MHn45

MHn45 – Northern Mesic Hardwood (Cedar) Forest

Natural Disturbance Regime, Stand Dynamics, and Tree Behavior

Summary and Management Highlights

Northern Mesic Hardwood (Cedar) Forests (MHn45) are a locally abundant community restricted to the Northern Superior Uplands ecological section, and especially the North Shore Highlands subsection along Lake Superior (Figure 1). Detailed descriptions of this community are presented in the DNR Field Guides to Native Plant Communities of Minnesota.

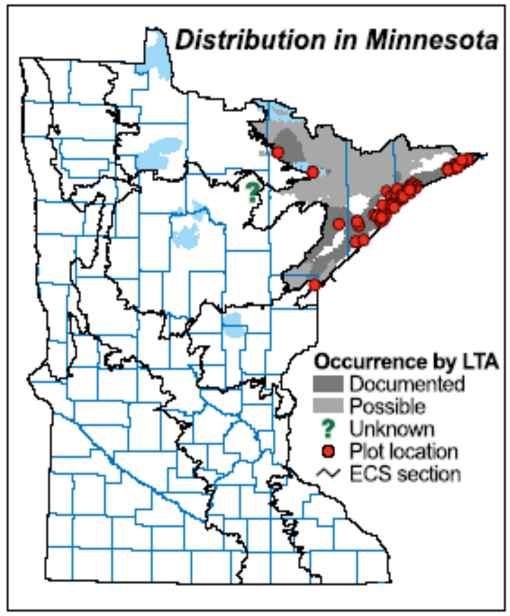


Figure 1. The range of MHn45 forests in Minnesota (shaded) and distribution of releve samples (red dots).

Commercial Trees and Management Opportunities

As a commercial forest, MHn45 sites offer a wide selection of crop trees and few possible structural conditions. Sugar maple, yellow birch, paper birch, and white cedar are all ranked as excellent choices as crop trees by virtue of their frequent occurrence and high cover when present on MHn45 sites (see Suitability Tables). Basswood, white spruce, balsam fir, and red maple are ranked as good crop trees, and stands can be managed to perpetuate these trees as co-dominants, especially when present or with evidence of former presence (e.g. stumps) in a particular stand. Quaking aspen and white pine are ranked as just fair choices of crop trees, but stands can be managed to maintain their presence as minor trees.

Among these species, sugar maple, paper birch, balsam fir, yellow birch, white cedar, and white spruce were the dominant native trees that have occupied MHn45 sites for a long time and have had the opportunity through successive generations to adapt to physical conditions typical of these sites **(PLS/FIA-1)**. Quaking aspen and basswood are likewise native to MHn45 sites but occurred naturally at lower abundance. The consequence of commercial logging, and settlement in the past century has been to promote much more quaking aspen, balsam fir, and paper birch than was usual. Past history and land use as also encouraged the ingress of species that were not significant in native MHn45 stands such as red maple and possibly black spruce.

Natural Silvicultural Approaches

It is very important to point out that dynamics in MHn45 forests is as of this writing unique. None of the site conditions associated with stand-regenerating disturbance apply. There were no examples of open habitat with lots of exposed mineral soil. Shade tolerance sequences or disturbance regimes don't explain succession. The rotations are so long that one must always keep in mind that the forest matrix was old-growth. Amazingly, every species can perform as a large-gap strategist according to our combined scoring of species behavior in the PLS, FIA, and releve data (see Species Behavior). Our dynamic model must be based upon the instances where the survey corners fell within the regeneration gaps – given that advance regeneration, seed trees, and largely organic seedbeds were ever present as the forest legacy. A useful simplification is to consider MHn45 sites as always having a core presence of sugar maple regardless of age – if not in the canopy, then in the subcanopy where it is uniformly dominant **(R-2)**. Thus a key strategy of natural silviculture is learning to manipulate advance regeneration and then create canopy gaps of the appropriate size to favor the desired crop tree.

The peculiar character of MHn45 forests to not experience stand-scale disturbance or be even-aged severely limits the set of silvicultural systems that might reproduce the natural stand dynamics. Only the selective system or the newer retention systems would match the appropriate level of canopy removal and also maintain the all-aged stand structure.

Another oddity is that gap forming events were rather divorced from establishment events – which is unlike traditional silvicultural systems where tree removal and regeneration go hand-in-hand. All data point to recruitment of advance regeneration that we figure was pole-sized or nearly so, and the formation of the gap had little effect on the comparative ability of different species to establish seedlings or recruit in diameter classes under an inch. Getting crop trees to the pole stage would resemble stand improvement harvesting or tending practices more so than any silvicultural system.

Though we struggle for the appropriate forestry verbiage, several key principles are evident regardless of silvicultural tactics. First, management of non-maples must be accomplished about a core population of sugar maple. Sugar maple is king on MHn45 sites and short of ecosystem destruction, there will always be some sugar maple. It is unfortunate that on these sites sugar maple is short-lived and plagued with disease and deformity that doesn't affect fitness. Sugar maple's mastery is in the understory, where it has perfect indices of regeneration **(R-2)**. Nothing can be done about sugar maple's superior establishment, but recruitment is another matter. Only in the sapling and pole stage do other species of trees have abundance approaching that of sugar maple. Cleaning sugar maple regeneration about small, non-maple crop trees or releasing them from overtopping maples is a strategy that might help to recruit other species to the point where they would be the likely successors in a harvest gap.

Second, other than sugar maple, red maple, and balsam fir, all other trees are having problems getting established **(R-2)**. The lack of regenerants is a problem with either light or seedbed or both. It is probably significant that the larger-seeded maple are prevailing over small-seeded species. The duff layer of MHn45 stands is a smothering and thick blanket of sugar maple leaves that small seeds are not likely to penetrate. In this environment, nurse logs play a critical role in seedling establishment for white cedar and yellow birch, but we suspect that paper birch and white pine also find logs to be the best available substrate. Site preparations that mix the soil, coupled with modest (<10%) overstory removal could help to establish a desirable mix of young trees than can be tended and selected from until the appropriate time to remove the canopy. Harvesting instructions to leave culls on the ground as future nurse logs might also help to promote a more mixed future forest.

Finally, the fate of conifers on MHn45 sites is inexplicably related to balsam fir. Historically, a pulse of fir regeneration accomplished something that tipped the climax scales towards white cedar and white spruce and away from a sugar maple. We really don't understand the connection but if there is a natural maple herbicide, it is a dense understory of fir. Perhaps this was enough to select for existing cedar and spruce regeneration or it was the event that promoted their establishment. Today, there are more stands than ever experiencing this fir pulse **(PLS/FIA-1)** and it would seem to be an opportunity to establish white cedar or white spruce outside of the traditional plantation. Underplanting cedar or spruce in these stands at the beginning or end of a fir pulse could be a winning silvicultural strategy.

Management Concerns

MHn45 communities occur mostly on stony, sandy loam till overlying the scoured bedrock terrain of northeastern Minnesota. In many cases, especially where white cedar and yellow birch are abundant, there is a highly compactable cap of silt. Thus, soil compaction is a major concern and field assessment of soil conditions is required (see Acceptable Operating Season to Minimize Compaction tables). However, on some sites the stones can lend structural strength for heavy equipment. Because the till is dense and compact, it can perch water and may require long drying times in the spring and after storms. Rutting is less a concern because of the stones and generally good drainage.

The landscape balance of MHn45 forests has been severely altered by commercial logging. Historically 55% of MHn45 forests were older than 95 years and most would have met the requirements old-growth forest. Today, just 15% of these stands are older than 95 years and there seem to be no examples of stands in excess of 155 years outside of a few state parks and other protected sites. A full 64% of MHn45 stands are now younger than 75 years, in comparison to just 29% historically. Also, there was no historic precedent for stand-sized openings and today fragmentation at that scale is typical. Although linear by nature, the MHn45 landscape arguably provided some of the most continuous and old forest habitat for forest-interior animals in the state.

One reason for the imbalance of growth-stages is the lack of long-lived conifers that contributed most to survey corners estimated to be older than 95 years. Most striking is the loss of white spruce in the mature and very old growth-stages. Supercanopy white spruce were once a common feature of this community as it represented 37-54% of the trees in older MHn45 forests. In addition to low percentages of spruce today (2-15%) it is more important to realize that stands this old are just gone, meaning that many acres of young, spruce-impoverished forest have replaced the old growth. Equally discouraging is the loss of white cedar. Cedar's real grasp on this community occurred during the mature growth-stage where it was 25% of the bearing trees and now has 5% abundance at FIA subplots estimated to be between 95-155 years old. Cedar's peril seems more serious than that of white spruce as cedar just isn't often seen in any kind of regenerating situation (situations 11,12,13; FIA-1). White spruce silviculture has been directed towards plantations, which don't resemble any natural MHn45 forest, but at least they succeed in putting seed trees back on the landscape.

Natural Disturbance Regime

Natural rotation of catastrophic and maintenance disturbances were calculated from Public Land Survey (PLS) records at 619 corners within the primary range of the MHn45 community. At these corners, there were 1,460 bearing trees comprising the species that one commonly finds in MHn45 forests. This is a small sample compared to other MHn forests, and is a reflection of its limited range on the highlands along Lake Superior.

Natural Rotations of Disturbance in MHn45 Forests Graphic	
	Banner text over photo
Catastrophic fire photograph	3,100 years
Catastrophic windthrow photograph	3,100 years
Partial Canopy Loss, photograph	3,100 years

The PLS field notes described less than 1% of the MHn45 landscape as recovering from stand-regenerating fire. Fire was mentioned at just 3 survey corners. From these data, a rotation of 3,100 years was calculated for stand-replacing fire.

By chance, the surveyors mentioned stand-damaging wind at 3 survey corners as well, also resulting in the same calculated rotation of 3,100 years.

There was but a single survey corner where bearing tree distances would suggest some kind of partial canopy loss. Using a five-year recognition window for maintenance disturbance, this also results in a calculation of 3,100 years for such disturbances.

The small sample size of just 619 corners contributed to the chance calculation of equal rotations for catastrophic fire, stand-regenerating windthrow, and maintenance events. We have little faith in the accuracy of these estimates, but we believe that the magnitude is roughly correct – rotations were very much longer than any disturbance regime imparted by managing them as commercial forest. It is hard to imagine any terrestrial environment in Minnesota where one could assemble a set of 600 geographically cohesive survey corners and have no mention of disturbance. Most surprising is the lack of corners where long distances to bearing trees would suggest some partial canopy loss. MHn45 stands alone among all forests in having consistently short distances from the corner to the bearing trees – indicating fully stocked, undisturbed forest. Consistent with the long rotation idea, is the exceptionally thick duff layer and ability of trees to use nurse logs rather than mineral soil seedbeds in unmanaged remnants of MHn45 forest. This is an amazing fact given the tendency of forests to be fire-dependent beyond the moderating effect of Lake Superior on local climate.

Natural Stand Dynamics & Growth-stages

We found no evidence that fire or extensive windthrow created young MHn45 forests. In the entire analysis, there were but 7 PLS corners with 16 bearing trees where we assumed some kind of disturbance affecting canopy trees **(PLS-3)**. About 99% of the historic MHn45 forest was interpreted to be mature, undisturbed forest. This does not preclude a consistent pattern of succession, but we must recognize that the scale of openings was very fine in comparison to communities periodically affected by fire, wind, or even widespread outbreaks of pests. We suspect that the primary agents of mortality were root diseases, which are as native and natural to MHn45 sites as the trees. Patches of regenerating forest must have been big enough so that the PLS surveyors were often inclined to scribe full complements of 4 bearing trees of similar diameter.

The overall pattern of succession of trees in a regeneration patch was remarkably uniform and steady, except for modest accelerated change between the 70- and 100-year age-classes **(PLS-4)**. The steady movement of age-classes in ordination space is the primary reason that we were inclined to recognize several stages of stand maturation **(PLS-1)**. The general pattern of compositional change is for young patches to be hardwood-dominated and for old patches to be enriched in long-lived conifers. With the possible exception of paper birch, no deciduous tree is entirely eliminated in old-growth because of lack of seedbed or adequate tolerance. Most of the hardwoods had their peak recruitment in the young growth-stage **(PLS-5)**, which for species like sugar maple is exactly backwards of it usual pattern where its regeneration usually improves with stand age to the point where we consider it to be the climax, old-growth species. This suggests to us that regeneration patches could have released advance regeneration of all species, and what we perceive as succession amounts to little more than differences in survival and longevity from that point. Most likely regeneration patches would lose in succession: any aspen, paper birch, heart-leaved birch (?), sugar maple, and then yellow birch. As this happened, stands tended to accumulate conifers, with white cedar appearing at mid-succession, and white spruce later in succession.

Early in the process of stand maturation, MHn45 stands achieved tree densities that were fairly stable, and indicative of true forest conditions. Temporal change in tree density initially followed the textbook concept of young, small-diameter forests being tightly packed – followed by older, large-diameter stands with trees more widely spaced. Presumably, crown competition among canopy trees causes this. Young MHn45 forests under 75 years had mean distance of just 15 feet from survey corners to the bearing trees. This is tighter than usual for MHn communities. It would seem that whatever killed patches of canopy trees on MHn45 sites left dense, advance regeneration intact. Transitioning forests 75-95 years old had bearing trees 18 feet away from their corners on average. Even in the mature growth-stage (95-155) tree density was still high as bearing trees were only about 20 feet from their corners. We were surprised to see tree density increase in the second transition (155-195 years; mean distance 18 feet) and in very old forest (>195; mean distance 17 feet). Possibly this increase in density is the result of spruce requiring smaller crown space than old hardwoods. Forests affected by fire or pest outbreaks that can synchronously kill canopy trees tend to have standard deviations of tree distances about equal to their means. In contrast the standard deviations of tree distances are half of their means in MHn45 forests. Thus, these forests were dense and the trees evenly spaced. We interpret this as further evidence of the lack of disturbance in this community and the tendency of canopy gaps to be fairly small and appear at different times.

Young Growth-stage: 0- 75 years

About 29% of the MHn45 landscape in pre-settlement times was covered by regenerating patches estimated to be under 75 years old **(PLS-1)**. While this sounds like a lot, it is important to note that most trees were in the older age-classes within this range. Post-disturbance, there were very few (~1%) small-diameter trees that we estimated to be under about 20-30 years of age **(PLS-3)**. This suggests that canopy trees were most often replaced by advance regeneration that was already at pole size. About 88% of the survey corners in young stands were of mixed composition, which is typical of northern hardwoods. To some extent, this argues that the mortality agent was not species specific and that a mixture of species in the sapling and pole layers were prepared to replace canopy trees. Ever present, generalist diseases like *Armillaria* would fit our observations and scale of disturbance. Surprisingly all monotypic survey corners were cases where bearing trees were all cedar or all spruce, neither of which was particularly abundant in the young growth-stage. The preponderance of young survey corners were mixtures of trees; sugar maple, balsam fir, yellow birch, and paper birch contributed most to the mix.

An amazing fact is that for each species, the current mean cover of their saplings and poles in our releves is quite comparable to their relative abundance as bearing trees in the young growth-stage. The current mean cover of saplings (5-10m) when present are: sugar maple 34%, paper birch 6%, balsam fir 4%, yellow birch 6%, white cedar 9%, and white spruce 2%. While there are some departures among the less frequent trees, their is general correspondence with table **PLS-1**. For this plant community there is a disproportionate sampling of mature and old MHn45 forests in preserved areas, in which we believe the modern forests are quite similar to their historic counterparts because fire-suppression or other indirect effects of settlement on vegetation are not an issue. It seems to us that the cover and abundance of advance regeneration is entirely predictive of initial success in regeneration gaps. This implies that a key to MHn45 silviculture is to learn how to manipulate the composition of the sapling layer prior to creating canopy gaps.

First Transition: 75-95 years
About 16%, of the historic MHn45 landscape were regeneration gaps undergoing some compositional change **(PLS-1)**. Presumably this episode is reflective of competition among a large number of saplings in the gaps to recruit to tree height. Although the change is modest, this episode was the fastest that the average MHn45 patch would experience in the course of succession **(PLS-4)**. Sugar maple, paper birch, and yellow birch all decline during the transition while cedar and white spruce increase. At this time most corners were mixed (74%), but this is a decrease from the young growth-stage (88%), meaning that there is a slight trend for monotypic patches to form. As in the young growth-stage, corners where all bearing trees were cedar are common. It was also common at this time for sugar maple to represent the full contingent of bearing trees at a corner. Otherwise the mixed corners involved the hardwoods in decline and balsam fir.

The response of cedar and spruce to hardwood decline was not immediate. Rather, the fall and rise is separated by a period where fir was abundant. In fact, most of the compositional movement during the transition **(PLS-4)** results from the collapse of the fir pulse at the close of the young growth-stage. By the age of 40-60 years, fir trees represented as much as 30% of all trees, but shortly thereafter it drops precipitously to about 5% relative abundance in the initial age-classes of the transition **(PLS-2)**. This pulsing behavior is shared with many other communities in the Northern Superior Uplands Section of the state where white spruce is the ultimate climax species rather than sugar maple. The usual explanation is that fir is the only species sufficiently tolerant of shade to establish seedlings during self-thinning of aspen and birch. How fir accomplished the same thing among sugar maples is a bit of a puzzle, especially because our vision of gap-filling in this community is that recruiting trees were well-established saplings or poles. If thicket-like growth occurred in MHn45 canopy gaps, it was most likely that of mountain maple, beneath which fir is quite capable of establishing seedlings, and possibly it was favored over other species in that environment. The seeming function of fir pulses is to somehow prepare sites for ingress of conifers. In this case ingress of white cedar, white spruce, and some white pine follow the fir pulse, but their regeneration was not below fir – meaning that fir's role was not that of a cover crop. Normally, we attribute fir's soil-acidifying effect as a prerequisite for making seedbeds more receptive to conifers. Here, it is hard to imagine how fir could overcome so much base-rich maple litter. Also, some acidification might favor establishment white spruce, but cedar prefers base-rich seedbeds. Regardless of our confusion, it remains a fact that substantial declines in fir abundance initiates the first transition, and ingress of conifers follows.

Another mystery of the transition is the decline of hardwoods that are certainly capable of living longer than 75 years in most of Minnesota's habitats. There are three possible explanations. First, that hardwoods die because they are consistently overtopped by cedar and white spruce. However, the delay in conifer response would suggest that it was more a matter of these conifers being released by the death of overtopping hardwoods. Second, possibly there is a direct interaction between fir and hardwoods leads to hardwood decline. In stands experiencing a fir pulse, its effect on hardwood seedlings and saplings is devastating, but we have no evidence or reason to believe that fir in any way promotes the decline of established hardwood trees. Finally, it could just be that birch and maple really don't live as long on MHn45 sites as they do elsewhere. For paper birch, the timing (75-95 years) is about right for natural senescence and decline. For heart-leaved birch it seems early, but past research and even our own releve database has generally ignored the difference between these species and it is hard to say much about the longevity of heart-leaved birch. For yellow birch and sugar maple, these trees usually live a long time and their local populations are commonly subsidized by establishment and recruitment by age 95 or so. However, for sugar maple there is some indication that they plagued by the early onset of disease and senescence in the North Shore Highlands and similar places on the Canadian shield. Research in Canada shows that by age 65 – conveniently close to the onset of our transition at age 75 – the average diameter of a sugar maple is 5.5" and with 20% of the bole infected by fungi or affected by stain traceable to wounds. Off of the Canadian shield, as is most sugar maple habitat in Minnesota, by age 65 sugar maple trees have average diameter of about 8.5" and just 5% of the wood affected by fungi and stain. Our interpretation is that on MHn45 sites sugar maples accumulate infection, possibly aided by the high humidity of this special environment, to the point where they are senescent and subject to windthrow by age 75. Presumably, this gives white cedar and white spruce the opportunity to emerge as dominants in older regeneration patches. We simply don't know if yellow birch has the same experience as sugar maple on these sites.

The transition is concluded by yet another enigma. Typical of almost any upland community where cedar is an important component of old forests is a pulse of regeneration at about age 80. For MHn45 this pulse adds to compositional movement in the last age-classes of the transition and first age-classes of the mature growth-stage **(PLS-4)**. At about age 90, it rises from about 7% relative abundance to about 26% in the course of 20 years or so **(PLS-2)**. It persists at high abundance until about age 130 where it starts a gradual, persistent decline in all older age-classes, averaging just 8% presence in very old forests **(PLS-1)**. Similar pulses are seen in fire-dependent forests, wet forests, rich forested peatlands, and other mesic hardwood communities within the range of cedar. We are at a loss to explain two things – how any inherent stand maturation process at age 80 can induce a sharp pulse of regeneration, and how such a late-successional phenomenon could be shared among so many functionally different ecological systems. Alternatively, because we are relying upon PLS notes to create successional models, it could just be that somewhere around 1790-1820 AD, a regional event favored the expansion of cedar populations throughout its range and in all habitats. If this is true, it hasn't been repeated since. Most reconstructions of individual stand histories (from tree rings) confirm our interpretation that white cedar is a mid- or late-successional tree but still we wonder why, given the rather universal lack of regenerative success under a canopy **(R-2)**.

Mature Growth-stage: 95-155 years

About 38% of the historic MHn45 landscape was mature forest **(PLS-1)** where the rate of successional change slowed **(PLS-4)**. Regeneration patches in this stage were mostly mixed (80%), but once again the unusual trend of patches becoming more monotypic is evident. Patches of pure cedar were most common, but there were instances of all bearing trees being white spruce or yellow birch. The more common mixed corners involved sugar maple mixed with other trees. Trees mentioned most often as sharing a survey corner with sugar maple were cedar, yellow birch, paper birch, and balsam fir. The list of associated species though is long, suggesting that mature MHn45 forests supported many species of trees at low abundance.

Mature MHn45 forests fit the classic concept of climax forest, as there was essentially no catastrophic disturbance (see Natural Disturbance Regime). The appearance and functioning of these forests revolved around a fairly stable base of sugar maple at about 20% relative abundance and yellow birch at about 15% relative abundance **(PLS-1)**. Sugar maple's "hold" or dominance on MHn45 sites is seemingly evident in the understory, with presence of 89% in releves **(R-2)**, and 79% mean cover-when-present at heights under 10m – regardless of the amount of cedar, spruce, or yellow birch in the overstory. Amazingly, MHn45 forests never became pure stands of sugar maple in spite of maple's obvious success and dominance in all understory strata. Throughout the mature growth-stage, the relative abundance of sugar maple slowly declines and that of the long-lived conifers increases slowly. We believe this happens for two reasons. First, white cedar, white spruce, and possibly yellow birch just live much longer than sugar maple on these sites. Second, the real recruitment pool seems to be pole-sized trees, where sugar maple is still most common but not overwhelmingly so compared to heart-leaved birch, yellow birch, white cedar, and white spruce.

Second Transition: 155-195 years

Just 3%, of the historic MHn45 landscape was experiencing some kind of accelerated change in composition **(PLS-4)**. This is caused by the apparent demise of white cedar and local extirpation of paper or heart-leaved birch **(PLS-1)**. Cedar's fall is as mysterious as its rise. Northern white cedar is arguably the longest-lived species in Minnesota and is among the record-setters on the continent, with some individuals over 1,000 years old. It has virtually no serious pests or diseases in comparison to other trees in the state. Fire is the only serious threat to old cedars and there is just no evidence of fire in the MHn45 community. Nonetheless, there are enough old age-classes for MHn45 to convince us that there was certainly less cedar in very old forests than in mature ones. The same decline is seen in other communities and in all cases, cedar loses to white spruce. During this transition, the rise in spruce abundance mirrors the decline of cedar. White spruce has fair amounts of small-diameter regeneration in the mature growth-stage **(PLS-5)**, which must have been adequate to support its increase during the second transition and dominance of very old forests.

Very Old Growth-stage: >195 years

In the historic MHn45 landscape, 14% of the survey corners were estimated to have trees older 195 years **(PLS-1)**. This is a lot in comparison to other communities, but quite consistent with our estimates of catastrophic rotations (see Natural Disturbance Regime). We really don't know how old stands were and our fitted curves relating tree diameters to their ages are somewhat imaginative as few trees on the modern landscape achieve great diameter. Here though there were some giants in excess of 35" dbh for which we guessed ages in excess of 300 years. Most survey corners (66%) were of mixed composition, involving about equally sugar maple, yellow birch, white cedar, and white pine. It is highly unusual for old forests to become monotypic if previous growth-stage were mixed, but here nearly 44% of the old survey corners were attended only by very large white spruce or less often white pine. Our interpretation is that given enough time (>200 years) white spruce will eventually exert canopy dominance on MHn45 sites. Why then, given the astronomically long fire and wind rotations were not most MHn45 forests spruce-dominated? Unlike the hardwoods and cedar, white spruce is susceptible to widespread demise as outbreaks of spruce budworm in this region of the state occur rather frequently. Our vision of mature and older MHn45 forests with significant amounts of white spruce is that there was an emergent supercanopy of white spruce above rather continuous and fairly old hardwood forest. If spruce budworm outbreaks killed most of the supercanopy spruce, we would never detect the residual forest as having been regenerated using our PLS methods.

Tree Behavior

Tree "behavior" is an important element of silviculture and we are interested in it because we want to predict how a tree or stand of trees will respond given a management activity. For example, can we increase the relative abundance or yield of certain crop trees by doing this? Will individual trees grow, die, branch, make seeds, sprout, etc. if we do that?

Behavior is influenced by many things comprising a wide variety of scientific disciplines such as: genetics, physiology, population ecology, and community ecology. Tradition has been to focus on the first three of these as they are properties of a species. Nearly all silvicultural information is currently organized about species – but most authors admit that species properties vary substantially as they interact with other plants and the environment.

Our Native Plant Community (NPC) Classification allows us to contemplate a few elements of community-dependent behavior which can then be blended with the traditional silvics to create a fuller understanding of tree behavior. We view our NPC Classification as an empirical measure of the mind boggling interaction of trees with soil moisture conditions, nutrient availability, competing plants, diseases, pests, and wildlife that occupy the same place. Using this framework is an important paradigm shift because maintenance of these complex interactions is now a stated goal in forest management – in contrast to agricultural approaches where disrupting these interactions was the primary means of getting uniform and desired responses from crop trees.

To this end, we have performed analyses using Public Land Survey records, FIA subplots, and releves to answer three very basic questions as to how trees behave in their community context:

- Suitability – for each NPC Class, how often and in what abundance do we see certain tree species in stands where there has been no obvious effort to silviculturally alter abundance or remove competition?
- Succession – for each NPC Class, what was the natural reaction to fire and windthrow and how did the different species succeed one another?
- Regeneration strategies – for each common species within a NPC Class, what were/are the natural windows of opportunity for regeneration throughout the course of succession?

Sugar Maple

- ***excellent habitat suitability rating***
- ***early-successional***
- ***small-gap (large-gap) regeneration strategist***
- ***regeneration window at 40-50 years***

Identification Problems

The PLS surveyors did not consistently distinguish between sugar and red maple. We believe that red maple was not common historically, but it has increased in abundance since settlement and active land management on MHn45 sites. Thus, we rely on both PLS records and modern data to characterize the behavior of sugar maple; for red maple we rely mostly on modern data. MHn45 releve samples show that for plots with maple present: 14% have both species present; just 5% have red maple without sugar maple; 81% have sugar maple without red maple.

Suitability

MHn45 sites provide ***excellent habitat*** for sugar maple trees. The perfect ***suitability rating*** of 5.0 for sugar maple is influenced mostly by its very high presence (80%) as trees on these sites in modern forests **(R-1)**. When present sugar maple is the dominant tree, contributing 48% mean cover in mature stands. The ranking is perfect because no other tree or plant has a higher presence and cover on MHn45 sites as sampled by releves. Northern mesic hardwood communities in general offer excellent-to-good habitat for sugar maple (see Suitability Tables). Sugar maple is the highest ranked tree when in occurs in the better drained communities: MHn45, MHn45, and MHn35.

Young Growth-stage: 0-75 years

Historically, sugar maple was the dominant tree in young MHn45 regeneration gaps **(PLS-1, PLS-2)**. There were too few trees at disturbed survey corners to draw any conclusions about sugar maple's reaction to significant disturbance **(PLS-3)**. Rather, regeneration patches reflect the composition and structure of advance regeneration. Sugar maple dominates these openings because it dominates all strata of the understory in older forests **(R-2)**. Because, the relative abundance of sugar maple is at its greatest during this episode, we are forced to conclude that it is an ***early-successional*** species keeping in mind that we are describing a gap-filling process within a matrix of old forest. We detected little small-diameter regeneration until the 40-year age class **(PLS-5)**. At this time it was about equally likely for sugar maple to be the smallest tree at a corner as it was for it to be the largest tree. We interpret this as diameter variation of sugar maple advance regeneration as it is well represented in all understory strata of mature forests. Surprisingly, sugar maple occurred only in mixture with other species when bearing trees were small enough to guess that they were younger than 75 years. They were mostly mixed with fir, and we believe that this is a consequence of fir establishment beneath and within self-thinning sugar maple.

Transition: 75-95 years

As stands transitioned to mature conditions sugar maple abundance declines **(PLS-2)**. Compositional change in MHn45 forests late in the young growth-stage and throughout the transition was characterized by pulses in fir and cedar populations, ingress of white spruce, about a declining core population of mesic hardwoods. The decline of sugar maple was surprising to us as it is longer-lived in most habitats, but there is some research to suggest that on the Canadian shield (as is MHn45), it is likely to decline at transition ages due to accumulated injury, frost-cracking, and fungal rots (see Natural Stand Dynamics). We did not detect much small-diameter regeneration during the transition using our restrictive rules **(PLS-5)**. During this time though, maple was abundant and about equally likely to be the smallest tree at a survey corner as it was to be the largest. Once again, we attribute this to the fact that there was a broad range of maple diameters in the advance regeneration when the regeneration gaps formed. Also, it is possible that maple was showing highly variable growth after release, as it is common for seedling and sapling sugar maples to show incredible range in age in spite of similar stature. Suppressed seedlings and saplings can be incredibly old and such individuals may respond more slowly to release than more recently established seedlings. At this time it was far more likely for sugar maple to occur at survey corners where all bearing trees were sugar maple (13% of all corners). We attribute this to the loss of fir at the start of the transition as fir-maple mixtures were common in young regeneration gaps.

Mature Growth-stage: 95-155 years
The mature growth-stage is a period of slowed, but directional compositional change **(PLS-4)** during which sugar maple starts a steady decline that will continue throughout the life of a regeneration gap **(PLS-2)**. We believe this is accelerated decline of sugar maple due to accumulated disease and weakening of the boles by root and butt rots. During this period, we believe that sugar maple loses to cedar because cedar lives longer, and it loses to white spruce due to overtopping. Cases of monotypic maple survey corners are gone in this stage, and now it is about 3-times as likely for a maple to be the smallest tree at a corner than it was for it to be the largest. Although the canopy maples are in decline, it seems clear that up to this point, sugar maples have not relinquished their dominance of lower strata **(R-2)**.

Second Transition and Very Old Growth-stage: 155-195 years and older
By the time a regeneration gap is older than 155 years, maple was no longer a dominant canopy tree, but at 11-12% relative abundance it was still fairly common **(PLS-1)**. If for any reason that there were patches of the MHn45 landscape where yellow birch, cedar, and white spruce were in short supply, there is no reason to suspect that sugar maple couldn't replace itself and maintain significant presence in old forests by establishment and recruitment. In most habitats, sugar maple is unequalled at replacing itself and its perfect indices of regeneration in MHn45 forests **(R-2)** would seem to be a clear indication of its ability to do so here by using small-gaps. Unfortunately, there were not enough small-diameter maple bearing trees at corners this old to confirm if smaller maple bearing trees among larger ones was the usual case.

Regeneration Strategies
Sugar maple's primary regenerative strategy on MHn45 sites is to develop a pervasive bank of seedlings, saplings, and poles capable of recruiting in gaps **(R-2)**. Because of the paucity of survey corners estimated to be younger than about 55 years (~9%) and reference to just a few trees following disturbance **(PLS-3)**, the PLS notes add little to our understanding of regeneration strategies. The fact that there were survey corners with all trees under about 6" dbh, suggests that there were occasions where corners fell within gaps where the surveyors were forced to use smaller-diameter trees for referencing corners. However, given the low mean distance to bearing trees (~15 feet), gaps would not have needed to be much larger than a couple tree lengths across. Because we believe *Armillaria* or similar pocket diseases to be the primary agents to cause gaps, we envision gaps starting small and expanding to fit more often within our concept of large-gaps involving groups of trees up to an acre in size. The leading evidence that sugar maple used large gaps is its high presence as poles in tree stands (situation 23), which we normally associate with ***large-gap*** species in other communities **(FIA-1)**. However, sugar maple's good abundance as seedlings among larger trees (situations 12 and 23), is more in line with ***small-gap*** strategists. In the releve data, sugar maple's perfect set of tree and regeneration index values is the hallmark of a small-gap species **(R-2)**.

Historic Change in Abundance
Today, sugar maple is still a dominant tree on MHn45 sites, but its distribution among growth-stages has changed rather dramatically **(PLS/FIA-1)**. Today, at 17% relative abundance, it is far less common in young forests than it was historically where it represented 33% of the bearing trees. It is important to remember that today's young MHn45 stands cover tens of acres and are nothing like the historic regeneration gaps that were something under an acre in size at inception. In this open environment, paper birch and aspen often out-compete sugar maple for growing space. In mature and old MHn45 forests, sugar maple is about three-times as abundant now (34-38%) as it was historically (11-12%). This increase in maple is most likely linked to over-exploitation of cedar, white spruce, and yellow birch across the landscape. Historically, when

these species were abundant, they would successfully out-compete or just outlive sugar maple in older forests. The pattern of change in sugar maple abundance today matches the natural pattern other hardwood communities – where discussion of succession starts with the advent of some catastrophe. It is clear to us that clear-cut logging is the modern catastrophe on the MHn45 landscape.

Yellow Birch

- ***excellent habitat suitability rating***
- ***early-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 40-70 years***

Identification Problems

The PLS surveyors usually distinguished yellow from paper birch or heart-leaved birch, but not always. Thus, interpretations of PLS data for the more common yellow birch on MHn45 sites should always be done knowing that some of these trees were likely paper or heart-leaved birch. MHn45releve samples show that for plots with birch present: 1% had all three species; 2% were heart-leaved birch only; 34% were paper birch only; 45% were yellow birch only; 1% had joint presence of heart-leaved birch with yellow birch; 17% had joint presence of paper and yellow birch. For this analysis, tree records were biased towards yellow birch because we assigned generic references to "birch" to yellow birch because of its higher presence than the others.

Suitability

MHn45 sites provide ***excellent habitat*** for yellow birch trees. The ***suitability rating*** of 4.8 for yellow birch is influenced mostly by its presence (46%) as trees on these sites in modern forests **(R-1)**. When present, yellow birch can be an important co-dominant tree, contributing 17% mean cover in mature stands. The ranking is second behind sugar maple on MHn45 sites as sampled by releves. Northern mesic hardwood communities offer excellent habitat (see Suitability Tables) for yellow birch *only* when the soils are silty. Otherwise yellow birch is just an incidental species. Both MHn45 and MHn47 occur in regions of Minnesota where soils are often silt-capped and the sites with abundant yellow birch.

Young Growth-stage: 0-75 years

Historically, yellow birch was abundant in young MHn45 regeneration patches **(PLS-1, PLS-2)**. There were no yellow birch trees at disturbed survey corners, making it impossible to draw any conclusions about yellow birch's reaction to significant disturbance **(PLS-3)**. Rather, regeneration patches reflect the composition and structure of advance regeneration. Yellow birch was probably common in these openings because it has high survivorship as saplings 2-10m tall in older forests **(R-2)**. Also, increased sunlight on the forest floor in large gaps could have contributed to establishing some yellow birch seedlings because it seems to have some establishment problems under a canopy (R-index, 2.5) related to either light or seedbed. Because, the relative abundance of yellow birch is at its greatest during this episode, we are forced to conclude that it is an ***early-successional*** species keeping in mind that we are describing a gap-filling process within a matrix of old forest. We detected good regeneration during the young growth-stage **(PLS-5)**, and the shape of the regeneration curve suggests that its greatest success was between about 40-70 years near the conclusion of the growth-stage. At this time it was about equally likely for yellow birch to be the smallest tree at a corner as it was for it to be the largest tree. We interpret this as diameter variation of yellow birch advance regeneration as it is well represented in seedling to sapling sizes in mature forests.

Transition: 75-95 years

As stands transitioned to mature conditions yellow birch starts to decline in relative abundance **(PLS-1, PLS-2)**. We estimate that this decrease occurred throughout the transition and stabilized at about 10-15% at the conclusion of the period. Small-diameter yellow birch regeneration was essentially absent in the transition **(PLS-5)**. However, it was especially common for yellow birch to be the smaller tree at a corner, but not meet our half-diameter rule for calling it new regeneration. When it was the smaller tree, it seemed to be able to come in among sugar maple, paper birch, or itself. Our interpretation is that the decline of yellow birch was caused by the loss of individuals released when the gap first formed. Its stabilization seems to be the result of its modest ability to regenerate and recruit beneath a canopy. The dynamics of yellow birch follows that of sugar maple, but unlike sugar maple, we know of no research that would indicate natural decline at ages typical of the transition.

Mature Growth-stage, Second Transition, and Very Old Growth-stage: 95-155 years, 155-195 years, and older

Following the first transition, the relative abundance of yellow birch is stable and seemingly oblivious to the pulsing of cedar and ingress of white spruce. It had 11-15% relative abundance in all of these periods **(PLS-1)**. Thus, it would seem that yellow birch had the ability to maintain a local population of trees by establishment and recruitment beneath a canopy. Small-diameter yellow birch regeneration was essentially absent during this growth-stage according to our strict rules for that analysis **(PLS-5)**. At this time, it was about equally likely for yellow birch to be the largest tree at a mixed corner, the smallest tree at a mixed corner, or present at corners where all trees were yellow birch. This suggests to us that there was at least some establishment and recruitment, and that it was especially good beneath parent yellow birch as some monotypic patches formed. Although it has only fair establishment ability in forests of similar age today, its survival in taller strata is good **(R-2)**. From the modern data, it seems to us that its regenerative abilities beneath a canopy are good enough to maintain 11-15% relative abundance in the canopy of older MHn45 forests.

Regeneration Strategy

The primary regenerative strategy of yellow birch on MHn45 sites is to fill ***large-gaps***. Its high initial abundance in young regeneration gaps **(PLS-1)**, tells us that it had good presence as advance regeneration in older forests. That it competes well with sugar maple in these gaps suggests to us that they were probably large-gaps as we would expect sugar maple to prevail in small-gaps. The PLS data contribute nothing to our understanding of its reaction to disturbance as it was absent from any such survey corners **(PLS-3)**. Yellow birch seems inclined to maintain high presence and abundance in the subcanopy of modern forests, which it typical of species that we associate with the large-gap strategy (high SA-index, **R-2**). Normally, this fact is corroborated by high presence as poles in tree stands (situation 23) in the FIA data, but amazingly the FIA plots picked up just trace amounts of yellow birch within the primary range of the MHn45 community. In stark contrast is our releve sampling of undisturbed MHn45 forests where yellow birch is rather common. In the releves, yellow birch has just fair ability to establish seedlings beneath a canopy **(R-2)**. Its regenerant index is typical of trees requiring rather open conditions and soil disturbance for recruitment. However, we believe that the establishment bottleneck is due mostly to the general lack of mineral soil seedbeds in mature, undisturbed MHn45 stands. Its good seedling and sapling indices are quite in line with trees that tend to recruit in large-gaps.

Historic Change in Abundance

Today yellow birch is in peril on MHn45 sites. Only trace amounts occur in forests of any age sampled by FIA plots **(PLS/FIA-1)**. To us, this is an amazing and unexpected result because within the very limited range of the MHn45 community, the presence of any yellow birch should have resulted in immediate assignment of that FIA plot to the MHn45 community. The releve data paint a quite different picture. Yellow birch has 46% presence as a tree in releves **(R-1)**, and nearly every sample with trees has at least some yellow birch present as advance regeneration **(R-2)**. Other than modest difficulties establishing seedlings, the releves indicate that yellow birch is doing just fine in undisturbed forest. If one believes the FIA inventory, the average managed forest is devoid of yellow birch. This just doesn’t fit our field experience as we commonly see yellow birch in second-growth stands, but the distribution of yellow birch is patchy enough to see why random plots might usually miss its presence. We believe that at the stand scale there is usually some yellow birch on MHn45 sites, but without silvicultural attention it just might face extirpation.

Paper Birch

- ***excellent habitat suitability rating***
- ***early-successional***
- ***large-gap (open) regeneration strategist***
- ***regeneration window at 70-100 years***

Identification Problems

The PLS surveyors usually distinguished paper birch and heart-leaved birch from yellow birch, but not always. This interpretation of PLS data for paper birch is complicated by the necessity of assigning generic "birch" tree records to the more common yellow birch. Often though the surveyors called paper birch by its full name or called it "white birch" or "canoe birch." Those explicit records are what constitute the following analysis. MHn45releve samples show that for plots with birch present: 1% had all three species; 2% were heart-leaved birch only; 34% were paper birch only; 45% were paper birch only; 1% had joint presence of heart-leaved birch with paper birch; 17% had joint presence of paper and paper birch. Most foresters find paper birch and heart-leaved birch indistinguishable and consider them silvicultural equivalents. Our experience would suggest that heart-leaved birch is intermediate in ecological behavior between paper and yellow birch. There is so little heart-leaved birch that there are insufficient data for any kind of consideration here. We believe that the following account of paper birch is close enough to not worry about major silvicultural error if applied to heart-leaved birch.

Suitability

MHn45 sites provide ***excellent habitat*** for paper birch trees. The ***suitability rating*** of 4.7 for paper birch is influenced mostly by its presence (37%) as trees on these sites in modern forests **(R-1)**. When present, paper birch can be an important co-dominant tree, contributing 16% mean cover in mature stands. The ranking is third behind sugar maple and yellow birch on MHn45 sites as sampled by releves. Northern mesic hardwood communities in general offer excellent habitat (see Suitability Tables) for paper birch.

Young Growth-stage: 0-75 years

Historically, paper birch was fairly common in young MHn45 regeneration patches **(PLS-1, PLS-2)**. There were but two paper birch trees at disturbed survey corners, making it impossible to draw any conclusions about paper birch's direct reaction to significant disturbance **(PLS-3)**. We believe that regeneration patches initially reflect the composition and structure of advance regeneration, but this is a problem for paper birch as it has considerably less ability to bank advance regeneration than sugar maple and yellow birch **(R-2)**. Of the trees with peak presence in young regeneration gaps, paper birch is the only species with poor indices of regeneration. Its peak presence in the initial cohort implies that newly created gaps offered at least some microhabitats favorable for birch establishment that are largely absent in older forests. Management experience would suggest that they need some soil mixing, as site preparation below a canopy is known to stimulate a catch of paper birch seedlings before canopy removal. The newly formed tip-up mounds are the most obvious character of a new gap that might enhance paper birch's chance at regeneration on mixed soils.

In many communities of northeastern Minnesota, paper birch is the only hardwood seemingly stimulated by pulses of balsam fir in the understory. The obvious effect of fir pulses is to kill advance regeneration of competitive hardwoods like sugar maple that prefer to establish seedlings on base-rich litter. For MHn45 the population trends of birch and fir seem tied **(PLS-1)**, and it is possible that the abundance of paper birch in young regeneration gaps is tied to the fir pulse. It is unfortunate that our dataset of small-diameter regeneration is so sparse in the young growth-stage, but the few cases of small-diameter paper birch were in the presence of larger fir. Most small-diameter birch regeneration appeared later (70-100 years, **PLS-5**) in conjunction with the ingress of cedar and white spruce rather than fir.

By whatever mechanism, it is a fact that young regeneration patches were enriched in paper birch. For that reason we consider paper birch to be an ***early-successional*** species on MHn45 sites. This seems to clearly be the case today as the disturbances associated with timber harvesting have led to significant increases in the abundance of paper birch in young MHn45 stands **(PLS/FIA-1)**.

First Transition: 75-95 years
As stands transitioned to mature conditions paper birch decreased rather dramatically in relative abundance **(PLS-1)**. We estimate that this decrease started at about age 65 and would continue until there was very little paper birch in stands older than 130 years. Small-diameter paper birch regeneration was present throughout the transition **(PLS-5)**, but this does not seem to translate into many trees as birch's relative abundance continued to drop. At this time, it was about twice as likely for paper birch to be the largest tree at a survey corner as it was for it to be the smallest tree. These larger trees were probably those in the initial gap cohort. Our interpretation is that the decline of paper birch was caused by the loss of individuals released when the gap first formed. Our guess is that paper birch is naturally senescent at about this time, but there must be considerable variability in longevity as the decline is slow and extends to about the 130-year age-class. It is possible that the longer-lived birch were heart-leaved birch.

Mature Growth-stage: 95-155 years
The mature growth-stage is a period of slowed, but directional compositional change **(PLS-4)** during which the abundance of paper birch steadily declines to just trace amounts. We believe paper birch just doesn't live much longer than 95-130 years in this environment. In spite of some recruitment during the first transition **(PLS-5)**, few of those trees were able to recruit and subsidize the local population of declining birch trees. At this time it was about four-times as likely for a paper birch to be the largest tree at a survey corner as it was for it to be the smallest tree. A preponderance of large-diameter trees with few smaller ones is the sign that a species is in decline and unlikely to recover through establishment and recruitment. This idea is corroborated by the releve data in that paper birch is arguably the poorest species at establishing and recruiting seedlings beneath the canopy of a mature forest **(R-2)**.

Second Transition, and Very Old Growth-stage: 155-195 years, and older
In forests older than 155 years, paper birch was essentially absent and had no influence on stand dynamics **(PLS-1)**. This seems odd to us in that most communities of northeastern Minnesota able to reach an old-growth condition enriched in white spruce (e.g. FDn43) tend to carry substantial amounts of paper birch into the older age-classes. That is, we usually see birch doing well in old forests as long as white spruce is a canopy dominant. Conversely, we tend to see paper birch in just trace amounts in very old forests where sugar maple is the canopy dominant (e.g. MHn47). Our vision of second transition and very old MHn45 forests is that the spruce canopy was emergent from a rather continuous canopy of old-growth hardwood forest. Apparently, paper birch did poorly in MHn45 forests this old because it was responding to the more proximal hardwood canopy and the groundlayer conditions that it created. We believe that paper birch persisted in patches where spruce was totally dominant, keeping seed trees within range of newly formed canopy gaps where it was immediately successful.

Regeneration Strategies
The primary regenerative strategy of paper birch on MHn45 sites is to fill ***large-gaps***. Its high initial abundance in young regeneration gaps **(PLS-1)**, is the primary reason to assume this strategy. That it competes well with sugar maple in these gaps suggests to us that they must have been fairly large as we would expect sugar maple to prevail in small-gaps. The PLS data contribute nothing to our understanding of its direct reaction to disturbance as it was nearly absent from any such survey corners, and disturbances able to create open conditions were rare **(PLS-3)**. Its delayed window of recruitment is a puzzle **(PLS-5)**. Initial cohort trees almost always have high recruitment in the initial age-classes, but in this case there was very little in the way of small-diameter birch regeneration. We attribute this to chance as the total number of regenerating trees is very low in the young age-classes. As usual, birch regeneration accompanies ingress of

conifers during the first transition, but these trees must have rarely reached the canopy as birch abundance declines throughout that period. The high abundance of paper birch poles in tree stands (situation 23) in the FIA data **(FIA-1)** is consistent with trees tending to do well in large canopy gaps. Our most reliable source of data are the releves. In this case, paper birch has such poor regenerant and seedling indices (1.3) that we would normally consider such species to be obligate ***open-strategists*** **(R-2)**. The reaction of paper birch to the usual open conditions after timber harvest supports the idea that creating very large gaps or openings will promote more paper birch on MHn45 sites **(PLS/FIA-1)**. Our management experience tells us that the establishment bottleneck evident in the releve data, is related most to the lack of mineral soil seedbeds in the average mature MHn45 forest.

Historic Change in Abundance

Today paper birch is far more abundant on MHn45 sites as it ever was. Its modern abundance is nearly double that of historic times in young and mature MHn45 forests, and its high presence in the few examples (<1% of the landscape) of very old forests today was unheard of historically **(PLS/FIA-1)**. We attribute this increase to the fact that modern management has created open conditions on MHn45 sites that were unprecedented. Only rarely, did natural disturbances offer paper birch a chance at mineral soil seedbeds and open conditions.

Northern White Cedar

- ***excellent habitat suitability ranking***
- ***mid-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 80-90 years***

Suitability

MHn45 sites provide ***excellent habitat*** for white cedar trees. The ***suitability rating*** of 4.6 for white cedar is influenced mostly by its high presence (35%) as trees on these sites in modern forests **(R-1)**. White cedar can be an important co-dominant when present, averaging 15% cover. The ranking is fourth, following sugar maple, yellow birch, and paper birch on MHn45 sites as sampled by releves. Among the northern mesic-hardwood forest communities (MHn), only MHn47 and MHn45 offer excellent habitat for white cedar. This is so because these communities commonly offer a silty soil surface that favors establishment of white cedar (see Suitability Tables).

Young Growth-stage: 0-75 years

Historically, white cedar was present in low abundance within young MHn45 regeneration patches **(PLS-1, PLS-2)**. Young cedars were absent at survey corners that had experienced notable disturbance **(PLS-3)**. Small-diameter, white cedar regeneration coming in among larger trees was not detected in the post-disturbance window **(PLS-5)**. In modern forests, cedar has poor ability to establish seedlings, but is fairly common as saplings **(R-2)**. Most likely, the initial cohort-cedars in regeneration gaps were recruited from saplings or poles present in the understory before the canopy trees were removed.

First Transition: 75-95 years

Typical of almost any upland community where cedar is an important component of old forests is a pulse of regeneration in transitions. At about age 80, it rises from about 7% relative abundance to about 26% in the course of 20 years or so **(PLS-2)**. It persists at high abundance until about age 130 where it starts a gradual, persistent decline in all older age-classes, averaging just 8% presence in very old forests **(PLS-1)**. During this period, it was about equally probable for cedars to be: (1) the largest tree at mixed corners, (2) the smallest trees at mixed corners, or (3) present at corners where all bearing trees were cedars. This is typical of trees having extended success of recruitment, which is true of white cedar throughout the transition **(PLS-5)**. The tendency of cedar to form pure groves within MHn45 stands apparently started in the first transition. Our interpretation is that stand dynamics involving the decline of hardwoods and a preceding pulse of fir abundance somehow prepares sites for ingress of white cedar – though we don't understand the mechanism.

Similar cedar pulses are seen in fire-dependent forests, wet forests, rich forested peatlands, and other mesic hardwood communities within the range of cedar. We are at a loss to explain two things: (1) how any inherent stand maturation process at age 80 can induce a sharp pulse of regeneration, and (2) how such a late-successional characteristic could be shared among so many functionally different ecological systems. Alternatively, because we are relying upon PLS notes to create successional models, it could just be that somewhere around 1790-1820 AD, a regional event favored the expansion of cedar populations throughout its range and in all habitats. If this is true, it hasn't been repeated since. Most reconstructions of individual stand histories (from tree rings) confirm our interpretation that white cedar is a mid- or late-successional tree but still we wonder why, given the rather universal lack of regenerative success under a canopy today **(R-2)**.

Mature Growth-stage: 95-155 years

Just into the mature growth-stage white cedar reaches its peak abundance as a bearing tree at about 33% in the 100-year age class **(PLS-2)**. Because cedar shows a peak of abundance during the mature growth-stage, we consider it to be a ***mid-successional*** species – able to replace initial-cohort trees but dropping in relative abundance as stands aged **(PLS-1)**. We believe that the cedars in the mature growth-stage were those recruited during the preceding first transition **(PLS-5)**. At this time its was most common for cedar bearing trees to be the largest tree at a survey corner. Sometimes the smaller trees were other species, but often they were other cedars, which adds to the general concept that cedar tends to form monotypic groves within the MHn45 community.

Second Transition: 155-195 years
The apparent demise of white cedar in MHn45 forests older than about 150 years is the primary reason for recognizing a second transition **(PLS-1)**. That cedars recruited at about age 80 should die some 70-120 years later is a bit of a mystery to us. Northern white cedar is arguably the longest-lived species in Minnesota and is among the record-setters on the continent with some individuals over 1,000 years old. It has virtually no serious pests or diseases in comparison to other trees in the state. Fire is the only serious threat to old cedars, and there is just no evidence of fire in the MHn45 community. Nonetheless, there are enough old age-classes for MHn45 to convince us that there was certainly less cedar in very old forests than in mature ones. The same decline is seen in other upland communities and in all cases, cedar loses to white spruce. That old cedars are about to die without replacement in modern forests is no mystery, as there is near total failure of cedars to establish vigorous seedlings beneath a canopy **(R-2)**. Blame is commonly cast upon deer browsing, but our experience is that cedar seeds are germinating on any safe-site available (nurse logs, exposed mineral soil, etc.) and that survival beyond a few years is minimal with mortality occurring well before the tiny cedars are deer food. We favor the lack of light available in old MHn45 forests as the primary culprit as these forests exhibit many canopy strata – supercanopy spruce, hardwood canopy, sugar maple mid-canopy, and often fair amounts of mountain maple and beaked hazelnut. The only difference between this stratification where cedar regeneration seemingly fails and that of the first transition where it succeeds, is the presence of a spruce supercanopy. We don't know why the presence of spruce should be so influential, but this pattern is repeated in other communities.

Very Old Growth-stage: >195 years
By the time MHn45 stands achieved antiquity, white cedar was an occasional tree at 8% relative abundance **(PLS-1)**. We attribute this to cedar's longevity as there is little evidence of cedar establishment and recruitment beyond the first transition **(PLS-5)**. These trees must have been the lingering survivors of the large population characteristic of the mature growth-stage. Our best guess is that within the MHn45 landscape, there were microhabitats that were unaffected by whatever killed so many cedar during the second transition. If forced to guess, we would predict that these are sites with deeper soil, sub-irrigation, and little overtopping white spruce.

Regeneration Strategy
We believe that white cedar's primary regenerative strategy on MHn45 sites is to fill ***large-gaps***. The primary historic evidence for this is the fact that it responds to declines in the hardwood populations, where we envision groups of trees going down in *Armillaria* pockets. Otherwise, the sparse historic data are not especially helpful. Cedar is an infrequent tree in the FIA sampling as well. Arguably it has peak regenerative presence as poles in tree stands (situation 23) which we associate with other large-gap strategists **(FIA-1)**. Our most reliable dataset are the releves, in which white cedar has poor regenerant and seedling indices (1.8), but a fairly good sapling index (3.5, **R-2**). The poor indices are usually indicative of a tree needing full sunlight; the good sapling index is usually associated with large-gap species. For now we are blaming the poor establishment on lack of suitable seedbeds, and we favor the idea that large-gaps are the favored canopy condition for recruitment.

Historic Change in Abundance
Today, white cedar is in peril on MHn45 sites. It is essentially absent from managed stands younger than about 75 years old, where it once was occasional (6% abundance, **PLS/FIA-1**). In mature MHn45 forests the modern abundance of white cedar (5%) is a fifth of what it was historically (25%). Given that most MHn45 forests were mature (38%), this is a significant loss of

cedar-dominated acres. Very old forests are virtually gone from the MHn45 landscape, but in the rare cases where they occur, white cedar is an abundant tree. In all cases, the seeming lack of successful establishment and recruitment to heights over 2m is cause for alarm **(R-2)**. Without research, silvicultural attention, and experimentation, white cedar is in trouble in the MHn45 forests along the North Shore.

Basswood

- ***good habitat suitability rating***
- ***early successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 30-50 years***

Suitability
MHn45 sites provide ***good habitat*** for basswood trees. The ***suitability rating*** of 3.2 for basswood is the result of rather balanced presence (11%) and mean cover-when-present (15%, **R-1**). The ranking is fifth, behind sugar maple, yellow birch, paper birch, and white cedar on MHn45 sites as sampled by releves. Northern mesic hardwood communities in general offer excellent-to-good habitat for basswood (see Suitability Tables). Among these, MHn45 is the poorest community choice as a place to raise basswood as a primary crop tree.

Young Growth-stage: 0-75 years
Historically, at about 2% relative abundance basswood was a minor tree in young MHn45 regeneration patches **(PLS/FIA-1, PLS-2)**. There were not enough basswood bearing trees at disturbed corners to draw any conclusions about its reaction to disturbance **(PLS-3)**. Although modest, basswood has peak abundance in some age-classes of the young growth-stage, and for this reason we consider basswood an ***early successional*** species on MHn45 sites. However, it is more accurate to describe it as consistently present at about 2% relative abundance until the 150-year age class, after which we did not detect any basswood bearing trees. Basswood in young regeneration patches could be either stump sprouts or advance regeneration as it has good ability to persist in the understory, especially as saplings 2-10m tall **(R-2)**. Small-diameter basswood regeneration coming in among larger trees was only in the older age-classes of the young growth stage **(PLS-5)**. Our interpretation is that in regeneration gaps involving mature basswoods, they were quick to re-sprout. We believe also that advance regeneration had the potential to reach the canopy given enough time and some luck competing with sugar maple.

Transition: 55-95 years
As regeneration gaps stands transitioned to mature conditions, basswood abundance was stable and just slightly less than it was in the young growth-stage **(PLS/FIA-1)**. Small-diameter basswood regeneration was not detected in the transition **(PLS-5)**. There were not enough basswood bearing trees to guess as to whether there was a preference to recruit beneath other species or itself. Our interpretation is that basswood established at the onset of gap formation were living through the transition.

Mature Growth-stage: 95-155 years
Basswood bearing tree were consistently present throughout the mature growth-stage at about 1-2% relative abundance **(PLS-1)**. Its presence was most likely the result of some recruitment at the close of the young growth-stage **(PLS-5)** followed by good survivorship. Basswood has the ability to establish and recruit seedlings beneath a canopy, and it might have sustained its presence in mature MHn45 forest by replacing itself **(R-2)**. However, like so many trees in MHn45 forests, it has problems with establishment that we attribute to seedbeds characterized by incredibly thick duff layers. It would seem that basswood loses ground to sugar maple and perhaps white spruce because there aren't many safe-sites for establishment in mature regeneration gaps.

Second Transition and Very Old Growth-stage: 155-195 years and older
Except for a single tree in the 200-year age-class, we did not pick up any basswood bearing trees at corners estimated to be older and 155 years. It is possible that the ingress of white cedar and white spruce had an adverse effect on basswood trees or its ability to establish seedlings. The total number of trees contributing to these older growth-stages is rather small, and it is also possible that by chance a minor tree like basswood was overlooked.

Regeneration Strategy

On MHn45 sites basswood exhibits regenerative flexibility, which allows it to be a minor, but consistently present tree for the first 150 years in the life of a regeneration gap. Basswood sprouts effectively following disturbances that kill the main stem, and it is able to carry its density as a tree into young growth stages. Its slightly higher abundance in the young growth stage **(PLS-1)** could be due to the fact that that it was a much better at sprouting than sugar maple. Basswood also maintains a bank of advance regeneration capable of recruiting in gaps of any size. However in the seedling layer, it is overwhelmed by sugar maple. Chance would predict modest to poor success relative to sugar maple if basswood needed to recruit from the seedling layer. Most likely, successful basswood trees were recruited from the sapling or pole strata, where it is more equal in presence to sugar maple and the other hardwoods **(R-2)**. In the PLS data we suspect that basswood is a ***large-gap strategist*** because: (1) it has peak abundance in the initial age-classes of what we believe were large-regeneration gaps, and (2) is was present only at undisturbed, mature survey corners where we assume trees must use gaps to persist. Because basswood was a minor tree in historic MHn45 forests, the PLS interpretation is less reliable than modern data from forests where it now had higher abundance **(PLS/FIA-1)**. At FIA subplots, basswood has peak regenerative presence as poles in tree stands (situation 23), which is typical of large-gap species. In the releves, basswood's regeneration indices (2.8-3.5) are in line with species that tend to recruit in large-gaps **(R-2)**. Its fair regenerant index reflects a general lack of appropriate seedbeds in mature MHn45 forests.

Historic Change in Abundance

Today, basswood is more abundant on MHn45 sites than it was historically **(PLS/FIA-1)**. Its populations have essentially doubled in historic time. Basswood had consistent abundance at about 2% in age-classes younger than 150 years, and now it has about 4-6% abundance at FIA subplots. This is not much change given the rather dramatic difference in disturbance of MHn45 sites between logging and the natural gap process. We believe that basswood is destined to be a minor tree on these sites regardless of conservation or management objectives.

White Spruce

- ***good habitat suitability rating***
- ***late-successional***
- ***small-gap (large-gap) regeneration strategist***
- ***regeneration window at >120 years***

Identification Problems
The PLS surveyors did not distinguish between white and black spruce. MHn45 releve samples show that for plots with spruce present: 2% are black spruce without white spruce; 98% are white spruce without black spruce. Because white spruce are so overwhelmingly abundant, it is safe to assume that the spruce bearing trees at MHn45 corners were white spruce.

Suitability Ratings
MHn45 sites provide ***good habitat*** for white spruce trees. The ***suitability rating*** of 4.1 for white spruce is influenced mostly by its high presence (40%) as trees on these sites in modern forests **(R-1)**. When present, white spruce is a minor co-dominant tree, contributing just 4% mean cover in mature stands. This ranking is sixth among trees common on MHn45 sites. Of the northern mesic hardwood communities (MHn) only the MHn44 and MHn45 communities offer opportunities to manage for white spruce.

Young Growth-stage: 0-75 years
Historically, at 6% relative abundance white spruce was an occasional tree in young MHn45 stands **(PLS-1)**. Of all MHn45 trees, white spruce was the most likely tree to immediately occupy a disturbed forest **(PLS-3)**. We can think of no reason why spruce would be favored over other species, and it is possible that this was just a chance result due to the very low abundance of any disturbed survey corners. Small-diameter white spruce regeneration was detectable in the young growth-stage, but at quite low abundance **(PLS-5)**. We believe that spruce was not especially favored over hardwoods in young regeneration gaps, but there were enough cases where the parent forest was spruce-dominated and likely to result in spruce replacing itself to explain 6% abundance in the young growth-stage.

Transition: 75-95 years
As stands transitioned to mature conditions white spruce started to increase in abundance **(PLS-1)**. This increase is very modest, but it is the beginning of a trend that will continue through old-growth where white spruce is the dominant tree **(PLS-2)**. Small-diameter white spruce regeneration coming in among larger trees was detected but at such low abundance that there is no hope of drawing conclusions **(PLS-5)**. A common anecdote among Minnesota foresters is that balsam fir serves as a nurse crop for white spruce. This comes mostly from observations in modern forests where it is far more common (2-3 times in our releves) to have fir in stands without spruce than to have white spruce without any fir. Remarkably, this seems even more true in the historic data where ingress of spruce always follows an initial pulse of fir abundance as it does in MHn45 forests. Here, there just wasn't enough data to see if white spruce preferred to come in under larger firs. In other communities, it was clear that fir was not a cover crop for spruce as spruce seemed to prefer to replace hardwoods. Our interpretation is that it seems plausible that ingress of white spruce in the transition stage was the consequence of balsam fir altering the habitat in some way that promotes establishment or recruitment of white spruce.

Mature Growth-stage: 95-155 years
In the mature growth-stage white spruce abundance increases dramatically **(PLS-1, PLS-2)**. At this time it has fair presence of small-diameter regeneration **(PLS-5)**. In comparison to other communities where white spruce is a dominant tree in old forests, its regenerative efforts are minimal on MHn45 sites. White spruce has good regeneration indices **(R-2)**, but they are lower than those of sugar maple and balsam fir which were common in younger age-classes. Why white spruce should overtake maple and fir seems odd in that these trees seem better equipped to replace themselves through establishment and recruitment. Off of the Canadian shield, it is

unprecedented for spruce to overtake sugar maple as the climax species (e.g. MHn47, MHn35). Only where sugar maple is absent, does spruce serve as the climax tree cross central Minnesota (e.g. MHc26, MHn44). We can only guess that spruce's success on MHn45 sites is a consequence of incredibly high survivorship and longevity, and that these traits are expressed more so along Lake Superior than they are in central Minnesota. The converse notion would be to suspect that fir and sugar maple are shorter-lived than usual along the lake. Fir is shorter-lived than white spruce everywhere. Also, there is evidence that sugar maple if far less likely to live a full life on the Canadian shield as it seems to pay for every wound in its life in the form of frost cracks and decay. Regardless, the cumulative regeneration and recruitment of white spruce from gap inception to mature forest **(PLS-5)**, positions spruce to dominate MHn45 forests.

A different way to look at this is to suspect that on MHn45 sites sugar maple is doing what it always does – dominating the advance regeneration and replacing itself. For spruce to increase relative to sugar maple there must be an increase in available growing space. It seems clear that such an increase was not in stem density as the distances to bearing trees was consistently between 17-20 feet in older forests. However, there is space vertically as the mature growth-stage is just about the time we would expect white spruce to emerge as supercanopy trees. Perhaps the correct vision of mature or very old MHn45 forests is that of supercanopy spruce above a hardwood forest that is little different between the North Shore and central Minnesota.

Second Transition and Very-old Growth-stage: 155-195 years and older
In these older MHn45 forests, large-diameter white spruce accumulated steadily until they represented at least half of the trees **(PLS-1)**. This tendency is the main reason that we consider white spruce a ***late-successional*** tree on these sites. We detected no small-diameter regeneration of white spruce during these episodes, but that is typical of all trees and of PLS data in general **(PLS-5)**. There are not many cases where white spruce was the smaller tree at a survey corner, but all cases were of white spruce beneath other white spruce. The trend for spruce to form monotypic patches extends from the beginning of the mature growth-stage to very old forest. Most likely this is due to chance as white spruce became the most abundant tree. Our impression is that white spruce can live for a very long time on these sites and that they continued to dominate the supercanopy until some catastrophe. Most likely, spruce budworm was the historic agent to eliminate supercanopy spruce as it does today.

Regeneration Strategies
White spruce's primary regenerative strategy on MHn45 sites is to steadily accumulate advance regeneration in the long course of gap succession and to recruit when gaps of any size form above them. In the PLS data its ***small-gap*** strategy is most evident in its having successful recruitment in the I-1 ingress window **(PLS-5)**. In the FIA data, white spruce has fairly high presence in any subordinate situation (12, 13, and 23 situations) which could be assigned to species with either small- or ***large-gap*** tendencies **(FIA-1)**. Spruce's high situation 22 presence is the consequence of modern plantations. White spruce shows incredible consistency in establishment and recruitment beneath a canopy in our releves **(R-2)**. Its good indices are typical of trees that recruit well in large-gaps. Like most trees of the MHn45 community, establishment below a canopy is the primary hurdle. Soil mixing might provide more safe sites for germination and establishment than is normally offered in older MHn45 stands.

Historic Change in Abundance
Today white spruce is in peril on MHn45 sites. The most obvious problem is the lack of second transition and very old MHn45 forests on the landscape where spruce was the dominant tree **(PLS/FIA-1)**. In young forests, spruce accounts for just 3% of the trees where once it accounted for 6%. This is not a serious departure and we attribute the modest presence of spruce to plantation efforts. The mature growth stage, which was the most common natural condition, is where it is clear the spruce has taken a fall. Historically spruce had 37% relative abundance in mature MHn45 forests, whereas today it is nearly absent. Modern logging rotations just don't allow for spruce to accumulate on the MHn45 landscape as it once did. Most attempts at raising spruce are in plantation, and this model of having young spruce-dominated stands has no historic

precedent. Another complicating factor is the chronic presence of spruce budworm in northeastern Minnesota. Outbreaks of this pest in modern times seem too frequent to allow for 14% very old spruce-dominated forest on MHn45 sites as was once the case. Most MHn45 sites sit within a landscape matrix of FDn43 forest, in which would periodically cleanse fir from the young regenerating forest. Today fir is almost universally present across the landscape and it has led to resident populations of spruce budworm that most likely will complicate silvicultural attempts at restoration. Silvicultural attempts to increase the abundance of white spruce in the understory, conservation of seed trees, and the willingness to allow MHn45 forests to achieve old age would all benefit white spruce.

Balsam Fir

- ***good habitat suitability rating***
- ***early-successional***
- ***large-gap (small-gap) regeneration strategist***
- ***regeneration window at 40-50 years***

Suitability
MHn45 sites provide ***good habitat*** for balsam fir trees. The ***suitability rating*** of 3.0 for balsam fir is influenced mostly by its presence (19%) as trees on these sites in modern forests **(R-1)**. When present, balsam fir is a minor co-dominant tree, contributing 8% mean cover in mature stands. The ranking is seventh, tied with red maple, among trees commonly found on MHn45 sites as sampled by releves. Northern mesic hardwood forests offer variable habitat for balsam fir, which tends to be favored on the moister portion of the gradient in MHn44 (see Suitability Tables). MHn45 and MHn46 offer good habitat, and they tend to have fir because they are usually embedded in a landscape where fir is prevalent in nearby communities.

Young Growth-stage: 0-75 years
Historically, at 11% presence balsam fir was an initial-cohort tree in young MHn45 regeneration patches **(PLS-1)**. Its high initial abundance is evidence that few canopy gaps were created by fire, to which balsam fir is very sensitive. Fir abundance pulses between the 30- and 60-year age-classes **(PLS-2)** suggesting that it has especially good recruitment at about the time the regeneration gap is self-thinning **(PLS-5)**. Balsam fir bearing trees did not occur at any survey corners where we presume widespread disturbance **(PLS-3)**. During the young growth-stage balsam fir was about equally likely to be the largest tree at a survey corner as it was to be the smallest tree. Our interpretation is that fir had good advance regeneration in most forests and that regeneration gaps allowed for some recruitment of fir from any stratum. Also, we believe that establishment and recruitment improved at about 40-50 years when overstocked regeneration gaps started to thin. Supporting these arguments is the excellent-to-good performance of balsam fir under a canopy in modern stands, with high indices of regeneration **(R-2)**. Balsam fir's ability to react immediately in abundance when regeneration gaps formed is the main reason that we consider it to be an ***early-successional*** tree on MHn45 sites.

This pulsing behavior of fir is shared with many other communities in the Northern Superior Uplands Section of the state where white spruce is the ultimate climax species rather than sugar maple. In this case it is delayed about 20 years in comparison to the other communities and this delay is partly responsible for the long, young growth-stage. The usual explanation is that fir is the only species sufficiently tolerant of shade to establish seedlings during self-thinning of aspen and birch. How fir accomplished the same thing among sugar maples is a bit of a puzzle, especially because our vision of gap-filling in this community is that recruiting trees were well-established saplings or poles. If thicket-like growth occurred in MHn45 canopy gaps, it was most likely that of mountain maple, beneath which fir is quite capable of establishing seedlings, and possibly it was favored over other species in that environment.

Transition: 75-95 years
The transition to mature conditions is influenced by significant decline in fir abundance in the last age-classes of the young growth-stage and the first age-classes of the transition **(PLS-2)**. By the age of 40-60 years, fir trees represented as much as 30% of all trees, but shortly thereafter it drops precipitously to about 5% relative abundance in the initial age-classes of the transition. During this period it was about twice as likely for fir to be the smallest tree at a survey corner as it was for it to be the largest. The cases of it being the largest are probably the cohort of saplings or poles released when the gap formed. The smaller diameter trees were probably a following cohort established by fir when it was at peak abundance at age 40-60.

Mature Growth-stage, Second Transition, and Very Old Forest: 95-155 years, 155-195 years and older

At the close of the first transition, balsam fir abundance stabilized at about 4% and it persisted at similar abundance throughout the older growth-stages **(PLS-1)**. Balsam fir's relative abundance in these older growth-stages is certainly the result of its ability to maintain a healthy bank of regenerants and seedlings beneath a canopy **(R-2)**. Apparently, these seedlings find small canopy gaps and recruit often enough to maintain 2-4% relative abundance of trees in old MHn45 forests. The persistence of fir in old growth-stages is an important ecological feature because it allows for a response of fir in fresh canopy gaps, which seems an important, but poorly understood element of succession that allows white spruce to replace sugar maple.

Regeneration Strategies

Balsam fir's primary regenerative strategy on MHn45 sites is to maintain a bank of regenerants and seedlings in older forests that recruit well in newly-formed canopy gaps. We believe that seedling fir can recruit in gaps of any size, but the pulse of fir abundance at the close of the young growth-stage was almost certainly a ***large-gap*** phenomenon. Other than that, most evidence points towards a ***small-gap*** strategy. In the historic PLS data this interpretation is supported by: (1) the fact that balsam fir abundance is steady throughout the older growth-stages **(PLS-1)** and, (2) it is most abundant at survey corners in mature, undisturbed conditions **(PLS-3)**. The high percentage of balsam fir seedlings in the FIA data (situations 12 and 13) is also characteristic of species successful in small gaps **(FIA-1)**. Most significant though, is its incredible ability to establish and recruit seedlings under a canopy in modern stands **(R-2)**.

Historic Change in Abundance

Today populations of balsam fir are considerably higher in MHn45 forests than they were historically **(PLS/FIA-1)**. We believe that this is a consequence of short commercial rotations and fir's obvious abilities to function as a shade-tolerant, small-gap strategist. Nearly 64% of the MHn45 landscape is now in the young growth-stage where fir had maximum abundance. The FIA plots suggest that fir is the dominant species in young MHn45 forests at 29% relative abundance, compared to just 11% historically. Equally impressive is fir's 17% relative abundance in mature forests compared to 4% historically. It is important to remember that fir was not eliminated naturally by fire on MHn45 sites and its modern success has to be linked to forest management more than fire suppression. In other communities fir is very successful under quaking aspen (e.g. MHn44), and we believe that the conversion of MHn45 sites to quaking aspen for pulpwood production has brought with it substantial increases in balsam fir.

Red Maple

- ***good habitat suitability rating***
- ***mid-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 90-120 years***

Identification Problems

The PLS surveyors did not consistently distinguish between red and sugar maple. Although most references were just to "maple," the explicit references "soft maple" were interpreted as red maple and references to "sugar" or "hard maple" were interpreted as sugar maple. Because sugar maple is dominant on MHn45 sites, especially with regard to cover, we were forced to assign most generic "maple" references to sugar maple in our PLS analyses. From the perspective of understory presence (27%), red maple is actually rather common. MHn45 releve samples show that for plots with maple present: 14% have both species present; 5% are red maple without sugar maple; 81% are sugar maple without red maple. We consider sugar maple and red maple to be ecologically similar for most silvicultural considerations, but there seemed to be enough difference in the modern data to treat the species separately. The low number of explicit references to "soft maple" complicate our interpretation of the historic data.

Suitability

MHn45 sites provide ***good habitat*** for red maple trees. The ***suitability rating*** of 3.0 for red maple is influenced mostly by its presence (17%) as trees on these sites in modern forests **(R-1)**. When present, red maple is a minor co-dominant, contributing just 8% mean cover in mature stands. This ranking is seventh, tied with balsam fir, among trees common on MHn45 sites. Northern mesic hardwood forests (MHn) offer fair-to-poor habitat for red maple (see Suitability Tables). Red maple is favored on the more disturbed communities, and not communities like MHn45 or MHn47 where disturbance was naturally rare.

Young Growth-stage: 0-75 years

Historically, there were but a few explicit references to soft maple in young MHn45 regeneration gaps **(PLS/FIA-1)**. There were no records of red maple at survey corners showing any disturbance **(PLS-3)**. A few red maple bearing trees occurred as small-diameter regeneration in the young growth-stage **(PLS-5)**, but this is not enough to draw any conclusions about natural recruitment. The FIA data show low abundance (3%) of red maple in the post-harvest stands (situation 11, **FIA-1**). It would seem from the FIA data that disturbance at the stand scale has done little for red maple. We believe that historic, young MHn45 gaps might have had the odd red maple, but it was not significant in comparison to sugar maple.

Transition: 75-95 years

As regeneration gaps transitioned to mature conditions red maple bearing trees were a rarity at levels below a percent **(PLS/FIA-1)**. There just are not enough bearing tree records to draw conclusions about the behavior of red maple during the transition from historic data. In modern stands, the FIA data show consistent presence at about 3% relative abundance in the transition years. Most likely, there was some red maple in these gaps, but as was the case for the young growth-stage, it was minimal.

Mature Growth-stage: 95-155 years

Red maple had but trace presence as a bearing tree in the mature growth-stage **(PLS-FIA-1)**. The releve sampling of modern mature forests shows considerable amounts of red maple as either a tree with 17% presence **(R-1)** or in the understory at 27% presence **(R-2)**. It is hard to look at these data and not suspect that red maple was present also in mature stands historically. It is clear to us that our choice to assign generic references of "maple" bearing trees has hampered our interpretation. It is significant that the regeneration indices of red maple (3.3-3.8) are actually rather good **(R-2)**, and there is no reason to think that red maple couldn't maintain some abundance in mature forests even in the presence of sugar maple. In stands regenerated by logging, red maple shows a clear peak in abundance during the mature growth-stage. However, a very large proportion (~3/4) of these trees are small-diameter regeneration among larger sugar maples. Because of this peak we have concluded that red maple is a ***mid-successional*** species today. It seems us that its role is that of a subcanopy tree, able to reach reproductive age and establish seedlings, but rarely reaching the canopy when competing with the native MHn45 trees.

Regeneration Strategies

Red maple's primary regenerative strategy on MHn45 sites is establish advance regeneration and then to fill ***large-gaps or small-gaps*** as overstory trees die. If it was at all like sugar maple, the historic data would suggest that gap size didn't much matter as long as there was substantial advance regeneration. The FIA data would suggest that red maple is an effective gap species as it has very high presence in subordinate situations (situations 12, 23, and 13; **FIA-1**). In the releve data, its regeneration indices (3.3-3.8) are more in line with large-gap strategists **(R-2)**.

Historic Change in Abundance

Populations of red maple have been expanding in Minnesota. Statewide, red maple abundance has at least doubled since pre-settlement times. This is most evident in communities historically dominated by intolerant or mid-tolerant hardwoods, unlike the MHn45 community where sugar maple prevails. We have estimated that red maple abundance has increased from trace amounts in historic stands to about 3-5% today **(PLS/FIA-1)**. We doubt that this modest increase in red maple will hamper silvicultural attempts to manage the native trees, but it does seem to be occupying considerable mid-canopy space with little prospect of producing a useable product.

(PLS-1) Historic Abundance of MHn45 Trees in Natural Growth-stages

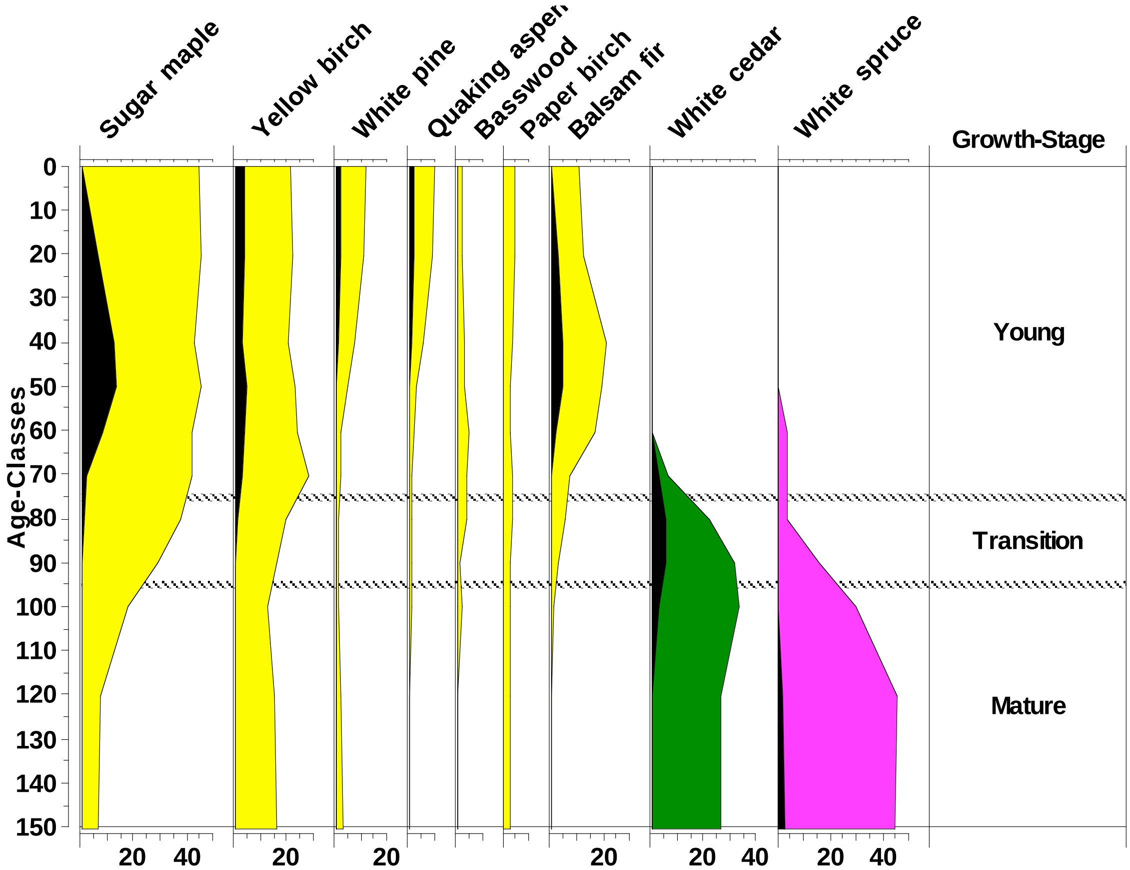
Table values are relative abundance (%) of Public Land Survey (PLS) bearing trees at corners modeled to represent the MHn45 community by growth-stage. Growth-stages are periods of compositional stability during stand maturation. Arrows indicate periods of compositional change during which tree abundances increase or decrease substantially. Yellow, green, and purple shading groups trees with abundance peaks in the same growth-stage. Percents on the bottom row represent a snapshot of the balance of growth-stages across the landscape *ca.* 1846 and 1908 AD.

Dominant Trees	Forest Growth Stages in Years				
	0 - 75	75 - 95	95 - 155	155 - 195	> 195
	Young	T1	Mature	T2	Very Old
Sugar Maple	**33%**	||	**12%**	|	**11%**
Paper Birch	**13%**	|	**6%**	|	**–**
Balsam Fir	**11%**	|	**4%**	|	**2%**
Yellow Birch	**22%**	|	**11%**	⌉	**15%**
White Cedar	**6%**	⌉⌉	**25%**	||	**8%**
White Spruce	**6%**	⌉⌉	**37%**	⌉⌉	**54%**
Miscellaneous	**9%**		**5%**		**10%**
Percent of Community in Growth Stage in Presettlement Landscape	**29%**	**16%**	**38%**	**3%**	**14%**

See linked text on brief methods and silvicultural application for Table PLS-1, file *Figures_Tables_Documentation*

(PLS-2) Abundance of trees throughout succession in MHn45

Graphed for the individual species of MHn45 trees is their relative abundance (%) as PLS bearing trees by age class. Species with good-to-excellent suitability have graphs colored as follows: early successional (yellow); mid-successional (green); late-successional (magenta). The data were smoothed from adjacent classes (3-sample moving average). Black insets show the proportion of bearing trees that were small-diameter trees that were presumably recruiting to bearing tree size (~4" dbh, see PLS-5). Not shown are the second-transition and very old growth-stages due to sparse data.



MHn45, J.C. Almendinger, April 2008

See linked text on brief methods and silvicultural application for Table PLS-2, file *Figures_Tables_Documentation*

(PLS-3) Historic Abundance of MHn45 Trees Following Disturbance

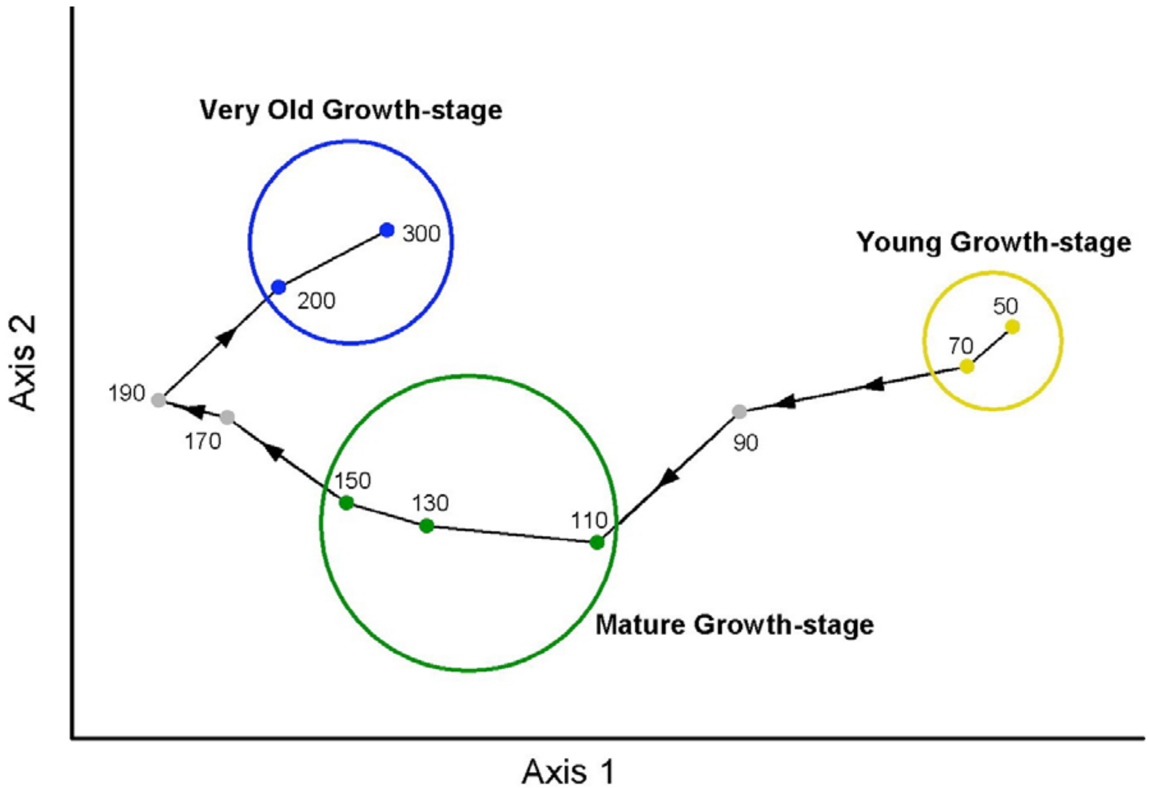
Table values are raw counts and (percentage) of Public Land Survey (PLS) bearing trees at survey corners likely to represent MHn45 forests. The columns represent our interpretation of disturbance at the survey corners. Shading associates trees that peak in the same disturbance category.

Tree	Burned		Windthrown		Maintenance		Mature	
White spruce	**6**	**100%**	**4**	**57%**	**0**	**0%**	**340**	**23%**
Sugar maple	**0**	**0%**	**2**	**43%**	**1**	**33%**	**325**	**22%**
Basswood	**0**	**0%**	**1**	**14%**	**0**	**0%**	**29**	**2%**
Paper birch	**0**	**0%**	**0**	**0%**	**2**	**67%**	**116**	**8%**
Yellow birch	**0**	**0%**	**0**	**0%**	**0**	**0%**	**228**	**15%**
White cedar	**0**	**0%**	**0**	**0%**	**0**	**0%**	**286**	**19%**
Balsam fir	**0**	**0%**	**0**	**0%**	**0**	**0%**	**97**	**7%**
Red maple	**0**	**0%**	**0**	**0%**	**0**	**0%**	**1**	**0%**
Quaking aspen	**0**	**0%**	**0**	**0%**	**0**	**0%**	**14**	**1%**
White pine	**0**	**0%**	**0**	**0%**	**0**	**0%**	**44**	**3%**
Total (% of grand total, 1496)	**6**	**0%**	**7**	**1%**	**3**	**0%**	**1480**	**99%**

See linked text on brief methods and silvicultural application for Table PLS-3, file *Figures_Tables_Documentation*

(PLS-4) Ordination of Historic MHn45 Age-classes

The distance between age-class points reflect change in composition from one age-class to another. Long distances between age-classes indicate species mortality and replacement by other species. Short distances suggest little change in composition. Circled are growth-stages where we interpreted little change. Age-classes not in circles and with arrow connections represent episodes of significant compositional change.



See linked text on brief methods and silvicultural application for Table PLS-1, file *Figures_Tables_Documentation*

(PLS-5) Historic Windows of Recruitment for MHn45 Trees

Windows of recruitment are stretches of contiguous age classes where Public Land Survey (PLS) trees recruit to acceptable bearing tree size (~4" dbh) in the presence of trees twice their diameter. We interpret this as their establishment in response to canopy conditions that change during the course of natural stand maturation. The table presents species' peak recruitment window and comparative success in post-disturbance, gap, and ingress windows.

Initial Cohort*	Species	Peak years	P-D 0-70 years	G-1 70-110 years	I-1 110-150 years	G-2 150-190 years	I-2 >190 years
Minor	Quaking aspen	0-30	Poor to 40	--	--	--	--
Minor	Basswood	30-50	Poor	--	--	--	--
Minor	White pine	40	Fair	--	--	--	--
Minor	Balsam fir	40-50	Excellent	--	--	--	--
Yes	Sugar maple	40-50	Excellent	--	--	--	--
Yes	Yellow birch	40-70	Good	--	--	--	--
Yes	Paper birch	70-100	Fair	Good	Fair	--	--
Yes	White cedar	80-90	--	Good	--	--	--
Minor	Red maple	90-120	Fair	Excellent	Good	--	--
Yes	White spruce	>120	Poor	Poor	Fair	--	--

Recruitment windows from ordination PLS-4:

- **P-D:** post-disturbance filling of understocked gaps, 10-70 years
- **G-1:** gap filling during decline of "initial-cohort" sugar maple, paper birch, yellow birch, and balsam fir, 70-110 years
- **I-1:** ingress of seedlings under canopy of white spruce, white cedar, and sugar maple, 110-150 years
- **G-2:** gap filling during decline of white cedar and paper birch, 150-190 years
- **I-2:** ingress of seedlings under a canopy of white spruce, yellow birch, and sugar maple

***Note:** Catastrophic disturbance was so rare in MHn45 forests that there are almost no records to describe the initial cohort. It seems that the effect of a disturbance was to release established seedlings of later-successional trees (except quaking aspen) with peak recruitment in older age-classes.

-- : No trees were recorded as < half the diameter of the largest bearing tree. A property of PLS data is that diameter variation among bearing trees at the same corner decreases with increasing diameter. Corners estimated to be older than about 100 years only rarely have subordinate bearing trees and should not be taken to mean that small diameter trees didn't occur at all.

Shading: light yellow = trees with peak regeneration immediately after disturbance; **gold =** trees with peak regeneration later in the P-D window; **light green** = trees with peak regeneration in gaps formed during the decline of the initial cohort; **purple** = trees with peak regeneration by ingress under a mature canopy or by filling small gaps in old forests

See linked text on brief methods and silvicultural application for Table PLS-1, file *Figures_Tables_Documentation*

(R-1) Suitability Ratings of Trees on MHn45 Sites

This table presents an index of suitability for trees in MHn45 forests. The index is based upon releve samples from modern forests. Trees that occur often (high percent presence) and in abundance (high mean percent cover-when-present) have high suitability indices. Suitability ratings indicate our interpretation of likely success of natural regeneration and growth to crop tree status with little silvicultural manipulation.

Dominant canopy trees of MHn45			
Tree	**Percent Presence as Tree**	**Mean Percent Cover When Present**	**Suitability Index***
Sugar maple (Acer saccharum)	**80**	**48**	**5.0**
Yellow birch (Betula alleghaniensis)	**46**	**17**	**4.8**
Paper birch (Betula papyrifera)	**37**	**16**	**4.7**
White cedar (Thuja occidentalis)	**35**	**15**	**4.6**
Basswood (Tilia americana)	**11**	**15**	**3.2**
White spruce (Picea glauca)	**40**	**4**	**3.1**
Balsam fir (Abies balsamea)	**19**	**8**	**3.0**
Red maple (Acer rubrum)	**17**	**8**	**3.0**
Quaking aspen (Populus tremuloides)	**7**	**19**	**2.9**
White pine (Pinus strobus)	**8**	**14**	**2.5**
*Suitability ratings: **excellent**, **good**, **fair**			

See linked text on brief methods and silvicultural application for Table R-1, file *Figures_Tables_Documentation*

(R-2) Natural Regeneration and Recruitment of Trees in Mature MHn45 Stands

This table presents an index of regeneration for MHn45 trees in four height strata: regenerants, seedlings, saplings and trees. The index is based upon releve samples of modern, mature forests. Index ratings express our interpretation of how successful tree species are in each stratum compared to other trees that one commonly finds in MHn45 communities. Changes in the index values from one stratum to another can be used to estimate regenerative bottlenecks, whether establishment (R-index) or recruitment (SE-, SA-, or T-indices).

Natural regeneration indices for regenerants, seedlings, saplings, and trees common in the canopy of Northern Mesic Hardwood (Cedar) Forest – MHn45

Trees in understory	% presence R, SE, SA	R-index	SE-index	SA-index	T-index
Sugar maple (Acer saccharum)	89	5.0	5.0	5.0	5.0
Balsam fir (Abies balsamea)	70	4.2	4.3	3.7	3.0
White spruce (Picea glauca)	52	3.0	3.2	3.2	3.5
Yellow birch (Betula	41	2.5	3.0	3.8	4.5
White cedar (Thuja occidentalis)	28	1.8	1.8	3.5	4.3
Red maple (Acer rubrum)	27	3.8	3.8	3.3	3.5
Paper birch (Betula papyrifera)	23	1.3	1.3	2.8	4.5
Basswood (Tilia americana)	12	2.8	3.0	3.5	3.8
White pine (Pinus strobus)	8	1.8	1.5	1.3	3.3
Quaking aspen (Populus	6	2.7	2.3	2.0	3.3

Index ratings: **Excellent**, **Good**, **Fair**, **Poor**, N/A

% presence: the percent of 115 MHn45 sample plots with that species present under 10m tall (R, SE, SA layers)
R-index: index of representation as true seedling or under 10cm tall
SE-index: index of representation as seedlings under 2m tall
SA-index: index of representation as saplings 2- 10m tall
T-index: index of representation as a tree >10m tall
All indexes: equally weight (1) presence, (2) mean cover when present, and (3) mean number of reported strata, the frequency distributions of which are segmented equally by area into 5 classes.

See linked text on brief methods and silvicultural application for Table R-2, file *Figures_Tables_Documentation*

(FIA-1) Structural Situations of Trees in Mature MHn45 Stands

This table presents percentages of structural situations for trees as recorded in Forest Inventory Analysis (FIA) subplots that we modeled to be samples MHn45 forests. The purpose of the table is to provide a general impression of how often a species is seen certain regenerative situations: canopy of a regenerating forest (situations 11, 22), in the subcanopy (situations 12, 23), or in the seedling bank below a remote canopy (situation 13). The situation of trees in older stands at tree height (33) provide no insight about regeneration. Species are ordered by the sum of their percents in 12 and 13 situations, which generally ranks them as would shade-tolerance ratings. The total number of trees counted for each species is presented to provide a sense of reliability.

Species	Tree Count	Structural Situations					
		11	22	12	23	13	33
Sugar maple	320	3%	18%	17%	22%	20%	21%
Yellow birch	3	0%	33%	0%	0%	0%	67%
Balsam fir	357	6%	15%	30%	18%	28%	2%
White cedar	26	0%	12%	0%	4%	0%	85%
Basswood	83	0%	14%	4%	33%	6%	43%
Red maple	60	3%	23%	25%	18%	22%	8%
White spruce	52	8%	46%	8%	10%	13%	15%
Paper birch	316	6%	42%	9%	17%	4%	21%
Quaking aspen (Populus	272	6%	26%	10%	17%	3%	39%
White pine	10	0%	0%	0%	10%	0%	90%

Canopy Situations
- 11 = Sapling in a young forest where saplings (dbh <4”) are the largest trees
- 22 = Poles in a young forest where poles (4”<dbh<10”) are the largest trees
- 33 = Trees in a mature stand where trees (>10”dbh) form the canopy

Subcanopy Situations
- 12 = Saplings under poles
- 23 = Poles under trees

Understory Situation (remote canopy)
- 13 = Saplings under trees

See linked text on brief methods and silvicultural application for Table FIA-1, file *Figures_Tables_Documentation*

(PLS/FIA-1) Abundance of MHn45 trees in Pre-settlement and Modern Times by Historic Growth-stage

Table values are relative abundance (%) of trees at Public Land Survey corners and FIA subplots modeled to represent the MHn45 community and estimated to fall within the young, mature, and old growth-stages. Arrows indicate increase or decrease between historic growth-stages only and for the more common trees. Green shading and text was used for the historic PLS data and blue was used for the FIA data. Percents on the bottom row allow comparison of the balance of growth-stages across the pre-settlement landscape (*ca.* 1846-1908 AD) and the modern landscape (*ca.* 1990 AD).

Dominant Trees	Forest Growth Stages in Years									
	0 - 75		75 - 95		95 - 155		155 - 195		> 195	
	Young		T1		Mature		T2		Very Old	
Sugar Maple	33%	17%	| |		12%	34%	|		11%	38%
Paper Birch	13%	21%	|		6%	14%	|		–	13%
Balsam Fir	11%	29%	|		4%	17%	|		2%	0%
Yellow Birch	22%	0%	|		11%	1%	⌉		15%	0%
White Cedar	6%	0%	⌉⌉		25%	5%	| |		8%	25%
White Spruce	6%	3%	⌉⌉		37%	2%	⌉⌉		54%	13%
Quaking Aspen	2%	19%			–	7%			0%	0%
Basswood	2%	4%			2%	6%			1%	0%
Red Maple*	–	3%			–	5%			–	0%
Black Spruce*	–	0%			–	3%			–	0%
Miscellaneous	5%	4%			3%	6%			9%	11%
Percent of Community in Growth Stage in Presettlement and Modern Landscapes	29%	64%	16%	20%	38%	15%	3%	0%	14%	0%

Natural growth-stage analysis and landscape summary of historic conditions is based upon the analysis of 4,074 Public Land Survey records for section and quarter-section corners. Comparable modern conditions were summarized from 10,595 FIA subplots that were modeled to be MHn45 sites. *Red maple and black spruce could not be separated in the PLS notes and were included with sugar maple and white spruce respectively in the PLS percentages.

See linked text on brief methods and silvicultural application for Table PLS/FIA-1, file *Figures_Tables_Documentation*

Forest Health

Sugar Maple

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Maple borer	Pole-sized and larger	Volume loss/ degrade
Stem cracks	"	Volume loss
Stem decay	"	Volume loss

WATCHOUTS!

• When thinning, discriminate against maples with maple borer galleries and/ or stems with cracks.

• When planning intermediate or final harvests, write sale specifications to penalize wounding of residual trees and supervise sale closely to prevent wounding. The major entry points for decay fungi include mechanical wounds to the bole, dead branches, and dead or broken tops.

Paper Birch

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Forest tent caterpillar	"	Defoliation
Bronze birch borer	Pole-sized and larger	Mortality
Inonotus canker & decay	"	Volume loss
Stem decay	"	Volume loss

WATCHOUTS!

• Declining birch stands should be harvested within two years to prevent loss of the sites to invading brush species.

•Avoid thinning in birch during a drought and/or defoliation event. It is best to wait one growing season after the drought or defoliation is over to thin or harvest.

• Maintain optimal stocking in high-value stands to avoid mortality losses due to bronze birch borers and Armillaria root disease.

• Attempt to maintain a closed canopy in existing stands because soil temperature increases of as little as 4E can cause root death leading to tree mortality.

• Promote dense regeneration to help shade the soil and prevent excessive temperatures.

• The presence of fruiting bodies of Inonotus canker (sterile conk of birch) indicates serious decay. The presence of two fruiting bodies on a single stem usually indicates that the stem is cull due to decay.

• When planning intermediate or final harvests, write sale specifications to penalize wounding of residual trees and supervise sale closely to prevent wounding. The major entry points for decay fungi include mechanical wounds to the bole, dead branches, and dead or broken tops.

White Cedar

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Stem decay	"	Volume loss

WATCHOUTS!

• Encourage and preserve all white cedar regeneration. Consider retaining white cedar during harvests to ensure a local seed source.

• When planning intermediate or final harvests, write sale specifications to penalize wounding of residual trees and supervise sale closely to prevent wounding. The major entry points for decay fungi include mechanical wounds to the bole, dead branches, and dead or broken tops.

Basswood

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Stem decay	Pole-sized and larger	Volume loss

WATCHOUTS!

• When planning intermediate or final harvests, write sale specifications to penalize wounding of residual trees and supervise sale closely to prevent wounding. The major entry points for decay fungi include mechanical wounds to the bole, dead branches, and dead or broken tops.

White Spruce

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Spruce budworm	"	"
Yellow-headed spruce sawfly	Seedlings and saplings	Topkill, mortality
White pine weevil	Seedlings to pole-sized	Forking, multi-stemmed
Spruce decline	Pole-sized and larger	Growth loss, mortality
Spruce beetle	"	Mortality
Stem decay	"	Volume loss

WATCHOUTS!

• Both white pine weevil and yellow-headed spruce sawfly damage can be prevented by planting/ regenerating seedlings under a light overstory until the seedlings are at least 12-20 feet tall.

• Inspect young, open-grown plantations in early June for YHSS larvae. Use contact insecticides on seedlings with active feeding. Repeat inspection in mid to late June.

• In northeast and north central counties, presalvage/ salvage stands as budworm defoliation starts to cause topkill in the dominant trees.

• Along the North Shore, salvage spruce beetle-caused mortality. Contact the RFHS for more information about prevention, timing and sanitation.

• If a white spruce plantation does not respond to its first commercial thinning or mortality losses increase, it may be declining. Contact the RSS or the RFHS for more information.

• When planning intermediate or final harvests, write sale specifications to penalize wounding of residual trees and supervise sale closely to prevent wounding. The major entry points for decay fungi include mechanical wounds to the roots and stem, dead branches, and dead or broken tops.

Balsam Fir

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Spruce budworm	"	"
Stem decay	"	Volume loss

WATCHOUTS!

• In northeast and north central counties, use a rotation age of 45-50 years and presalvage/ salvage stands as budworm defoliation starts to cause topkill in the dominant trees. Promote mixed species in regeneration.

• Discriminate against balsam fir regeneration in white spruce stands and in areas where budworm outbreaks are common.

• When planning intermediate or final harvests, write sale specifications to penalize wounding of residual trees and supervise sale closely to prevent wounding. The major entry points for decay fungi include mechanical wounds to the roots and stem, dead branches, and dead or broken tops.

Red Maple

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Maple borer	Pole-sized and larger	Volume loss/ degrade
Stem cracks	"	Volume loss
Stem decay	"	Volume loss

WATCHOUTS!

• When thinning, discriminate against maples with maple borer galleries and/ or stems with cracks.

• When planning intermediate or final harvests, write sale specifications to penalize wounding of residual trees and supervise sale closely to prevent wounding. The major entry points for decay fungi include mechanical wounds to the bole, dead branches, and dead or broken tops.

MHn45 - Acceptable Operating Season to Minimize Compaction and Rutting

Primary Soils	Secondary Soils	Not Applicable

Surface Texture [1]	Drainage [2]	Depth to Semipermeable Layer (inches) [3]	Landscape Position [4]	Acceptable Operating Season [5]	
				Compaction	Rutting
Coarse (sand & loamy sand)	Excessive & Somewhat Excessive	Not Applicable	Top, Mid-slope, Level	All	All
			Toe & Depression	Wf > Sd > Fd > W > S	All but spring break up
	Well	> 12	Any	Wf > Sd > Fd > W > S	All but spring break up
		< 12	Top, Mid-slope, Level	Wf > Sd > Fd > W > S	Wf > Sd > Fd > W > S > F
			Toe & Depression	Wf > Sd > Fd > W	Wf > Sd > Fd > W > S > F
	Moderately Well	> 12	Top, Mid-slope, Level	Wf > Sd > Fd > W > S	Wf > Sd > Fd > W > S > F
			Toe & Depression	Wf > Sd > Fd > W	Wf > Sd > Fd > W > S
		< 12	Any	Wf > W	Wf > Sd > Fd
	Somewhat Poor	Any	Any	Wf > W	Wf > Sd > Fd
	Poor	Any	Any	Wf	Wf > Sd
Medium (sandy clay, silty clay, fine sandy loam, clay loam, sandy clay loam, silty clay loam, loam, v fine sandy loam, & silt loam)	Excessive & Somewhat Excessive	Not Applicable	Top, Mid-slope, Level	Wf > Sd > Fd > W > S	Wf > Sd > Fd > W > S > F
			Toe & Depression	Wf > Sd > Fd > W	Wf > Sd > Fd > W > S > F
	Well	> 24	Any	Wf > Sd > Fd > W	Wf > Sd > Fd > W > S > F
		< 24	Top, Mid-slope, Level	Wf > Sd > Fd > W	Wf > Sd > Fd > W > S > F
			Toe & Depression	Wf > W	Wf > Sd > Fd > W > S
	Moderately Well	> 24	Top, Mid-slope, Level	Wf > W	Wf > Sd > Fd > W > S
			Toe & Depression	Wf	Wf > Sd > Fd > W
		< 24	Any	Wf	Wf > Sd > Fd > W
	Somewhat Poor	Any	Any	Wf	Wf > Sd > Fd
	Poor	Any	Any	Wf	Wf > Sd
Fine (clay & silt)	Excessive & Somewhat Excessive	Not Applicable	Top, Mid-slope, Level	Wf > Sd > Fd > W > S	Wf > Sd > Fd > W > S > F
			Toe & Depression	Wf > Sd > Fd > W	Wf > Sd > Fd > W > S > F
	Well	> 24	Top, Mid-slope, Level	Wf > Sd > Fd > W	Wf > Sd > Fd > W > S > F
			Toe & Depression	Wf > W	Wf > Sd > Fd > W > S
		< 24	Any	Wf > W	Wf > Sd > Fd > W
	Moderately Well	> 24	Top, Mid-slope, Level	Wf > W	Wf > Sd > Fd > W
			Toe & Depression	Wf	Wf > Sd > Fd
		< 24	Any	Wf	Wf > Sd > Fd
	Somewhat Poor	Any	Any	Wf	Wf > Sd > Fd
	Poor	Any	Any	Wf	Wf > Sd
Peat & Muck	Poor	Any	Any	Wf	Wf
	Very Poor	Any	Any	Wf	Wf

Plants below indicate wetter inclusions in MHn45 that are more susceptible to compaction and rutting. They are listed in descending order of presence.

Mountain maple (*Acer spicatum*)
Lady fern (*Athyrium filix-femina*)
Nodding trillium (*Trillium cernuum*)
Common oak fern (*Gymnocarpium dryopteris*)
Shining firmoss (*Huperzia lucidula*)
Yellow birch (C) (*Betula alleghaniensis*)
Yellow birch (U) (*Betula alleghaniensis*)
Alpine enchanter’s nightshade (*Circaea alpina*)
Swamp red currant (*Ribes triste*)
Long beech fern (*Phegopteris connectilis*)

(U) – understory **(C) - canopy** **Footnotes on back**

Foot Notes

1. Surface Texture and Landform Affinity – the dominant texture within 12 inches of the mineral soil surface, listed in ascending order of moisture holding capacity; landforms are listed when distinct associations with soil texture are evident

2. Soil Drainage
   Excessive – water moves very rapidly through the soil; saturation does not occur during the growing season except for brief periods

   Somewhat Excessive – water moves rapidly through the soil; saturation occurs greater than 60 inches below the surface but within the rooting zone periodically during the growing season

   Well – water moves readily through the soil; saturation occurs 40 inches or more below the surface during the growing season

   Moderately Well – water saturation occurs within 20 to 40 inches of the surface periodically during the growing season

   Somewhat Poor – water saturation occurs within 20 inches of the surface periodically during the growing season

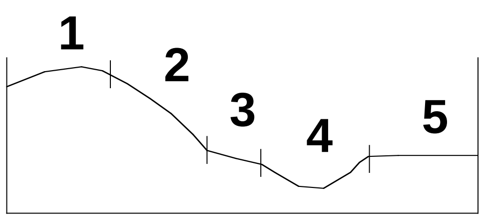
   Poor – water saturation occurs within 10 inches of the surface for most of the growing season

   Very Poor – water saturation occurs at the surface or within 10 inches of the surface for most of the growing season

3. Semipermeable Layer – any feature that retards downward water movement such as: hardpan, clay layer, bedrock, contrasting soil texture.

4. Landscape Position

   1 – Top
   2 – mid-slope
   3 – toe
   4 – depression
   5 – level



5. Acceptable Operating Season
   Listed in order of decreasing preference and increasing risk for compaction based on duration of dry conditions

   Wf Winter with frozen soil - ground is frozen enough to support heavy equipment

   Sd Dry Summer – extended periods without rain during the growing season when surface soil is dry; delay operations for brief periods after rain

   Fd Dry Fall - extended periods without rain in the fall when surface soil is dry; cease operations when significant rain occurs (1”-2” cumulative)

   W Winter – the ground is snow covered or partially frozen

   S Summer – the growing season; delay operations for a brief period after rain

   F Fall – after leaves fall until the ground is snow covered or frozen

   Sp Spring – after the frost goes out until herbaceous forest plants have reached full size (commonly two to three weeks after tree canopy leaf-out); delay operations during break-up

The presence of an intact duff layer and slash on the surface together with use of low ground pressure equipment may help reduce the risk, severity, and extent of compaction.

Public Land Survey

Natural stand dynamics and disturbance were evaluated using data from the original Public Land Survey (PLS) of Minnesota. The investigation begins by selecting from all section corners in the state, the set that possibly occurred on sites of the Native Plant Community (NPC) under consideration. Selected corners had to: occur on landforms (LandType Associations, LTAs) where we have modern samples of the community, have the full set of 4 bearing trees, have bearing trees typical of the community (>30% frequency in our sample set), and NOT have trees atypical of the community (<5% frequency). It is possible for an individual corner to contribute to the analysis of more than one community but more often, corners were eliminated from all analyses because of atypical species combinations. This commonly happens in Minnesota because of the incredible amount forest acreage in riparian edge between terrestrial forest and wetlands or lakes. Also, the glaciated terrain of Minnesota results in many sharp contacts between sorted materials and till, creating System-level changes in forest communities and further elimination of survey corners from the analysis.

From this set of corners for a NPC we assigned a stand age to the corner based upon the diameter and modeled age of the largest/oldest tree present. Presumably, the age of the oldest tree at a corner is a minimum estimate of how long the stand has avoided a catastrophic disturbance. Corners were then placed into 10-year age classes with the exception of the initial 15-year class that matches the 15-year disturbance "recognition window" used to calculate the rotations of fire and windthrow. Experience shows that when applied to PLS data, a 15-year window for catastrophic disturbance and a 5-year window for maintenance disturbance results in a reasonable match with far more reliable, but local studies of disturbance using techniques of fire-scar analysis, stand origin mapping, and the analysis of charcoal in varved lake sediments. Small diameter (<4") bearing trees were "forced" into age class 0-15 when they occurred at corners described as burned or windthrown. Otherwise, corners were assigned to age classes when the diameter of the oldest tree would lead us to believe that it was between 15-25 years old, 25-35 years old, etc. The fundamental property of an age-class in our analyses is the relative abundance of the component species.

By ordinating age-classes (PLS Figure 4) we can discover natural periods of stability known as growth-stages, as well as periods of instability known as transitions. Summarizing data by growth-stages and transitions allows us to present a general model of stand dynamics and succession for the NPC Classes. Such models can be presented in tabular (PLS Table 1) or graphic form (PLS Figure 2).

It is important to remember that ***this is a landscape composite of tree abundance by age. One should not expect a particular stand of a certain age to match exactly the composition suggested by the table or graphic.*** A universal result in habitats with several tree species is that the younger age classes are highly variable and often monotypic, presumably the result of variation in the intensity and type of regenerating disturbance. As stands age, they become more mixed, often to the point where the relative abundance of trees in the landscape age-classes match what one sees in a stand.

Modern Forest

Releve Samples

Releves are large (400m2) sample plots that we used to sample ecologically intact and generally mature forests in Minnesota. This means that most of the stands sampled were regenerated from events that pre-date the Forest Inventory Analysis (FIA, below) and post-date the Public Land Survey (PLS) data (above). The releves are the basis for the Native Plant Community (NPC) classification itself. For silvicultural interpretation releve data were used to develop two important concepts.

First, releves were used as a means of determining just how well adapted the different species of trees are to living with other plants in the NPC and to important soil characteristics like drainage and water-holding capacity. Based upon how often we find certain trees in a community and how abundant it is when we do find it, we created an Index of Suitability for trees (Table R-1). The most important use of this table is understanding the variability of ecological potential that trees have among the different NPCs. This table was used to define the set of trees to be addressed in this document.

Secondly, releves were used to interpret of the ability of trees to regenerate and then recruit germinants to taller strata beneath a canopy. Indices of seedling (SE-index) and sapling (SA-index) success allows the tree species to be ranked by their success in recruiting germinants to seedling (<2m) or sapling (2-10m) status whereby one extreme is characterized by species capable of ingress and growth under a full canopy, versus species that seem to need the full sunlight and soil conditions that follow major disturbance and opening of the canopy (Table R-2).

For more information on the releve method and NPC Classification:

Link to the releve handbook.
Link to the NPC Field Guides

FIA Samples

Forest Inventory Analysis (FIA) data were used to confirm aspects of species behavior interpreted from the Public Land Survey analyses and also to provide a general feeling for just how much Minnesota's forests have changed after a century of management. Because comparison to PLS analyses was a major goal, FIA subplots were treated as point samples similar to PLS survey corners. For abundance comparisons (e.g. Table PLS/FIA-1) , FIA subplots were "reduced" to approximate PLS section corners by selecting randomly a tree > 4" dbh in each quadrant around the point. For structural comparisons (e.g. Table FIA-1) all trees at FIA subplots were used. In both cases PLS data and FIA data were pooled and analyzed by the same computer programs so that comparisons could be made.

Similar rules were used for deciding which FIA plots and subplots and PLS survey corners could belong to a dataset for each forested NPC Class. The FIA analysis began by selecting from all FIA subplots the set that possibly occurred on sites of the Native Plant Community (NPC) under consideration. Selected subplots had to: occur on landforms (LandType Associations, LTAs) where we have modern samples of the community, have trees typical of the community (>30% frequency in our sample set), and NOT have trees atypical of the community (<5% frequency). If FIA plots, with either 10 or 4 subplots, were heterogeneous with regard to subplot community assignments, only the subplots with the dominant NPC were used. If no NPC occurred on more than 3 of 10 or 2 of 4 subplots (i.e. 30% or more), then entire FIA plot was eliminated from the analysis. It is possible for an individual subplot to contribute to the analysis of more than one community but more often, subplots were eliminated from all analyses because they didn't meet plot homogeneity rules. This commonly happens in Minnesota because of the incredible amount forest acreage in riparian edge between terrestrial forest and wetlands or lakes. Also, the glaciated terrain of Minnesota results in many sharp contacts between sorted materials and till, creating System-level changes in forest communities and further elimination of FIA plots from the analysis.

From this set of subplots for a NPC we assigned a stand age to the corner based upon the diameter and modeled age of the largest/oldest tree present. Presumably, the age of the oldest tree at a subplot is a minimum estimate of how long the stand has avoided a catastrophic disturbance. Corners were then placed into the same age-classes as were the PLS survey corners: 0-15, 15-25, 25-35, etc. The fundamental property of an age-class in our analyses is the relative abundance of the component species. From this dataset it is possible to perform analyses parallel to those done for PLS bearing trees. Table PLS/FIA-1 is such a comparison of tree abundance by growth-stage.

The FIA data were too sparse to construct a table similar to PLS-5 so that we could guess at regeneration windows based upon diameter subordination. The main reason for this is that quaking aspen dominates a lot of modern forests and populations of most conifers have crashed in historic times. For example, FIA plots retrieve very little data for trees like jack pine and tamarack, even on sites that were historically dominated by these trees. By simplifying the FIA data into just three broad diameter classes, we were able to perform a similar analysis (Table FIA-1) that can confirm or cause us to re-examine our interpretations of table PLS-5.

A great advantage of FIA data is the re-sampling of plots from one inventory cycle to another. The fate of individual trees on these plots can thus be tracked and we can examine how stand conditions might have influenced their survival or mortality. By the time FIA plots were winnowed by homogeniety rules and assigned to 52 forested plant communities, the total number of tracked trees is rather low ... especially for minor species of some communities and for the conifers that have declined significantly in the past century. Because of the low sample numbers, we present no summary tables for observed mortality or survivorship. However, these are real observations that were not dismissed in writing the individual species accounts in this document. These observations are very useful in confirming or dismissing our inferences about mortality and replacement in the PLS data.

For more information on the FIA methods and inventory in Minnesota:

Link to the USFS website, north central