Eastern hemlock (Tsuga canadensis) in north central Wisconsin. Report 104 1980

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EASTERN HEMLOCK
(Tsuga canadensis)

in

North Central Wisconsin

by

Ronald G. Eckstein
Forest Habitat Coordinator
Rhinelander

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ABSTRACT

Hemlock was once thought to be a declining species in the northern forests as a result of factors inherent in forest communities. Recent studies have shown that without high deer populations, hemlock communities are stable entities and that hemlock growing on podzolized soils will be present in the terminal forests.

In northern Wisconsin's original forests, deer populations averaged less than 10 deer/mile^2 and hemlock dominated various areas by the strategy of: (1) extreme shade tolerance, slow growth, site deterioration, and extreme age; and (2) as a result of periodic catastrophic events. The absence of seedling hemlock has been blamed on deer browsing, when poor seedbeds and dense overstories may be the causal factors.

A management strategy based on a shelterwood system of cutting may solve the problems of the initial establishment of hemlock seedlings and eventually enable hemlock to grow beyond the reach of white-tailed deer.

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INTRODUCTION

Most of the forest management techniques used to promote forest wildlife are logical outgrowths of sound timber management. The clearcutting of aspen, white birch, and spruce-fir types benefits forest game species and provides a sustained yield of forest products. Wildlife managers recognize that forest types such as northern white-cedar and hemlock are key ingredients of the winter range of deer in north central Wisconsin. Ecologists consider these forest types a valuable component of the forest system. However, both cedar and hemlock are slow growing, relatively uneconomical trees, and are not regenerating across most of Wisconsin's northern forest. This presents land managers with a dilemma. Sound wildlife management dictates maintenance of these forest types while sound forest management dictates conversion to faster-growing more economical timber types.

ECOLOGY

A hemlock stand is defined as a stand composed of: (1) white pine and hemlock which are predominant in mixture, (2) hemlock which is pure or predominant over any single associate, and/or (3) hemlock and yellow birch which are predominant in mixture.

Hemlock is a major component of three Society of American Foresters' (1975) forest types in Wisconsin: White Pine-Hemlock (Type 22), Hemlock (Type 23), and Hemlock-Yellow Birch (Type 24). It also occurs in ten other forest types in the Lake States (Fowells, 1965).

Hemlock's main range in Wisconsin is in the northeast and north central portions of the state. It extends west to Bayfield, Rusk and Clark Counties and south to Marathon, Shawano, Brown, and Manitowoc Counties (Goder 1961). Isolated stands are found in Douglas and Washburn Counties and on steep north-facing hills and cliffs in southwestern Wisconsin (Iowa, Sauk, Grant and Richland Counties). Hemlock reaches the western limits of its range in isolated stands in northeastern Minnesota (Fowells 1965).

Flaccus and Ohmann (1964) indicated that the dropping out of hemlock and yellow birch as one proceeds westward from north central Wisconsin is associated with decline in effectiveness of precipitation. They believed that discrete stands were able to exist beyond the species' main range because of past catastrophic events and because of site characteristics which compensate for the climatic changes.

Hemlock was a significant component of the northern mesic forests of Wisconsin prior to 1850 (Curtis 1959). Extensive logging followed by wildfires and land clearing resulted in massive conversion of hemlock-hardwood communities to second growth northern hardwoods or aspen-white birch.

Natural History of Hemlock Trees

Hemlock is a medium-sized tree which grows to a height of 100 ft and a diameter of 30 in. Under favorable conditions, pure virgin stands attain yields of about 20,000 BF/acre (Wilde 1976).

Hemlock can grow in dense shade for 25 to 200 years, can grow rapidly once released (Frothingham 1915), and has a longevity potential of 600 years (Kozlowski 1971)--the record being 988 years (Fowells). Bourdeau and Laverick (1958) found the chlorophyll content in the sun needles of hemlock was about the same as that of shade needles in red and white pine. Hemlock trees of less than 1 in. diameter are sometimes over 100 years old and 2- to 3-in. saplings may be as much as 200 years old. One 10-in. tree in a dense virgin stand was 359 years old, while other trees of the same age but of dominant crown class were 24 to 36 in. in diameter (Fowells 1965).

Hemlock produces good seed crops in about two of every three years (Godman and Mattson 1976). As many as 13½ million sound hemlock seeds/acre can be present in a good seed year (Davis and Hart 1961). There is, however, poor viability in Wisconsin with only approximately 25% of the seed crop capable of germinating. Dominant hemlock trees begin to bear viable seed at 30 to 50 years of age in fully stocked stands. Old-growth trees continue to produce viable seeds for up to 450 or more years (Fowells 1965). Hygroscopic cone scales and small seed size insure widespread dispersal.

Since hemlock seeds are relatively small, the radical has great difficulty penetrating even small thicknesses of forest litter and it is usually unable to penetrate a mat of sugar maple leaves or hemlock needles. Lutz (1930), Hough (1943), Potzger (1946), Stearns (1951), and Goder (1956) found that hemlock seedlings became established only on rotten fallen logs, stumps, or on tip-up mounds. Moss-covered logs and stumps are organic sites that remain moist throughout the growing season and provide suitable seedbeds for germination and early seedling survival.

Germination occurs best at a temperature of 59^{o}F on a mixed humus-mineral soil seedbed (Godman, pers. comm.). The vast majority of hemlock seeds do not germinate in Wisconsin because of various environmental conditions on the forest floor. If a seedling does germinate, it may be: (1) smothered by hardwood leaf fall, (2) desiccated during frequent hot, dry periods during the summer, (3) killed by damping-off (Rhizoctonia) or root-rot fungi, (4) eaten by mammals such as the red-backed vole, snowshoe hare, and the white-tailed deer, or (5) damaged by frost heaving.

Seedlings usually grow 1-2 in. the first year, reaching 10-20 in. in height after 4-7 years. Early seedling survival depends on consistent moisture in the upper soil horizons during the growing season, adequate light, and freedom from competition from other trees and shrubs. Dense understory growth of raspberries, mountain maple, red maple, or sugar maple inhibits hemlock seedlings growth.

Mature hemlock trees are resistant to fall frosts and put out shoot growth late in spring. The tree is usually shallow rooted and thus easily injured by drought, damage to the roots, sudden exposure after heavy logging, and windthrow. Windshake is present in most old growth stands. Hemlock trees are susceptible to heavy damage by the sapsucker, the porcupine, and the hemlock borer. For a discussion of diseases and insect pests (of which there are few) see Baker (1972), Fowells (1965), and Hepting (1971). Hemlock is susceptible to spruce budworm, but only during very heavy infestations.

Natural History of Hemlock Communities

The hemlock community has been described both: (1) as a self-perpetuating community, and (2) as a long-lived seral community which gives way to a maple-basswood community. Brown and Curtis (1952) stated:

> Tsuga is a tree which presents troubling problems that have provoked a great deal of research. Briefly stated these are: how does a stand of Tsuga originate and is it self-perpetuating? According to Hough (1936) and Hough and Forbes (1943) Tsuga probably seeds in best after a disaster. They found that in a large forest in northwestern Pennsylvania the Tsuga trees could be separated into definite age classes. If Tsuga were capable of becoming established under a mature forest canopy, the trees would be of all ages. Stearns (1951) made age determinations on many trees in Wisconsin and found that some had been suppressed for many years before finally gaining a place in the canopy, but that others started in the open. He found a suggestion of periodicity such as that described by Hough. Lutz (1930) and Graham (1941) both felt that Tsuga was capable of self-perpetuation but Lutz did mention that in dense stands reproduction was scanty.

Because of the lack of hemlock reproduction in hemlock or hardwood forests, Brown and Curtis (1952) and Curtis (1959) believed that hemlock was not as tolerant as sugar maple and that hemlock forests would eventually be replaced by forests dominated by sugar maple.

McIntosh (1972) found that hemlock communities in the Catskill Mountains of New York began as nearly pure stands which slowly became mixed as northern hardwoods encroached on them.

> Their long life span perpetuates these trees for extended periods, but in this they are analogous to pine-hardwood stands. It seems improbable that...climax forests of hemlock eventually break up and deteriorate, only to return once more, gradually as the dominant form of vegetation...as Langford and Buell

(1969) interpreting Hough and Forbes (1943) suggest, except as the result of periodic disturbance. Contrary to this view and to Martin's (1959) assertion that hemlock is the climactic climax species and encroaches on hardwood forests, hemlock is not climax in the Catskills and gives no evidence of spreading effectively into hardwood forests at any altitude.

On the other hand, Goff (1967) studied the forests of the Menominee Indian Reservation in Wisconsin and concluded that hemlock communities were the terminal forests on stratified loamy sands and sandy loams, as well as on loams and shallow silt loams. He found an intimate relationship between surface organic soil horizons, particularly the litter layer, and tree species replacement patterns. The overstory tree species determined the nature of the soil surface organic layers with their annual increment to the litter, and by the degree of interception of atmospheric moisture. In hemlock communities there was a thick, acid mor litter layer under which the mineral soil became acid and low in nutrients and ion exchange capacity. Beneath a solid hemlock overstory, invading trees and shrubs were subjected to veritable desert conditions. This was in sharp contrast to the rich ephemeral ground layer in the maple-basswood forests of the silt loams.

Goff (1968) and Goff and Zedler (1972) studied the successional sequence of tree species on the Menominee Indian Reservation. They determined that the post-fire successional sequence on medium-textured soils progressed from aspen to white pine to hemlock to sugar maple and other tolerant hardwoods. They concluded that there was a relatively stable association of hemlock and yellow birch which occurred between the rich old growth maple basswood forests and the lowland forests. Hemlock was found to be a long-lived seral species on the deep silt loams, but was a member of the terminal forest on the sandy loams.

It is interesting to note that Brown and Curtis (1952) and Curtis (1959) studied hemlock in areas with deer populations in excess of 25 deer/mile^2 of range, with deer populations below 10 deer/mile^2.

Population Stucture and Cycles

The negative exponential form of population structure has been used to measure the displacement of the diameter distribution due to growth and to predict the removal from each diameter interval required to maintain a northern hardwood forest on a sustained yield basis (Leak 1964).

Goff and West (1975) studied density-diameter relationships. They found that figures presented by Goodman (1930) for the old growth hemlock-hardwood Goodman Tract in Florence and Forest Counties clearly approximated a negative exponential distribution of density against diameter. They pointed out that Hough (1932) found a similar distribution in virgin forests in northwestern Pennsylvania. Hough believed that such curves resulted not from a truly all-aged condition of single species, but rather from the fact that different species reached their peak density at a different point along the diameter axis.

Goff and West (1975) studied old growth hemlock-hardwood stands on the Menominee Indian Reservation and found variations in growth and mortality rates caused by a forest stand's vertical structure. In small or structurally uniform old-growth stands there were several populations: the understory with a low growth rate and high seedling and sapling mortality, the vigorous overstory with a high growth rate and low mortality rate, and the senescent overstory with a low growth rate and high mortality rate. The resulting density-diameter curve consisted of three distinct phases which combined to form a population structure curve of rotated sigmoid form on semi-log graph paper. I believe that this population structure typifies most of the small, undisturbed hemlock stands in north central Wisconsin.

Hett and Loucks (1976) studied hemlock in Ontario, Canada and on the Menominee Indian Reservation. They were interested in the development of models to describe age structures of long-lived species such as hemlock and depletion of individual trees over long periods of time.

> Hough and Forbes (1943) suggested that hemlock was cyclical in seedling establishment. In their view, the shallow rooting of this species intensifies competition for water near the surface of the soil. In our opinion, it is the shallow rooting of the saplings that imposes an intense depletion rate while a sapling colony is present. Decades later the saplings have developed to trees, they are more deeply rooted, and the geometry of the canopy is such that more light penetrates. The result is a lower depletion rate until a new wave of seedlings form another sapling layer. Thus, population cycles are induced by conditions influencing survivorship rather than first-year seedling establishment. Hough & Forbes identified three waves from their study of hemlock in Pennsylvania, and these are approximately 165 to 155 years apart. These intervals are consistent with the short-interval periodicity found in this study, and they suggest an alternate cycle totaling 320 years.

Hett and Loucks (1976) concluded that these cycles are inherent in the biological characteristics of the species expressed through systematic changes in forest structure over centuries. Thus, deviations from a negative exponential density-diameter curve in hemlock stands should not be interpreted as an unbalanced condition which needs to be altered through management. Hemlock-hardwood stands should be managed with silvicultural techniques (shelterwood) that duplicate and enhance natural processes. The use of an uneven-aged silvicultural system, in the presence of fire control and high deer populations, will result in the conversion of hemlock communities to maple communities.

Establishment Following Fire

There are conflicting opinions concerning the role of fire in the establishment of hemlock. Stearns (1949) studied an undisturbed hemlock-hardwood forest in Forest County, Wisconsin, and concluded that fire was rarely of much importance as the initial agent of catastrophe, although it often followed windfall. Stearns found that hot slash fires burned from the surrounding cutover lands to the edge of the old growth, but rarely penetrated more than a few rods.

Graham (1941) believed that fire played an important role in northern forests, but found that hemlock could reproduce without fire. He believed that no hemlock became established during dry years and that mass reproduction took place during a series of wet years. At other times, occasional trees in especially favorable spots gained a foothold. When fires occurred the older trees survived while the others perished. Repeatedly burned stands exhibited an even-aged structure. Graham admits that under certain conditions hemlock mass established after fire. Nevertheless, he maintained that hemlock was not a fire species and that it can and does reproduce on the forest floor.

Studies have shown, however, that many seedbeds suitable for hemlock regeneration were created through fire in northern Wisconsin (Maissurow 1941):

> Of 1,722 reproduction plots studied, only 14 showed the presence of individual (hemlock) seedlings. Its reproduction, however, is often found on areas burned over, where it grows in association with paper birch, tolerant hardwoods, and softwoods.
>
> The age structure of hemlock-hardwood stands is simple. Without a single exception, the stands are essentially even-aged, and contain a considerable admixture of white pine and even paper birch. Their fire origin is unquestionable. This is fully substantiated by the composition of young stands springing up on areas burned over and made up of hemlock overtopped by white birch or mixtures of hemlock with aspen, white birch, tolerant hardwoods, white spruce, and balsam.

Goff (1967) found that hemlock established in very high densities following surface fire beneath an intact overstory. He found a dense hemlock fire-fringe in many areas along the Shawano-Menominee County line where fire burned into the Menominee pine-hemlock stands from adjacent cutover areas. Trees of 1-6 in. dbh often exceed 1,000/acre in this fire fringe.

Miles and Smith (1960) studied three hemlock stands in Nova Scotia. They found that all three stands were essentially even-aged and all could be traced to major fires 70, 150, and 150+ years ago. They concluded that fire was a major factor in the development of even-aged hemlock stands in Nova Scotia.

In north central Wisconsin, examples of dense, fire-origin hemlock can be found in Section 12, T39N, R4E; Section 1, T38N, R9E; Sections 11 and 12, T35N, R9E (Oneida County); and Section 27, T34N, R10E (Langlade County).

Current Research

Godman (pers. comm.) is conducting research on optimum field germination temperatures of hemlock and associated species. He found that the measurements of surface soil temperatures correlate well with the presence and absence of hemlock according to the literature -- even though this factor was not inferred or considered by earlier investigators.

> The current research on germination temperatures shows that hemlock germinates best at a temperature of 59°F. In contrast, sugar maple germinates best at 34°F, northern white-cedar at temperatures above 65°F with other species falling between these extremes. Yellow birch germinates best at temperatures similar to hemlock. Under field and stand conditions the problem is maintaining the optimum germination temperature for an adequate period to achieve germination. Scarification or burning results in a marked increase of surface soil temperature (closer to optimum for hemlock and yellow birch) that will occur earlier in the growing season when surface moisture conditions are more reliable.
>
> This information infers that sugar maple is always present because it has a low germination temperature requirement rather than because of its tolerance. Hemlock and white-cedar are more tolerant than sugar maple, but have much higher germination temperature requirements that are seldom achieved in nature or by management. In addition, the often stated concept of "cool-moist" conditions for hemlock and yellow birch, since they occur on logs and stumps, may be a misinterpretation. Thermometers placed on stumps, logs and raised sites show consistently higher temperatures than the soil surface; thus, warm-moist conditions are indicated.

Browsing by White-tailed Deer

Many authors have studied the effect of deer browsing on the regeneration of hemlock-hardwood forests (DeBoer 1947, Swift 1948, Arbogast and Heinselman 1950, Graham 1954 and 1958, Dahlberg and Guettinger 1956, Stoeckeler et al. 1957, Beals 1960, and Hough 1965). These authors found that deer eliminated northern white cedar, hemlock, and ground hemlock understories, and caused heavy damage to sugar maple and other hardwoods. These findings have been confirmed by numerous field biologists and foresters.

In a recent study in northern Wisconsin, Anderson and Loucks (1977) very clearly stated that browsing by deer can have a significant effect on hemlock regeneration. They indicated that once heavily browsed, hemlock had little potential for regrowth. However, heavily browsed sugar maple seedlings readily resprouted and could easily outgrow deer browsing if given relief from browsing for a few years. The differential response of hemlock and sugar maple to browsing favored the success of sugar maple in the understory and the reduction of hemlock. They concluded that heavy browsing did cause the absence of hemlock reproduction observed by Stearns (1951), Brown and Curtis (1952), and Curtis (1959).

Anderson and Loucks studied hemlock regeneration in a deer exclosure on the Flambeau River State Forest, Sawyer County, Wisconsin. They found that upon removal of browsing pressure, hemlock seedlings became established, although it may take a century before an all-aged structure returns to the forest. Twelve years of protection from browsing resulted in recovery of only the seedling class. It is interesting that three other hemlock stands studied on the Flambeau River State Forest had no hemlock seedlings after four years of protection.

Godman (pers. comm.) has questioned the significance of deer browsing in inhibiting hemlock regeneration. He points out the absence of a heavily browsed hemlock seedling layer below the annual snow level. Godman believes a variety of environmental factors inhibit hemlock seedling establishment and where these limiting factors are absent a dense hemlock seedling layer can be established. Poor seedbed conditions may explain the absence of hemlock seedlings in some of the exclosures on the Flabeau River State Forest. Extensive studies by Godman and Krefting (1960), Tubbs (1969), Godman and Tubbs (1973), and Godman and Mattson (1976) on yellow birch showed that seedbed and canopy played a very important role in seedling establishment.

A hemlock stand in Section 4, T38N, R7E, Oneida County had, over a period of years, occasional sawtimber hemlock trees removed and had the understory duff and humus layers periodically removed by raking (used as mulch in a nearby nursery). These operations resulted in high canopy light penetration on a mineral soil seedbed. As a consequence, there are abundant hemlock seedlings and saplings in the treated areas in spite of a deer population of 20 to 25 deer/mile^2 of range.

On the Menominee and Lac du Flambeau Indian Reservations in Wisconsin, deer densities are in the range of 5-10 deer/mile^2 and many of the forests of these reservations contain an abundant hemlock seedling and sapling class. It seems that when deer populations drop below 10 deer/mile^2, hemlock will very slowly establish itself provided that seedbed, moisture, and temperature are conducive to the germination, establishment, and growth of hemlock.

In Wisconsin, it is evident that deer have had a severe effect on hemlock seedlings and saplings from the early 1930's to the present. Most studies of deer damage to forest reproduction were conducted during this period which coincided with deer populations of from 25 to over 40 deer/mile^2 of range. Such high deer populations eliminate understory hemlock and enable sugar maple to dominate.

STATUS OF HEMLOCK--1979

Hemlock stands make up only one-half of one percent of the 1.3 million acres of public forest lands in north central Wisconsin. This is, at most, 6,412 acres (Table 1). Many of these hemlock stands are in poor condition because of heavy cutting and hardwood invasion, but other stands are in good condition and can be maintained for very long periods (Table 2). Characteristically, there are no hemlock seedlings or saplings in the present hemlock stands. A heavy understory of sugar maple, red maple, mountain maple, and raspberries exists in most disturbed hemlock stands. Consequently, once the overstory hemlock is removed, the understory red maple and sugar maple dominate the site and the hemlock type is lost. The use of northern hardwood management guides in hemlock stands and high deer populations have resulted in the degradation of hemlock stands.

Approximately 20 million BF of saw timber hemlock for industrial roundwood is harvested in Wisconsin each year (Blyth et al. 1976). During the 1970's, large volumes of hemlock were removed from the Wisconsin Trust Land holdings in northeastern Wisconsin in an effort to convert to northern hardwoods. National, state, and county foresters selectively thinned hemlock stands on public forest lands for many years. This resulted in the gradual conversion to hardwoods. In the past, the Eagle River Ranger District (Nicolet National Forest) removed large volumes of hemlock. Some old growth hemlock stands were clearcut and the hemlock component of hardwood stands was systematically removed. The Northern Highland-American Legion State Forest continues a selective harvest in hemlock stands under a "Big Tree Silviculture" program. The Oneida, Lincoln and Langlade County forests cut hemlock on a very limited basis.

The major industrial forests with significant stands of hemlock are the Connor Lumber Company of Laona and U.O.P., Inc., a subsidiary of the Singer Company of California. U.O.P., Inc. currently owns the old Goodman Block in Forest and Florence Counties. Foresters for these companies indicate that single tree selection is being used to manage their hemlock-hardwood forests and that there is very little hemlock regeneration. Connor Lumber Company owns about 8,000 acres of old growth stands which contain hemlock. Consolidated Papers, Inc. has a small acreage of hemlock in the Summit Lake Block, Langlade County. Hemlock is declining on all of these industrial forests.

TABLE 1. Acres Typed as Hemlock-Hardwood on Public Lands in the North Central District

Public Lands	Total Forest Acres	Hemlock Acres	Percent of Total Forest	Number of Stands	Mean Stand Size (acres)
State Forests					
Northern Highland	150,480	1,397	0.9	45	31
American Legion	48,930	498	1.0	23	22
County Forests					
Langlade	121,710	822*	0.7	78	10
Lincoln	97,689	158	0.2	10	16
Oneida	79,289	190	0.2	8	24
Vilas	36,211	10	0	1	10
Forest	10,856	20	0.2	1	20
Marathon	24,810	0	0	-	-
Nicolet National Forest	652,001	1,402**	0.2	-	-
Wis. State Trust Lands	59,127	1,915[1]	3.2	-	-
TOTAL	1,281,103	6,412			

*There are 66 stands with 15 acres or less.
**From 1975 Nicolet Timber Inventory (an expansion of a 15% sample).
[1] An estimate from inspection of aerial photos and field checks. Many stands have been recently cut.

TABLE 2. Summary of Hemlock-Hardwood Stand Acreage on Some Public Lands in North Central Wisconsin. 1971.

Stands	Stocking	Large Sawtimber	Small Sawtimber	Pole Timber	Seedling and Sapling
Northern Highland	Good	158	401	0	0
	Medium	110	380	0	0
	Poor	30	81	0	0
American Legion	Good	129	0	0	0
	Medium	200	42	0	0
	Poor	0	57	0	0
Langlade County F.C.L.	Good	3	12	104	3
	Medium	14	23	554	0
	Poor	20	12	77	0
Lincoln County F.C.L.	Good	0	7	0	0
	Medium	0	36	13	7
	Poor	4	66	0	0
Oneida County F.C.L.	Good	0	0	63	0
	Medium	0	0	0	0
	Poor	0	0	5	0
TOTALS		668	1,117	816	10

VALUES

Hemlock is an important biological resource of Wisconsin. It has ecological, scientific, and aesthetic values which necessitate special management procedures and considerations.

It is desirable to maintain hemlock as winter cover for white-tailed deer. Pure hemlock stands, because of their dense, closed-canopy condition, significantly reduce wind velocity and snow depth. Deer actively seek out hemlock stands in the winter months and utilize them mainly as cover. There may also be a relationship between porcupine use, windfall, and deer use in hemlock stands. Most hemlock stands are used by some deer during the winter. In addition, deer are able to utilize hemlock-hardwood stands which would not be utilized if the hemlock component was removed. The cover value of hemlock-hardwood stands diminishes as the individual hemlock trees become widely spaced. Successive thinnings and salvage operations will eventually eliminate the hemlock if selective cutting continues.

Current deer yard management plans developed by the Department of Natural Resources call for a deferral of cutting in hemlock stands until reliable regeneration techniques can be developed. Small hemlock groves (from 6 trees to several acres in size) should not be thinned, but rather maintained in a dense, uncut condition. This is particularly significant along swamp edges and in hardwood stands located adjacent to wintering areas. These small islands of green cover enable deer to move to and from browsing areas during severe weather. In deer yards, hemlock is managed as a cover species, not a food species.

Scattered hemlock trees and small hemlock stands act as islands of green cover and add habitat diversity to the northern hardwood forest. Habitat diversity is the key to management of wildlife in the extensive forest. Habitat diversity will be increased by developing an interspersion of age classes among stands, while maintaining the greatest number of naturally occurring tree and shrub species.

MANAGEMENT

Objectives

1. To maintain the existing hemlock acreage and avoid invasion by sugar maple, red maple, or upland brush.

2. To begin hemlock regeneration in selected stands by developing dense sapling stands through shelterwood cuts in an even-aged silvicultural system. The shelterwood sequence makes conditions favorable for a new wave of hemlock seedlings below a hemlock canopy. Because of the very small acreage in hemlock, and because of the unreliable regeneration techniques, I strongly recommend deferral of most hemlock stands until reliable regeneration techniques are developed.

Strategy

The strategy for management includes the following points:

1. Do not convert existing hemlock stands to northern hardwoods (i.e., avoid establishing an understory of tolerant hardwoods).

2. If a hemlock stand cannot be managed for hemlock because of time or budget constraints, defer the stand until such management can be undertaken.

3. Relatively pure hemlock stands which show good vigor should be deferred.

4. The biological rotation age of a hemlock stand (cycles occurring at 150 and 320 years) is very much longer than the economic rotation age.

5. Unless obvious mortality will occur without removal, do not cut or thin the scattered hemlock trees or the small hemlock groves which occur in hardwood or swamp conifers stands. Maintain dense, closed canopy hemlock.

6. Do not use northern hardwood marking guides in hemlock stands.

Recommendations

The following key is designed to aid in making management decisions for the limited number of hemlock stands to be treated in hemlock regeneration tests.

KEY

1. Stand has important aesthetic or scientific characteristics, show good vigor and little hardwood invasion, or occurs on extremely hilly terrain........................Defer.

1. Stand has none of the above characteristics......................Manage stand (2)

    2. Stand immature......Release hemlock understory

    2. Stand mature......................(3)

3. Stand essential for deer shelter.......... Maintain closed evergreen canopy. Do not promote understory hardwood regeneration.

3. Stand not essential for deer shelter...(4)

    4. Stand has abundant (fully stocked) hardwood sapling regeneration which cannot be removed, or the stand has less than 60% crown cover....Manage for hardwoods (see section on Intermediate Treatment). Maintain overstory hemlock to pathological rotation.

4. Stand does not have the above characteristics.....Manage for hemlock...........(5)

5. Hardwood poles abundant.........Intermediate treatment

5. Hardwood poles scarce....Begin Shelterwood Sequence

Discussion of Recommendations

There are no reliable methods for regenerating hemlock. The following procedures for regenerating hemlock stands are modifications of Godman and Krefting (1960), Godman and Tubbs (1973), Tubbs (1969, 1977, and 1978), and recommendations of R. M. Godman (pers. comm.). Research being coordinated by R. M. Godman on various Lake States National Forests and on the Argonne Experimental Forest will eventually develop more detailed recommendations.

Hemlock may be regenerated by an even-aged silvicultural system. Hemlock is a light-seeded species which requires particular seedbed conditions. These include:

a. Warm, moist, exposed soil for germination.

b. Freedom from competition of deciduous trees and shrubs.

c. High canopy crown cover (approximately 80%).

d. Protection from damping-off fungi.

The technique described here has not been widely used in Wisconsin and should be tried on an experimental basis until current research is completed.

Hemlock regeneration depends on three factors: (1) successful, massive germination of seeds, (2) successful, massive establishment of seedlings (30,000/ acre), and (3) protection of saplings from deer browsing. So far, we have not successfully accomplished factors (1) and (2). Protection from browsing by deer will occur when the overstory is clearcut. Clearcutting will exclude wintering deer from the stand.

Shelterwood Sequence

The shelterwood sequence consits of thinning the overstory, preparing the seedbed, direct seeding, and removal of the overstory in two cuts. The seedbed can be prepared before or after logging.

1. Rotation age for timber production is approximately 150 years. Scarify at least 75% of the area. Scarification can be done after maple seed and leaf fall or in early spring. A small crawler tractor (T6 fire cat) and Athens disc or a small crawler tractor with blade can be used to carefully mix the humus and mineral soil. This operation will destroy maple seeds and remove advance maple regeneration. A mixed humus-mineral soil seedbed will remain moist during dry periods. Ground fire is an alternative to mechanical seedbed preparation. Fire may be able to control the various damping-off fungi which are present in the soil. Spring scarification or burning should be done after surface temperatures become too high for maple germination but ideal for hemlock germination (59°F).

2. Thin the stand from below to 80% crown cover. Do not use basal area marking guides. Discriminate against sugar maple, red maple and tolerant hardwoods and leave good quality sawtimber hemlock and yellow birch. Remove as many understory trees as possible, but maintain a uniform 80% crown cover. Do not cut below 80% crown cover. When spacing permits, remove the largest sugar maple trees first. If manpower is available, remove unmerchantable sugar maple from the understory. The resulting stand should have a park-like appearance.

3. Direct seed the area with at least one-half pound of hemlock seeds per acre. Seeding can be done in early winter to prevent rodent damage. Spring seeding requires a properly stratified seed. Treat the hemlock seed with a fungicide (Arasan-75).

4. After at least six years and when a vigorous hemlock seedling understory has developed, thin the stand from below to 60% crown cover. Do not cut below 60% crown cover. Discriminate against tolerant hardwoods. The length of the establishment period will depend on the particular site. Logging should occur during snowcover.

5. When the hemlock is at least 5 ft in height, clearcut the overstory during the winter months. Overstory removal may not be necessary if the management goal is aesthetics or natural diversity. In this case, let the hemlock saplings develop slowly as the overstory slowly opens up. Rotation age for cover and aesthetics is up to 250 years (Tubbs 1978).

Intermediate Treatment

Intermediate treatment consists of thinning the stand from below. Understory sugar maple, red maple, and other tolerant hardwoods are to be marked and cut. A uniform, high canopy 80% crown will be maintained. Do not encourage scattered openings in the canopy.

Some hemlock stands have abundant hardwood sapling advance regeneration. It is difficult and expensive to eliminate this low competition. Killing hardwood advance regeneration with fire or herbicides has several shortcomings (Godman and Tubbs 1973:7). A combination of a herbicide treatment followed by discing may prove successful in eliminating large hardwood saplings. When it is apparent that the advance hardwood regeneration cannot be controlled, manage the stand for hardwoods. However, do not cut the existing hemlock. Maintain these trees to biological maturity.

The above recommendations are based on the premise that hemlock is a desirable species which should be maintained in the forest system. Because of the very limited acreage of hemlock on the public lands, great care should be taken to protect the integrity of existing hemlock stands. Marking crews should have a complete understanding of the management techniques.

Our main challenge is to maintain the present hemlock acreage on our public lands through preservation and regeneration. This is essential because of the small and rapidly diminishing hemlock acreage in Wisconsin.

Common and Scientific Names of Plants and Animals

Plants

Aspen	*Populus tremuloides*
Balsam fir	*Abies balsamea*
Basswood	*Tilia americana*
Birch, yellow	*Betula alleghaniensis*
Birch, paper	*Betula papyrifera*
Elm, American	*Ulmus americana*
Hemlock, eastern	*Tsuga canadensis*
Hemlock, ground	*Taxus canadensis*
Maple, mountain	*Acer spicatum*
Maple, red	*Acer rubrum*
Maple, sugar	*Acer saccharum*
Pine, white	*Pinus strobus*
Pine, red	*Pinus resinosa*
Spruce, white	*Picea glauca*
White cedar, northern	*Thuja occidentalis*
Blackberries	*Rubus* sp.
Raspberries	*Rubus* sp.
Beaked hazel	*Corylus cornata*
Witch-hobble	*Viburnum alnifolium*

Animals

Deer, white-tailed	*Odocoileus virginianus*
Hare, snowshoe	*Lepus americanus*
Porcupine	*Erethizon dorsatum*
Sapsucker, yellow-bellied	*Sphyrapicus varius*
Squirrel, red	*Tamiasciurus hudsonicus*
Vole, red-backed	*Clethrionomys gapperi*
Hemlock Borer	*Melanophila fulvoguttata*
Budworm	*Choristoneura fumiferana*

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Anne G. Chacon, Copy Editor

REFERENCES

Adams, M. S. and O. L. Loucks

1971. Summer air temperatures as a factor affecting net photosynthessis and distribution of eastern hemlock (*Tsuga canadensis* L. (Carriere)) in southwestern Wisconsin. Am. Midl. Nat. 85(1):1-10.

Anderson, R. C., O. L. Loucks, and A. M. Swain

1969. Herbaceous response to canopy cover, light intensity, and throughfall precipitation in coniferous forests. Ecology 50:255-263.

Anderson, R. C. and O. L. Loucks

1977. White-tailed deer (*Odocoileus virginianus*) influence on structure and composition of *Tsuga canadensis* forests. (In prep.)

Arbogast, C. Jr., and M. L. Heinselman

1950. Damage to natural reproduction by deer browsing. U.S. For. Serv. Lake States For. Exp. Sta. Tech. Note 332. 1p.

Auclair, A. N.

1974. Intraspecific diameter differentiation as a measure of species replacement potential. Can. J. For. Res. 4:424-433.

Auclair, A. N. and F. G. Goff

1971. Diversity relations of upland forests in the western Great Lakes Area. Am. Nat. 105(946):499-526.

Baker, W. L.

1972. Easternforest insects: U.S. For. Serv. Misc. Publ. No. 1175. 642 pp.

Baldwin, H. I.

1930. Effect of after-ripening on germination of eastern hemlock seed. J. For. 28:853-857.

1934. Further notes on the germination of hemlock seed. J. For. 32:99-100.

Baldwin, H. I. and D. A. Rock

1960. Diameter growth and reproduction following selection cutting in hemlock. For For. Note No. 79. 1 p.

Beals, E. W., G. Cottam and R. J. Vogl

1960. Influence of deer on vegetation of the Apostle Islands, Wisconsin. J. Wildl. Manage. 24:68-80.

Bjorkbom, J. C. and R. G. Larson

1977. The Tionesta scenic and research natural areas. U.S. For. Serv. Northeast For. Exp. Sta. Gen. Tech. Rep. NE-31.

Blyth, J. E., E. F. Landt, J. W. Whipple, and J. T. Hahn

1976. Primary forest products industry and timber use, Wisconsin, 1973. U.S. For. Serv. North Cent. For. Exp. Sta. Res. Bull. NC-31. 61 pp.

Bormann, F. H. and R. B. Platt

1958. A disjunct stand of hemlock in the Georgia Piedmont. Ecology 39:16-23.

Bormann, F. H. and M. F. Buell

1964. Old age stand of Tsuga canadensis - Northern hardwoods forest in central Vermont. Bull. Torrey Bot. Club 91:451-65.

Bourdeau, P. F.

1959. Seasonal variations of the photosynthetic efficiency of evergreen conifers. Ecology 40:63-67.

Bourdeau, P. F. and M. L. Laverick

1958. Tolerance and photosynthetic adaptability to light intensity in white pine, red pine, hemlock and Ailanthus seedlings. For. Sci. 4(3):196-207.

Braun, E. L.

1950. Deciduous forests of eastern North America. Hafner, New York. 596 pp.

Bray, W. L.

1930. The development of the vegetation of New York State. N. Y. State Coll. For. Tech. Publ. 29, 189 pp.

1956. Gap phase replacement in a maple-basswood forest. Ecology 37:598-600.

Brown, J. H., Jr.

1960. The role of fire in altering the species composition of forests in Rhode Island. Ecology 41:310-316.

Brown, R. T. and J. T. Curtis

1952. The upland conifer-hardwood forests of northern Wisconsin. Ecol. Monogr. 22:217-234.

Burns, G. P.

1923. Studies of tolerance of New England trees. IV. Minimum light requirements referred to a definite standard. Vt. Agr. Exp. Sta. Bull. 235. 32 pp.

Cayford, J. H. (ed.)

1973. Direct seeding symposium. Dep. Environ. Can. For. Serv. Pub. 1339. Ottawa.178 pp.

Christenson, E. M.

1959. A historical view of the ranges of the white-tailed deer in northern Wisconsin forests. Am. Midl. Nat. 61:230-238.

Clepper, H. E.

1944. Hemlock: The state tree of Pennsylvania. Pa. Dep. Forests and Waters Bull. 52. 27 pp.

Cunningham, R. N. and H. G. White

1941. Forest resources of the Upper Peninsula of Michigan. USDA Misc. Publ. 429. 32 pp.

Curtis, J. T.

1959. The vegetation of Wisconsin: An ordination of plant communities. Univ. Wis. Press, Madison. 657 pp.

Cushing, E. J.

1965. Problems in the Quaternary phytogeography of the Great Lakes Region. In H. E. Wright, Jr. and D. G. Frey (eds.), The Quaternary of the United States. Princeton Univ. Press, Princeton, N.J. 922 pp.

Dahlberg, B. L. and R. C. Guettinger

1956. The white-tailed deer in Wisconsin. Wis. Conserv. Dep. Tech. Bull. No. 14. 282 pp.

Darlington, H. T.

1930. Vegetation of the Porcupine Mountains, northern Michigan. Mich. Acad. Sci., Arts, and Lett. 13:9-84.

Daubenmire, R. R.

1930. The relation of certain ecological factors to the inhibition of forest floor herbs under hemlock. Butler Univ. Bot. Stud. 1:61-76.

1931. Factors favoring the persistence of a relic association of eastern hemlock in Indiana. Butler Univ. Bot. Stud. 2:29-32.

Davis, G. and A. C. Hart

1961. Effect of seedbed preparation on natural reproduction of spruce and hemlock under dense shade. U.S. For. Serv. Northeast For. Exp. Sta. Pap. No. 160. 12 pp.

DeBoer, S. G.

1947. The damage to forest reproduction survey. Wis. Conserv. Bull. 12(10):1-23.

Doran, W. L.

1941. Propagation of hemlock by cuttings. Am. Nurseryman 74:18-19.

1952. The vegetative propagation of hemlock. J. For. 50:126-129.

Egler, F. E.

1940. Berkshire Plateau vegetation. Ecol. Monogr. 10:145-192.

Eyre, F. H. and W. M. Zillgitt

1953. Partial cutting in northern hardwoods in the Lake States. USDA Tech. Bull. 1076. 124 pp.

Flaccus, E. and L. F. Ohmann

1964. Old-growth northern hardwood forests in northeastern Minnesota. Ecology 45(3):448-459.

Fowells, H. A.

1965. Silvics of the forest trees of the United States. U.S. For. Serv. Agr. Handb. No. 271. 762 pp.

Friesner, R. C. and J. E. Potzger

1932. Studies in forest ecology. I. Some factors concerned in hemlock reproduction in Indiana. II. The ecological significance of *Tsuga canadensis* in Indiana. Butler Univ. Bot. Stud. 2:133-149.

1934. Climax conditions and ecological status of *Pinus strobus*, *Taxus canadensis*, and *Tsuga canadensis* in the Pine Hills region of Indiana. Butler Univ. Bot. Stud. 3:65-83.

1936. Soil moisture and the nature of the *Tsuga-Pinus* forest associations in Indiana. Butler Univ. Bot. Stud. 3:207-209.

1944. Survival of hemlock seedlings in a relic colony under forest conditions. Butler Univ. Bot. Stud. 6:102-115.

Frothingham, E. H.

1915. The eastern hemlock. USDA Bull. 152. 43 pp.

Gates, F. C. and G. E. Nichols

1930. Relation between age and diameter in trees of the primeval northern hardwood forest. J. For. 28:395-398.

Gleason, H. A.

1924. Ecological investigation in the hemlock forest. J. N.Y. Bot. Gard. 25:313-316.

Goder, H. A.

1956. A phytosociological study of Tsuga canadensis near the termination of its range in Wisconsin. PhD. Thesis, Univ. Wis., Madison.

1961. Hemlock reproduction and survival on its border in Wisconsin. Wis. Acad. Sci. Arts and Lett. 50:175-181.

Godman, R. M. and L. W. Krefting

1960. Factors important to yellow birch establishment in Upper Michigan. Ecology 41:18-28.

Godman, R. M. and C. H. Tubbs

1973. Establishing even-age northern hardwood regeneration by the shelterwood method - preliminary guide. U.S. For. Serv. North Cent. For. Exp. Sta. Res. Pap. NC-99. 9 pp.

Godman, R. M. and G. A. Mattson

1976. Seed crops and regeneration problems of 19 species in northeastern Wisconsin. U.S. For. Serv. North Cent. For. Exp. Sta. Res. Pap. NC-123. 5 pp.

Goff, F. G.

1967. VI. Upland vegetation. In C. J. Milfred, G. W. Olsen and F. D. Hole. Soil Resources and Forest Ecology of Menominee County, Wisconsin. Wis. Geol. and Nat. Hist. Surv. Bull. 85, Soil Ser. No. 60. 203 pp.

1968. Use of size stratification and differential weighting to measure forest trends. Am. Midl. Nat. 79(2):402-418.

Goff, F. G. and P. H. Zedler

1967. Structural gradient analysis of upland forests in the western Great Lakes area. Ecol. Monogr. 38:65-86.

Goff, F. G. and D. West

1975. Canopy-understory interaction effects on forest population structure. For. Sci. 21:98-108.

Goodman, R. B.

1930. Conditions essential to selective cutting in northern Wisconsin hardwoods and hemlock. J. For. 28:1070-1075.

Gordon, R. B.

1940. The primeval forest types of southwestern New York. N.Y. State Mus. Bull. 321. 102 pp.

Graham, S. A.

1941. Climax forests of the Upper Peninsula of Michigan. Ecology 22:355-362.

1941. The question of hemlock establishment. J. For. 39:567-569.

1943. Causes of hemlock mortality in northern Michigan. Mich. Univ. School For. and Conserv. Bull 10. 62 pp.

1954. Changes in northern Michigan forests from browsing by deer. Trans. N. Am. Wildl. Conf. 19:526-533.

1958. Results of deer exclosure experiments in the Ottawa National Forest. Trans. N. Am. Wildl. Conf. 23:478:490.

Harlow, S. H.

1900. Roots of the hemlock. J. N.Y. Bot. Gard. 1:100-101.

Hepting, G. H.

1971. Diseases of Forest and Shade Trees of the United States. U.S. For. Serv. Agric. Handb. No. 386. 658 pp.

Hett, J. M.

1971. A dynamic analysis of age in sugar maple seedlings. Ecology 52:1071-74.

Hett, J. M. and O. L. Loucks

1968. Application of life-table analysis to tree seedlings in Quetico Provincial Park, Ontario. For. Chron. 44:29-32.

1976. Age structure models of balsam fir and eastern hemlock. J. Ecol. 64(3):1029-1044.

Hough, A. F.

1932. Some diameter distributions in forest stands in northwestern Pennsylvania. Ecology 17:9-28.

1936. A climax forest community on East Tionesta Creek in northwestern Pennsylvania. Ecology 17:9-28.

1936. Height growth of hemlock and hardwood seedlings in a virgin stand on East Tionesta Creek. U.S. For. Serv. Allegheny (Northeast) For. Exp. Sta. Tech. Note 12. 2 pp.

1936. The dying of hemlock and other species on the Allegheny National Forest. U.S. For. Serv. Allegheny (Northeast) For. Exp. Sta. Tech Note 7. 2 pp.

1942. Soils in a virgin hemlock-beech forest on the northern Allegheny Plateau. Soil Sci. 54:335-341.

1943. Soil factors and stand history in a virgin forest valley on the northern Allegheny Plateau. Soil Sci. 56:19-28.

1948. Frost pocket and other microclimates in forests of the northern Allegheny Plateau. Ecology 26:235-250.

1960. Silvicultural characteristics of eastern hemlock. U.S. For. Serv. Northeast For. Exp. Sta. Pap. 132. 23 pp.

1965. A twenty-year record of understory vegetational change in a virgin Pennsylvania forest. Ecology 46:370-373.

Hough, A. F. and R. D. Forbes

1943. The ecology and silvics of forests in the high plateaus of Pennsylvania. Ecol. Monogr. 13:299-320.

Hussain, A. and R. D. Shenefelt

1959. The hemlock borer. Wis. Conserv. Dep. Tech. Bull. 19. 25 pp.

Jacobs, R. D.

1965. Growth and development of deer-browsed sugar maple seedlings. J. For. 67:870-874.

Jordan, J. S. and W. M. Sharp

1967. Seeding and planting hemlock for ruffed grouse cover. U.S. For. Serv. Northeast For. Exp. Sta. Res. Pap. NE-83. 17 pp.

Keever, C.

1973. Distribution of major forest species in southeastern Pennsylvania. Ecol. Monogr. 43:303-358.

Kenoyer, L. A.

1942. Forest associations of Ottawa County, Michigan at the time of the original survey. Pap. Mich. Acad. Sci. 28:47-49.

Koroleff, A.

1954. Leaf litter is a killer. J. For. 52:178-82.

Kozlowski, T. T.

1971. Growth and development of trees. Vol. 2. Seed germination, ontogeny, and shoot growth. Acad. Press New York. 443 pp.

Krefting, L. W.

1975. The effects of white-tailed deer and snowshoe hare browsing on trees and shrubs in northern Minnesota. Agr. Exp. Sta. Tech. Bull. 302-1975. For. Series 18. Univ. Minn. 43 pp.

Leak, W. B.

1964. An expression of diameter distribution for unbalanced, uneven-aged stands and forests. For. Sci. 10(1):39-50.

1970. Successional change in northern hardwoods predicted by birth and death simulation. Ecology 51:794-801.

Leak, W. B., D. S. Solomon, and S. M. Filip

1969. A silviculturist guide for northern hardwoods in the northeast. U.S. For. Serv. Northeast For. Exp. Sta. Res. Pap. NE-143. 34 pp.

Lutz, H. J.

1928. Trends in silvicultural significance of upland forest successions in southern New England. Yale Univ. School For. Bull. 22. 68 pp.

1930. Original forest composition in northwestern Pennsylvania as indicated by early land survey notes. J. For. 28:1098-1103.

1930. The vegetation of Heart's Content, a virgin forest in northwestern Pennsylvania. Ecology 9:1-29.

Maissurow, D. K.

1941. The role of fire in the perpetuation of virgin forests of northern Wisconsin. J. For. 39:201-207.

Marshall, R.

1927. The growth of hemlock before and after release from suppression. Harvard For. Bull. 11. 41 pp.

Martin, N. D.

1959. An analysis of forest succession in Algonquin Park, Ontario. Ecol. Monogr. 29:187-218.

McIntosh, R. P.

1972. Forests of the Catskills, New York. Ecol. Monogr. 42:143-161.

Mergen, F.

1958. The distribution of reaction wood in eastern hemlock as a function of its terminal growth. For. Sci. 4(2):98-109.

Merrill, P. H. and P. C. Hawley

1924. Hemlock: its place in the silviculture of the southern New England forest. Yale Univ. School For. Bull. 12. 68 pp.

Meyer, H. A. and D. O. Stevenson

1943. The structure and growth of virgin beech-birch-maple-hemlock forests in northern Pennsylvania. J. Agr. Res. 67:465-484.

Miles, M. L. and E. C. Smith

1960. A study of the origin of hemlock forests in southwestern Nova Scotia. For. Chron. 36:375-390.

Moore, B., H. M. Richards, and A. B. Stout

1924. Hemlock and its environment. I. Field records. N.Y. Bot. Gard. Bull. 12:325-350.

Morey, H. F.

1936. Age-size relationship of Heart's Content, a virgin forest in northwestern Pennsylvania. Ecology 17:251-257.

1936. A comparison of two virgin forests in northwestern Pennsylvania. Ecology 17:43-55.

Nichols, G. E.

1935. The hemlock-white pine-northern hardwood region of eastern North America. Ecology 16:403-422.

Nienstaedt, H.

1958. Height growth is indicative of the relative frost resistance of hemlock seed sources. U.S. For. Serv. Lake States For. Exp. Sta. Tech. Notes 525. 2 pp.

1961. Effects of photoperiod and source on seedling growth of eastern hemlock. For. Sci. 7:81-86.

Nienstaedt, H. and H. B. Kriebel

1955. Controlled pollination of eastern hemlock. For. Sci. 1(2):115-120.

Nienstaedt, H. and J. S. Olson

1955. Heredity and environment: Short-cut study shows how both affect hemlock growth. Conn. Agr. Exp. Sta. Frontiers of Plant Sci. 7:7.

Ohmann, L. F. and M. F. Buell

1968. Forest vegetation of the New Jersey Highlands. Bull. Torrey Bot. Club 95:287-298.

Olmsted, N. W. and J. D. Curtis

1947. Seeds of the forest floor. Ecology 28:49-52.

Olson, J. S.

1954. Germination and survival of eastern hemlock seedlings in Connecticut seedbeds. Ecol. Soc. Am. Bull. 35(3):60.

1957. Heat budget of eastern hemlock hardwood forests. Ecol. Soc. Am. Bull. 38(3):80.

Olson, J. S. and H. Nienstaedt

1957. Photoperiod and chilling control growth of hemlock. Science 125(3246):492-494.

Olson, J. S., F. W. Stearns, and H. Nienstaedt

1959. Eastern hemlock seeds and seedlings: Response to photoperiod and temperature. Bull. Conn. Agr. Exp. Sta. No. 620. 70 pp.

Oosting, H. J. and D. W. Hess

1956. Microclimate and relict stand of Tsuga canadensis in the lower Piedmont of North Carolina. Ecology 37:28-39.

Parker, J.

1961. Seasonal changes in cold resistance of some northeastern woody evergreens. J. For. 59:108-111.

Potzger, J. E.

1946. Phytosociology of the primeval forest in central northern Wisconsin and upper Michigan and a brief post-glacial history of the Lake Forest formation. Ecol. Mono. 16:213-234.

Potzger, J. E. and R. C. Friesner

1937. Soil acidity and hemlock reproduction in relict colonies in Indiana. Ind. Acad. Sci. Proc. 46:93-99.

Randall, C. E.

1968. Hemlock, tree of tranquility. Am. For. March 1968:24-27.

Schmelz, D. V. and A. A. Lindsey

1965. Size-class structure of old-growth forests in Indiana. For. Sci. 11(3):258-264.

Schopmeyer, C. S.

1974. Seeds of the woody plants in the United States. U.S. For. Serv. Agr. Handb. No. 450. 883 pp.

Sears, P. B.

1948. Forest sequence and climate change in northeastern North America since early Wisconsin time. Ecology 29:326-333.

Secrest, H. C., H. J. MacAlney, and R. C. Lorenz

1941. Causes of the decadence of hemlock at the Menominee Indian Reservation, Wisconsin. J. For. 39:3-12.

Shugart, H. H., Jr., T. R. Crow and J. H. Hett

1973. Forest succession models: a rationale and methodology for modeling forest succession over large areas. For. Sci. 19:203-212.

Society of American Foresters

1975. Forest cover types of North America (exclusive of Mexico). Soc. Am. For., Washington, D.C. 67 pp.

Spencer, J. S. and H. W. Thorne

1972. Wisconsin's 1968 timber resource - a perspective. U.S. For. Serv. North Cent. For. Exp. Sta. Res. Bull. NC-15. 80 pp.

Spurr, S. H.

1956. Natural restocking of forests following the 1938 hurricane in central New England. Ecology 37:443-451.

Stearns, F. W.

1949. Ninety years change in a northern hardwood forest in Wisconsin. Ecology 30:350-358.

1951. The composition of the sugar maple-hemlock-yellow birch association in northern Wisconsin. Ecology 32:245-265.

Stearns, F. and J. Olson

1958. Interaction of photoperiod and temperature affecting seed germination in Tsuga canadensis. Am. J. Bot. 45:53-58.

Stickel, P. W.

1933. Drought injury in hemlock-hardwood stands in Connecticut. J. For. 31:573-577.

Stoeckler, J. H.

1950. Porcupine damage in a northern hardwood-hemlock forest of northeastern Wisconsin. U.S. For. Serv. Lake States For. Exp. Sta. Tech. Note 326. 1 p.

Stoecker, J. H. and C. Arbogast, Jr.

1955. Forest management lessons from a 1949 windstorm in northern Wisconsin and Upper Michigan. U.S. For. Serv. Lake States For. Exp. Sta. Pap. 34. 11 pp.

Stoecker, J. H., R. O. Strothmann, and L. W. Krefting

1957. Effect of deer browsing on reproduction in the northern hardwood-hemlock type in northeastern Wisconsin. J. Wildl. Manage. 21(1):75-80.

Swartley, J. K.

1950. Directions for rooting and growing of hemlock cuttings. The Hemlock Arboretum Bull. No. 69.

Swift, E.

1948. Wisconsin deer damage to forest reproduction survey. Final Rep. Wis. Conserv. Dep. Publ. 347. 24 pp.

Switzenberg, D. F., T. C. Nelson, and B. C. Jenkins

1955. Effect of deer browsing on quality of hardwood timber in northern Michigan. For. Sci. 1(1):61-67.

Taylor, J. C.

1959. A preliminary study of forest tree succession after clearcut of mature hemlock stands in southwest Nova Scotia. For. Chron. 35(1):50-58.

The Nature Conservancy

1975. The preservation of natural diversity: A survey and recommendations. Final Rep. The Nature Conservancy. 312 pp.

Toumey, J. W. and E. J. Neethling

1924. Isolation a factor in the natural regeneration of certain conifers. Yale Univ. School For. Bull. 1. 63 pp.

Tubbs, C. H.

1969. Natural regeneration of yellow birch in the Lake States. In Proc. Birch. Symp., August 1969, pp. 74-78. U.S. For. Serv. Northeast For. Exp. Sta. 183 pp.

1969. The inflence of light, moisture and seedbed on yellow birch regeneration. U.S. For. Serv. North Cent. For. Exp. Sta. Pap. NC-27. 12 pp.

1977. Managers handbook for northern hardwoods in the North Central States. U.S. For. Serv. North Cent. For. Exp. Sta. Gen. Tech. Rep. NC-39. 29 pp.

1978. How to manage eastern hemlock in the Lake States. U.S. For. Serv. North. Cent. For. Exp. Sta. 3 pp.

Tubbs, C. H. and F. T. Metzger

1969. Regeneration of northern hardwoods under shelterwood cutting. For. Chron. 45:333-337.

Tucker, G. F. and W. H. Emmingham

1977. Morphological changes in leaves of residual western hemlock after clear and shelterwood cutting. For. Sci. 23:195-203.

Turberville, H. W. and A. F. Hough

1939. Errors in age counts of suppressed trees. J. For. 37:417-418.

U.S. Forest Service

1973. Silvicultural systems for the major forest types of the United States. Agr. Handb. No. 445, U.S. Gov. Print. Off. Washington, D.C. 114 pp.

Voigt, G. K.

1960. Distribution of rainfall under forest stands. For. Sci. 6(1):2-10.

Webb, W. L.

1957. Interpretation of overbrowsing in northeastern forests. J. Wildl. Manage. 21(1):101-103.

Webb, W. L., R. T. King, and E. F. Patric

1956. Effect of the white-tailed deer on mature northern hardwood forest. J. For. 54:391-398.

Wilde, S. A.

1976. Woodlands of Wisconsin/Science, art, and letters of growing timber. Univ. Wis. Ext., Madison, Wis. 150 pp.

Wilson, L. R.

1937. Post-glacial history of vegetation in northern Wisconsin. Rhodora 40:137-175.

Wisconsin Conservation Commission.

1967. Forest management plan Menominee Enterprises, Inc., 1968-1982. Wis. Conserv. Comm., Madison, Wis. 81 pp.

Wright, H. E.

1964. Aspects of the early post-glacial forest succession in the Great Lakes Region. Ecology 45:439-48.