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ESTABLISHING EVEN-AGE NORTHERN HARDWOOD REGENERATION BY THE SHELTERWOOD METHOD– A PRELIMINARY GUIDE

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ESTABLISHING EVEN-AGE NORTHERN HARDWOOD REGENERATION BY THE SHELTERWOOD METHOD--A PRELIMINARY GUIDE

Richard M. Godman and Carl H. Tubbs

Shelterwood cuttings are proving to be one of the most reliable methods for establishing even-aged stands of northern hardwoods (fig. 1) (Behrend and Patric 1969, Curtis and Rushmore 1958, Leffelman and Hawley 1925, Metzger and Tubbs 1971, Tubbs and Metzger 1969). This system provides a partial canopy that encourages full stocking of desirable species, stimulates early seedling growth to shorten the establishment period, and restricts the intensity of competition from grasses and herbaceous plants. Other methods of establishing even-aged stands in the Lake States, such as heavy diameter-limit cutting and various forms of clearcutting, have generally given less consistent results (Metzger and Tubbs 1971). They have yielded great variation in both stocking and height development and frequently converted areas to grassy openings or patches dominated by partial stocking of pioneer species.

Shelterwood trials in northern hardwood types of the Lake States have all been successfu in establishing even-aged reproduction although the length of time it takes has varied. Advantages of the shelterwood method are its adaptability to mechanized harvesting, its desirable esthetic appearance while a new stand is becomin

Figure 1.--*Shelterwood stand 3 years after the initial cut.*

established, and its flexibility for wildlife habitat improvement and recreational use. Results from eight shelterwood cuttings and several other studies were used to develop this guide for shelterwood harvesting in the Lake States. Some of the recommendations are preliminary and will be refined as more results become available.

The first shelterwood trials were established in 1958 on the Argonne Experimental Forest in northeastern Wisconsin and the Upper Peninsula Experimental Forest in the Upper Peninsula of Michigan. The soils in these areas are silt loams and sandy loams, respectively; average site index was 65 for sugar maple (Acer saccharum Marsh.) and yellow birch (Betula alleghaniensis Britton) and 70 to 75 for basswood (Tilia americana L.) and white ash (Fraxinus americana L.) in both areas. Reproduction was present under both Argonne and Upper Peninsula stands at the time of the initial cut although in some treatments the advanced regeneration was removed.

OBJECTIVES OF THE TWO-CUT SHELTERWOOD SYSTEM

The objective of the shelterwood system is to develop dense, uniform, seedling stands during the regeneration period. Stand density influences not only growth and yield but also largely determines stem quality (Godman and Books 1971). Since the role of density is important throughout the stand rotation, the regeneration system must assure adequate stocking with a minimum establishment period. Under Lake States conditions, a two-cut shelterwood system will establish even-aged northern hardwood stands of tolerant species within an acceptable time. With a few modifications it also is suitable for establishing stands of less tolerant species.

The two-cut shelterwood cannot be used to secure natural regeneration in stands younger than 40 years or in stands having trees smaller than about 8 inches d.b.h. This is the age and size when sugar maple, the most abundant tree of the tolerant species, begins to produce seed.

GENERAL GUIDELINES

Making the First Cut

The residual crown cover is the key to successful establishment of even-aged stands by shelterwood cuttings. The amount and uniformity of the residual crown cover affect the intensity and duration of the light reaching the seedlings on the forest floor. Adequate shade must be provided to prevent the shallow-rooted seedlings from drying out until the root systems have developed. A transition period must also be provided for the seedlings to adapt and develop in a more open environment. Partial shade is also necessary to retard herbaceous competition which responds rapidly to increases in light intensities (Stroempl 1971, Metzger and Tubbs 1971).

After the first cut the residual canopy should admit about 40 percent of full sunlight. This compromise amount will permit good seedling establishment while restricting herbaceous competition somewhat. If severe competition is expected, more crown cover should be left. Regeneration is usually best obtained under a high, uniformly distributed canopy of large trees. Marking must therefore be from below, and all residual trees should be considered part of the residual overstory.

Experienced marking crews can estimate the proper amount of residual crown cover by eye. Normally they should try to leave a canopy that covers slightly more than one-half of the ground area.

The percent crown cover of a given area can be obtained more accurately by first summing the crown areas of individual trees, listed according to tree diameter and species (tables 1-3, column 2), and expressing the sum as a percent of the plot area (table 4).

Basal area should be disregarded in marking for crown cover because the basal area-crown area relationship varies sharply with both the diameter and species involved. Although average crown width increases with stem diameter for all species, there are significant differences in crown width among species groups in typical northern hardwood stands (fig. 2). In addition, small diameter trees (except for the hemlock-conifer group) have disproportionately wider crowns per inch of stem diameter than larger trees. Consequently, marking stands to the same basal area without regard to diameter and species will result in considerable variation in the percent of actual crown cover (fig. 3).

The fact that basal area is a poor indicator of crown cover can be further shown by comparing three plots with crown covers ranging from 37 to 57 percent, but all having about the same basal area (table 4).

Residual trees should have a full crown, be vigorous and able to withstand a more open site, and be capable of making good volume growth during the regeneration period. A diameter increase will often raise the grade of the butt log and increase economic returns from the removal cut. Fully crowned, vigorous trees will grow better and are not likely to have epicormic sprouts that could cause degrade. Trees with pronounced forks should not be left, particularly those with large diameter limbs and heavy callous growth at the fork. They are likely to split in open stands, reducing both the crown cover and tree value.

Table 1.--*Crown area of northern hardwood species by diameter classes and theoretical stocking for different levels of crown cover*

D.b.h.	Crown area	Crown cover (percent)								
		50			60			70		
		Trees	Basal area	Spacing	Trees	Basal area	Spacing	Trees	Basal area	Spacing
	Sq ft	No.	Sq ft	Ft	No.	Sq ft	Ft	No.	Sq ft	Ft
1	20	1,089	6	6	1,306	7	6	1,525	8	5
2	37	589	13	9	706	15	8	824	18	7
3	56	389	19	11	467	23	10	544	27	9
4	78	279	24	12	335	29	11	391	34	11
5	104	209	29	14	251	34	13	293	40	12
6	133	164	32	16	196	39	15	229	45	14
7	164	133	36	18	159	43	16	186	50	15
8	199	109	38	20	131	46	18	153	54	17
9	238	92	40	22	110	48	20	128	57	18
10	279	78	43	24	94	51	22	109	60	20
11	325	67	44	26	80	53	23	94	62	22
12	373	58	46	27	70	55	25	82	64	23
13	422	52	48	29	62	57	26	72	67	25
14	480	45	48	31	54	58	28	64	68	26
15	536	41	50	33	49	60	30	57	70	28
16	598	36	51	35	44	61	32	51	71	29
17	662	33	52	36	40	62	33	46	73	31
18	728	30	53	38	36	63	35	42	74	32
19	803	27	53	40	32	64	37	38	75	34
20	881	25	54	42	30	65	38	35	76	36
21	952	23	55	44	27	66	40	32	77	37
22	1,035	21	56	46	25	67	42	30	78	38
23	1,120	19	56	47	23	67	43	27	79	40
24	1,207	18	57	49	22	68	45	25	79	42

Table 2.--*Crown area of basswood by diameter classes and theoretical stocking for different levels of crown cover*

D.b.h.	Crown area	Crown cover (percent)								
		50			60			70		
		Trees	Basal area	Spacing	Trees	Basal area	Spacing	Trees	Basal area	Spacing
	Sq ft	No.	Sq ft	Ft	No.	Sq ft	Ft	No.	Sq ft	Ft
1	11	1,980	11	5	2,376	13	4	2,772	15	4
2	22	990	22	7	1,188	26	6	1,386	30	6
3	33	660	32	8	792	39	7	924	45	7
4	43	506	44	9	608	53	8	709	62	8
5	54	403	55	10	484	66	10	565	77	9
6	69	316	62	12	379	74	11	442	87	10
7	86	253	68	13	304	81	12	355	95	11
8	103	212	74	14	254	89	13	296	103	12
9	126	173	76	16	207	92	14	242	107	13
10	153	142	78	18	171	93	16	199	109	15
11	181	120	79	19	144	95	17	168	111	16
12	207	105	83	20	126	99	19	147	116	17
13	241	90	83	20	108	100	20	126	117	19
14	274	80	85	23	95	102	21	111	119	20
15	312	70	86	25	84	103	23	98	120	21
16	349	62	87	26	75	105	24	87	122	22
17	388	56	88	28	67	106	25	79	124	24
18	427	51	90	29	61	108	27	71	126	25
19	470	46	91	31	56	110	28	65	128	26
20	518	42	92	32	50	110	29	59	128	27
21	567	38	92	34	46	111	31	54	129	28
22	614	36	94	35	43	112	32	50	131	30
23	665	33	94	36	39	113	33	46	132	31
24	712	31	96	38	37	115	35	43	134	32

Table 3.--*Crown area of hemlock-conifers by diameter classes and theoretical stocking for different levels of crown cover*

D.b.h.	Crown area	Crown cover (percent) 50			60			70		
		Trees	Basal area	Spacing	Trees	Basal area	Spacing	Trees	Basal area	Spacing
	Sq ft	No.	Sq ft	Ft	No.	Sq ft	Ft	No.	Sq ft	Ft
1	1	21,780	119	1	26,136	142	1	30,492	166	1
2	4	5,445	119	3	6,534	142	3	7,623	166	2
3	10	2,178	115	4	2,614	138	4	3,049	166	4
4	17	1,281	112	6	1,537	134	5	1,794	156	5
5	27	807	112	7	968	134	7	1,129	156	6
6	38	573	112	9	688	134	8	802	156	7
7	52	419	112	10	503	134	9	586	156	9
8	68	320	112	12	384	134	11	448	156	10
9	87	250	111	13	300	133	12	351	156	11
10	107	204	111	15	244	133	13	285	156	12
11	129	169	111	16	203	133	15	236	156	14
12	154	141	111	18	170	133	16	198	156	15
13	181	120	111	19	144	133	17	168	156	16
14	209	104	111	20	125	133	19	146	156	17
15	241	90	111	22	108	133	20	126	156	19
16	274	80	111	23	95	133	21	111	156	20
17	309	70	111	25	85	133	23	99	156	21
18	346	63	111	26	76	133	24	88	156	22
19	386	56	111	28	68	133	25	79	156	24
20	427	51	111	29	61	133	27	71	156	25
21	471	46	111	31	56	133	28	65	156	26
22	518	42	111	32	50	133	29	59	156	27
23	563	39	111	34	46	133	31	54	156	28
24	612	36	111	35	43	133	32	50	156	30

Sensitive species, such as yellow birch, normally should not be left. Yellow birch is susceptible to severe attack by sapsuckers in the open environment of a shelterwood cut and may be killed outright or subject to top damage and reduced growth.

Unmanaged northern hardwood stands often include small areas that are well stocked with saplings. These may be left at the forester's discretion if they are extensive enough. Scattered saplings should be removed.

Response of Tolerant Seedlings to Varying Amounts of Crown Cover

Stocking and height growth of the regeneration varies with percent crown cover left in the overstory following the initial cut (table 5). In the oldest study 60 percent crown cover resulted in all quadrats being stocked with desirable species at a density in excess of 44,000 seedlings per acre. Little crown cover or removal of the canopy in a single cut (Metzger and Tubbs 1971) can result in inadequate numbers and partial stocking but much cover tends to suppress seedling establishment. Variations in crown cover do not necessarily result in changes in species composition (Tubbs 1968).

Height growth of the seedlings under the 60 percent crown cover was slowing down at the end of the 7-year period. At this stage the crown cover had increased to 76 percent (table 5). Although seedling growth should continue at this amount of crown cover (as suggested by stand 2, table 5) there will obviously be a gradual reduction in future growth rates. This suggests that greater amounts of crown cover might be used to hold the regeneration at browse height for a longer use period in the vicinity of winter deeryards.

Factors Influencing Herbaceous and Shrub Growth

Grass and shrubs commonly invade heavily cut hardwood stands. In some cases these species appear to retard tree reproduction for lengthy periods. Both intensity of cut and season of logging appear related to invasions by grass and shrubs. Site and geographic location are also factors.

Logging while the ground is snow covered has advantages over summer logging for both the initial and removal cuts. Winter cuttings result in lower seedling mortality, less ground competition, and less damage to seedling stems. In one initial cutting trial, the summer-logged area had only one-third as many seedlings as the

Table 4.--*Comparison of three 1/10-acre plots marked to the same basal area but having different percentages of crown cover*

D.b.h.	Number of trees: Northern hardwoods	Basswood	Hemlock	Plot total: Basal area	Crown area1/
				Sq ft	Sq ft
LARGER TREES OF MIXED CROWN WIDTH					
8	2			0.7	398
10					
12					
14			1	1.1	209
16		1		1.4	349
18					
20	1			2.2	881
Total				2/5.4	3/1,837
SMALLER TREES OF A SINGLE CROWN WIDTH					
8	2			0.7	398
10	1			.5	279
12	2			1.6	746
14	1			1.1	480
16	1			1.4	598
Total				4/5.3	5/2,501
SMALLER TREES OF A MIXED CROWN WIDTH					
8		2		0.7	206
10			1	.5	107
12		2		1.6	414
14		1		1.1	274
16	1			1.4	598
Total				6/5.3	7/1,599

1/ Average crown area per tree given in Column 2, tables 1, 2, and 3.

2/ Basal area per acre = 54 sq ft.

3/ Percent crown cover = $\frac{1,837}{4,356}$ = 42.

4/ Basal area per acre = 53 sq ft.

5/ Percent crown cover = $\frac{2,501}{4,356}$ = 57.

6/ Basal area per acre = 53 sq ft.

7/ Percent crown cover = $\frac{1,599}{4,356}$ = 37.

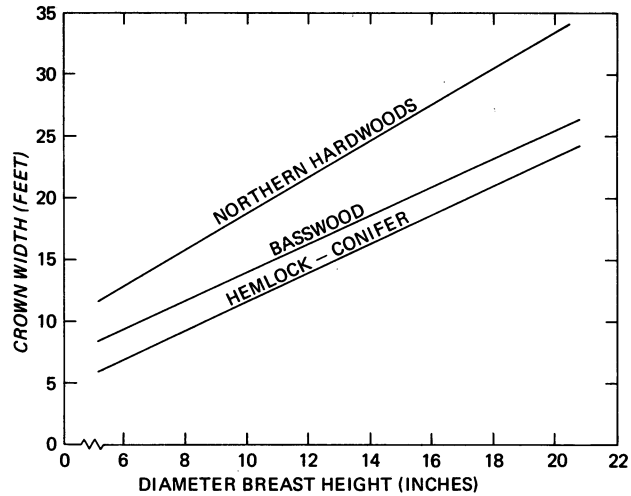

Figure 2.--*Average crown width by stem diameter and species group.*

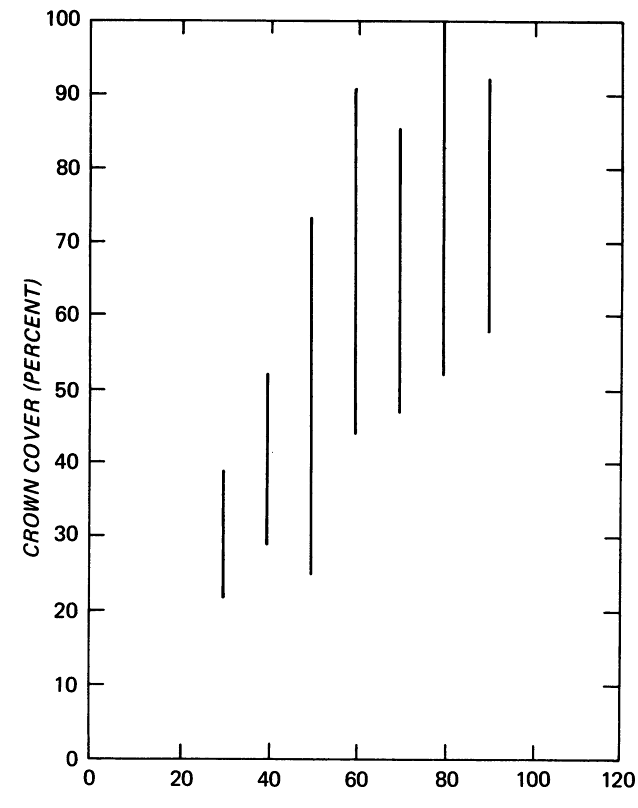

Figure 3.--*Observed variation in percent of crown cover associated with different basal area densities in northern hardwood stands.*

area that was cut in winter, and raspberries were dominant on 75 percent of the quadrats at the end of the third growing season. It appears that the summer-logged area will require a much longer time to establish regeneration because of competition from herbaceous vegetation. The stocking may also remain sparse because of seedling loss from skidding.

Geographical location and site also determine if competition from herbaceous vegetation will be harmful to regeneration. In the Upper Peninsula Experimental Forest raspberry growth fostered by heavy cuttings ultimately had little adverse effect on tree regeneration. Foresters must make use of local experience in deciding whether shrubs and herbaceous vegetation will be a significant factor.

Overstory Removal

The shelterwood overstory should be harvested as soon as the established seedlings

Table 5.--*Influence of different amounts of crown cover on stocking and height growth 7 years after a shelterwood cutting*

Stand number	Crown cover: Initial cut	Crown cover: After 7 years	Quadrats stocked	Seedlings per acre: Total	Seedlings per acre: More than 3.6-feet tall
	Percent	Percent	Percent	Number	Number
1	60	76	100	44,040	9,800
2	76	94	100	33,400	2,500
3	130	158	100	17,100	700

have deep root systems, are capable of responding to full sunlight, and dominate the competing vegetation. Normally these conditions are met when the seedlings are at least 3-feet tall. At this stage they generally retain dominance over herbaceous competition. If advanced regeneration was present before the initial cut, it is usually well enough established within 3 to 8 years to remove the overstory.

Trees that are not financially mature at the second cutting may be left if there are enough to make a cut economic at a later date. However, increasing the number of cuttings will inevitably result in a stand of many size classes.

The overstory should be logged when there is snow cover to minimize seedbed disturbance and damage to seedlings. However, we have found that as much as 50 percent of the reproduction can be damaged without permanent adverse effects. Damaged seedlings grow rapidly and the minor crooks that develop in the early stages disappear as stem size increases (Jacobs 1969). We find that leader growth can exceed 3 feet during the year after stem breakage, which rapidly brings the seedling sprouts back to the level of the more slowly growing, undamaged seedlings.

Lopping slash also damages seedlings. Since hardwood slash deteriorates rapidly in this type and fire danger is normally low (Eyre and Zillgitt 1953), lopping may be less necessary here than in other forest types.

MODIFICATIONS TO INCREASE THE PROPORTION OF YELLOW BIRCH

There are two major requirements for the establishment of large numbers of rapidly growing yellow birch seedlings. First, the seedbed must be cool and moist during the germination period (Tubbs 1969a). Second, competition from tolerant species (especially sugar maple) should be reduced either by choosing sites that are less suitable for those species, or removing advanced reproduction, or both (Tubbs and Metzger 1969, Tubbs 1970).

Site Selection

Hemlock-hardwood sites have proven to be the easiest on which to establish birch. These sites are relatively cool and wet, and advanced reproduction of competing species is often deficient.

Yellow birch makes good growth on moderately to well drained soils but these are also good sugar maple sites. Even after scarification, birch numbers and growth are relatively low because the maple re-invades rapidly and inhibits birch growth (Tubbs and Metzger 1969).

The sandier hardwood soils which tend toward excessive drainage are natural birch sites in the north but birch establishment after scarification is scanty on them because of the dry, infertile nature of the seedbed.[1/] These sites have a low priority because successful birch reproduction will probably be infrequent. However, on sandy soil with a high water table birch sometimes reproduces in fair numbers.

Seedbed Preparation

Scarification to expose the mineral soil gives the best results over the widest range of conditions. Scarification should mix the humus and mineral soil thoroughly and destory as much advance regeneration as possible. The mineral soil provides a cool, moist environment for germination; the humus stimulates growth (Tubbs and Oberg 1966). Simply scraping the humus away on typical podsols exposes the A_2 horizon which is deficient in nutrients and often of moisture.

Ideally, 50 percent or more of the area (Godman and Krefting 1960) should be scarified after leaf fall in a good seed year and before harvesting operations begin. Scarified seedbeds generally remain suitable for 2 or 3 years. Yellow birch has at least moderate seed crops every 3 years (USDA Forest Service 1965) so that the chance of having adequate numbers of seed is good even if scarification cannot be done during a seed year. On poorly drained soils low mounds help birch establishment (Tubbs 1963).

1/ Unpublished data on file at the Northern Hardwoods Laboratory, Marquette, Michigan.

Mounds need only be a foot or two in height and rounded or flat on top.

Prescribed fire is an inexpensive way to remove advanced growth and forest litter; in 1969 costs were estimated at less than $1 per acre in Ontario (Burton et al. 1969). To be most effective, burning should be done in the spring during or immediately after the leaf-out period when advanced seedling numbers can be drastically reduced.

Although burning has the virtue of being cheap and easier than scarifying on some sites, it has several shortcomings. The number of days that are conducive to spring burning are few. The resulting seedbed is dark colored and hot; on well-drained sites both germination and survival rates may be low (Tubbs 1969b). A recent trial has shown that fires hot enough to expose the mineral soil (which is more moist and cooler than burned litter) may kill overstory trees. In one study, this opened the canopy enough to encourage herbaceous species which reduced birch survival drastically. Overstory kill can be minimized by burning before harvesting when fuel quantities are low. Light burns cause no significant changes in nutrient status or soil microbial populations (Burton et al. 1969).

Killing advanced seedlings with foliage sprays during the growing season has resulted in increases of birch (Tubbs and Metzger 1969). Because the litter is not removed, however, only about half as much birch will become established as after scarification.

The First Cut

Overstory density is important to yellow birch establishment on most sites because of its influence on seedbed moisture, temperatures, and herbaceous competition. Full sunlight following clearcutting is detrimental to germination and establishment in most situations because yellow birch cannot tolerate the high temperatures and moisture conditions which result (Godman 1959, Tubbs 1969a). Open stand conditions promote raspberry growth and grass invasion which can also contribute to birch failures (Metzger and Tubbs 1971, Tubbs 1969a, Godman and Krefting 1960). After seedlings are well established, however, full sunlight promotes the best growth (Burton et al. 1969). Consequently, the first cut should provide the cool, moist conditions necessary for establishment while the second cut releases the seedlings. A wide range (from 30 to 70 percent) of overstory results in satisfactory establishment of yellow birch. In areas where development of heavy herbaceous competition is expected, heavy shade (up to 70 percent crown cover) will probably be necessary to control competition if birch is to succeed. More shade than this, however, generally results in poor seedling vigor.

Good birch sites are often moist so the most abundant species tend to be shallow rooted and subject to post-logging decadence. Prudence dictates that special attention be paid to leaving vigorous trees in the overstory, especially if a long establishment period is expected. Epicormic sprouts will develop but should not be important for short periods; when sprouts are small, these defects will be slabbed off along with defects from logging wounds (Meyer et al. 1966).

Because yellow birch seedlings compete poorly with sugar maple, some attempt should be made to discriminate against sugar maple in the overstory. Sugar maple normally does not produce moderate seed crops until reaching 10- to 14-inches d.b.h. (USDA Forest Service 1965) and the larger trees will obviously produce the most seed. Thus, where spacing permits, remove the largest sugar maples first.

Leaving many yellow birch in the overstory for seed probably will not increase birch stocking and may lead to losses from decadence and mortality (Jacobs 1960). Seed has been shown to be adequate 5 chains from the source (Benzie 1959). In another study enough seed was produced on a scarified area containing four trees per acre to provide over 1/2 million seedlings per acre (Godman and Krefting 1960). One seed-bearing birch per acre should provide adequate insurance against unfavorable climatic conditions or seed crop failures.

Seeding and Planting

Seeding and planting to augment natural regeneration seldom have been practiced. Earlier experimental evidence (Stoeckeler and Limstrom 1950) indicates that planting in open conditions often will be unsuccessful. However, recent trials have shown that yellow birch seedlings can be successfully planted on moist soils under a shelterwood overstory. Establishment can be improved by removing half the seedling stem before planting (Godman and Mattson 1971).

Direct seeding has been successful on small plots under a shelterwood canopy. Tree percent may be low, however, even on favorable sites (Tubbs 1969a). At least 1/4 pound of seed is needed per acre on scarified sites to get a dense stocking.[2/] In the Upper Peninsula of Michigan seed sown before January germinates well the following spring; seed sown after this date germinates late in the summer (Tubbs 1964).

Overstory Removal

Overstories may be removed when the yellow birch seedlings average 2 to 4 feet in height.

2/ Number of seed varies from 330,000 to 1 million per pound.

The establishment period runs from a minimum of 3 years (Burton *et al*. 1969) to 7 or 8 years (Tubbs and Metzger 1969) at which time birch should be an acceptable height. In controlled studies, removal of shade from vigorous birch of this size had no effect on growth the following growing season (Tubbs and Metzger 1969). Damage to the reproduction should be light if removal is made during the winter but seedling birch apparently recover from any damage short of uprooting. Winter logging that removed 20 or more square feet of basal area resulted in insignificant mortality of birch reproduction (Tubbs and Metzger 1969). In another study, severely top-damaged young birch seedlings sprouted back to make better height growth than undamaged seedlings (Tubbs 1969a).

SUMMARY OF RECOMMENDATIONS FOR APPLYING TWO-CUT SHELTERWOOD IN NORTHERN HARDWOOD STANDS

General Rules for Tolerant Species

1. Stands selected should be moderately well stocked with advanced regeneration of desirable species. At the minimum, stands should average at least 8 inches d.b.h.

2. Marking must be from below. Leave 60 percent crown cover at regular spacing. All trees left must be considered part of the residual crown cover.

3. Initial logging should be done only when the ground is snow covered to minimize seedling loss.

4. The overstory can be removed when the reproduction attains a height of 3 to 4 feet. Log when the ground is snow covered, removing all stems. Lopping of slash should be minimized and restricted to esthetic or access areas.

Modifications to Favor Yellow Birch

1. Attempts to regenerate yellow birch should focus on cool, moist (hemlock-hardwood) sites.

2. Marking should tend to discriminate against sugar maple in the residual overstory. Leave no more than 70 percent crown cover of the most vigorous trees.

3. Scarify 50 percent or more of the surface area after leaf fall and prior to logging. Scarification should aim at mixing the humus and mineral soil and destroying advance regeneration. Kill advanced regeneration prior to cutting on sites too difficult to scarify.

4. Make the first cutting during moderate or better seed year, or direct seed before midwinter at a rate of at least 1/4 pound per acre on the scarified area. One seed tree per acre may be left for insurance.

LITERATURE CITED

Behrend, D. F., and E. F. Patric. 1969. Influence of site disturbance and removal of shade on regeneration of deer browse. J. Wildl. Manage. 33(2): 394-398.

Benzie, John W. 1959. Sugar maple and yellow birch seed dispersal from a fully stocked stand of mature northern hardwoods in the Upper Peninsula of Michigan. USDA For. Serv., Lake States Forest Exp. Stn. Tech. Note 561, 1 p.

Burton, D. H., H. W. Anderson, L. F. Riley. 1969. Natural regeneration of yellow birch in Canada. Northeast. For. Exp. Stn. Birch Symp., Durham, N. H., August 1969: 55-73.

Curtis, R. O. and F. M. Rushmore. 1958. Some effects of stand density and deer browsing on reproduction in an Adirondack hardwood stand. J. For. 56: 116-121.

Eyre, F. H., and W. M. Zillgitt. 1953. Partial cuttings in northern hardwoods of the Lake States--twenty year experimental results. U.S. Dep. Agric. Tech. Bull. 1076, 124 p., illus.

Godman, R. M. 1959. Are water table levels an important factor in the establishment and growth of yellow birch? Mich. Acad. Sci., Arts, Letters XLIV: 183-190.

Godman, R. M., and D. J. Books. 1971. Influence of stand density on stem quality in pole-size northern hardwoods. USDA For. Serv. Res. Pap. NC-54, 7 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Godman, R. M., and Laurits W. Krefting. 1960. Factors important to yellow birch establishment in Upper Michigan. Ecology 41(1): 18-28.

Godman, R. M., and G. A. Mattson. 1971. Top pruning may benefit yellow birch planting stock. USDA For. Serv. Tree Plant. Notes 22(1): 24-25.

Jacobs, Rodney D. 1960. Top-dying of yellow birch, Upper Michigan 1955-59. USDA For. Serv., Lake States For. Exp. Stn. Tech. Note 585, 2 p.

Jacobs, R. D. 1969. Growth and development of deer-browsed sugar maple seedlings. J. For. 67: 870-874.

Leffelman, L. J., and R. C. Hawley. 1925. Studies of Connecticut hardwoods. The treatment of advance growth arising as a result of thinnings and shelterwood cuttings. Yale Univ. Sch. For. Bull. 15.

Metzger, F. T., and C. H. Tubbs. 1971. The influence of cutting method on regeneration of second-growth northern hardwoods. J. For. 69(9): 559-564.

Meyer, Gene, John H. Ohman, and Russell Oettel. 1966. Skidding hardwoods--articulated rubber-tired skidders versus crawler tractors. J. For. 64(3): 191, 194-196.

Stoeckeler, J. H., and G. A. Limstrom. 1950. Reforestation research findings in northern Wisconsin and Upper Michigan. USDA For. Serv., Lake States For. Exp. Stn., Stn. Pap. 23, 34 p. St. Paul, Minn.

Stroempl, G. 1971. Planting of basswood is successful in hardwood cutovers. USDA For. Serv. Tree Plant. Notes 22(1): 26-29.

Tubbs, Carl H. 1963. Artificially constructed mounds show promise in yellow birch regeneration. USDA For. Serv. Res. Note LS-32, 2 p. Lake States For. Exp. Stn., St. Paul, Minn.

Tubbs, Carl H. 1964. Germination of yellow birch seed following natural stratification in Upper Michigan. USDA For. Serv. Res. Note LS-34, 2 p. Lake States For. Exp. Stn., St. Paul, Minn.

Tubbs, Carl H. 1968. The influence of residual stand densities on regeneration in sugar maple stands. USDA For. Serv. Res. Note NC-47, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Tubbs, Carl H. 1969a. The influence of light, moisture, and seedbed on yellow birch regeneration. USDA For. Serv. Res. Pap. NC-27, 12 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Tubbs, Carl H. 1969b. Natural regeneration of yellow birch in the Lake States. Northeast. For. Exp. Stn. Birch Symp., Durham, N.H., August 1969: 73-78.

Tubbs, C. H. 1970. The competitive ability of yellow birch (Betula alleghaniensis Britton) seedlings in the presence of sugar maple (Acer saccharum Marsh.) with specific references to the role of allelopathic substances. Ph.D. Thesis, Univ. Mich. 80 p.

Tubbs, C. H., and F. T. Metzger. 1969. Regeneration of northern hardwoods under shelterwood cutting. For. Chron. 45(5): 333-337.

Tubbs, C. H., and R. R. Oberg. 1966. Growth response of seedling yellow birch to humus-mineral soil mixtures. USDA For. Serv. Res. Note NC-6, 2 p. North Cent. For. Exp. Stn., St. Paul, Minn.

USDA Forest Service. 1965. Silvics of forest trees of the United States. U.S. Dep. Agric Agric. Handb. 271, 762 p.

NORTH CENTRAL FOREST EXPERIMENT STATION

50 YEARS

1923 1973