso sites for convenience and the 1971 plots were deliberately located in very wet sites because they happened to be relatively homogenous. By this time site productivity was coming to the foreground so that the 1972 and 1973 plots were deliberately located in very dry sites bearing in mind Coile's suggestion. This was equally true in the selection of the softwood sites in the following years. The underlying idea being that if truly significant differences showed up between extremely wet and meso sites and between extremely dry and meso sites than a future study expanding into somewhere between 9 and 13 sites would be appropriate. The assumption being that failure to show significant differences would then be justification for combining two or more units of the classification scheme.

Thinnings

The two silvicultural arguments supporting a thinning program in fully stocked immature stands are (1) the density of very young stands which decreases rapidly with increased age and (2) the increase in the number of standing dead trees with age (Table 1). That table should be examined in conjunction with Table 7 which shows the spacing between trees with varying number of trees per acre. A spacing of six by six feet or 1200 trees per acre was the standard for planting throughout the United States for many years but that is now being reduced to

700-800 trees per acre.

Thinning at the most judicious moment or moments in young stands would permit the remaining trees to grow more rapidly after they had expanded into the released space and the material removed in thinning would increase the production of useful material from the forest. It must be borne in mind that thinning simultaneously reduces the photosynthetic potential and the root absorbing surfaces per acre so that the biomass production will be temporarily reduced. At the end of the rotation the total biomass of the thinned material and the final crop will be equal to or less than the total biomass if the stand had not been thinned. The thinned stand will have more material of higher quality than the unthinned stands and will, therefore, provide a greater income.

Prior to 1900 the European literature was replete with studies of thinning regimes in dense natural stands. Since 1900 most of the European studies and virtually all from Africa, Australia and New Zealand have involved softwood plantations. Kramer (1977) summarizes his experience with Norway Spruce thinning studies in Germany which can be related to some extent, to the spruce-fir stands in Maine. He shows that the thinning practice and the frequency of thinning is a function of (a) age, (b) species, (c) harvesting equipment available and (d) local environmental conditions.

McLintock (1954) observed that there would be very little windthrow if selective cutting of mature stands did not remove more than 45% of the merchantable volume. Comparable data for immature softwood stands in Maine is not available. However, for planning purposes a thinning of 45% of the biomass of living trees plus removal of the standing dead trees can be used as a guideline. Experimental plots of a demonstration nature with thinning ranging from 20-60% of the living biomass in immature stands of different age classes could be established to determine the optimum thinning from a silvicultural point of view. The harvesting patterns described by Kramer (1977) could be used with biomass determinations made by combining tree measurements with established regression equations. Since March 1977 the Seven Islands Land Company has been thinning dense, fully stocked stands in the vicinity of Rangeley, Maine. Measurements of these areas should provide invaluable data as they represent commercial field trial with available equipment and some specifically developed for the thinnings.

Immature fully stocked hardwood stands according to Table 4 have a much lower stand density than softwood stands of the same age on similar sites. The biomass of very young hardwood stands is so low that even though thinning may be silviculturally desirable a commercial thinning may not be economically feasible unless special thinning equipment is developed. Unfortunately, no field data was collected on standing dead trees in hardwood stands but observation supported by Table 4 do not suggest that the number would be very large.

Harvesting Equipment for Thinnings

Self propelled feller-bunchers, skidders, forwarders and chiparvestors that can utilize all above ground material are strong evidence of the advance of mechanized harvesting during the past 25 years. These reflect the response of equipment manufacturers to the requirements of the logging industry for harvesting mature stands. We can only hope that continually increasing national wood requirements coupled with awareness of the thinning potential of our forests will stimulate equipment manufacturers to produce an equivalent array of harvesting equipment fo thinnings.

Many forest land owners will buy thinning equipment that woul not become involved in logging mature stands. In addition, there probably would be many contractors who would specialize in thinning woodlo for small owners. Hopefully the Fuels for Biomass Section of the Depar men of Energy will assist in this by supporting the development of prototype thinning equipment by private industry for a public demand for thinning equipment should be evident in the early eighties.

Since 1970 (Samset 1978) the Division of Forest Operations of the Norwegian Forest Research Institute has worked on thinning equipment through the evolution of seven prototypes. The seventh, the NISK-delimber for thinnings, is now in commercial production. This machine is designed to efficiently thin young stands without damaging those tha are not felled. It is typical of the development effort in thinning machines that has been underway in the northern European countries for a good many years. American equipment manufacturers could gain much by becoming acquainted with European developments for it is well known "that the easiest way to be tall is to stand on a tall man's shoulders'

Stump-root Systems

The stump-root systems were deliberatedly omitted from the field work because (1) the added time that would be required on each plot and (2) data on individual trees established that the stump-root system is usually 21-27% of the total weight of the complete tree. If we assume that the majority of the immature stands are in the 35-55 ye age class and on meso sites than by using Table 3 as a guide there will be about 11.0 oven dry ton equivalents in the stump-root systems of such stands. In dense stands the root systems extend beyond adjacent trees making it inadvisable to remove the stump-root systems in thinnings operations. This should be established by field trials when new thinning equipment for stump-root systems is developed because the stump-root systems of the thinnings would be sufficient raw material to product many megawatts of electric power in Maine.

SUMMARY AND CONCLUSIONS

The above ground biomass on 205 plots representing a variety of age classes in immature hardwood and softwood stands on meso, wet and dry sites was cut and weighed including the standing dead trees on softwood sites. In addition, 45 point sample biomass plots were located and measured in mature all aged stands. Graphical analysis was used to relate stand characteristics to age by site and species groups for the immature stands. The significant findings were as follows:

1. Immature, fully stocked natural stands of softwood contain many more trees per acre than immature, fully stocked stands of hardwoods.

2. With increased age there is a rapid decrease in the number of trees per acre on all sites and species groups and a pronounced increase in the number of standing dead trees per acre in the softwood stands.

3. Meso sites are more productive for hardwood stands than either wet or dry sites for all ages studied. Productivity for all sites are similar for very young softwood stands but with increased age the meso sites are more productive.

4. Annual dry matter production is greatest at the youngest age

class studied for all species and decreases from then on. This is probably due to mortality under the dense conditions.

5. Thinning regimes in young stands regardless of species composition are desirable (1) to permit more rapid growth of improved quality of the trees remaining in the stand, and (2) to increase the yield from the forest principally in the form of material that can be used for energy, reconstituted products and the chemical industries when such markets become available.

6. The key to moving thinnings from a potential to a reality is the development of economically feasible equipment that will leave the standing forest undamaged.

7. Last and of most importance, biomass as a quantitative measure has demonstrated itself to be a sensitive measure for differentiating between productivity of different sites and thinning studies, both for immature stands and mature stands.

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