OLD-GROWTH NORTHERN HARDWOOD STANDS NEAR DULUTH, MINNESOTA

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Introduction

In 1980 I took data to characterize three old-growth northern hardwood stands in northeastern Minnesota. These three stands had been similarly studied in 1960 or 1961 as part of a larger project concerning 10 northern hardwood stands throughout the Arrowhead region in northeastern Minnesota (Flaccus and Ohmann, 1964). I duplicated the methods of the earlier study as closely as possible to facilitate comparison between the two studies.

The Duluth area, where the three sites are located, lies near the western edge of the range of northern hardwoods in North America. Although investigators differ somewhat as to the limits of this range, it is generally thought to extend eastward through New England and dip into the northern parts of Indiana, Ohio and Pennsylvania. It also extends southward along the Appalachian mountains at higher elevations. It has been characterized as a transitional zone between the boreal forest to its north and the eastern deciduous forest to its south (Braun, 1950; Weaver and Clements, 1951).

Several different tree species take a dominant position in the forest in one part of the range or another. Sugar maple (*Acer saccharum* Marsh) is the only one that appears as a dominant throughout the entire range. Beech (*Fagus grandifolia* Ehrh.) is found in the east and south, while Basswood (*Tilia americana* L.) is more common in the west. Hemlock (*Tsuga canadensis* (L.) Carr.) is seen in areas other than the southern and western portions of the region, and yellow birch *Betula alleghaniensis* Britt) is among the dominants in the north (Woods, 1984). The three study sites represent the sugar maple cover type of Godman et al. (1980).

Because northern hardwood stands typically have a dense summer canopy, they usually have a depauperate shrub layer, and most of their herbaceous species flower in the early spring. As is implied by the names that some authors have given the forest (e.g., hemlock - white pine - northern hardwoods, Braun, 1950), it often contains coniferous species such as white spruce Picea glauca (Moench Voss) and white pine Pinus strobus L.), which may occur in small numbers, or Tsuga canadensis, which is a dominant in many regions.

A considerable amount of work has been done on the sugar maple-basswood forests in southern Minnesota, including analysis of the "Big Woods" by Daubenmire (1936) and Grimm (1984). Little time has been spent studying or even describing the northern hardwood stands in northern Minnesota. Thus, one of the objectives of Flaccus and Ohmann (1964) was to document some of these forests in the northeastern part of the state.

Flaccus and Ohmann (1964) found Betula alleghaniensis among the dominant species in their stands. The literature is rich with studies on Betula alleghaniensis in northern hardwoods forests in other parts of the country, partly due to its economic value. Before the 1960-1961 field study, little mention was made of the species in Minnesota.

The role played by Betula alleghaniensis in northern hardwoods stands is interesting, since it is often one of the dominants but does not have all the qualities of a typical dominant species. In general, the seedlings have some trouble becoming established if a thick leaf mat is present or if consistently moist exposed soil is not available. Seedlings and saplings are only moderately shade-tolerant and do not thrive under the canopy trees, whether they are yellow birch or other dominants.

Flaccus and Ohmann (1964) located and studied ten old-growth northern hardwood stands in northeastern Minnesota, all of which were essentially undisturbed. Nine of the stands were located near the north shore of Lake Superior, all within 16 km of the lake. The tenth was near Grand Rapids, Minnesota, about 110 km northwest of Duluth. They were interested in stands that were in late stages of succession, and felt that these stands met that criterion.

Sugar maple was in the dominant category in all ten stands and yellow birch appeared there in eight of the stands. Basswood entered into the dominant class in the five westernmost sites, including those stands I studied in 1980.

Several of the 10 stands were logged out after the 1960-1961 field work. The three stands that I resampled were spared because of their location in either Magney-Snively Park in the city of Duluth or Jay Cooke State Park in Carlton County. More detailed descriptions of the locations of these stands will appear later in this paper.

According to Eyre and Zillgitt (1953), the typical soil for a healthy northern hardwoods stand is some kind of loam. They felt that the exact textural classification, such as sandy loam or clay loam, is not as important for forest growth as is humus type, degree of podzolization, structure and ground water level.

Although I did not collect soil samples or describe the soils at the three sites, I still feel it is important to note features of the soils present.

During the 1960-1961 field sampling, soil samples taken from each of the ten sites were characterized as to profile, texture and chemical content. Flaccus and Ohmann (1964) also classified the soils into larger categories based on United States Department of Agriculture maps and their own field observations. Although they noted that the soils at the two Magney sites differed from that at Jay Cooke, the soils at all three were either Brown Podsolics or weakly developed Podsols.

Unfortunately, the soil classification scheme that Flaccus and Ohmann employed is no longer in common use. A new one has been developed (Soil Survey Staff, 1975) and based on that, the soils at the Magney sites are Inceptisols (Minnesota Soils Atlas, 1977). The area is glacial till and was originally above the water line of glacial Lake Duluth. It is characteristically well-drained to moderately well-drained and forms a sandy loam, which matches Flaccus and Ohmann's textural description. The organic matter content is low and coarse rock fragments are common.

The soil at the Jay Cooke site belongs to the Alfisol category (Minnesota Soils Atlas, 1977). These soils are also typically well-drained to moderately well-drained and occur in lake plains, which is what the Jay Cooke site is. It was below the water line of glacial Lake Duluth.

The clay content is higher than the Inceptisols because of lake sediments, which also coincides with the 1960 soil sample data.

Objectives

The basic objective of my study was to see what changes, if any, had occurred in the three northern hardwood stands over 20 years time. If there were changes, I hoped to be able to tell why they occurred. The three stands were also compared to one another.

Part of this entailed making comparisons to see if the forest was maintaining itself. In 1960-1961 these stands were theoretically climax forest, and in the absence of disturbance the dominant species should have been replacing themselves.

I wanted to pay special attention to yellow birch, both because it was the species that made these stands somewhat unusual in the region and because it may hold a tenuous position among the dominants.

Although Flaccus and Ohmann (1964) did not make any concrete predictions about the future of the stand succession, the fact that they referred to the stands as the most terminal type of forest on upland sites in the area says something about their view of what was to come. They made no effort to take their own sapling data and use it to forecast the future, but I can still compare it to my data to see if the trends their data indicated actually have been borne out.

I also wanted to look for any evidence of disturbances at each site, since these could cause considerable changes in forest composition.

Description of Study Area

TABLE 1

Stand	Location	County	Altitude Above Sea Level	Distance From Lake Superior Kilometers
Magney 9	T49N R15WS33	St. Louis	384m	14.4
Magney 10	T49N R15WS33	St. Louis	350	14.4
Jay Cooke	T49N R16WS9	Carlton	299	9.6

Although the 10 original sites spanned a wide area in northeastern Minnesota, the three I studied were quite close to each other. Two, Magney 9 and Magney 10, are in the same section. They are within the city limits of Duluth in Magney-Snively City Park, in the western section of the city near Spirit Mountain ski area. The park has not been highly developed for recreational use, and is mainly used by hikers and skiers. Both stands are adjacent to an unpaved road. They seem little affected by human traffic except for a ski trail that runs through each stand.

The Jay Cooke site is in a forested area of Jay Cooke State Park about 12 km west-southwest of the Magney sites. It is accessible via one of the foot trails running through the park; although parts of the park are very heavily traveled, the study site did not appear to be. The trail is used by skiers and hikers.

In choosing stands for inclusion in their study, Flaccus and Ohmann used the following criteria:

1. Completely or nearly undisturbed in the stand's life time.

2. At least 6 hectares (ha) in size.

3. Trees of one or more of the three dominants at least 48 cm diameter breast height (dbh).

The authors judged all stands to be homogeneous.

Since my objective was to compare my results to theirs, I simply relocated their stands and sampled them without judging them against any standards. Statistical comparisons of the three sites within each year will be mentioned in the results section, and a more detailed description of the methods of comparison appears in the materials and methods section.

Literature Review

Characteristics of Northern Hardwood Stands

There are few data about northern hardwood stands in Minnesota containing yellow birch. Most research has been done in New England; because other species such as beech and hemlock are important components of the dominant class there, the species' interactions differ from those in Minnesota.

A number of studies were done in northern Wisconsin or upper Michigan that can shed some light on my project. The work of J.T. Curtis of the University of Wisconsin and his students and associates has added a great deal to the general knowledge about sugar maple-basswood-yellow birch stands in the area. Curtis (1959) described stands similar to those in the current study in his discussion of northern mesic forests. They show a great deal of compositional stability, have few shrubs and mostly spring-flowering herbs. Yellow birch is present in the dominant class, but begins to drop out toward the western edge of Wisconsin. Stearns (1949, 1951) noted that sugar maple is well represented in the seedling class but mortality is high. Numbers of hemlock, which is present in some Wisconsin stands, and yellow birch seem to be declining over time, and both species are under-represented in the smaller size classes.

Yellow birch seems to keep a spot in the dominant class by taking advantage of openings in the canopy cover rather than reproducing regularly under the closed canopy (Linteau, 1948). Basswood rarely reproduces through seedlings, due to low light levels on the forest floor. Sprouting from the base of existing trees is much more common (Fowells, 1965).

Braun (1950), in her discussion of the lake region of northern Wisconsin, noted that sugar maple-basswood-yellow birch stands are often found on the higher regions of the gently rolling knolls, while yellow birch-hemlock stands are found in lower areas. Winget et al. (1969) were surprised by the fact that yellow birch was seen as a dominant over a wide range of sites and species associations in Wisconsin.

In New England and eastern Canada work has been done on the cyclic nature of the dominant class in northern hardwood stands. Again, those stands generally have beech and/or hemlock as important components, which my stands lacked, and yellow birch is seen more regularly in the smaller size classes than in northern Minnesota.

Forcier (1975) used Cole's index of association (Cole, 1957) to determine which species of seedlings and saplings were positively or negatively associated with which canopy species. In stands with about equal proportions of sugar maple, yellow birch, and beech, no species had younger trees positively associated with their own overstory. Sugar maple did well under a yellow birch canopy, and beech did well under sugar maple. Nothing did well under beech, and yellow birch did not do well under any canopy. The proposed scheme for forest succession in this study is yellow birch followed by sugar maple, followed by beech, which dies out and leaves room for the more opportunistic yellow birch.

The role of canopy-understory interactions has been investigated in hemlock-northern hardwood stands (Woods and Whittaker, 1981; Woods, 1984). They found that canopy trees influenced the understory through shade or litter quality, nutrient or water use, and root competition. Individual species' influences were similar to those that Forcier (1975) found, except that yellow birch was seen as ' taking a more opportunistic or "gap-phase" role. Bellefleur and LaRocque (1983a), in studies conducted in the field with tree seedlings found that yellow birch grew faster than other dominants in full sunlight.

The difference in yellow birch's role in the two studies may be explained by the fact that Woods and Whittaker's study plots were scattered throughout the northern hardwood range, coming as far west as Wisconsin, and Forcier's sites were located in a much more limited area in New England. In addition, when basswood was in the overstory in Woods and Whittaker's stands, seedlings of all species were discouraged.

Although fires are not as much of a problem in northern hardwood stands in northeastern Minnesota as windfall (Fowells, 1965), they are more of a concern in eastern regions. According to Maissurow (1941), light surface fires favor the reproduction of sugar maple, while hotter fires are better for yellow birch, basswood and hemlock. Yellow birch reproduces well after fires, and patches of pure growth may follow; these are rarely seen otherwise. Maissurow (1941) feels that abundant reproduction in any dominant species besides sugar maple can be traced to fire. In contrast, Potzger (1946) reported that in north central Wisconsin and upper Michigan, fires generally favor sugar maple because dead logs, which are favorite germination sites for yellow birch and hemlock, are destroyed.

Competition for sunlight, water, heat and space are considered in papers by Bellefleur and LaRocque (1983b), and Bellefleur and Petillon (1983). In their studies in Quebec, the investigators found that the dominant species, yellow birch, sugar maple and beech, were not adversely affected by other woody species alone, but the combination of woody and herbaceous species did affect the tree's growth. Sugar maple and beech were hit harder by competition for sunlight and yellow birch and beech were hurt more by competition for space.

Characteristics of Dominant Species

Sugar maple, the most prevalent species in any stands, is also the most widely distributed dominant tree in northern hardwood stands throughout North America. The Magney and Jay Cooke stands are in the westernmost part of its range, which reaches almost as far as the prairie-forest border in western Minnesota (Flaccus, 1965). The species is very shade-tolerant and is also windfirm, which is an important factor in this part of the country, since windfall can be a major mortality factor among other northern hardwood dominants. Sugar maple is a producer of abundant seeds, many of which germinate but die as seedlings. Trees also reproduce vegatively through sprouting and root suckers (Godman, 1957). Deer browsing and insect injury are not major problems (Eyre and Zillgitt, 1953). Seeds are dispersed before snowfall, earlier than yellow birch, and also germinate earlier in the spring than yellow birch (Benzie, 1959).

Basswood reproduces most often from sprouts around the base of the living tree. Seedlings are very uncommon in northern hardwood stands in this area, and are thought to require more light than is available at the forest floor (Stearns, 1951). Recovery from serious fires, as mentioned before, may be due to sprouting ability. The range of basswood, like sugar maple, extends westward almost to the prairie margin (Flaccus, 1965) and also into the prairie along water courses. Trees appear to have no limiting insect pests (Fowells, 1965).

Yellow birch, the third dominant in the stands in my study, is also near the western edge of its range. It has been noted in lowlands near Itasca State Park near Bemidji (Buell and Niering, 1957), but it begins to disappear from upland northern hardwoods stands going west across Wisconsin (Curtis, 1959).

Although it is the most shade-tolerant of the birch species (Winget, 1964), yellow birch is not as tolerant as the other dominants in my stands (Fowells, 1965). Since the shade on the forest floor is inhibitory, the species seems to maintain itself by taking advantage of small openings in the canopy (Linteau, 1948).

Yellow birch is a prolific seed producer, but few seeds make it to the germination stage. The seeds are very small and light (447,000 per pound, Godman and Krefting, 1960), so they can be transported a long distance by the wind. They fall at a time when snow usually covers the ground, and can be blown across the surface of the snow (Gilbert, 1960).

The small size of the seeds and resulting seedlings puts yellow birch at a disadvantage for several reasons. Rootlets may have difficulty penetrating the leaf litter, especially in stands with sugar maple, since the venation of maple leaves prevents them from rolling up and a thick mat is thus formed (Koroleff, 1954; Burton et al., 1969). Smaller seedlings, which begin development later in the summer than those of many other species, may also be buried by the newly fallen leaves in autumn (Winget, 1964).

Seeds also have strict soil and moisture requirements for germination. Seed beds must be moist and cool (Gilbert, 1960) and exposed mineral soil with humus is best for germination (Fowells, 1965).

As I mentioned before, yellow birch seeds often germinate on dead fallen logs. They provide moisture and protection, and yellow birch seeds are small enough to lodge in spots where other larger seeds cannot fit. This environment may be better for mycorrhizal associates as well (Hutnick, 1952). The resulting seedlings often have stilt roots, which can be detrimental when the fallen log decays. This germination habit may also lead to a clumped distribution of yellow birch (Potzger, 1946).

Although it has many limiting qualities, yellow birch has opportunistic attributes as well. Seedlings are capable of rapid growth in light (Linteau, 1948), more so then sugar maple or beech

(Bellefleur and LaRocque, 1983a). Seeds, as noted earlier, can travel longer distances then other northern hardwood species. Seedlings can become established on rocks, which is not true of other northern hardwood dominants. Yellow birch's long life allows it to remain as part of a community after most pioneer species have died out.

Yellow birch adapts poorly to environmental changes and has a number of natural enemies. They include several species of fungi that cause stem decay, insects that are leaf feeders, and deer and moose which can cause problems by browsing. The lower phenolic content of the yellow birch leaves as compared to sugar maple (Schultz et al., 1982; Baldwin and Schultz, 1984) may be less discouraging to insects that feed on leaves.

Several investigators, including Winget (1964) and Woods (1984), refer to yellow birch as a gap phase species because it is dependent on disturbance and is not replacing its numbers through regular competition. In the case of this species, the disturbance may be as small an event as the death of one large dominant tree, which opens a space in the canopy.

Succession in Northern Hardwoods

The cyclic nature of the dominant species' interactions in some northern hardwood stands has been noted, but this is not the case in all stands. Maycock and Curtis (1960) note that the consensus in literature at the time was for sugar maple, yellow birch, hemlock and possibly basswood and beech to be climax species in northern hardwood stands in the Great Lakes region.

Graham (1941), in his paper on climax forests in upper Michigan, wrote that the two requirements for a climax trees are tolerance in the face of competition and capacity for seedlings to become established on the forest floor with little or no organic matter exposed. He says that sugar maple and basswood qualify and that yellow birch does not fit the criteria, but is still considered climax by many other authors. Graham (1941) also refered to a true climax community as a phantom and implies that the concept may be too static. Weather, insects and other factors continue to keep stands at developmental stages.

Whittaker (1953) held a similar view, referring to climax as a dynamic balance dictated to by environmental gradients and other factors. Woods and Whittaker (1981) stated that successional change is based on the modification of the environment by existing species and chance factors such as seed sources and distribution.

Northern hardwood stands in Minnesota, Wisconsin and upper Michigan appear to have some level of stability, with shade-tolerant canopy species being replaced by themselves or other similar species (Stearns, 1949; Maissurow, 1941).

Regeneration in Northern Hardwoods

Accounts of efforts to perpetuate northern hardwood stands, especially in the Great Lakes states, abound in the literature. Yellow birch is the main species of concern in these studies, and economics seems to be the reason. Yellow birch is a very valuable species. Its wood is used in furniture, doors, paneling, veneer, airplane and truck construction, and bowling pins. It is the most valuable of the northern hardwood trees and has become much more popular since World War II (Erdman et al., 1982).

Several authors (Hough, 1937; Marquis, 1969; Tubbs, 1969) have looked at natural regeneration of yellow birch in northern hardwood stands. Its strict germination and growth requirements, which were discussed earlier, make this a difficult problem. Marquis (1969) noted that forestry policies such as light cutting and uneven age management earlier in this century have not helped yellow birch's cause. He said that there are two general requirements for its regeneration: (1) adequate seed to desired place at the right time, and (2) moisture, temperature, light, nutrients and other environmental factors that are conducive to growth. According to his work, the missing link in yellow birch may be its seeds. Although many are produced, they have problems such as varying quality and ability to germinate, as well as a number of enemies. Marquis felt that since seed crops can be predictable, good management could help the situation.

Tubbs (1969) felt that grasses and shrubs may be competing with yellow birch, either directly through competition or indirectly through environmental changes. He noted that any combination of factors that results in a cool, moist environment is favorable.

Other species such as sugar maples and ironwood, which produce sprouts in response to stress may out-compete yellow birch, which is known to sprout but seldom does so in this area (Hough, 1937).

As I noted before, even a small disturbance such as one large tree dying and leaving a gap in the canopy can help yellow birch to become established. Zillgitt and Eyre (1945) noted that a small opening of 0.1 acre seemed best.

Many different methods of physically changing the forest habitat to encourage yellow birch have been advocated. They include several cutting strategies, from clear-cutting, to creating small canopy openings, to two separate cuts a number of years apart. Soil preparation and seeding have also been suggested.

Although two studies in Quebec show good results with clear-cutting (Boivin, 1971; Winget, 1968), this procedure does not seem to produce the same results in the Lake States (Tubbs, 1977). An older study by Ostrom (1938) noted that yellow birch and beech are nearly eliminated by clear-cutting and Tubbs (1977) found that moderately tolerant (such as yellow birch) and intolerant species do not always do well after this rather severe procedure.

Eyre and Zillgitt (1953) did a 20 year follow up study on northern hardwood forests in upper Michigan, and found that initially yellow birch did better with light cutting and small canopy openings.

After 20 years, however, yellow birch was not well-represented under those conditions. They ultimately advocated selective cutting of mature trees, but as many other authors also noted, even the best methods must be weighed against their cost-effectiveness.

Old-growth northern hardwood stands, also in upper Michigan, were selectively cut and followed for nine years by Willis and Johnson (1978). They found that initially yellow birch seemed to be regenerating well, but by the end of the study the seedlings were at their lowest number in the nine years of the study and in poor condition, and saplings were few. They concluded that cutting methods may help, but soil conditions, canopy openings and other community parameters must also be favorable as well.

Shelterwood cutting is suggested by some authors as an alternative (Tubbs, 1969; Jacobs, 1974; Godman and Tubbs, 1973; Godman and Erdman, 1981). This method involves an initial cutting that leaves some overstory trees to provide shade that seedlings require, and later removing those trees when seedlings are well established. This is usually after about 10 years or when saplings are 0.6 to 1.3 m high (Tubbs, 1969). It met with success in a study in New York (Kelty and Nyland, 1981) when used in combination with control of deer density.

Godman and Tubbs (1973) noted other positive factors of this method, such as ability to harvest trees mechanically, aesthetic appearance, game and wildlife habitat preservation, and its ability to restrict competition by grasses and herbs. Some damage may be done to young trees during removal of an overstory, but according to Jacobs (1974), it is less than the damage done by insects and deer.

Since soil has been noted as an important factor in yellow birch reproduction, some investigators (Marquis, 1969; Hatcher, 1966) suggest scarification to expose mineral soil and remove excess leaf litter which, as noted earlier, can be lethal to yellow birch seedlings.

A comprehensive view of the situation is advocated by a number of authors (Roberge, 1977; Eyre and Zillgitt, 1953; Barrett et al., 1962). Godman and Erdman (1981) summarized by suggesting that seed supply, suitable seedbed, uniform overstory and shelterwood cutting system may all be needed for success.

Allelopathy

Tubbs (1973, 1976) first noted that the tendency in northern hardwoods stands for sugar maple to often grow in numbers while yellow birch declines may be influenced by chemical factors produced by sugar maple. He discovered that a leachate from growing maple roots inhibited root formation in yellow birch. The material was unstable over time. It also suppressed several conifer species including tamarack (*Larix laric*) (Du Roi) K. Koch, white spruce jack pine (*Pinus banksiana*) Lamb, northern white cedar (*Thuja occidentalis*) L. and black spruce (*Picea mariana*) (P. Mill.) B.S.P.

Additional work on the substance was done by Mensah (1972). Although he did not fully characterize it, he found that the substance was phenolic, and noted that similar substances are widespread in the plant world and reported to be inhibiting.

This phenolic chemical was produced when leaves were present and roots were actively growing, which translated to midsummer, when yellow birch growth was most rapid. The substance was first noted in roots; although it could be obtained from leaves and seeds, the method of extraction was unlike any event in nature. The author notes that leaching by water is probably how the substance travels naturally, and using that as a model, the chemical was obtained only from seeds and actively growing roots.

Mensah (1972) further demonstrated that yellow birch was not influenced at the time of germination but rather during seedling development, probably through root-to-root interaction with sugar maple. He also found the substance to be more stable than Tubbs did.

Water-soluble and volatile compounds were isolated from the decaying leaves of the maple species (not including sugar maple) by Kokino et al. (1973). Some of these compounds were found to have inhibiting effects while others were stimulatory.

In woodland habitats, many herbaceous species are also thought to produce allelopathic substances (Rice, 1984). Grasses and ferns, especially, have been shown to produce chemicals that inhibit species, both herbacous and woody.

Materials and Methods

Field

The field methods from the 1960-61 study were duplicated as closely as possible. Trees, with a diameter breast height (dbh) of >10 cm, saplings, with a dbh of 2.5 to 9.9 cm, and shrubs and herbs were studied. My study differed from the earlier one in that I did not examine soil properties. As in the earlier work, no effort was made to characterize the mosses, liverworts or other non-vascular plants at the site.

The three stands from the earlier study were located with the help of maps from the original work and written communication from the authors. Their field notes concerning the terrain and landmarks were helpful to me in confirming the locations.

I used the point-quarter method of Maycock and Curtis (1960) to gather information about both trees and saplings. Employing this method, points were distributed throughout the study site, in this case along a transect line. The area surrounding each point was divided into four quadrants (NE, NW, SW, SE) and the tree and sapling nearest the point in each quadrant were noted. The species of the plant, the distance from the point to the center of the tree or sapling and the dbh were recorded. I measured the dbh by taking the circumference at about 1.5 meters above the ground with a tape that was specially calibrated to read the diameter of the tree being measured.

Data were collected from 20 points per stand, thus yielding information on 80 trees and 80 saplings for each location. Points were located 25 single-step paces apart along a transect line that look several 90° turns at each site. The same pattern was repeated in the 1980 study in order to locate the new points as close as possible to the original ones.

At every other point in each stand, I obtained data on occurrence of shrubs, herbs, and trees that measured 2.5 cm dbh, for a total of 10 sample points per stand. A 1m square quadrat was placed with the transect points directly in its center; all species present within the square were recorded.

Statistical

Information from the 1980 point-quarter sampling was organized and calculated in a manner identical to the earlier study so that comparisons could easily be made. Since all the field data from the 1960-61 study were available to me, it was also possible to look at additional aspects that were not included in the published material.

For each tree and sapling species at each site, relative density, relative frequency and relative dominance were estimated (Curtis and McIntosh, 1951). The formulas for each of these three measures are as follows:

$$\text{relative density} = \frac{\text{number of individuals of a species}}{\text{total number of individuals of all species}} \times 100$$

$$\text{relative frequency} = \frac{\text{frequency value for a species}}{\text{total of frequency values for all species}} \times 100$$

$$\text{relative dominance} = \frac{\text{dominance for a species}}{\text{total dominance for all species}} \times 100$$

Relative density thus yields the percent of the total number of trees at a stand that is made up of the species in question.

Relative frequency gives an indication of the number of points per stand at which a species is represented. The frequency value for a species is simply the number of points possible, in this case 20 for each stand. The total frequency value is a summation of the frequency values for all species at a particular site.

Relative dominance, also called relative coverage, is a function of the size of the trees samples as well as their density. Dominance for a species is the basal area covered by the trees of that species samples at a given site. Basal area for a tree is calculated from the dbh by using the formula for the area of circle (πr^2).

These three relative measures are added together to arrive at the importance value (IV) for each species. The IV can be used to rank species within a stand or to compare species between stands.

Two of the factors which make up the IV, relative density and relative dominance, may be added together and converted to a percentage called the relative density-relative dominance index. This measure puts less weight on the number of trees present. Flaccus and Ohmann (1964) used it to compare their own data to that from other investigations in which data had been collected and recorded differently.

A number of other indexes were calculated from the point-quarter data (Mueller-Dombois and Ellenberg, 1974). Total density for trees and for saplings was determined for each stand by squaring the mean point-to-plant distance and dividing the units desired by that number. Density for each species is determined by multiplying the total density by the relative density for that species.

Dominance for a species in a given stand is derived from multiplying the density of the species times the mean dominance value (mean basal area) for the species. Total basal area or total coverage for a stand is simply the summed density of all the species times the mean basal area per tree.

Trees and saplings were also grouped and ranked by size classes as a way to visualize how species compare to one another as well as how stands compare.

For comparing data between stands or between years, several different tests were employed. When looking at similarities or differences between two groups, I used the t-test. If more than two groups were considered, an analysis of variance and the F-test were appropriate.

In cases where there appeared to be an association or an antagonistic relationship between two species, I used a chi-square test. This helped to determine how the observed data related to what was expected due to chance alone, and if these findings were significant.

In dealing with the data on shrubs and herbs, the possibilities for comparisons were limited because of some information that was missing from the 1960-61 study. For two of the three stands sampled, the point-by-point lists of the species observed were lost. A summary of all the species recorded at the sites was available, and although that did not allow for any frequency comparison, a community coefficient using only presence could be calculated.

Sørensen (1948) describes an index of similarity that I used as the coefficient to compare the 1980 data to that from the earlier study for each of the three stands. To calculate the index, the number of herb or shrub species in each stand was totaled and the number of species in common between the two stands is noted. The formula is:

$$\frac{2 \text{ x the number of species in common}}{\text{number of species in stand A + number of species in stand B}} \text{ x } 100$$

For each stand which had a list of the species given at each point, frequency values were calculated and compared between the earlier study and this one.

Results

1980 Data

In my three stands, a total of 46 species were sampled, including 13 tree species, three shrub species and 30 herbaceous species (Tables 2 to 7). Of the herbs, 86% were angiosperms , and 69% of these were spring-flowering (before June 7th). The average number of species per stand was 28.0, made up of an average of 8.0 tree species, 1.6 shrub species and 18.3 herbaceous species. Twenty-eight families were represented.

Importance values (IVs) for trees are listed in Table 8. Sugar maple took the most dominant role in each of the three stands, with IVs from 125-176. Recall that the highest possible IV is 300, which would be a pure stand of one species. At Magney 9, no other species came close to the value for sugar maple, with basswood, ironwood, red oak and yellow birch following in that order, all with IVs ranging from 20-41. Both yellow birch and basswood had much larger IVs at Magney 10, with five other tree species being only minimally represented. Yellow birch had a large IV at Jay Cooke, with basswood again next in importance, but not as prominant as it was at Magney 10.

While looking further at data on individual stands and tree species, it is useful to keep in mind the general size at the dominant trees in these stands. Yellow birch trees tend to be very large, at least at these sites, as do the basswood sampled. Ironwood is a small

TABLE 2

Species List - Magney 9 - 1980

Trees & Saplings	Shrubs	Herbs
Acer saccharum	Lonicera canadensis	Clintonia borealis
Betula alleghaniensis		Streptopus roseus
Ostrya virginiana		Solidago flexicaulis
Tilia americana		Taraxacum officinale
Quercus rubra		Milium effusum
Acer rubrum		Maianthemum canadense
Betula papyifera		Viola pubescens
		Aster macrophyllus
		Aralia nudicaulis
		Anemone quinquefolia
		Actaea pachypoda
		Trillium cernuum
		Osmorhiza claytoni
		Allium tricoccum
		Streptopus amplexifolius
		Trillium grandiflorum
		Carex pedunculata

TABLE 2
Species List - Magney 10 - 1980

Trees & Saplings	Shrubs	Herbs
Acer saccharum	Ribes sp.	Clintonia borealis
Tilia americana	Lonicera canadensis	Streptopus roseus
Betula alleghaniensis	Corylus cornuta	Maianthemum canadense
Picea glauca		Trillium glandiflorum
Quercus rubra		Carex pedunculata
Ostrya virginiana		Viola pubescens
Populus balsamifera		Polygonatum pubescens
Acer spicatum		Solidago flexicaulis
		Trillium cernuum
		Oryzopsis asperifolia
		Aster macrophyllus
		Galium boreale
		Impatiens sp.
		Lycopodium obscurum
		Dryopteris sp.
		Osmunda sp.

TABLE 4

Species List - Jay Cooke - 1980

Trees & Saplings	Shrubs	Herbs
Acer saccharum	*Corylus cornuta*	*Aster macrophyllus*
Tilia americana		*Streptopos roseus*
Betula alleghaniensis		*Asarum canadense*
Quercus rubra		*Equisteum sp.*
Picea glauca		*Milium effusum*
Thuja occidentalis		*Viola pubescens*
Fraxinus nigra		*Laportea canadensis*
Pinus strobus		*Carex sp.*
		Maianthemum canadense
		Trientalis borealis
		Impatiens sp.
		Dryopteris sp.
		Carex pedunculata
		Aralia nudicaulis
		Arisaema triphyllum

TABLE 5

Stand Summary - Magney 9 - 1980

Species	Frequency	Number of Trees	Absolute Density/ 100 m^2	Relative Density	Basal Area/ in^2/ha	Relative Coverage
Acer saccharum	100	55	4.04	8.75	335.95	60.54
Ostrya virginiana	40	9	0.64	11.25	13.55	2.44
Tilia americana	35	8	0.57	10.00	82.72	14.90
Betula alleghaniensis	15	3	0.23	3.75	48.97	8.82
Quercus rubra L.	15	3	0.23	3.75	68.10	12.27
Acer rubrum L.	5	1	0.06	1.25	2.77	0.50
Betula papyrifira Marsh.	5	1	0.06	1.25	2.85	0.51
				100.00		99.98

Saplings	Frequency	Number of Trees	Absolute Density/ 100 m^2	Relative Density
Acer saccharum	100	72	6.56	90.00
Tilia americana	25	5	0.44	6.25
Ostrya virginiana	10	2	0.22	2.50
Betula alleghaniensis	5	1	0.07	1.25

TABLE 6

Stand Summary - Magney 10- 1980

Species	Frequency	Number of Trees	Absolute Density/ 100 m^2	Relative Density	Basal Area/ in^2/ha	Relative Coverage
Acer saccharum	100	40	2.17	50.00	193.70	36.27
Betula alleghaniensis	60	16	0.87	20.00	203.82	40.25
Tilia americana	45	13	0.71	16.25	91.93	18.15
Ostrya virginiana	25	5	0.27	6.25	11.63	2.29
Acer rubrum	10	3	0.16	3.75	4.99	0.98
Picea glauca	5	1	0.05	1.25	6.53	1.30
Quercus rubra	5	1	0.05	1.25	1.37	0.27
Populus balsamifera L.	5	1	0.05	1.25	2.45	0.48
			100.00			99.99

Saplings	Frequency	Number of Trees	Absolute Density/ 100 m^2	Relative Density
Acer saccharum	100	55	6.81	68.75
Acer spicatum	50	17	2.10	21.25
Tilia americana	25	5	0.62	6.25
Ostrya virginiana	10	2	0.24	2.50
Acer rubrum	5	1	0.12	1.25
				100.00

TABLE 7

Stand Summary - Jay Cooke - 1980

Species	Frequency	Number of Trees	Absolute Density/ 100 m^2	Relative Density	Basal Area/ in^2/ha	Relative Coverage
Acer saccharum	100	51	3.23	63.75	184.27	29.00
Betula alleghaniensis	50	11	0.69	13.75	234.60	36.00
Tilia americana	20	9	0.57	11.25	86.29	13.58
Thuja occidentalis	15	3	0.19	3.75	25.42	4.00
Fraxinus nigra Marsh.	10	3	0.19	3.75	32.54	5.12
Quercus rubra	5	1	0.06	1.25	35.38	5.56
Picea glauca	5	1	0.06	1.25	3.65	.57
Pinus strobus	5	1	0.06	1.25	33.16	5.21
				100.00		99.96

Saplings	Frequency	Number of Trees	Absolute Density 100 m^2	Relative Density
Acer saccharum	100	72	6.81	90.00
Tilia americana	20	5	0.47	6.25
Ostrya virginiana	15	3	0.28	3.75
				100.00

TABLE 8

Importance Values - 1980

Trees (> 10 cm dbh)	Magney 9	Magney 10	Jay Cooke
Acer saccharum	176	125	140
Betula alleghaniensis	20	84	74
Tilia americana	41	52	34
Ostrya virginiana	32	18	-
Quercus rubra	23	3	9
Acer rubrum	4	8	-
Betula papyrifera	4	-	-
Picea glauca	-	5	4
Populus balsamifera	-	4	-
Thuja occidentalis	-	-	15
Fraxinus nigra	-	-	14
Pinus strobus	-	-	9

Saplings (2.5-9.9 cm dbh)	Magney 9	Magney 10	Jay Cooke
Acer saccharum	222	197	257
Betula alleghaniensis	7	-	-
Tilia americana	36	23	26
Ostrya virginiana	35	11	16
Acer spicatum	-	60	-
Acer rubrum	-	8	-

tree that would never be a part of the forest canopy here, and the same is true of mountain maple (Acer spicatum Lamb), which happens to appear only in the sapling class in this study. Sugar maple trees are generally somewhat smaller than yellow birch and basswood, but do occur occasionally in the larger size classes in my stands.

Size classes for each stand are graphed in Figures 1 to 5. In each stand, sugar maple appears in large numbers in the smaller size classes, but in each case in the 40.6-55.7 cm dbh category it is nearer in numbers to the other two dominants. In the largest grouping, 55.8 cm or more dbh, its numbers are smaller than at least one of the two other dominants in two stands out of the three.

Yellow birch is nearly absent from the Magney 9 stand in all size classes, but does appear in the larger classes in both Magney 10 and Jay Cooke. Basswood is seen in similar numbers at all three sites, with trees distributed quite evenly across the size classes in each stand.

IVs for saplings (Table 8) show sugar maple dominating each stand with large numbers. Even keeping in mind that this species tends to produce many seedlings and saplings which have a poor survival rate, the numbers here are still large. Yellow birch is virtually absent from the sapling class in all three cases, and basswood appears in small numbers in each stand.

Figure 1

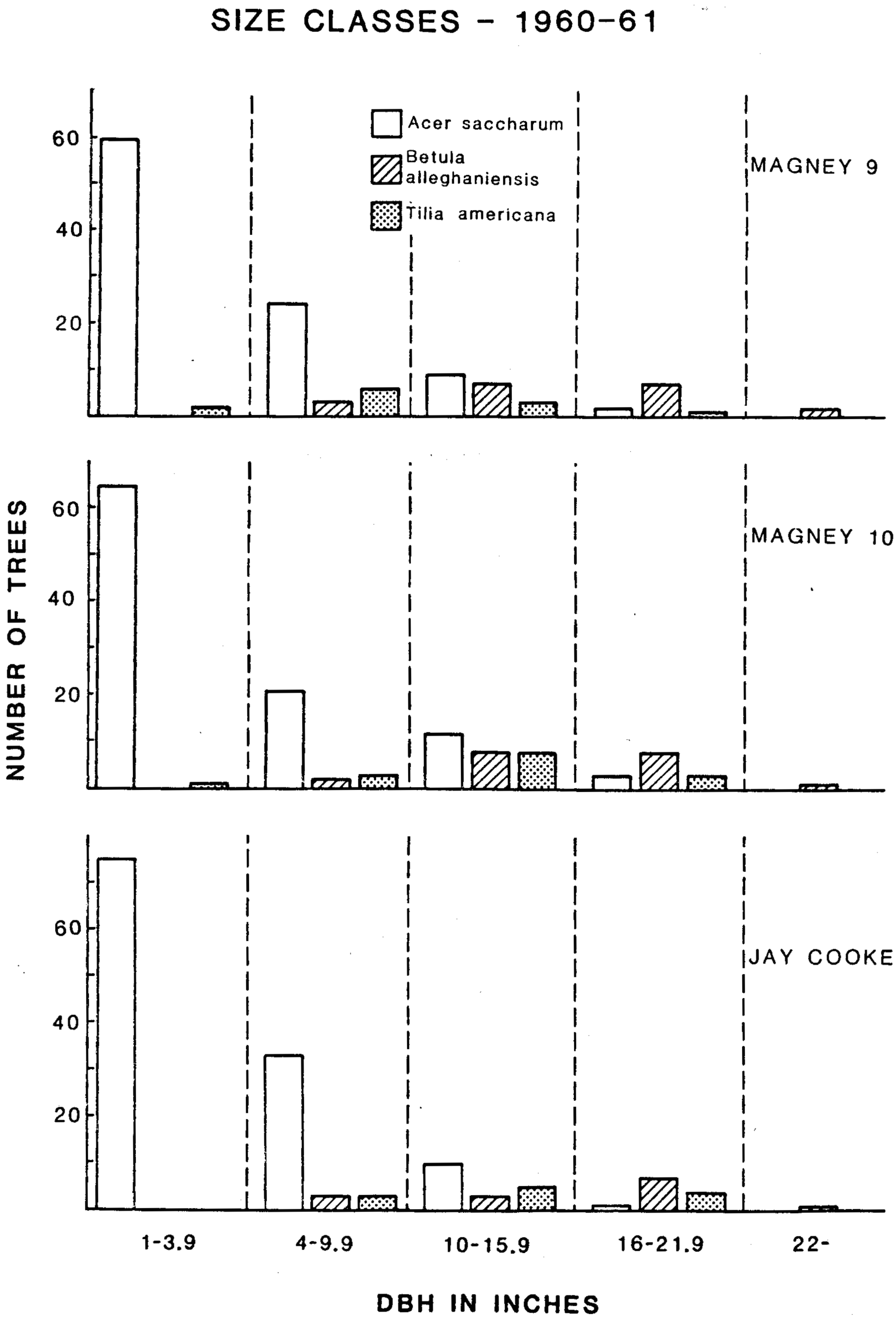

SIZE CLASSES - 1960-61
Acer saccharum
Betula alleghaniensis
Tilia americana
MAGNEY 9
MAGNEY 10
JAY COOKE
NUMBER OF TREES
60
40
20
1-3.9
4-9.9
10-15.9
16-21.9
22-
DBH IN INCHES

Figure 2

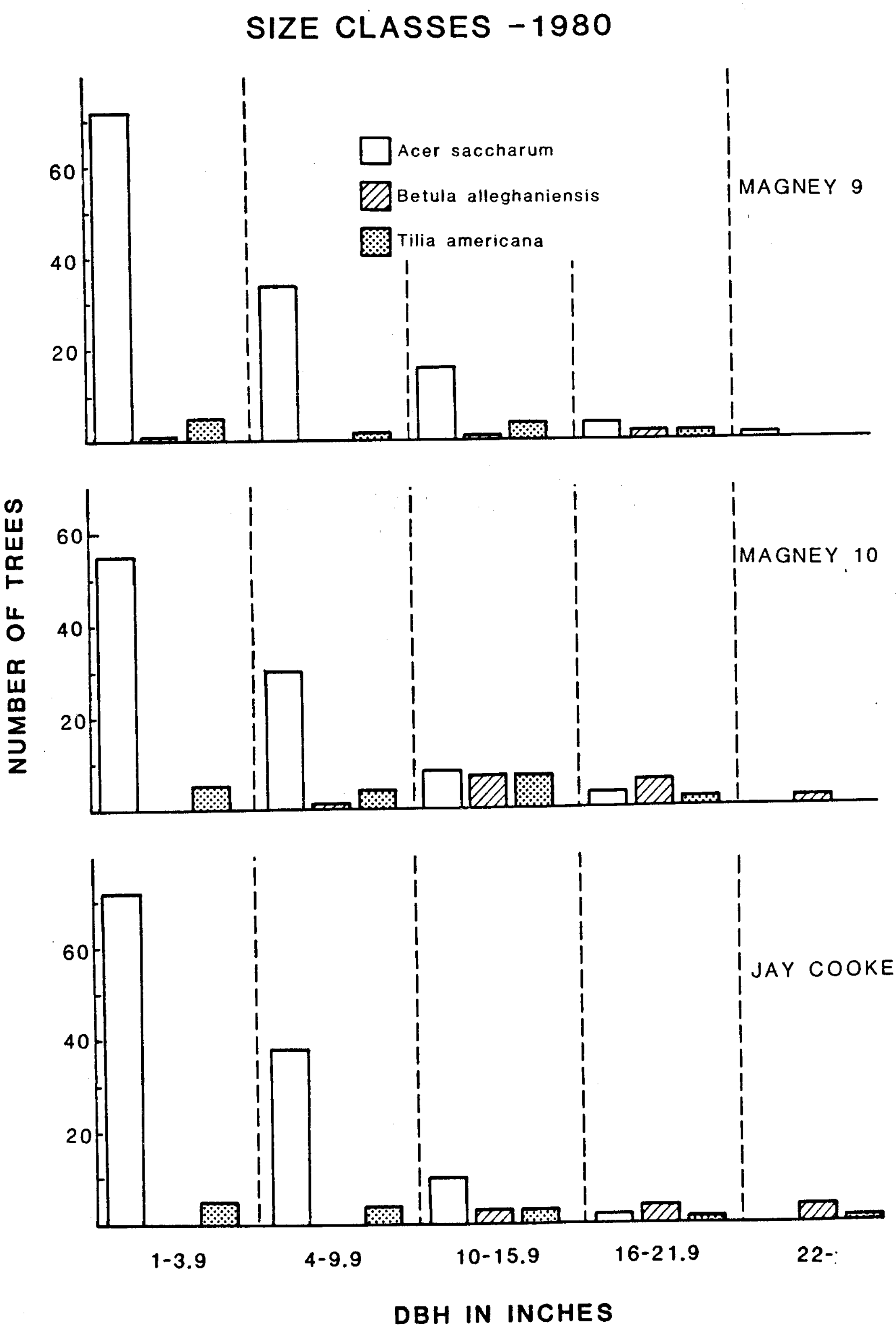

SIZE CLASSES -1980
Acer saccharum
Betula alleghaniensis
Tilia americana
MAGNEY 9
MAGNEY 10
JAY COOKE
NUMBER OF TREES
60
40
20
1-3.9
4-9.9
10-15.9
16-21.9
22-
DBH IN INCHES

Figure 3

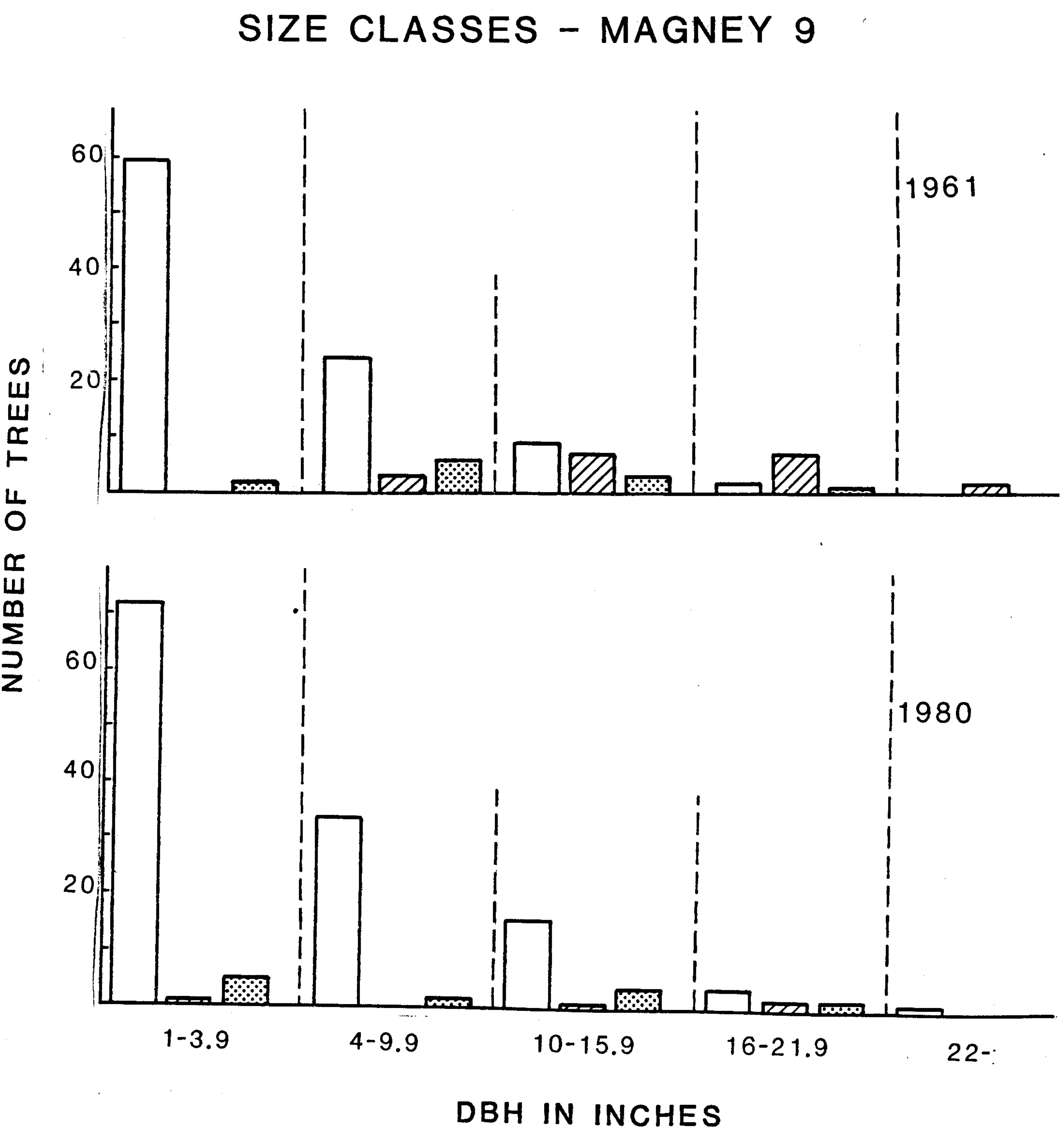

SIZE CLASSES - MAGNEY 9
NUMBER OF TREES
60
40
20
1961
60
40
20
1980
1-3.9
4-9.9
10-15.9
16-21.9
22-
DBH IN INCHES

Figure 4

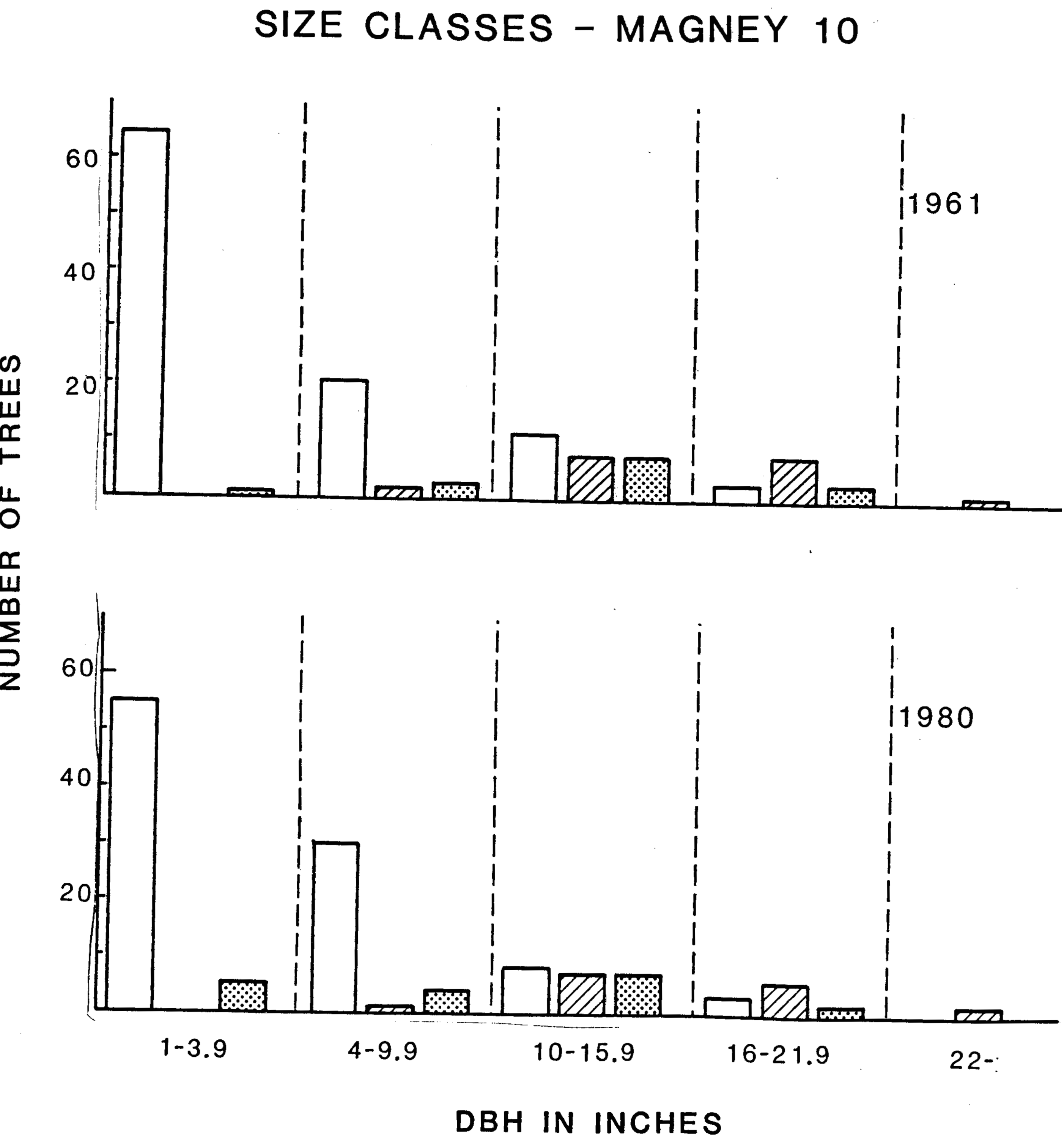
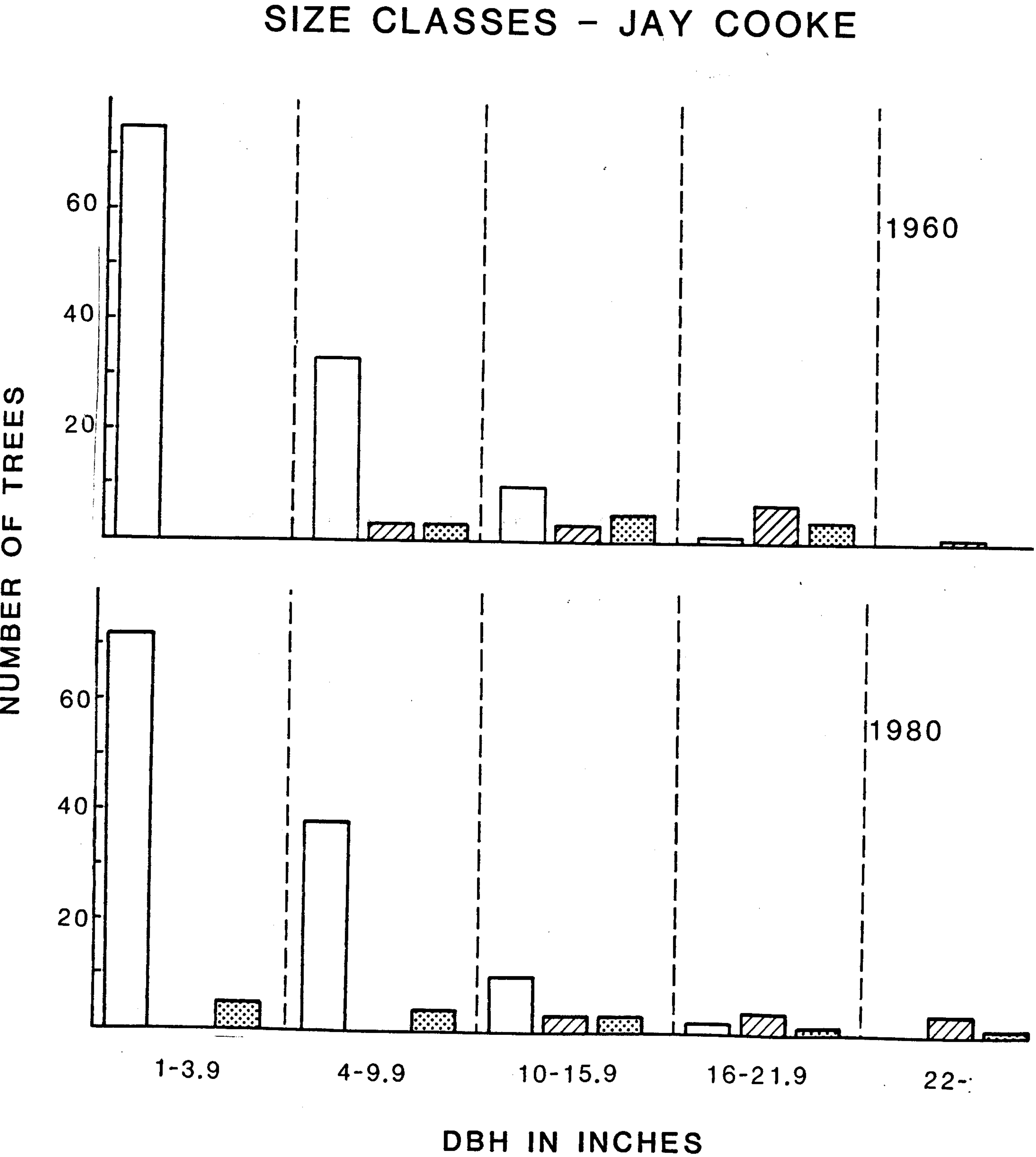

SIZE CLASSES - MAGNEY 10
NUMBER OF TREES
60
40
20
1961
60
40
20
1980
1-3.9
4-9.9
10-15.9
16-21.9
22-
DBH IN INCHES

Figure 5


SIZE CLASSES - JAY COOKE
NUMBER OF TREES
60
40
20
1960
60
40
20
1980
1-3.9
4-9.9
10-15.9
16-21.9
22-
DBH IN INCHES

The herbaceous species sampled are listed in Tables 2, 3 and 4. Of the 30 species identified, four were found at all three sites and eight were found at two of the three. The species seen at all three sites are *Aster macrophyllus* L., *Carex pedunculata* Willd., *Maianthemum canadense* Desf. and *Streptopus roseus* Michx. The shrub layer is very partly developed on any plot (Tables 2, 3 and 4) and in fact, two of the stands only had one species of shrub present among those species sampled.

Total tree and sapling densities are listed in Table 9. Magney 9, which contained none of the smaller sugar maple trees, had the highest tree density, and Magney 10, which contains the highest number of yellow birch and basswood trees, had the lowest. Sapling densities at Jay Cooke and Magney 9 were comparable; Magney 10 had a much higher density.

The only post-1961 disturbance that was noted at any of the sites was a single ski trail that passed through both the Magney 9 and Magney 10 stands. The Duluth city forester knew of no other catastrophic events that had taken place at my sites and the Park Manager at Jay Cooke State Park felt that the stand there had been undisturbed since the original study. However, a bad ice storm in April 1967 downed many

TABLE 9

Total Tree and Sapling Density

	Trees		Saplings	
	1960-61	1980	1960-61	1980
Magney 9	4.36	5.86 trees/ $100m^2$	5.67	7.59
Magney 10	3.87	4.35	7.59	9.91
Jay Cooke	5.24	5.07	4.66	7.57

trees at Cloquet, near Jay Cooke, according to Gordon Gullion, Cloquet Forestry Center (Duluth News Tribune, Sunday, November 20, 1982).

Comparison of Data From 1960-61 and 1980

Looking first at IV's of the three species, sugar maple has taken on a much larger role at the Magney 9 site (Table 10). Yellow birch has dropped considerably in importance at the site, while other species, including basswood, have remained about the same. Comparing the IV's for trees at Magney 10 and Jay Cooke (Tables 11 and 12) no striking differences are noted. Basswood has dropped in importance somewhat at the Jay Cooke site.

In comparing sapling IVs at Magney 9 (Table 10), basswood is the only dominant that has an appreciably larger value in 1980. Mountain maple, which had an IV of 59 in 1961, was absent in 1980. This is the stand where yellow birch numbers had diminished a great deal over the years and as I will mention later, there may be evidence of an association in these stands between birch in the overstory and mountain maple in the understory.

The number of sapling species was greater at Magney 10 in 1980 than in 1961, and the importance of sugar maple saplings has dropped somewhat (Tables 11 and 13). Basswood importance is greater and ironwood also appears in the sapling class in 1980.

The IV of sugar maple is greatest at the Jay Cooke stand. (Table 12) Basswood appears in smaller numbers at Jay Cooke in 1980 and mountain maple, which was present in 1960, has dropped out. Yellow birch is absent from the sapling category during both years.

TABLE 10

Importance Values - Magney 9

Species		
Trees	**1961**	**1980**
Acer saccharum	110	176
Betula alleghaniensis	93	20
Tilia americana	42	41
Picea glauca	8	-
Acer rubrum	7	4
Quercus rubra	12	23
Pyrus sp.	4	-
Ostrya virginiana	25	32
Betula papyrifera	-	4
Saplings		
Acer saccharum	213	222
Betula alleghaniensis	-	7
Tilia americana	11	26
Abies balsamea	7	-
Ostrya virginiana	11	35
Acer spicatum	59	-

TABLE 11

Importance Values - Magney 10

Species		
Trees	1961	1980
Acer saccharum	110	125
Betula alleghaniensis	89	84
Tilia americana	61	52
Picea glauca	11	5
Acer rubrum	12	-
Ostrya virginiana	17	18
Quercus rubra	-	3
Populus balsamifera	-	4
Saplings		
Acer saccharum	229	197
Betula alleghaniensis	-	-
Tilia americana	7	23
Acer spicatum	64	60
Ostrya virginiana	-	11
Acer rubrum	-	8

TABLE 12

Importance Values - Jay Cooke

Species		
Trees	1961	1980
Acer saccharum	124	140
Betula alleghaniensis	74	74
Tilia americana	54	34
Picea glauca	8	4
Thuja occidentalis	13	15
Fraxinus nigra	23	14
Quercus rubra	4	9
Ulmus americana	4	-
Pinus strobus	-	9
Saplings		
Acer saccharum	265	257
Fraxinus nigra	23	-
Acer spicatum	11	-
Ostrya virginiana	-	16
Tilia americana	-	26

TABLE 13

Importance Values - 1960 and 1961

Trees (> 10 cm dbh)	Magney 9	Magney 10	Jay Cooke
Acer saccharum	110	110	124
Betula alleghaniensis	93	89	74
Tilia americana	42	61	54
Picea glauca	8	11	8
Thuja occidentalis	-	-	13
Fraxinus nigra	-	-	23
Acer rubrum	7	12	-
Quercus rubra	12	-	4
Ulmus americana L.	-	-	4
Pyrus sp.	4	-	-
Ostrya virginiana	24	17	-

Saplings (2.5-9.9 cm dbh)	Magney 9	Magney 10	Jay Cooke
Acer saccharum	213	229	265
Betula alleghaniensis	-	-	-
Tilia americana	11	7	-
Abies balsamea (L.) P. Mill.	7	-	-
Fraxinus nigra	-	-	21
Ostrya virginiana	11	-	-
Acer spicatum	59	64	11

Comparing size classes of the dominant trees over time gives only a rather general indication of what is happening to the stands, but trends can be seen. In studying the changes at Magney 9 (Figure 3, Table 10),the obvious differences are an increase in sugar maple, especially in smaller trees and a sharp decrease in yellow birch over a range of sizes. This agrees with the IV information. Neither the Magney 10 nor Jay Cooke sites show any remarkable changes in sizes of the three dominant species.

As I mentioned in the materials and methods section, several measures besides the IV were used to compare stands to one another and the statistical significance of the differences between them was calculated. The parameters that were investigated were total tree density, total sapling density, total coverage of trees, relative coverage of tree species and relative density of tree and sapling species (Tables 14 to 19).

Data on the three stands in 1960-61 were compared to each other to judge their similarity and the same was done for the three stands in 1980. Each stand was also compared to itself 20 years later to look for any evidence of change. The cutoff for significance was the 0.05 level unless otherwise noted.

In comparing the three stands during the earlier sampling, the only place where a significant difference was noted was in the relative density of sugar maple trees. In the later study, significant differences between sugar maple's relative coverage and the relative density of trees and saplings were found.

TABLE 14

Statistical Comparisons Which Yielded Significant Differences

Significance at 0.05 Level Within Years

Acer saccharum	1960 - 1961	Relative density - trees
	1980	Relative coverage
		Relative density - trees
		Relative density - saplings

Significance at 0.05 Level Between Years

Magney 9	Relative coverage, *Acer saccharum* increase Relative density, *Acer saccharum* increase Relative density, *Betula alleghaniensis* decrease
Magney 10	none
Jay Cooke	Sapling density increase Relative density, *Tilia americana* decreased

Relative density for *Acer saccharum* saplings approached 0.05 in Magney 9 and 10

TABLE 15

Statistical Comparisons Within One Sampling Year - 1960-61

A=Magney 9, 1961
B=Magney 10, 1961
C=Jay Cooke, 1960

		Means		P-Values
Absolute Tree Density	A	537.38	trees/ha	
	B	458.80		0.531
	C	565.67		
Absolute Sapling Density	A	977.44	trees/ha	
	B	1155.55		0.141
	C	629.55		
Total Coverage Trees Only	A	55591.34	m^2/ha	
	B	48490.90		0.503
	C	64944.93		

Relative Coverage		Relative Frequency	Percent	P-Values
Acer saccharum	A	90	31.14	
	B	95	29.00	0.579
	C	90	30.37	
Betula alleghaniensis	A	60	45.49	
	B	60	42.64	0.898
	C	45	37.59	
Tilia americana	A	45	11.40	
	B	55	22.35	0.336
	C	50	20.18	
Ostrya virginiana	A	25	3.63	
	B	25	1.74	0.481
	C	0	-	

Relative Density Trees		Relative Frequency	Percent	P-Values
Acer saccharum	A	90	43.75	
	B	95	45.00	0.085
	C	90	55.00	
Betula alleghaniensis	A	60	23.75	
	B	60	23.75	0.996
	C	45	17.50	
Tilia americana	A	45	12.50	
	B	55	17.50	0.194
	C	50	12.50	
Ostrya virginiana	A	45	11.25	
	B	25	6.25	0.065
	C	0	-	

TABLE 15 (Continued)

Relative Density		Relative Frequency	Percent	P-Values
Saplings				
Acer	A	90	73.75	
saccharum	B	100	81.25	0.034
	C	100	93.75	
Betula	A	0	-	
alleghaniensis	B	0	-	-
	C	0	-	
Tilia	A	10	2.50	
americana	B	5	1.25	0.999
	C	0	-	
Acer	A	45	20.00	
spicatum	B	55	17.50	0.242
	C	10	2.50	

TABLE 16

Statistical Comparisons Within One Sampling Year - 1980

A=Magney 9, 1961
B=Magney 10, 1961
C=Jay Cooke, 1960

		Means		F-Values
Absolute Tree	D	649.90	trees/ha	
Density	E	508.78		0.917
	F	615.15		
Absolute Sapling	D	1066.16	trees/ha	
Density	E	1333.14		0.210
	F	923.11		
Total Coverage	D	55981.61	m^2/ha	
Trees Only	E	56802.00		0.399
	F	70198.37		

Relative Coverage		Relative Frequency	Percent	
Acer	D	100	60.54	
saccharum	E	100	36.27	0.042
	F	100	29.00	
Butula	D	15	8.82	
alleghaniensis	E	60	40.25	0.828
	F	50	36.92	
Tilia	D	35	14.90	
americana	E	45	18.15	0.913
	F	40	13.58	
Ostga	D	40	2.44	
virginiana	E	25	2.29	0.157
	F	0	-	

Relative Density		Relative Frequency	Percent	
Trees				
Acer	D	100	68.75	
saccharum	E	100	50.00	0.017
	F	100	63.75	
Betula	D	15	3.75	
alleghaniensis	E	60	20.00	0.438
	F	50	13.75	
Tillia	D	35	10.00	
americana	E	45	16.25	0.398
	F	40	11.25	

TABLE 16 (Continued)

Relative Density		Relative Frequency	Percent	P-Values
Ostrya virginiana	D	40	11.25	
	E	25	6.25	0.453
	F	0	-	
Saplings				
Acer saccharum	D	100	90.00	
	E	100	68.75	0.001
	F	100	90.00	
Betula alleghaniensis	D	5	1.25	
	E	0	-	-
	F	0	-	
Tilia americana	D	25	6.25	
	E	25	6.25	0.309
	F	20	6.25	
Acer spicatum	D	0		
	E	50	21.25	-
	F	0		

TABLE 17

Statistical Comparisons Between 1961 & 1980 - Magney 9

	Year	Means		P-Values
Tree Density	1961	537.38	trees/ha	0.320
	1980	645.90		
Sapling Density	1961	977.44	trees/ha	0.744
	1980	1066.15		
Total Coverage Trees Only	1961	55591.34	m^2/ha	0.979
	1980	55981.61		

Relative Coverage	Year	Relative Frequency	Percent	P-Values
Acer saccharum	1961	90	31.14	0.053
	1980	100	60.54	
Betula alleghaniensis	1961	60	45.49	0.678
	1980	15	8.82	
Tilia americana	1961	45	11.40	0.422
	1980	35	14.90	
Ostrya virginiana	1961	25	3.63	0.310
	1980	40	2.44	

Relative Density	Year	Relative Frequency	Percent	P-Values
Trees				
Acer saccharum	1961	90	43.75	0.14
	1980	100	68.75	
Betula alleghaniensis	1961	60	23.75	0.012
	1980	15	3.75	
Tilia americana	1961	45	12.50	0.864
	1980	35	10.00	
Ostrya virginiana	1961	25	11.25	0.148
	1980	40	11.25	
Saplings				
Acer saccharum	1961	90	73.75	0.169
	1980	100	90.00	
Betula alleghaniensis	1961	0	0.00	0.500
	1980	5	1.25	
Tilia americana	1961	10	2.50	0.500
	1980	25	6.25	
Acer spicatum	1961	45	-	0.069
	1980	10	-	

TABLE 18

Statistical Comparisons Between 1961 and 1980 - Magney 10

	Year	Means		P-Values
Tree Density	1961	458.80	trees/ha	0.617
	1980	508.78		
Sapling Density	1961	1155.55	trees/ha	0.561
	1980	1333.15		
Total Coverage Trees Only	1961	48490.89	m^2/ha	0.368
	1980	56802.00		
Relative Coverage		Relative Frequency	Percent	
Acer saccharan	1961	95	29.00	0.607
	1980	100	36.27	
Betula alleghaniensis	1961	60	42.64	0.952
	1980	60	40.25	
Tilia americana	1961	55	22.35	0.859
	1980	45	18.15	
Ostrya virginiana	1961	25	1.74	0.752
	1980	25	2.29	
Relative Density		Relative Frequency	Percent	P-Values
Trees				
Acer saccharum	1961	95	45.00	0.614
	1980	100	50.00	
Betula alleghaniensis	1961	60	23.75	0.408
	1980	60	20.00	
Tilia americana	1961	55	17.50	0.550
	1980	45	16.25	
Ostrya virginiana	1961	25	6.25	0.500
	1980	25	6.25	
Saplings				
Acer saccharum	1961	100	81.25	0.080
	1980	100	68.75	
Betula alleghaniensis	1961	0	-	-
	1980	0	-	
Tilia americana	1961	5	1.25	0.500
	1980	25	6.25	
Acer spicatum	1961	55	17.50	0.171
	1980	50	21.25	

TABLE 19

Statistical Comparisons Between 1960 and 1980 - Jay Cooke

	Year	Means			P-Values
Tree Density	1961	565.67	trees/ha		0.632
	1980	615.15			
Sapling Density	1961	629.55	trees/ha		0.050
	1980	923.11			
Total Coverage	1961	64944.93	m^2/ha		0.716
	1980	70198.37			
Relative Coverage		Relative Frequency		Percent	P-Values
Acer saccharum	1961	90		20.37	0.926
	1980	100		29.00	
Betula alleghaniensis	1961	45		37.59	0.450
	1980	50		36.92	
Tilia americana	1961	50		20.18	0.701
	1980	40		13.58	
Ostrya virginiana	1961	0		-	-
	1980	0		-	
Relative Density		Relative Frequency		Percent	P-Values
Trees					
Acer saccharum	1961	90		55.00	0.700
	1980	100		63.75	
Betula alleghaniensis	1961	45		17.50	0.173
	1980	50		13.75	
Tilia americana	1961	50		12.50	0.351
	1980	40		11.25	
Ostrya virginiana	1961	0		-	-
	1980	0		-	
Saplings					
Acer saccharum	1961	100		93.75	0.537
	1980	100		90.00	
Betula alleghaniensis	1961	0		-	-
	1980	0		-	
Tilia americana	1961	0		-	0.003
	1980	20		6.25	
Acur spicatum	1961	10		2.50	0.500
	1980	0		-	

In comparing the stands to themselves over time, no significant change was seen at the Magney 10 site. This is consistent with the indications that were noted from the IVs and the size classes. At the Jay Cooke site, the total sapling density increased and the relative density of basswood decreased significantly.

At Magney 9, the relative coverage of sugar maple increased, as did the relative density of trees of that species. The relative density of yellow birch trees decreased. This is again consistent with the IV and size class data.

The relative density of sugar maple saplings changed at both Magney 9 and 10, but the changes were significant only at the 0.10 level. Relative density increased over time at Magney 9 and decreased at Magney 10.

As was noted in an earlier section, comparison of the herbaceous species was hindered by the fact that only one of the three earlier stands had a quadrat-by-quadrat list of those species. For the Jay Cooke stand, which had the more specific list, frequencies from the earlier and later time points were compared. For the others, Sørensen's coefficient of community (Sørensen, 1948), which indicates similarity and requires knowledge of presence only, is used (Table). For both Magney 9 and Jay Cooke, the similarity was about 0.5 or 50% and for Magney 10 it was .38 or 38%.

Frequency data for shrubs and herbs appears in Tables 22, 23 and 24. Comparisons for Jay Cooke (Table 26) show few shrub species in both cases. As the presence data indicated, many of the same species are seen and, although it may be an artifact of the small plot size, different species are seen in large numbers in the two sampling years. Impatiens sp. and Rubus pubescens were seen most frequently by Flaccus and Ohmann (1964) and Dryopteris sp. Adans. was often seen in 1980. The species that Flaccus and Ohmann (1964) referred to as Viola pensylvanica may be Viola pubescyns Var. pennsylvanica and may thus be the same species that we call Viola pubescens (Kartesz and Kartesz, 1980).

As I noted earlier, there was an indication in the IVs that an association of some kind may exist between yellow birch trees and mountain maple saplings at the Magney sites. To investigate this further, the 1961 and 1980 field notes were checked to see which quadrants had yellow birch as the tree species sampled and how many of those quadrants had mountain maple as the sapling. A chi-square test was done on the combined data from both Magney stands during both sampling years, and the positive association proved to be significant only at the 0.10 level.

Finally, total basal area per stand was compared. Changes in total basal area may indicate whether the forests were growing or diminishing in size or number of trees a aging and dying trees are being replaced (Table 20). The stand that had very little change occurring over time according to the other measures, Magney 10, had no change in basal area over the 20 year period. Both Magney 9 and Jay Cooke stands, which each had some shifting of species numbers and roles, increased in basal area over time.

TABLE 20

Total Basal Area

	1960-1961	1980
Magney 9	4.39 in^2/m^2	5.58
Magney 10	4.66	4.67
Jay Cooke	5.74	6.33

TABLE 59

Sørensen's Index of Similarity for Stands Between Years

Magney 9	50
Magney 10	38
Jay Cooke	56

TABLE 60

Shrub and Herb Frequency - Magney 9 - 1980

Species	Frequency
SHRUB	
Lonicera canadensis Bartr.	10
HERBS	
Carex pedunculata Willd.	80
Viola pubescens Ait.	60
Aralia nudicaulus L.	50
Maianthenum canadense Desf.	50
Osmorhiza claytoni (Michx.) C.B. Clarke	40
Aster macrophyllus L.	30
Streptopus amplexifolius L. (DC.)	30
Streptopus roseus Michx.	30
Clintonia borealis Ait. Ref.	20
Trillium grandiflorum (Michx.) Salisb.	20
Actaea pachypoda Ell.	10
Allium tricoccum Ait.	10
Anemoe quinquefolia L.	10
Milium effusum L.	10
Solidago flexicalus L.	10
Taraxacum officinale Weber	10
Trillium cernuum L.	10

TABLE 23

Shrub and Herb Frequency - Magney 10 - 1980

Species	Frequency
SHRUB	
Ribes sp.	20
Corylus cornuta Marsh	10
Lonicera canadensis	10
HERB	
Carex pedunculata	90
Clintonia borealis	60
Maianthemum canadense	40
Viola pubescens	40
Dryopteris sp.	30
Aster macrophyllis	20
Circaea alpina L.	20
Polygonatum pubescense (Willd.) Pursh	20
Solidago flexicaulus	20
Trillium cernuum	20
Galium boreale	10
Lycopodium obscurum L.	10
Oryzopsis asperifolia Michx.	10
Osmunda sp. L.	10
Streptopus roseus	10
Trillium grandiflorum	10

TABLE 24

Shrub and Herb Frequency - Jay Cooke - 1980

Species	Frequency
SHRUB	
Corylus cornuta	10
HERBS	
Dryopteris sp.	60
Viola pubescens	50
Carex sp.	40
Carex pedunculata	30
Laportea canadensis (L.) Weddell	30
Aralia nudicaul s	20
Arisaema triphyllum (L.) Scott	20
Asarum canadense L.	20
Equisetum sp.	20
Circaea alpina	20
Streptopus roseus	20
Aster macrophyllus	10
Maianthemum canadense	10
Milium effusum	10
Trientalis borealis Raf.	10

TABLE 25

Shrub and Herb Frequency - Jay Cooke - 1960

Species	Frequency
SHRUBS	
Corylus cornuta	10
Lonicera canadensis	10
Ribes triste Pallas	10
HERBS	
Impatiens sp.	80
Rubus pubescens Raf.	60
Viola pensylvanica	50
Aralia nudicaulis	30
Dryopteris phegopteris	30
Carex pedunculata	20
Dryopteris disjuncta	20
Equisetum pratense Ehrh.	20
Laportea canadensis	20
Osmunda cinnamomea L.	20
Viola renifolia Gray	20
Asarum canadense	10
Aster macrophyllus	10
Aster simplex Willd.	10
Athyrium filix-femina (L.) Roth	10
Galeopsis tetrahit L.	10
Galium triflorum Michx.	10
Lycopodium lucidulum Michx.	10
Streptopus roseus	10
Trillium grandiflorum	10
Viola pubescens	10

TABLE 26

Shrub and Herb Frequency - Jay Cooke - 1960 & 1968

Species	Frequency	
SHRUB	1960	1980
Cornus canadensis	10	10
Lonicera canadensis	10	-
Ribes triste	10	-
HERBS		
Aralia nudicaulis	30	20
Arisaema triphyllum	-	20
Asarum canadense	10	20
Aster simplex	10	-
Aster macrophyllus	10	10
Athyrium filix-femina	10	-
Carex pedunculata	20	30
Carex sp.	-	40
Circaea alpina	20	-
Dryopteris disjuncta	20	-
Dryopteris phegopteris	30	-
Dryopteris sp.	-	60
Equisetum pratense	20	-
Equisetum sp.	-	20
Galium iniflorum	10	-
Galeopsis tetrahit	10	-
Impatiens sp.	80	-
Laportea canadensis	20	30
Lycopodium lucidulum	10	-
Maianthemum canadense	-	10
Milium effusum	-	10
Osmunda cinnamomea	20	-
Rubus pubescens	60	-
Streptopus roseus	10	20
Trientalis borealis	-	10
Trillium grandiflorum	10	-
Viola pensylvania	50	-
Viola pubescens	10	50
Viola renifolia	20	-

Discussion and Conclusions

Although the literature abounds with information on yellow birch and the difficulty that exists in trying to naturally rengerate it on undisturbed sites, few longer-term follow up studies similar to mine have been documented. Since the scope of the project was not great, changes in the stands can be noted but the reasons behind them are only conjecture at this point.

Since the field methods of Flaccus and Ohmarn (1964) were reproduced as closely as possible, I was locked into some procedures that may have been changed if I had designed the sampling methods myself. For example, I felt that the 10 - 1 m^2 quadrants used to record shrub and herbaceous species at each stand may have been too small a sample to yield a truly representative picture of the species composition. This may help explain why the community coefficients were so low.

Also, although the field methods were duplicated, I undoubtedly did not sample the same points Flaccus and Ohmann did at each stand, since they were not permanently marked. This could lead to differences in the data.

Importance values were relied upon heavily for comparisons in the earlier study and also in my study. I feel it is important to recall that the IV is calculated by adding three relative measures (relative density, relative frequency, relative dominance) so that units cannot be ascribed to it. Since it is the summation of values for three parameters that are not necessarily strongly related and had different units in their absolute forms, the use of the IV for comparison are limited. It does give an indication of a species' abundance and distribution in the community, however.

I noted earlier that the sapling data from 1960-61 indicated a growth in the importance of sugar maple. This seemed to be borne out although it seems straightforward in this instance. The sapling data may or may not be a good predictor of the future of a stand. Species habits vary and many other factors such as disturbance and a variety of habitat parameters may play key roles.

Habits of individual species can be useful to keep in mind when looking at many parameters. Neither yellow birch nor basswood are represented in high numbers in the smaller size classes. Each has growth habits which contribute to this; basswood generally reproduces by sprouting from the base of stumps or existing trees and yellow birch germinates with difficulty and competes poorly except under canopy gaps.

Disturbances have been noted to cause changes in species composition in northern hardwood forests (Stearns, 1949). Since my three stands experienced some changes, it would be convenient to be able to attribute these changes to some tangible event, but there was no evidence or information about disturbances.

As noted before, the size of disturbances that yellow birch can respond to can be very small, such as the death of one large tree. Changes such as that would be very difficult to document or even notice in a study such as mine, when a plot is sampled just once many years after the original study. It is therefore impossible for me to rule out the possibility that a very small change in stand structure could account for some of the differences that I saw, since I was unable to measure these changes.

The current study is by no means a large and all-encompassing one. Twenty years may or may not be long enough to get a comprehensive picture, but conclusions can still be drawn from the data. First of all, sugar maple seems to have increased in numbers and importance at some stands. Numbers of larger yellow birch trees remained constant in some cases but more often decreased, and there was no indication of an increase in the species at all. It was nearly absent from the sapling and small tree size classes. Also, these trees would substantiate the indications from the 1960-61 sapling data that sugar maple would increase and yellow birch would decrease. Finally, the estimates of total basal area indicate that the forest was not dying out, but rather maintaining and even growing in some cases.

In comparing my study to other investigators' work, I found similar results in several cases. Zillgitt and Eyre (1955) and Linteau (1948) noted that yellow birch cannot compete with sugar maple under a canopy. Tubbs (1977) reported that sugar maple seems to increase in importance over time and take over stands, but Bormann et al. (1970) suggested that while yellow birch regenerates poorly, its importance may not drop through time. Tubbs and Metzger (1969) said that the only way to increase yellow birch on a site that is predominantly sugar maple was to use the shelterwood cutting system, scarify the soil and poison the remaining sugar maples. Stearns (1951) indicates that sugar maple was often over-represented in the sapling class in stands where it was dominant, and both he and Leak (1975) note that yellow birch displayed irregularities in reproduction and age distribution. Bormann and Likens (1979) studied northern hardwood stands that seldom had fires or catastrophic storms. These stands displayed what they called a shifting-mosaic steady state in which small areas changed due to endogenous events such as single tree deaths, but the large picture remained more constant.

Literature Cited

Baldwin, I.T. and J. C. Schultz. 1984. Tannins lost from sugar maple (Acer saccarum Marsh) and yellow birch (Betula alleghaniensis Britt.) leaf litter. Soil Biol. Biochem. 16: 421-422.

Barrett, J.W., C.E. Farnsworth and W. Rutherford, Jr. 1962. Logging effects on regeneration and certain aspects of microclimate in northern hardwoods. J. For. 60: 630-639.

Bellefleur, P. and G. LaRocque. 1983a. Comparison de la croissance d'especes ligneuses en milieu ouvert et sous couvert forestier. Can. J. For. Res. 13: 508-513.

Bellefleur, P. and G. LaRocque. 1983b. Competition pour le rayonnement solaire en debut de succession secondaire dens une erabliere a bouleau jaune et hatne. Can. J. For. Res. 13: 514-521.

Bellefleur, P. and Y. Petillon. 1983. Experimentation sur la competition interspecifique par elimination selective d'especes forestrieres. Can. J. For. Res. 13: 522-532.

Benzie, J.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 Forest Service LSFES Technical Note 561.

Boivin, J.L. 1971. A study of regeneration after clear-cutting in mixed and hardwood cover types in eastern Quebec. Forestry Chron. 47: 82-85.

Bormann, F.H. and G.E. Likens. 1979. Catastrophic disturbance and the steady state in northern hardwood forests. Amer. Sci. 67: 660-669.

Bormann, F.H., T.G. Siccama, G.E. Likens and R.H. Whittaker. 1970. The Hubbard Brook ecosystem study: composition and dynamics of the tree stratum. Ecol. Monogr. 40: 373-388.

Braun, E.L. 1950. Deciduous forests of Eastern North America. The Blakeiston Co., Philadelphia.

Buell, M.F. and W.A. Niering. 1957. Fir-spruce-birch forest in northern Minnesota. Ecology 38: 602-610.

Burton, D.H., H.W. Anderson and L.F. Riley. 1969. Natural regeneration of yellow birch in Canada. USDA Forest Service NEFES Birch Symposium Proceedings: 55-73.

Cole, L.C. 1957. The measurement of partial interspecific association. Ecology 38: 226-233.

Curtis, J.T. 1959. The vegetation of Wisconsin. The University of Wisconsin Press, Madison.

Curtis, J.T. and R.P. McIntosh. 1951. An upland forest continuum in the prairie-forest region of Wisconsin. Ecology 32: 476-496.

Daubenmire, R.F. 1936. The "Big Woods" of Minnesota: its structure and relation to climate, fire and soils. Ecol Monogr 6: 233-268.

Erdman, G.G., R.M. Godman and R.M. Peters, Jr. 1982. How to release yellow birch in the lake states. USDA Forest Service NCFES.

Eyre, F.H. and W.M. Zillgitt. 1953. Partial cutting in northern hardwoods of the lake states - twenty year experimental results. USDA Forest Service Technical Bulletin 1076.

Flaccus, E. 1956. Distribution in Minnesota of Acer saccharum, Tilia americana and Betula lutea. J. Minn. Acad. Sci. 32: 95-97.

Flaccus, E. and L.F. Ohmann. 1964. Old-growth northern hardwood forests in northeastern Minnesota. Ecology 45: 448-459.

Forcier, L.K. 1975. Reproductive strategies and co-occurrence of climax tree species. Science 189: 808-810.

Fowells, H.A. 1965. Silvics of forest trees of the United States. USDA Forest Service Agriculture Handbook 271, Washington, D.C.

Gilbert, A.M. 1960. Silvical characteristics of yellow birch (Betula alleghaniensis). USDA Forest Service NEFES Station Paper 134.

Godman, R.M. 1957. Silvical characteristics of sugar maple. USDA Forest Service LSFES Station Paper 50.

Godman, R.M. and G.G. Erdman. 1981. How to regenerate yellow birch in the lake states. USDA Forest Service NCFES.

Godman, R.M., G. Gagnon, and Z. Majcen. 1980. Sugar maple. pp. 29-30 in F.H. Eyre (ed.). Forest cover types of the United States and Canada. Society of American Foresters, Washington, D.C.

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 shelterwood method - a preliminary guide. USDA Forest Service NCFES Research Paper NC-99.

Graham, S.A. 1941. Climax forests of the Upper Peninsula of Michigan. Ecology 22: 355-362.

Grimm, E.C. 1984. Fire and other factors controlling the big woods vegetation of Minnesota (USA) in the mid-19th century. Ecol. Monogr. 54: 291-312.

Hatcher, R.J. 1966. Yellow birch regeneration on scarified seedbeds under small canopy openings. For Chron 42: 350-358.

Hough, A.F. 1937. A study of natural tree reproduction in the beech-birch-maple-hemlock type. J. For. 35: 376-378.

Hutnick, R.J. 1952. Reproduction on windfalls in a northern hardwood stand. J. For. 50: 693-694.

Jacobs, R.D. 1974. Damage to northern hardwood reproduction during removal of shelterwood overstory. J. For. 72: 654-656.

Kartesz, J.T. and R. Kartesz. 1980. A synonymized checklist of the vascular elora of the United States, Canada and Greenland Volume II. The biota of North America. University of North Carolina Press, Chapel Hill.

Kelty, M.J. and R.D. Nyland. 1981. Regenerating Adirondack northern hardwoods by shelterwood cutting and control of clear density. J. For. 79: 22-26.

Kokino, N.A., M.P. Podlelok and N.I. Prutens Kaya. 1973 Dynamics of biologically active volatile and water soluble substances from fallen maple leaves. pp. 99-100 In A.M. Grodzinsky (ed.). Physiological - biological basis of plant interactions in Phytocenoses. Naukoua Kumka, Kiev.

Koroleff, A. 1954. Leaf litter as killer. J. For. 52: 178-182.

Leak, W.B. 1975. Age distribution in virgin red spruce and northern hardwoods. Ecology 56: 1451-1454.

Linteau, A. 1948. Factors affecting germination and early survival of yellow birch in Quebec. For. Chron. 24: 27-86.

Maissurow, D.K. 1941. Role of fire in the perpetuation of virgin forests of northern Wisconsin. J. For. 39: 201-207.

Marquis, D.A. 1969. Silvical requirements for natural birch regeneration. USDA Forest Service NEFES Birch Symposium Proceedings: 40-49.

Maycock, P.F. and J.T. Curtis. 1960. Phytosociology of boreal conifer-hardwood forests of the Great Lakes region. Ecol. Monogr. 30: 1-35.

Mensah, K.O.A. 1972. Allelopathy as expressed by sugar maple on yellow birch. Ph.D. Dissertation, University of Michigan.

Minnesota Soils Atlas, Duluth Sheet 1977 Agricultural Experiment Station, University of Minnesota, Misc. Report #148.

Mueller, Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, New York.

Ostrom, C.E. 1938. Clear cutting of young nothern hardwood stands. J. For. 36: 44-49.

Potzger, J.E. 1946. Phytosociology of primeval forest in central northern Wisconsin and upper Michigan, and a brief post-glacial history of the Lake Forest Formation. Ecol. Monogr. 16: 211-250.

Rice, E.L. 1984. Allelopathy, 2nd edition. Academic Press, New York.

Roberge, M.R. 1977. Influence of cutting methods on natural and artificial regeneration of yellow birch in Quebec northern hardwoods. Can. J. For. Res. 7: 175-182.

Schultz, J.C., P.J. Nothnagle and I.T. Baldwin. 1982. Seasonal and individual variation in leaf quality of two northern hardwoods tree species. Am. J. Bot. 69: 753-759.

Soil Survey Staff. 1975. Soil taxonomy. USDA Forest Service, Washington, D.C.

Sørensen, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. Det Kong. Danske Vidensk. Selsk. Biol. Skr. 5: 1-34.

Stearns, F.W. 1949. Ninety years of change in a northern hardwood forest in Wisconsin. Ecology 30: 350-358.

Stearns, F.W. 1951. Composition of sugar maple-hemlock-yellow birch association in northern Wisconsin. Ecology 32: 245-265.

Tubbs, C.H. 1969. Natural regeneration of yellow birch in the lake states. USDA Forest Service NEFES Birch Symposium Proceedings: 74-78.

Tubbs, C.H. 1973. Allelopathic relationships between yellow birch and sugar maple seedlings. For. Sci. 19: 139-145.

Tubbs, C.H. 1976. Effect of sugar maple root exudate on seedlings of northern confer species. USDA Forest Service NEFES Research Note NC-213.

Tubbs, C.H. 1977. Natural regeneration of northern hardwoods in the northern Great Lakes states. USDA Forest Service NCFES Research Papter NC-150.

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

Weaver, J.E. and F.E. Clements. 1951. Plant ecology. McGraw Hill, New York.

Whittaker, R.H. 1953. A consideration of climax theory: the climax as population and pattern. Ecol. Monogr. 23: 41-78.

Willis, G.L. and J.A. Johnson. 1978. Regeneration of yellow birch following selective cutting of old-growth northern hardwoods. MTU Ford Forestry Center, Research Note 26, Houghton, Michigan.

Winget, C.H. 1964. Silviculture studies of yellow birch and associated species in Wisconsin. Ph.D. Dissertation, University of Wisconsin, Madison.

Winget, C.H. 1968. Species composition and development of second growth hardwood stands in Quebec. For. Chron. 44: 5-10.

Winget, C.H., G. Cottam and T.T. Kozlowski. 1969. Species association and stand structure of yellow birch in Wisconsin. For. Sci. 11: 369-383.

Woods, K.D. 1984. Patterns of tree replacement: canopy effects on understory pattern in hemlock-northern hardwoods forests. Vegetatio 56: 87-107.

Woods, K.D. and R.H. Whittaker. 1981. Canopy-understory interaction and the internal dynamics of mature hardwood and hemlock-hardwood forests. pp. 305-323. In D.C. West, H.H. Shugart and D.B. Botkin (eds.). Forest succession: concepts and applications. Springer-Verlag, New York.

Zillgitt, W.M. and F.H. Eyre. 1945. Perpetuation of yellow birch in lake states forests. J. For. 43: 658-661.