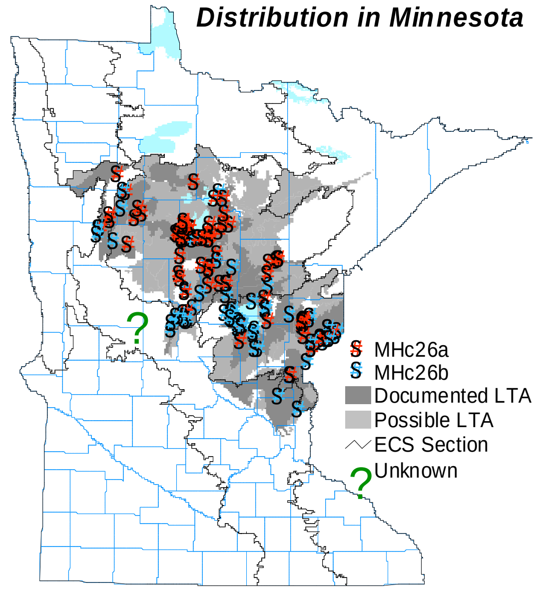
MHc26

MHc26 – Central Dry-Mesic Oak-Aspen Forest

Natural Disturbance Regime, Stand Dynamics, and Tree Behavior

Summary and Management Highlights

Central Dry-Mesic Oak-Aspen Forests (MHc26) are a common hardwood community found mostly within the Northern Minnesota Drift and Lake Plain and Western Superior Uplands ecological Sections of Minnesota. Detailed descriptions of this community are presented in the DNR Field Guides to Native Plant Communities of Minnesota.



The range of MHc26 forests in Minnesota (shaded) and distribution of releve samples (red and blue dots).

Commercial Trees

As a commercial forest, MHc26 sites offer a wide selection of crop trees and possible structural conditions. Northern red oak, quaking aspen, paper birch, red maple, basswood, sugar maple, bur oak, and big-toothed aspen are all ranked as excellent choices as crop trees by virtue of their frequent occurrence and high cover when present on MHc26 sites (see Suitability Tables). White pine and red pine 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.

Among these species, quaking aspen, paper birch, and northern red oak were the dominant native trees that have occupied MHc26 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)**. Bur oak, red maple, basswood, and white pine are likewise native to MHc26 sites but occurred naturally at lower abundance. The consequence of fire suppression, commercial logging, and settlement in the past century has been to promote much more red maple and basswood than was usual. In the understory, ironwood has expanded greatly. Past history and land use as also encouraged the ingress of species that were not significant in native MHc26 stands such as sugar maple. The increased abundance of these trees complicates our interpretations and the use of natural regeneration models as silvicultural strategies.

Natural Silvicultural Approaches

In the historic landscape, most MHc26 stands (45%) were mature forests 55-135 years old. These forests showed almost no tendency to succeed to shade-tolerant trees. We believe that surface fires maintained mature MHc26 forests by eliminating red maple, sugar maple, and ironwood, and by creating large-gaps in the canopy that could be exploited by less tolerant trees. Natural silvicultural approaches for maintaining mature MHc26 forests must approximate the formation of large canopy gaps and also have the effect of setting back advance regeneration of red maple, sugar maple, and ironwood. Except for sugar maple, all trees with commercial potential on MHc26 sites should react positively to large-gaps. Variants of shelterwooding should work for all species, assuming the presence of desirable trees in the understory whether natural or planted. Techniques like patch cutting and variants of seed tree systems would favor quaking aspen and paper birch as they thrive in either large gaps or in the open. Systems that create both large and small openings should favor trees like red oak, bur oak, white pine, basswood, and red maple. Group shelterwooding, irregular shelterwooding, and group selection are good candidates for trees with both large-gap and small-gap strategies. In cases where sugar maple has already overwhelmed the historic dominants of MHc26 sites, variants of selective harvesting would perpetuate sugar maple and the structure of mature forests.

About 31% of the historic landscape were MHc26 stands that were transitioning between the young and mature growth-stages. Roughly, these stands were 35-55 years old. At this time, senescence of initial-cohort trees created regeneration opportunities for trees ranging from single-tree gaps to large gaps up to an acre. Several silvicultural systems could be used to approximate the natural loss of initial-cohort trees and regeneration typical of transitioning MHc26 forests. Selective harvesting matches best the small-gap mortality pattern, and on MHc26 sites would favor sugar maple over all other species. Shelterwood variants or group selection match best with trees like basswood, red oak, and red maple, which can use large or small gaps on MHc26 sites. Bur oak, white pine, paper birch, and quaking aspen should do well in the larger gaps created by patch cutting or variants of seed-tree harvests. Because logging does not kill sugar maple as fires once did, many modern MHc26 stands in transition have inherited a substantial legacy of understory sugar maples that were not naturally a part of the gap-filling, transitional process. Controlling sugar maple and perhaps ironwood should be a consideration when attempting to mimic transitioning of MHc26 stands.

Young MHc26 forests were created mostly by stand-regenerating fire. At the time of the Public Land Survey about 21% of the MHc26 landscape was young forest under 35 years old. The effect of these fires was to “cleanse” MHc26 sites of late-successional trees and leave in their wake stands of young aspen mixed with some paper birch. The cleansing aspect of fire was most important in that it prepared MHc26 sites for the success of mid-tolerants later in the course of natural succession. Highly valued trees like red oak, white pine, and perhaps paper birch and basswood had success on MHc26 sites because of the way stands were re-initiated. Clear-cutting with reserves best matches our vision of post-fire MHc26 sites. The reserves should include target species that we hope will re-colonize the cut areas and replace the initial-cohort aspen and paper birch. On MHc26 sites, paper birch, red oak, bur oak, white pine, and basswood are the most likely candidates to re-colonize and eventually come through the matrix of aspen.

In the historic MHc26 landscape there was very little old MHc26 forest. Just 3% of the survey corners representing MHc26 stands were modeled to be older than 135 years. We believe that this growth-stage was represented by stands that, by chance, avoided fire and other events catastrophic to canopy trees. Mortality of single trees or small groups of trees was followed by replacement of the most tolerant MHc26 trees. Historically basswood, red maple, and possibly red oak were the most likely species to do well in small gaps. But in modern forests, sugar maple is the tree most likely to benefit from selective harvesting systems that approximate the natural small-gap pattern of morality and replacement.

Management Concerns

MHc26 communities occur often enough on medium textured soils to have concerns about heavy equipment compacting or rutting the soil. On till plains, this community occurs on coarse sandy loam drift and one should always determine the appropriate operating conditions by observing the soils on site. On stagnation moraines, this community rather consistently occurs on summer-operable sandy and gravelly soils, but one should expect compactable inclusions of other soils at the stand scale. On glacial river terraces, this community always occurs on coarse soils rated for summer operations. MHc26 sites are all sufficiently well-drained as to expect no impact of heavy equipment on the site’s hydrology.

The landscape balance of growth-stages and stand ages for the MHc26 community is rather different than it was historically. Today there is significantly less younger forest. Today just 13% of young forest under 35 years old exists, compared to 21% historically. Transitioning stands 35-55 years old have also been diminished to about 21% of the current landscape compared to 31% historically. Much more forest is now mature, 55-135 years old. MHc26 sites tend to be inclusions on landforms that supported a matrix vegetation of moister and richer central mesic-hardwood forests. As such, they were more prone to disturbance, and they provided much of the local early-successional habitat for both plants and animals.

Compositional changes are also a management concern. Sugar maple, red maple, and ironwood have been essentially taking over some of the best available habitat for growing mid-tolerant trees that the central floristic region has to offer **(PLS/FIA-1)**. A poor market and deferred management of poor-quality MHc26 maple stands has led to the landscape imbalance of stand ages favoring mature forest. Almost all of our advise on natural silviculture is contingent upon controlling red maple, sugar maple, and ironwood as fire did naturally. Regenerating young MHc26 forests free of excessive maple and ironwood is critical in providing management opportunities for high-value mid-tolerants later in the course of stand maturation. Also of concern is the loss of white pine and white spruce in older MHc26 forests. According to the FIA data there are almost no younger stands with the potential to become compositionally old because white pine and white spruce are essentially absent from these sites. From a practical standpoint, it makes sense to focus on creating some MHc26 stands with the potential to reach the composition characteristic of old MHc26 forest. This means targeting transitioning stands for underplanting white pine, and targeting mature stands for underplanting some white spruce.

Natural Disturbance Regime

Natural Rotations of Disturbance in MHc26 Forests Graphic	
Banner text over photos	
Catastrophic fire photograph	**370 years**
Catastrophic windthrow photograph	**910 years**
Partial Canopy Loss, photograph	**75 years**

Natural rotation of catastrophic and maintenance disturbances were calculated from Public Land Survey (PLS) records at 3,649 corners within the primary range of the MHc26 community. At these corners, there were 8,710 bearing trees comprising species that one commonly finds in MHc26 forests.

The PLS field notes described about 4% of the MHc26 landscape as recovering from stand-regenerating fire. Nearly all such records were of burned-over lands with some references to post-fire thickets. From these data, a rotation of 370 years was calculated for stand-replacing fire.

Elsewhere in the MHc26 landscape, the surveyors described lands as windthrown or as scattered timber without suitable-sized trees for scribing. Such corners were encountered at about 2% of the time, yielding an estimated rotation of 910 years for windthrow.

Far more common at MHc26 sites were references to what we have interpreted as some kind of partial canopy loss, without any explicit mention of fire or windthrow. Most references were to scattered timber or thickets with distances to bearing trees that were intermediate between the distances for burned/windthrown lands and what is typical for fully stocked mesic hardwood forests. About 7% of the survey corners were described as such, resulting in a calculated rotation of 75 years for disturbances that maintained early and mid-successional trees on MHc26 sites. That more corners were described as burned (136) compared to windthrown (25) suggests that surface fires were the more prevalent cause of partial canopy loss.

Compared to other mesic hardwood (MH) communities in Minnesota, MHc26 rotations of catastrophic disturbance are similar in that they exceed the longevity of any initial cohort species. This means that natural stand dynamics involved a few generations of trees and a shift from large regeneration gaps to smaller ones as stands matured. The rotation of 370 years for catastrophic fire is unusual and the shortest calculated for any MH community, including southern and northwestern floristic regions where mesic hardwoods occurred precariously close to fire-dependent forest and prairie. The rotation of 75 years it typical of central MH communities, being shorter than calculated for northern MH forests and longer than calculated for southern and northwestern MH forests. Maintenance disturbances were clearly effective in MHc26 communities because initial-cohort, pioneering species are able to persist into the older age-classes and shade-tolerant, late-successional species like sugar maple were effectively excluded.

Natural Stand Dynamics & Growth-stages

Views and Summaries for MHc26 sidebar	
PLS-1	**Summary of historic growth-stages:** relative abundance of bearing trees
PLS-2	**View line-graph of historic change:** bearing tree abundance across age-classes
PLS-3	**Summary of historic disturbance:** abundance of bearing trees at burned, windthrown or disturbed sites
PLS-4	**View historic rates of change:** ordination of bearing tree age-classes
PLS-5	**Summary of historic regeneration:** Species ratings regarding their ability to regenerate after disturbance, in gaps, and beneath a canopy
R-1	**Summary of tree suitability for a Native Plant Community:** Species ratings based upon modern forests
R-2	**Summary of understory recruitment in modern forests:** indices of species' success in the understory
FIA-1	**Summary of regeneration in modern forests:** FIA trees in multiple-cohort situations
PLS/FIA-1	**Summary of differences between modern and pre-settlement forests:** relative abundance of bearing trees and FIA trees by growth-stage.

Following stand-regenerating fire or possibly windstorms, the overall pattern of compositional change in MHc26 communities is for lots if initial change, which then decelerates as the stand becomes older **(PLS-4)**. This pattern is common for communities where fire overwhelmingly favors a one or two pioneer species and is capable of eliminating late-successional species sensitive to fire. For MHc26, quaking and big-toothed aspen are the species that benefit greatly from fire because they compete poorly with fire-intolerant species like red maple, sugar maple, and perhaps basswood on MHc26 sites.

Early in the process of stand maturation, MHc26 stands achieved tree densities that were fairly stable. Temporal change in tree density 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 MHc26 forests under 35 years had mean distance of just 17 feet from survey corners to the bearing trees. This is typical of fully stocked hardwood forests of comparable age. Transitioning forests 35-55 years old and mature forests 55-135 years old both showed mean distances of 23 feet. Bearing trees in old MHc26 forests were 28 feet from their corresponding corners on average. Compared to other communities, these distances are quite typical of naturally stocked hardwood forest.

Young Growth-stage: approximately 0-35 years

About 21% of the MHc26 landscape in pre-settlement times was covered by forests estimated to be under 35 years old **(PLS-1)**. By far, most of these stands were monotypic and dominated by quaking and possibly some big-toothed aspen as these species are not differentiated in the survey notes. In describing these very young, burned stands, the surveyors indicated that in addition to aspen, paper birch and red oak were common initial-cohort trees. Young stands recovering from windthrow also tended to be dominated by aspen, but much less so than burned stands. Red oak, paper birch, and bur oak were important initial cohort trees following windthrow. Elm, basswood, balsam poplar, and bur oak were infrequently listed as present at disturbed PLS survey corners. Other than balsam poplar, we believe that these species represent the occasional legacy trees that by chance were missed by fire or wind.

The ability of quaking aspen to dominate young MHc26 forests is a consequence of its persistence in the mature and old growth-stages. For a pioneer species, quaking aspen shows surprisingly good success in maintaining a bank of suckers and modest success in recruiting some to mid- and canopy heights in modern forests **(R-2)**. Apparently quaking aspen was successful enough to maintain clone rootstocks that could rapidly repopulate burned and windthrown areas. Big-toothed aspen is considerably less able to do this as it has only a fair ability to maintain suckers under a canopy.

Averaging the age-class data across the young growth-stage **(PLS-1)** masks what we believe was rather immediate compositional change **(PLS-4)**. Our interpretation is that following fire, young aspen suckers filled the matrix leaving stump-sprouting species like red oak, paper birch at the coarser spacing of canopy trees. Rapid self-thinning of the aspen suckers and higher survivorship of the stump sprouts caused the impression of red oak and paper birch increasing at the expense of aspen.

Transitional Stage: approximately 35-55 years
About 31% of the historic MHc26 landscape was forest undergoing considerable compositional change **(PLS-4)**. Stands in this stage were about twice as likely to be mixed than monotypic. Monotypic conditions were represented mostly by survey corners where all bearing trees were aspen. At survey corners with mixed composition, aspen is still the most cited species and it was usually mixed with paper birch, red oak, and red maple **(PLS-1, PLS-2)**.

Species succession during the transition stage is driven mostly by a precipitous decline in aspen **(PLS-2)**. We interpret this as a rather synchronous collapse of the initial cohort. This transition is early and short in comparison to other hardwood communities. Though well adapted to the MHc26 habitat, it would seem that aspen didn't live very long. For the entire community across all growth-stages, half of the aspen bearing trees were under 7 inches in diameter, meaning that most trees were younger than about 40 years old. In the FIA data, survivorship of aspen poles (4-10" dbh) in transitioning MHc26 stands from one inventory cycle to the next was just a 50/50 proposition. Surface fires could have maintained the rather small diameter distribution of aspen, but we favor the idea that disease was probably involved because the decline seems synchronous and obviously favored mid-tolerant trees that need large gaps for recruitment. Aspen rootstocks have maintained a steady presence on MHc26 sites, which perhaps increases the likelihood of chronic health issues and possibly shorter stem life.

The relative abundance of all other species increases during this transition period **(PLS-1, PLS-2)**. Such increases can happen in two ways. If self-thinning was the major source of tree mortality, initial-cohort species with better survivorship than aspen can appear to increase because the total number of trees is decreasing. Alternatively, young trees not dating to the regenerative disturbance can fill the space created when an initial cohort tree dies. The modest increases in red oak and possibly basswood and bur oak suggests that these trees are increasing in importance during the transition because they are outliving aspen. The tree to benefit most from the demise of aspen was paper birch. Its increase in relative abundance seems too high to be attributed entirely to greater longevity than aspen. Paper birch must have had some success establishing seedlings during the young growth-stage. We believe that this happened by filling gaps in post-fire stands because paper birch shows poor ability to establish seedlings in modern MHc26 stands under a closed canopy **(R-2)**. The decline of the aspen canopy during the transition must have released a lot of young paper birch.

Mature Growth-stage: approximately 55-135 years
About 45% of the historic MHc26 landscape was mature forest where the rate of successional change slowed greatly **(PLS-4, PLS-2)**. Stands in this stage were far more likely to be mixed than monotypic. Patches of pure paper birch or pure aspen were the most common monotypic conditions. Nearly all mixed corners involved paper birch or old aspen. Trees mentioned most often as minor components within the birch/aspen matrix were red oak, white pine, and red maple with some mention of basswood and red pine.

The most striking feature of mature MHc26 forests is that they were dominated by species that are not considered late-successional or particularly shade-tolerant. Paper birch, red oak, and aspen were most abundant, and they were apparently able to "hold" sites for 80 or more years **(PLS-1, PLS-2)**. The textbook model of succession in Minnesota, where ultimate dominance of sugar maple is assumed, rarely happened on MHc26 sites. A contributing factor must have been fairly synchronous decline of the initial cohort aspen **(PLS-2)**, perhaps caused by pocket disease, that created fairly large openings favoring regeneration of mid-tolerants like paper birch, white pine, white oak, bur oak, perhaps red oak, and probably even some aspen. Shade-tolerant species must have been absent because similar openings in modern forests simply release sugar maple and red maple seedling banks. We believe that maintenance disturbances, particularly surface fires, must have been involved. We calculated a rotation of 75 years for such disturbances (see Disturbance Regime), but our experience in watching sugar maple invade MHc26 forests suggests that a shorter, almost chronic level of surface fire would have been required. Aspen, red oak, paper birch, and bur oak were the species to most benefit from maintenance-scale disturbances **(PLS-3)**. We believe that mature MHc26 forests were compositionally stable because of chronic disturbance.

Old Growth-stage: approximately >135 years

Very little of the historic MHc26 landscape, just 3%, was estimated to have been MHc26 stands older than 135 years **(PLS-1)**. Nearly all (98%) of the corners with these large old trees were mixed in composition. Trees that one would find in the initial cohort – quaking aspen, bigtooth aspen, paper birch, and red oak – are still common in old MHc26 forests **(PLS-1, PLS-2)**. As discussed for the mature growth-stage, chronic disturbance must have been involved in maintaining these species.

The old growth-stage is recognized as something different because of the increased importance of white pine and white spruce. Both species ingress during the transition. White pine came into prominence in the old growth-stage through incredible survivorship of trees established in the 40-60 year age classes. White spruce came into prominence by gradually building a bank of seedlings and saplings during the mature and old growth-stages. Apparently, that bank of regeneration could indefinitely sustain white spruce's presence in old, native MHc26 forests. In modern forests we see large-old white pines, but not white spruce. Most likely, white spruce has been lost because there is almost no old MHc26 forest left. Historically there was very little old forest and there is even less today **(PLS/FIA-1)**. Still we would expect to see some white spruce as regeneration in mature forests. A more intriguing hypothesis is that white spruce tends to be the climax species in the absence of sugar maple. MHc26 is the only central mesic-hardwood community where, historically, there was little or no sugar maple. Because of fire suppression, sugar maple is an important tree in all growth stages of modern MHc26 forests. White spruce may be absent because it can't compete with sugar maple on MHc26 sites.

Growth Stage Key

Understanding natural growth-stages is important because it offers the opportunity to maintain stands indefinitely by mimicking maintenance disturbance regimes, or to direct succession during transitional episodes of mortality and replacement by other species. Use the following descriptions to determine the growth-stage of the stand you are managing.

Young Forests	• **Nearly all trees are initial cohort and < 6” dbh** • There is little height and diameter variation among the canopy trees • Mortality of very small diameter trees is evident and the consequence of self-thinning
Transitional Forests	• **Initial cohort trees still evident and have a diameter between 6” and 11” dbh** • Height and diameter variation among canopy trees is evident with smaller diameters (6”) more frequent than larger ones (11”) • Mortality of smaller diameter canopy trees is evident and the consequence of suppression and competition among canopy trees • Mortality of larger diameter canopy trees (decline) is often evident but usually less than half the trees • Second-cohort trees are present but at low abundance with smaller diameter trees (1”) more frequent than larger diameter trees (5”)
Mature Forests	• **Initial cohort trees are a small percentage of the canopy trees or are no longer evident; their diameters are are between 12” and 18” dbh** • Height and diameter variation among canopy trees is evident with highest frequency of 8” to 13” dbh trees and fewer trees with 14” to 18” dbh • Mortality of smaller diameter canopy trees is evident and the consequence of suppression • Mortality of larger diameter trees (decline) is evident and usually releasing trees in the sub-canopy • Small diameter trees (seedling bank, 1” to 3” dbh) have the greatest frequency in the stand • Trees in the 5” and 6” dbh classes have the lowest frequency as they are at heights between a well developed canopy and understory layer of regeneration
Old Forests	• **Obviously old stands with at least some canopy trees >18” dbh** • Stands should exhibit the structural characteristics of old-growth with regard to coarse woody debris, well developed height strata of living trees and seedling banks • There were too few FIA plot samples of old MHc26 stands to construct a composite diameter distribution

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 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?

Northern Red Oak

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

Suitability
MHc26 sites provide ***excellent habitat*** for red oak trees. The perfect ***suitability rating*** of 5.0 for red oak is influenced mostly by its very high presence (81%) as trees on these sites in modern forests **(R-1)**. When present, red oak is an important co-dominant and sometimes dominant tree, contributing 35% mean cover in mature stands. The ranking is perfect, because no other tree or plant has a higher presence and cover on MHc26 sites as sampled by releves. All central mesic-hardwood communities provide excellent habitat for red oak (see Suitability Tables). Among these, MHc26 provides the best opportunities for red oak.

Young Growth-stage: 0-35 years
Historically, northern red oak was an occasional tree in young MHc26 stands recovering mostly from fire **(PLS-1)**. Young red oaks represented 10% of the trees at survey corners described as burned, second only to quaking aspen and paper birch **(PLS-3)**. Our interpretation is that red oaks got their start on MHc26 sites mostly as stump sprouts in burned over lands where quaking aspen suckers filled gaps between red oak and birch snags at spacing typical of mature forests. Although windthrow was infrequent, red oaks represented 26% of the trees at corners affected by windthrow **(PLS-3)**. This is a high percentage, second only to aspen, and it would seem that windthrow was favorable for regenerating red oaks. Small-diameter red oak regeneration was rarely observed coming in among larger trees in the post-disturbance window **(PLS-5)**. In all cases, red oak regeneration was coming in under aspen. Because the abundance of red oak increases during the young growth-stage, we believe that it had some ability to recruit into under-stocked areas of burned stands. Because red oak regeneration was evident in the 20 and 30-year age-classes, we believe that the young growth-stage also offered a fair window of opportunity for red oaks to build a modest seedling bank under young quaking aspen.

Transition: 35-55 years
As stands transitioned to mature conditions red oak increased in abundance, presumably because of its ability to outlive initial cohort aspen **(PLS-1)**. We estimate that this increase started at low abundance following disturbance until it peaked at about age 60 **(PLS-2)**. Small-diameter, red oak regeneration coming in among larger trees was most abundant in the G-1 gap window **(PLS-5)**, especially the 40-year age-class. In most cases, red oak regeneration was coming in under aspen and sometimes under older red oaks. We interpret this as fair success at establishment and recruitment of seed-origin oak under a partial canopy of initial-cohort trees. Also, it seems likely that the collapse of the initial-cohort aspen released some red oak seedlings established during the young growth-stage.

Mature Growth-stage: 55-135 years
Red oak had peak presence as a co-dominant in mixed mature stands, which is why we consider red oak a ***mid-successional*** species – able to replace initial cohort trees but dropping (slightly) in relative abundance as stands aged **(PLS-1, PLS-2)**. Small-diameter red oak regeneration was present at the beginning of the mature growth-stage, but occurred only rarely after age 70 **(PLS-5)**. We interpret this as modest, but continued success of recruiting seed-origin trees under declining initial-cohort trees. At this stage (55-70 years) the young red oaks were coming in beneath quaking aspen, paper birch, and other red oaks.

Old Growth-stage: >135 years
Red oak persisted at about 11% relative abundance in the old growth-stage **(PLS-1, PLS-2)**. If persistence required regeneration and recruitment, then we must assume that red oak has

secondary strategies for behaving like a ***late-successional*** species able to respond to fine-scale or maintenance disturbances. The ability of red oak to germinate acorns and recruit seedlings through all height strata in modern MHc26 forests suggests that it can persist under a regime of fine-scale disturbance on MHc26 sites **(R-2)**. The benefit of maintenance events like surface fires to oaks in general is well-documented. This does not explain, however, the general lack of small diameter oaks in old MHc26 forests historically. The PLS records showed no red oak bearing trees with diameters less than half that of their nearest neighbors in old MHc26 forests beyond 70 years **(PLS-5)**. From this, one would assume that persistence is a matter of red oak's longevity and that trees established in the beginning of the mature growth-stage (~60-70 years) were surviving well in old MHc26 forests. When red oaks were the smallest tree at old survey corners, they were almost always in the presence of large, old white pines.

Regeneration Strategies

We believe that red oak's primary regenerative strategy on MHc26 sites is to fill ***large-gaps***. It was most successful at this when gaps formed in the canopy of declining quaking aspen and to some extent paper birch and other red oaks. In the historic PLS data this interpretation is supported by: (1) the fact that red oak abundance peaks in response to the decline of the initial cohort species **(PLS-1, PLS-2)**, (2) it is most abundant at survey corners showing partial canopy loss **(PLS-3)**, and it shows peak establishment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**. The high percent of red oak poles under trees (situation 23) in the FIA data is also a characteristic of species that tend to regenerate best in large gaps **(FIA-1)**. The releve sampling of mature MHC26 forests suggests, however, that red oak is able to function also as a ***small-gap*** strategist with excellent establishment and recruitment in all height strata **(R-2)**. It is significant that the sapling index for red oak (4.0) is approaching values typical of large-gap species. This suggests a slight bottleneck recruiting red oak seedlings to heights taller than 2m under a closed canopy.

The rotation of 75 years for maintenance disturbances on MHc26 sites would suggest that by the time forests reached the old growth stage (135 years) they would have experienced a couple of surface fires or similar events that result in partial canopy loss. Such events clearly favor trees like red oak that depend mostly on large-gaps for regeneration. We believe that such disturbances are the main reason that red oak persisted into the old growth-stage on MHc26 sites. We believe also that these fires were particularly effective at diminishing populations of trees like sugar maple that are superior to large-gap species in competing for resources.

Historic Change in Abundance

Today, it seems that red oak on MHc26 sites is in some peril based upon FIA data because there are very few sapling and pole stands with red oak in comparison to older stands **(FIA-1)**. However, a comparison with bearing tree data **(PLS/FIA-1)** suggests that mature and old MHc26 stands are about twice as abundant today than they were in the late 1800's. Our interpretation is that today's older, MHc26 red oak stands regenerated from disturbances that were not natural or similar to modern logging. Some historic investigation (e.g. air photo archives) and age-structure analyses of these older stands might yield a better understanding of red oak's regeneration needs on MHc26 sites under modern conditions.

Quaking and Big-toothed Aspen

- ***excellent habitat suitability ratings***
- ***early successional***
- ***open (large-gap) regeneration strategists***
- ***regeneration window at 0-30 years***

Identification Problems
The PLS surveyors did not distinguish between quaking and big-toothed aspen. Thus, interpretations of PLS data for the more common quaking aspen should always be done knowing that some of these trees were likely big-toothed aspen. MHc26 releve samples show that for plots with aspen present: 13% have both species present; 30% are big-toothed aspen without quaking aspen; 57% are quaking aspen without big-toothed aspen. We consider quaking and big-toothed aspen to be ecologically equivalent for most silvicultural considerations.

Suitability
MHc26 sites provide ***excellent habitat*** for **quaking aspen** trees. The ***suitability rating*** of 4.7 for quaking aspen is influenced mostly by its very high presence (41%) as trees on these sites in modern forests **(R-1)**. When present, quaking aspen is an important co-dominant and sometimes dominant tree, contributing 21% mean cover in mature stands. This ranking is second, tied with paper birch and following only red oak on MHc26 sites. In general, the poorer central mesic hardwood communities, MHc26, MHc36, and MHc37, offer excellent habitat for quaking aspen (see Suitability Tables). Among these, MHc26 offers the best opportunity for quaking aspen.

MHc26 sites offer ***excellent habitat*** for **big-toothed aspen**. The ***suitability rating*** of 4.2 for big-toothed aspen is based upon its 25% presence and 18% mean cover when present. This ranking is eighth, following northern red oak, quaking aspen, paper birch, red maple, basswood, sugar maple, and bur oak on MHc26 sites. Big-toothed aspen is restricted to the drier and poorer MHc26 and MHc36 communities (see Suitability Tables), with MHc26 offering the best opportunities.

Young Growth-stage: 0-35 years
Historically, aspen was the overwhelming dominant in young MHc26 stands recovering from stand-regenerating disturbance **(PLS-1, PLS-2)**. Young aspen represented 68% of the trees at survey corners described as burned, which is by far more than any other tree **(PLS-3)**. Aspen was also the leading species following windthrow, representing 41% of the trees at such survey corners. Young MHc26 corners with aspen trees present were mostly monotypic (72%) with all attending bearing trees being aspen. Its dominance in the young growth-stage and its leading abundance following fire and windthrow is why we consider aspen to be an ***early successional*** species on MHc26 sites. Small-diameter aspen regeneration was most abundant in the post-disturbance window **(PLS-5)**. This is typical of early successional species, and we interpret this as aspen showing excellent ability to recruit into under-stocked areas of burned or windthrown stands. The presence of smaller diameter aspen could be due natural variation among suckers that are more-or-less connected to parent rootstocks, but it is more likely that seed-origin trees were the smaller ones filling in among the suckers.

Transition: 35-55 years
Transitioning of young MHc26 forests was driven by the steady loss of initial-cohort aspen leaving longer-lived paper birch and red oaks **(PLS-1)**. We estimate that this decline started immediately and continued to about age 70 when aspen abundance stabilized at about 20% relative abundance **(PLS-2)**. Small-diameter aspen regeneration was coming in among larger trees until about age 50 **(PLS-5)**. In most cases, aspen regeneration was coming in under older aspen. We interpret this as limited replacement of itself in large-gaps as some of the initial-cohort aspen started to senesce. During the transition, aspen was present at nearly all survey corners and about half were still pure aspen. It is possible that a component of aspen establishment and

recruitment to bearing-tree size (~4" dbh) was the consequence of it being the only species present in monotypic pockets.

Mature and Old Growth-stage: 55-135 years and older
In mature MHc26 stands the relative abundance of aspen stabilizes at about 20% and it persists into the old growth-stage **(PLS-1, PLS-2)**. Although much diminished from earlier growth-stages, 20% abundance is still high for an individual species, second only to paper birch. If persistence required regeneration and recruitment, then we must assume that aspen has secondary strategies for behaving like a mid- or late-successional species able to respond to fine-scale or maintenance disturbances. The ability of aspen to recruit seedlings or suckers through all height strata in modern MHc26 forests suggests that it can persist under a regime of fine-scale disturbance on MHc26 sites **(R-2)**. Its good regeneration indices (3.7-3.0) are most in line with species that benefit from maintenance disturbances like surface fires that create large gaps. That aspen would respond positively to fire seems obvious from its post-disturbance behavior on burned sites **(PLS-3)**. For this reason, we believe that aspen persisted in mature and old MHc26 forests mostly because of surface fires. Even in mature and old MHc26 forests, smaller diameter aspen still tended to mostly be replacing other aspen trees, and less often replaced white pine, paper birch, or red oak, meaning that it was still competing with itself and other mid-tolerant species.

Regeneration Strategies
Aspen's primary regenerative strategy on MHc26 sites is to dominate ***open habitat*** after stand-regenerating disturbance. It was most successful after fire, but any agent or scale of disturbance resulted in aspen regeneration when it was present. In the historic PLS data this interpretation is supported by: (1) the fact that 76% of the bearing trees in young stands were aspen **(PLS-1)**, (2) aspen represented by far, the largest proportion of bearing trees at burned and windthrown corners **(PLS-3)**, and (3) aspen's peak regeneration was in the post-disturbance window **(PLS-5)** with it's absolute peak being the initial age-class. The high percent of aspen as saplings in sapling stands (situation 11) in the FIA data **(FIA-1)** is also characteristic of species that regenerate effectively in the open.

The releve sampling of mature MHC26 forests suggests, however, that aspen is able to function also as a ***large-gap*** strategist with good establishment and recruitment in the understory strata **(R-2)**. Modest abundance of aspen in subordinate situations (12, 23, 13) at FIA plots support also the idea that aspen can regenerate in large gaps **(FIA-1)**. The persistence of aspen in mature and old growth-stages is also consistent with the idea of aspen functioning as a large-gap strategist in pre-settlement forests. This had the consequence of aspen being present and "prepared" to overwhelmingly dominate sites after major disturbance regardless of the timing of such an event.

The rotation of 75 years for maintenance disturbances (see above) would suggest that by the time MHc26 forests reached the old growth stage (135 years) they would have experienced a couple of surface fires or similar events that result in partial canopy loss. Such events clearly favor trees that depend mostly on large-gaps for regeneration. Although this is a secondary strategy for aspen, we believe that such disturbances were the main reason that aspen persisted into the old growth-stage on MHc26 sites. We believe also that these fires were particularly effective at diminishing populations of trees like sugar maple that are superior to open or large-gap species in competing for resources.

Historic Change in Abundance
Today, aspen remains an important and often dominant tree on MHc26 sites **(PLS/FIA-1)**. About half of all young stands are dominated by aspen, which is less than the historic condition where aspen accounted for 76% of the trees in young stands. The most significant departure from historic times is the lack of aspen in the old growth-stage. This is due in part to the loss of long-lived species like white pine and white spruce, which cause us to model PLS survey corners as old stands. More importantly, fire suppression has allowed for sugar maple and basswood to dominate old MHc26 stands, where they are capable of excluding aspen.

Paper Birch

- ***excellent habitat suitability rating***
- ***mid-successional***
- ***large-gap (open) regeneration strategist***
- ***regeneration window at ~40 years***

Suitability
MHc26 sites provide ***excellent habitat*** for paper birch trees. The ***suitability rating*** of 4.7 for paper birch is influenced mostly by its high presence (58%) as trees on these sites in modern forests **(R-1)**. When present, paper birch is an important co-dominant and sometimes dominant tree, contributing 14% mean cover in mature stands. This ranking is second, tied with quaking aspen and second only to red oak on MHc26 sites. All central mesic hardwood communities offer excellent habitat for paper birch (see Suitability Tables). Among these, MHc26 offers poorer opportunities as paper birch prefers communities moister and richer than MHc26.

Young Growth-stage: 0-35 years
Historically, paper birch was an important co-dominant of young MHc26 stands recovering from fire or windthrow **(PLS-1)**. Young birch represented 13% of the trees at survey corners described as burned, second only to aspen **(PLS-3)**. Our interpretation is that birches got their start on MHc26 sites mostly as stump sprouts in burned over lands where quaking aspen suckers filled gaps between birch and red oak snags at spacing typical of mature forests. Although windthrow was infrequent, birches represented 18% of the trees at corners affected by stand-regenerating wind. This is a high percentage, following only aspen and red oak, and it would seem that windthrow was favorable for birch providing some opportunity for seeding or perhaps release of established seedlings. Because the abundance of paper birch increases during the young growth stage we believe that it had some ability to recruit into under-stocked areas of burned stands. Small-diameter birch regeneration is common throughout the post-disturbance window (0-30 years), and increases near it's conclusion. This offered a fair window of opportunity for birches to build a modest seedling bank under young quaking aspen **(PLS-5)**.

Transition: 35-55 years
As stands transitioned to mature conditions paper birch increased in abundance, in part because of its ability to outlive initial cohort aspen **(PLS-1, PLS-2)**. Also, it seems likely that the collapse of the initial-cohort aspen released some paper birch seedlings established during the young growth-stage. Small-diameter paper birch regeneration was at its peak in the G-1 recruitment window that corresponds with the transition **(PLS-5)**. We interpret this as increased success at establishment and recruitment of seed-origin birches under a partial canopy of initial-cohort trees. Other than a few cases where paper birch was subordinate to other birches, it almost always was coming in under the disintegrating canopy of aspen.

Mature Growth-stage: 55-135 years
Paper birch was the dominant tree of mature MHc26 forests, surpassing quaking aspen. Its high abundance (40%) in this growth-stage is why we consider paper birch to be a ***mid-successional*** species – able to replace initial cohort trees but dropping substantially in relative abundance as stands got older **(PLS-1, PLS-2)**. Small-diameter paper birch regeneration was present at the beginning of the mature growth-stage, but was rarely encountered past age 70 **(PLS-5)**. We interpret this as modest, but continued success of recruiting seed-origin trees under a remnant canopy of initial-cohort trees. At this stage, most young birch were coming in under other paper birch and quaking aspen, with some records of them as being subordinate to larger white pine and red oak.

Old Growth-stage: >135 years
In the old growth-stage paper birch looses its status as the canopy dominant in favor of more mixed stands involving for the first time conifers such as white pine and white spruce **(PLS-1, PLS-**

2). Its relative abundance though is still high (20%) and it remains an important co-dominant, second only to quaking aspen. If its persistence required regeneration and recruitment, then we must assume that paper birch has secondary strategies for behaving like a mid- or late-successional species able to respond to fine-scale or maintenance disturbances. The ability of paper birch to recruit seedlings in modern MHc26 forests though is poor based upon both its regenerative status in releves (R-2) and seedling situations on FIA plots (FIA-1). That paper birch responded positively to windthrow, fire, and partial canopy loss is obvious from its post-disturbance behavior on disturbed MHc26 sites (PLS-3). For this reason, we believe that paper birch persisted in old MHc26 forests mostly because of maintenance disturbances. Although infrequent, smaller-diameter birches in old stands were coming in among larger paper birch, white pine, and white spruce.

Regeneration Strategies
Paper birch's primary regenerative strategy on MHc26 sites is to fill ***large-gaps***. It was most successful at this when gaps formed within the declining canopy of quaking aspen and to some extent under other paper birch. In the historic PLS data this interpretation is supported by: (1) the fact that paper birch abundance peaks in response to the decline of the initial cohort species (PLS-1), (2) it is common at survey corners showing partial canopy loss (PLS-3), and (3) it show peak regeneration at 40 years (PLS-5) when the decline of initial-cohort aspen is most rapid (PLS-2). The high percentage of paper birch poles under trees (situation 23) and low presence as saplings in sapling stands (situation 11) in the FIA data is characteristic of species that tend to regenerate best in large gaps (FIA-1).

Nearly equal to its regenerative performance in large gaps is paper birch's role in occupying ***open habitats*** on MHc26 sites. Paper birch was a legitimate initial-cohort tree with fairly high relative abundance at PLS survey corners described as burned (13%) or windthrown (18%, PLS-3). Paper birch's poor-to-fair regenerative performance under a full canopy as sampled by releves in modern forests (R-2) is more in line with species well-known to require open habitat.

The rotation of 75 years for maintenance disturbances (see above) would suggest that by the time MHc26 forests reached the old growth stage (135 years) they would have experienced a couple of surface fires or similar events that result in partial canopy loss. Such events clearly favor trees like paper birch that can use large-gaps for regeneration. We believe that such disturbances were an important reason why paper birch persisted into the old growth-stage on MHc26 sites. We believe also that these fires were particularly effective at diminishing populations of trees like sugar maple that are superior to large-gap species in competing for resources.

Historic Change in Abundance
Today there is much less paper birch on MHc26 sites than in the pre-settlement landscape (PLS/FIA-1). There are significant declines in all growth-stages, but it is most severe in the mature and old growth-stages. It seems likely that paper birch is losing some ground to shade-tolerant trees like sugar maple that are increasing in abundance on MHc26 sites as a consequence of fire protection.

Red Maple

- ***excellent habitat suitability rating***
- ***mid- (late) successional***
- ***large-gap (small-gap) regeneration strategist***
- ***regeneration window at 30-50 years***

Identification Problems
The PLS surveyors did not distinguish between red and sugar maple. Although most references were just to "maple," the explicit references were to "soft maple" which we interpret as red maple or to "sugar" or "hard maple" which we interpret as sugar maple in upland habitats. Thus, interpretations of PLS data for the more common red maple should always be done knowing that some of these trees were likely sugar maple. MHc26 releve samples show that for plots with maple present: 24% have both species present; 26% are sugar maple without red maple; 50% are red maple without sugar maple. We consider sugar maple and red maple to be ecologically similar for most silvicultural considerations.

Suitability
MHc26 sites provide ***excellent habitat*** for red maple trees. The ***suitability rating*** of 4.5 for red maple is influenced mostly by its high presence (44%) as trees on these sites in modern forests **(R-1)**. When present, red maple is an important co-dominant, contributing 14% mean cover in mature stands. This ranking is fourth best, tied with basswood and following northern red oak, quaking aspen, and paper birch on MHc26 sites. Among central mesic hardwood communities, red maple is favored only on the driest and poorest end of the gradient (MHc26) and on the wettest and richest end (MHc47, see Suitability Tables). Presumably, red maple cannot compete with sugar maple in the more mesic MHc communities.

Young Growth-stage: 0-35 years
Historically, red maple was a minor (1%) component of young MHc26 stands recovering from catastrophic disturbance **(PLS-1, PLS-2)**. Red maple did not appear as a bearing tree often enough at young survey corners to evaluate its ecological contribution to the young community. A few red maple bearing trees occurred as small-diameter regeneration in the 30-year age class at the end of the young growth-stage **(PLS-5)**. Our interpretation is that such trees were advance regeneration present prior to windthrow, and that they appear as subordinates because they grow more slowly than aspen. Alternatively they were individuals that invaded MHc26 sites under a thicket-like growth of aspen. We believe that fire, the more common stand-regenerating event, eliminated most red maple from MHc26 sites at least through most of the young growth-stage.

Transition: 35-55 years
As stands transitioned to mature conditions red maple increased in abundance, perhaps because of its ability to outlive initial cohort aspen **(PLS-1, PLS-2)**. Although the percentages are low, the proportional increase of red maple from 1% in young stands to about 5% in mature stands seems significant. Small-diameter red maple regeneration was at its peak in the 30-50 year age-classes **(PLS-5)**. Our interpretation is that red maple was able to seed into young MHc26 stands and that it enjoyed limited success recruiting seedlings to tree status as the initial-cohort aspen canopy disintegrated.

Mature Growth-stage: 55-135 years
Red maple had peak presence as a co-dominant in mixed mature stands, which is why 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, PLS-2)**. Small-diameter red maple regeneration was present at the beginning of the mature growth-stage, but occurred only rarely after age 70 **(PLS-5)**. We interpret this as modest, but continued success of recruiting seed-origin trees under declining canopy of initial-cohort trees. At this stage (~55-70 years) the young red maples were coming in

beneath paper birch more so than quaking aspen and red oak. All records of smaller diameter red maples were at survey corners of mixed composition.

Old Growth-stage: >135 years
The PLS data suggest that red maple declined in abundance, to 2% in old MHc26 stands **(PLS-1)**. This seems contrary to its ability to regenerate and recruit under a full canopy in modern stands **(R-2)** and also its high presence as seedlings in mature stands (situation 13) as sampled in the FIA inventory **(FIA-1)**. These properties would suggest that red maple has secondary traits typical of ***late-successional*** species that would allow it to persist at low abundance in old forests. There are too few old PLS corners in the analysis to document the old-forest behavior of infrequent trees like red maple.

Regeneration Strategies
Red maple's primary regenerative strategy on MHc26 sites is to fill ***large-gaps***. It was most successful at this when gaps formed within a declining canopy of initial-cohort trees. Unlike most other species taking advantage of gaps in the initial-cohort canopy, red maple was coming in below paper birch more than aspen. In the historic PLS data the large-gap strategy of red maple is supported by: (1) the fact that red maple abundance peaks in response to the decline of the initial cohort species **(PLS-1, PLS-2)**, and (2) it shows peak establishment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**. The high percent of red maple poles under trees (situation 23) in the FIA data **(FIA-1)** is also a characteristic of species that tend to regenerate best in large gaps.

The releve sampling of mature MHC26 forests suggests, however, that red maple is able to function also as a ***small-gap*** strategist with excellent establishment and recruitment in all height strata **(R-2)**. Its high sapling index for (5.0) matches more closely with small-gap species like sugar maple and ironwood. Its peak presence as seedlings under a remote canopy (situation 13) is also more typical of small-gap species **(FIA-1)**.

Historic Change in Abundance
Populations of red maple have been expanding in Minnesota. Red maple abundance has at least doubled since pre-settlement times and is most evident in the young growth-stage of MHc26 sites where it has increased from trace amounts to about 12 % of the trees today **(PLS/FIA-1)**. This is due in part to its regenerative flexibility. Historically, it was a large-gap strategist on MHc26 sites but it relies more on its small-gap strategies in modern stands. Our interpretation is that this is the consequence of fire-suppression, in particular the lack of surface fires that periodically "cleansed" MHc26 stands of maple regeneration. Logging doesn't eradicate maple as did fire, and modern regeneration harvests simply release advance regeneration of red maple. We estimate that the rotation of such surface fires was 75 years, but the general lack of fire-sensitive species in historic MHc26 stands would suggest that they were either more frequent than we have calculated or extremely effective. The abnormal abundance of red maple on MHc26 sites may be a hindrance to managing these sites for the gap and open regeneration strategists that were more common historically.

Basswood

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

Suitability

MHc26 sites provide ***excellent habitat*** for basswood trees. The ***suitability rating*** of 4.5 for basswood is influenced mostly by its high presence (45%) as trees on these sites in modern forests **(R-1)**. When present, basswood is an important co-dominant tree, contributing 13% mean cover in mature stands. This ranking is fourth, tied with red maple and following northern red oak, quaking aspen, and paper birch on MHc26 sites. All central mesic hardwood communities provide excellent habitat for basswood (see Suitability Tables). Among these, MHc26 is the poorest choice because basswood is favored on moister and richer MHc sites.

Young Growth-stage: 0-35 years

Historically, basswood was a minor co-dominant in young MHc26 stands **(PLS-1, PLS-2)**. Young basswoods represented 3% of the trees at survey corners described as burned, well behind fire-tolerant species like aspen, paper birch, and the oaks **(PLS-3)**. Basswood bearing trees were not recorded at survey corners described as windthrown. Small-diameter basswood regeneration was consistently present in the post-disturbance recruitment window **(PLS-5)**, beginning at low abundance and increasing towards the end of the young growth-stage. Our interpretation is that stump sprouts contributed most to basswood's immediate presence in young burned over MHc26 sites. Because basswood regeneration increases throughout the young growth-stage, we believe there was some successful establishment and recruitment in response to aspen self-thinning and formation of a taller canopy.

Transition: 35-55 years

As stands transitioned to mature conditions basswood increased to about 3% relative abundance **(PLS-1, PLS-2)**. Most likely, the disintegration of the initial-cohort aspen canopy released basswood seedlings established during the young growth-stage. Small-diameter basswood regeneration had peak abundance in the 40-year age class and persisted at fair levels until 60 years **(PLS-5)**. We interpret this as basswood having some success establishing and recruiting seedlings under a partial canopy of initial-cohort trees.

Mature Growth-stage: 55-135 years

Basswood's relative abundance was stable at about 3% in the mature growth-stage **(PLS-1, PLS-2)**. All of these basswood bearing trees occurred at survey corners of mixed composition. Small-diameter basswood regeneration was detected only in the 60-year age-class **(PLS-5)**. We interpret this as modest, but continued success of recruiting seed-origin trees under declining initial-cohort trees. At this stage basswood regeneration and poles were coming in beneath quaking aspen, paper birch, and sometimes red oak.

Old Growth-stage: >135 years

Basswood persisted into the old growth-stage as a minor co-dominant, which is why we consider basswood to be mostly a ***late-successional*** species **(PLS-1, PLS-2)**. This interpretation is supported mostly by its obvious ability to recruit seedlings through all height strata in modern MHc26 forests **(R-2)**. Just 3% of the pre-settlement MHc26 landscape was old forest, and thus PLS records are sparse for an infrequent tree like basswood. The few records available are consistent with that of late-successional species showing basswood replacing mid-tolerant trees like paper birch and white pine.

Regeneration Strategies

Basswood's primary regenerative strategy in MHc26 sites is to fill gaps created by the demise of individual trees or tree groups in the canopy of mature and old stands. The historic PLS data favor the idea that basswood did best in ***large gaps*** because: (1) the fact that basswood abundance rises in response the decline of initial-cohort aspen **(PLS-1,PLS-2)**, (2) it has some presence at survey corners where we presume partial canopy loss **(PLS-3)**, and (3) its peak recruitment window is a gap window rather than post-disturbance or ingress window **(PLS-5)**. In modern forests, basswood's high abundance as poles in tree stands (situation 23) is characteristic of trees that recruit well in large gaps.

Basswood's behavior in our releve samples points more towards the strategy of filling ***small-gaps***. Basswood shows excellent ability in recruiting seedlings through all height strata in modern, mature forests with a closed canopy **(R-2)**. Its regenerant and seedling indices (4.0) are intermediate between values that we consider typical of either large- or small-gap strategists. Basswood also shows good ability to bank seedlings under a remote canopy (situation 13) in modern forests **(FIA-1)**, which is typical of small-gap strategists.

It is clear that basswood is flexible in its regenerative strategies. Its modest presence at burned PLS survey corners suggests that its sprouting ability allowed it to regenerate at low relative abundance in the open. Most of its modern presence in MHc26 forests is accomplished by establishment and recruitment in of gaps of any size.

Historic Change in Abundance

Populations of basswood have been expanding slightly in Minnesota. Basswood abundance has at roughly tripled since pre-settlement times on MHc26 sites and this is most evident in the young growth-stage where it has increased from trace amounts to about 6% of the trees today **(PLS/FIA-1)**. Our interpretation is that the modern expansion of basswood on MHc26 sites is the consequence of fire-suppression, in particular the lack of surface fires that periodically "cleansed" MHc26 stands of young basswood. Logging doesn't eradicate basswood as did fire, and modern regeneration harvests tend to release advance regeneration of basswood which is present in most MHc26 forests **(R-2)**.

Sugar Maple

- ***excellent habitat suitability rating***
- ***late-successional***
- ***small-gap regeneration strategist***
- ***no historic regeneration window***

Identification Problems

The PLS surveyors did not distinguish between sugar and red maple. “Hard maple” or “sugar” were clear references to sugar maple in Minnesota. On occasion the surveyors would refer to “soft maple” which we interpret as red maple in upland habitats. Most references were just to “maple,” which we have assigned to red maple in this analysis leaving but a few explicit references to hard/sugar maple for our historic interpretation. MHc26 releve samples show that for plots with maple present: 24% have both species present; 50% are red maple without sugar maple; 26% are sugar maple without red maple. We consider sugar maple and red maple to be ecologically similar for most silvicultural considerations.

Suitability

MHc26 sites provide ***excellent habitat*** for sugar maple trees. The ***suitability rating*** of 4.3 for sugar maple is influenced mostly by its presence (29%) as trees on these sites in modern forests **(R-1)**. When present, sugar maple is an important co-dominant tree, contributing 16% mean cover in mature stands. This ranking is sixth, tied with bur oak and following northern red oak, quaking aspen, paper birch, red maple, and basswood on MHc26 sites. All central mesic hardwood communities provide excellent habitat for sugar maple (see Suitability Tables). Among these, MHc26 provides the poorest opportunities because the growth of sugar maple is limited by drier and poorer soils than is optimal.

Growth-stages

There are insufficient historic data in the PLS notes to reconstruct by growth-stage the natural behavior of sugar maple on MHc26 sites. Explicit references to “hard maple” or “sugar” were scant. Today, sugar maple is an important component of MHc26 stands, accounting for 13-17% of all FIA trees in young, mature, and old growth stages **(PLS/FIA-1)**. The FIA data show increasing abundance as stands age, which is characteristic of ***late-successional*** species. Advance regeneration is present in 71% of mature stands sampled by releves **(R-2)**. This strongly suggests that sugar maple will be an important species on MHc26 sites into the future.

Regeneration Strategy

Among the common trees in MHc26 forests, sugar maple shows the best ability to germinate and recruit seedlings and saplings in the understory of mature stands **(R-2)**. Likewise, the FIA data show that sugar maple is most abundant in subordinate canopy situations (13, 12, 23) especially as saplings beneath a tree canopy **(FIA-1)**. There seems to be a burst of sugar maple regeneration as the main canopy attains tree height. The ability to develop a large seedling bank, is the hallmark of trees able to regenerate in ***small-gaps***.

Historic Change in Abundance

Sugar maple populations have exploded on MHc26 sites in recent times. Sugar maple was never present above trace amounts in any growth-stage of the pre-settlement community. Today it is a co-dominant in all growth-stages with 13-17% relative abundance **(PLS/FIA-1)**. MHc26 sites tend to be gravelly inclusions within landforms of finer-textured parent material that were dominated by sugar maple. Surface fires occurred on MHc26 sites just enough to exclude sugar maple. Our interpretation is that sugar maple populations have expanded greatly on MHc26 sites because of fire suppression and the fact that logging doesn’t kill sugar maple as fire once did. The abnormal abundance of sugar maple on MHc26 sites, especially in the young growth stage, may be a hindrance to managing these sites for the large-gap and open regeneration strategists that were historically the dominant trees.

Bur and White Oak

- ***excellent habitat suitability rating for bur oak***
- ***fair habitat suitability rating for white oak***
- ***mid-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 50 years***

Identification Problems
The PLS surveyors did not distinguish between bur and white oak. Thus, interpretations of PLS data for the more common bur oak should always be done knowing that some of these trees were likely white oak. MHc26 releve samples show that for plots with these oaks present: 2% have both species present; 75% are bur oak without white oak; 23% are white oak without bur oak. The lack of overlap in the releve data would suggest that species are not at all alike. However, they have quite similar patterns of regeneration in modern forests **(R-2, FIA-1)** and for that reason we consider bur and white oak to be ecologically equivalent for most silvicultural considerations.

Suitability
MHc26 sites provide ***excellent habitat*** for **bur oak** trees. The ***suitability rating*** of 4.3 for bur oak is influenced mostly by its high presence (28%) as trees on these sites in modern forests **(R-1)**. When present bur oak is a co-dominant, contributing 17% mean cover when present. This ranking is sixth, tied with sugar maple and following northern red oak, quaking aspen, paper birch, red maple, and basswood on MHc26 sites. Except for MHc38, central mesic hardwood communities offer excellent habitat for bur oak (see Suitability Tables).

MHc26 sites provide just ***fair habitat*** for **white oak** trees. The ***suitability rating*** **(R-1)** for white oak is mostly the consequence of low presence (9%), but it is not so different from bur oak with regard to cover when present (15%). The ranking is eleventh among trees common on MHc26 sites. White oak's occurrence in central mesic hardwood communities is sporadic and only the MHc38 community offers excellent habitat (see Suitability Tables).

Young Growth-stage: 0-35 years
Historically, bur and white oak were infrequent in young MHc26 stands **(PLS-1, PLS-2)**. Young bur and white oaks represented just 2% of the trees at survey corners described as burned, well behind red oak, aspen, and paper birch **(PLS-3)**. Bur and white oaks have significantly higher presence (10%) at windthrown corners. Our interpretation is that these young oaks were sprouts among aspen suckers on burned lands, and that they were the wind-hardy survivors in windthrown stands. Bur and white oak bearing trees were not recorded as small-diameter regeneration in the post-disturbance window **(PLS-5)**, suggesting that this growth-stage offered little opportunity for seedling establishment. Because the relative abundance of bur and white oak increases during the young growth stage we believe that oak survivorship was much higher than for the surrounding aspen.

Transition: 35-55 years
As stands transitioned to mature conditions bur and white oak increased in abundance **(PLS-2)**. Because they were nearly absent in young forests, we interpret this increase to be the consequence of limited success seeding into young MHc26 stands. Both species show peak occurrence of small-diameter regeneration in the G-1 gap window that corresponds with the transition **(PLS-5)**. Apparently large-gaps in the canopy of declining aspen provided the right habitat for establishing seed origin bur and white oaks.

Mature Growth-stage: 55-135 years
Bur and white oaks were minor, co-dominants of mature MHc26 forests **(PLS-1, PLS-2)**. Because their abundance peaks slightly in the mature stage and seems to have done so in response to the decline of initial-cohort trees, we consider bur and white oak to be a ***mid-successional*** species.

Small-diameter regeneration of these oaks was present until about age 70 **(PLS-5)**, and we interpret this as limited success of recruiting seed-origin trees under the remnants of initial cohort aspen and less often, under red oak.

Old Growth-stage: >135 years

Bur and white oak persisted in slightly lower abundance into the old growth-stage **(PLS-1)**. There are no records of smaller diameter bur and white oaks in old MHc26 forests that would suggest regeneration **(PLS-5)**. Also, bur and white oak show just fair ability to regenerate and recruit seedlings in modern, mature forests **(R-2)**. Thus, we believe that their persistence into the old growth-stage is a consequence of longevity more than ability to regenerate under a canopy.

Regeneration Strategy

The primary regenerative strategy of bur and white oak on MHc26 sites to fill ***large-gaps***. It was most successful at this when gaps formed under a declining canopy of initial-cohort quaking aspen. In the historic PLS data this interpretation is supported by: (1) their peak abundance in response to the decline of the initial-cohort species **(PLS-1)**, (2) they were important species at survey corners showing partial canopy loss **(PLS-3)**, and (3) they show peak recruitment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**. The high percentage of bur oak poles under trees (situation 23) in the FIA data **(FIA-1)** is also a characteristic of species that tend to regenerate best in large gaps.

The rotation of 75 years for maintenance disturbances (see above) would suggest that by the time MHc26 forests reached the old growth stage (135 years) they would have experienced a couple of surface fires or similar events that result in partial canopy loss. Such events clearly favor trees like bur and white oak that depend mostly on large-gaps for regeneration. We believe that such disturbances are the main reason that bur and white oak persisted into the old growth-stage on MHc26 sites. We believe also that these fires were particularly effective at diminishing populations of trees like sugar maple that are superior to large-gap species in competing for resources.

Historic Change in Abundance

The modern abundance of bur and white oak is not much different from that of historic times on MHc26 sites **(PLS/FIA-1)**. Here, and in other communities, these oaks have the reputation of constant presence and indifference to disturbance. This is usually attributed to their physiological ability to build large rootstocks and store considerable resources below ground. Today, they seem as indifferent to logging as they were to fire and windthrow historically.

White Pine

- ***good habitat suitability rating***
- ***late-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 40 years***

Suitability
MHc26 sites provide ***good habitat*** for white pine trees. The ***suitability rating*** of 3.5 for white pine is influenced mostly by its cover when present (19%) on these sites in modern forests **(R-1)**. Presence of white pine is low (10%) probably due to historic exploitation. The ranking is ninth among trees common on MHc26 sites, but the fact that its cover-when-present exceeds its presence would suggest that it would move up in the ranking if its seed source were restored or if it were more often planted. Among the central mesic hardwood communities, only the MHc26 and MHc38 communities provide habitat for white pine (see Suitability Tables).

Young Growth-stage: 0-35 years
Historically, white pine was an infrequent tree in young MHc26 stands **(PLS-1, PLS-2)**. The few occurrences of young white pines were at survey corners described as burned **(PLS-3)**. Just a single tree was recorded at a windthrown survey corner. Although white pine can be an important post-fire tree in other communities, it played no immediate role in young MHc26 forests. Small-diameter white pine regeneration was increasingly abundant in the post-disturbance window and peaked in the G-1 gap window **(PLS-5)**. We believe that on MHc26 sites, some seed-origin white pines got their start in what must have been thicket-like growth of 20-30 year old aspen.

Transition: 35-55 years
As stands transitioned to mature conditions white pine increased slightly in abundance **(PLS-2)**. Because it was nearly absent in young forests, we interpret this increase to be the consequence of modest success seeding into young MHc26 stands followed by successful recruitment during the transition. White pine's peak abundance as small-diameter regeneration was at age 40 **(PLS-5)**, suggesting that openings in the initial-cohort aspen canopy were good places for recruitment and perhaps establishment beyond the young growth-stage.

Mature Growth-stage: 55-135 years
White pine was a minor, co-dominant of mature MHc26 forests **(PLS-1, PLS-2)**. White pine was present as small-diameter regeneration until about age 60 **(PLS-5)**, and we interpret this as limited success of recruiting seed-origin trees under the remnants of the initial-cohort trees. As the smaller diameter tree at survey corners, white pine was mostly coming in beneath paper birch and sometimes under aspen.

Old Growth-stage: >135 years
White pine peaks as an important co-dominant MHc26 tree in the old growth-stage, which is why we consider white pine to be a ***late-successional*** species **(PLS-1, PLS-2)**. There is little evidence though that white pine became important in the old growth-stage because it was regenerating in response to fine-scale disturbance. There were almost no records of small diameter white pines in old MHc26 forests. White pine shows limited ability in recruiting seedlings under a canopy **(R-2, FIA-1)**, which is why we believe that most MHc26 white pines were established under more open conditions that accompanied the collapse of the initial-cohort trees. Its abundance in this stage must have been a consequence of longevity.

Regeneration Strategy
White pine's primary regenerative strategy on MHc26 sites is to fill ***large-gaps***. It was most successful at this when gaps formed in the declining canopy of paper birch or quaking aspen. In the historic PLS data this interpretation is supported by: (1) the fact that white pine responds to the decline of the initial cohort species **(PLS-1, PLS-2)**, (2) it is most abundant at survey corners

showing partial canopy loss **(PLS-3)**, and (3) it shows peak establishment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**.

The rotation of 75 years for maintenance disturbances (see Disturbance Regime) would suggest that by the time MHc26 forests reached the old growth-stage (135 years) they would have experienced a couple of surface fires or similar events that result in partial canopy loss. Such events clearly favor trees like white pine that depend mostly on ***large-gaps*** for regeneration. We believe that such disturbances are the main reason that white pine persisted into the old growth-stage on MHc26 sites. We believe also that these fires were particularly effective at diminishing populations of trees like sugar maple that are superior to large-gap species in competing for resources.

Historic Change in Abundance

Today, white pine is hardly mentioned at FIA subplots modeled to be MHc26 sites and no regeneration was recorded as saplings or poles **(FIA-1)**. The loss of white pine is most evident in the old growth-stage where it once represented 10% of all bearing trees, but now did not occur at all **(PLS/FIA-1)**. In releve samples of modern MHc26 forests, white pine shows up mostly as small seedlings **(R-2)**. Recruitment of seedlings to sapling-sized trees is poor. Our interpretation is that on MHc26 sites, white pines are struggling to rise above snow-level. Winter herbivory by deer and snowshoe hare depredation are the usual explanations for the lack of success above the snow line. In the absence of seed trees to constantly augment the bank of seedlings, it is unlikely that white pine will achieve the population levels required to overcome herbivory.

Red Pine

- ***good habitat suitability rating***
- ***unknown successional status***
- ***unknown regeneration strategy***
- ***unknown regeneration window***

Suitability
MHc26 sites provide ***good habitat*** for red pine trees. The ***suitability rating*** of 3.4 for red pine is influenced mostly by its cover when present (20%) on these sites in modern forests **(R-1)**. Presence of red pine is low (10%) probably because of historic exploitation and the general lack of seed trees on the modern landscape. The ranking is tenth among trees common on MHc26 sites, but the fact that its cover when present exceeds its presence would suggest that it would move up in the ranking if its seed source were restored or if more red pine was planted. MHc26 is the only central mesic hardwood community that offers habitat for red pine (see Suitability Tables).

Growth-stages
There are insufficient historic data in the PLS notes to reconstruct by growth-stage the natural behavior of red pine on MHc26 sites. Today, it seems to be a late-successional species as it occurs almost exclusively in the mature forests sampled by releves. However, its regeneration strategy would suggest just the opposite, as we recorded almost no young red pines in mature forests **(R-2)**. From this one would conclude that it required the open conditions of a post-disturbance stand in order to establish itself on MHc26 sites.

Historic Change in Abundance
Red pine's presence of 10% on releves is surprisingly high given its virtual absence in the PLS data (2 trees) and FIA data (1 tree). Not only were there some red pines on the releve plots, but red pine stumps were often mentioned in the field notes when trees were not present. Our samplings span forests that regenerated in different eras: PLS *ca.* 1850-1900, releves *ca.* 1930-1960, and FIA 1977-present. It would seem that red pines responded to some unknown circumstance of the mid-1900's that was not historically captured in the PLS notes or apparent in the past 30 years.

(PLS-1) Historic Abundance of MHc26 Trees in Natural Growth-stages

Table values are relative abundance (%) of Public Land Survey (PLS) bearing trees at corners modeled to represent the MHc26 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 - 35	35 - 55	55 - 135	~ 135	> 135
	Young	T1	Mature		Old
Quaking (Big-toothed) Aspen	**76%**	ǀǀ	**22%**	⌉	**26%**
Paper Birch	**13%**	⌉⌉	**40%**	ǀǀ	**20%**
Red Oak	**4%**	⌉	**12%**	ǀ	**11%**
Red Maple	**1%**	⌉	**5%**	ǀ	**2%**
Bur (White) Oak	**–**	⌉	**5%**	ǀ	**4%**
Basswood	**1%**	⌉	**3%**	↔	**3%**
White Pine	**–**	⌉	**2%**	⌉	**10%**
White Spruce	**–**	⌉	**2%**	⌉	**12%**
Miscellaneous	**6%**		**12%**		**15%**
Percent of Community in Growth Stage in Pre-settlement Landscape	**21%**	**31%**	**45%**		**3%**

PLS-1

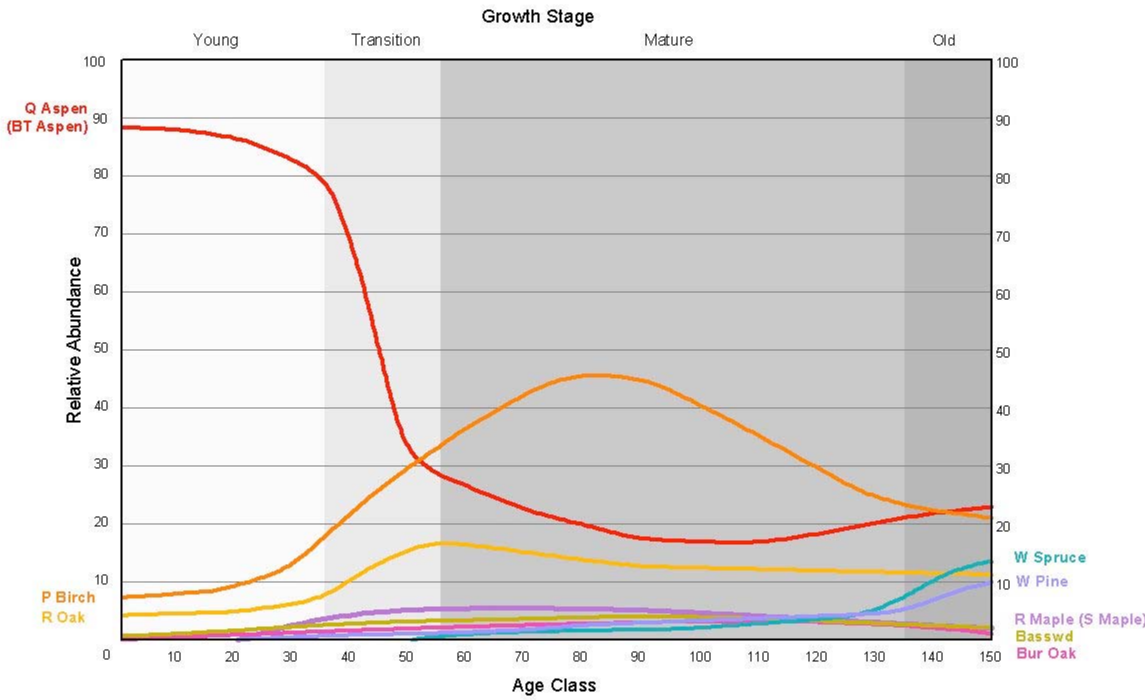
Trees included in Table PLS-1 are species with greater than 3% relative abundance in at least one growth-stage. Species that are now abundant in MHc26 forests, but were rare historically appear in Table **PLS/FIA-1**.

On MHc26 sites, the PLS surveyors did not consistently distinguish the more prevalent quaking aspen from big-toothed aspen, or the more prevalent bur oak from white oak.

Public Land Survey linked text

(PLS-2) Abundance of trees throughout succession in MHc26

Caption: Graphed for the different species of MHc26 trees is their relative abundance (%) as PLS bearing trees by age class. The data were initially smoothed from adjacent classes and then by visually fitting lines to illustrate general trends.



Documentation for Figure PLS-2

**Public Land Survey linked text

(PLS-3) Historic Abundance of MHc26 Trees Following Disturbance

Table values are raw counts and (percentage) of Public Land Survey (PLS) bearing trees at survey corners likely to represent MHc26 forests. The columns represent our interpretation of disturbance at the survey corners. Trees in parentheses are minor species that occur in modern forests but couldn't be separated from more common trees because the surveyors did not distinguish them in their field notes. Shading associates trees that peak in the same disturbance category.

Tree	Burned		Windthrown		Maintenance		Mature	
Quaking (Big-toothed) Aspen	221	68%	48	41%	200	40%	2524	35%
Bur (White) Oak	7	2%	12	10%	38	8%	221	3%
Northern Red Oak	32	10%	30	26%	146	30%	826	11%
White Pine	6	2%	1	1%	13	3%	129	2%
Paper Birch	41	13%	21	18%	74	15%	2614	36%
Red (Sugar) Maple	2	1%	2	2%	6	1%	378	5%
Basswood	9	3%	0	-	7	1%	232	3%
Total (% of grand total, 8154)	323	4%	116	1%	494	6%	7221	89%

PLS-3

Table PLS-3 includes only trees ranked as having excellent, good, or fair suitability for MHc26 sites. Tree sums will not match the totals in the Natural Disturbance Regime text, because trees of poorer suitability were included in that analysis.

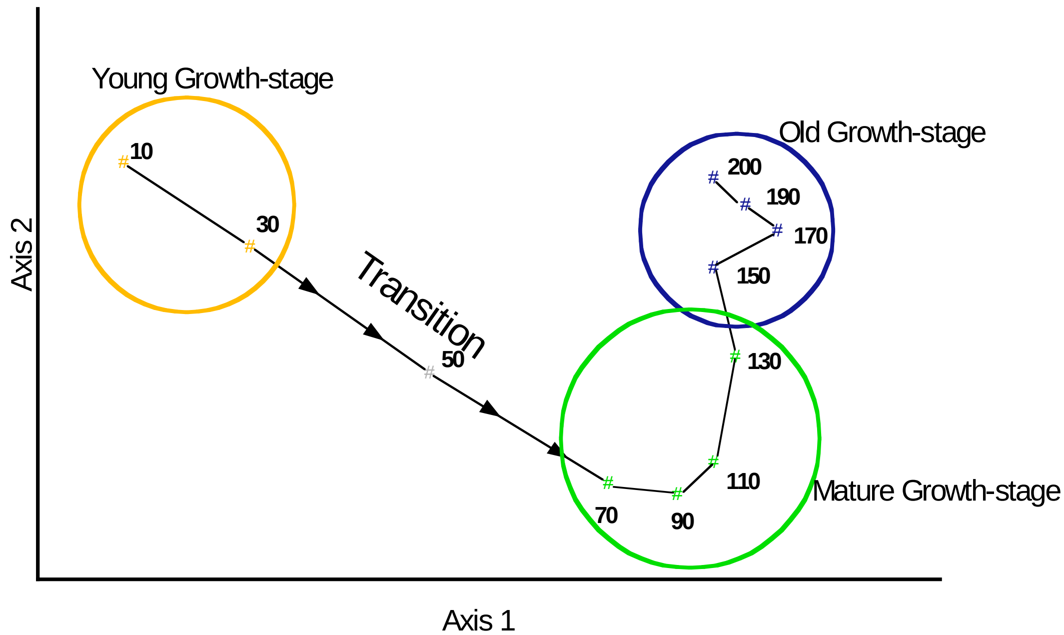
PLS survey corners were assigned to four disturbance categories:

1. The burned category is based upon explicit reference by the surveyors to burned timber or burned land.
2. The windthrown category is based upon explicit reference by the surveyors to windthrown timber.
3. The maintenance category includes corners with structural conditions requiring chronic disturbance (e.g. barrens, openings) OR forest where bearing tree distances match more closely the distances observed in the other structural categories. This category is our inference of partial canopy loss.
4. The mature category includes corners with no explicit or implicit reference to disturbance and has bearing trees at distances typical of fully stocked forest.

Public Land Survey linked text

(PLS-4) Ordination of Historic MHc26 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.



PLS-4

For each PLS survey corner we estimated stand age based on the diameter of the largest tree. The corners were placed into 20-year age-classes for this analysis. We used coarse age-classes mostly because the surveyors tended to estimate diameters coarsely in even inches. For each age-class the relative abundance of each bearing tree type was calculated and used to characterize and ordinate the age-classes. Detrended Correspondence Analysis provided the smoothest ordinations, meaning that the age-classes tend to sequentially track across the ordination plot. There is always some subjectivity and uncertainty in placing the seams between growth-stages and transitions in these diagrams. When uncertain, we placed seams that match process transitions (self-thinning to density-independent mortality, ingress of shade-tolerants, etc.) described in more general models of stand dynamics in silvicultural literature.

(PLS-5) Historic Windows of Recruitment for MHc26 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 0-30 years	G-1 30-70 years	I-1 70-110 years	G-2 110-150 years	I-2 >150 years
Yes	Quaking Aspen[1]	0-30	Excellent	Fair to 50	--	--	--
Yes	Paper Birch	40	Fair	Good to 70	--	--	--
No	Red Maple[2]	30-50	Fair after 20	Good to 70	--	--	--
Yes	Red Oak	40-50	Fair	Fair to 70	--	--	--
No	White Pine	40	Poor	Fair to 60	--	--	--
Minor	Basswood	40	Poor	Fair to 60	--	--	--
Minor	Bur Oak[3]	50	--	Poor	--	--	--
No	White Spruce	120-150	--	Poor	Good	Good	Good

Recruitment windows from ordination PLS-4:

- **P-D:** post-disturbance filling of understocked areas, 10-30 years
- **G-1:** gap filling during decline of initial-cohort quaking aspen and big-toothed aspen, 30-70 years
- **I-1:** ingress of seedlings under canopy of paper birch with some quaking aspen, big-toothed aspen, red oak, red maple, and bur oak, 70-110 years
- **G-2:** gap filling during decline of birch and some red maple, 110-150 years
- **I-2:** ingress of seedlings under a canopy of quaking aspen, big-toothed aspen, paper birch, red oak, white pine, and white spruce.

-- : 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; **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

1. Quaking aspen bearing trees couldn't be segregated from big-toothed aspen in the PLS notes for this community. The quaking aspen data probably include big-toothed aspen, which we consider ecologically similar to quaking aspen.
2. Red maple bearing trees couldn't be segregated from sugar maple in the PLS notes for this community. The red maple data probably include sugar maple, which we consider ecologically similar to red maple.
3. Bur oak bearing trees couldn't be segregated from white oak in the PLS notes for this community. The bur oak data probably include white oak, which we consider ecologically similar to bur oak.

PLS-5

Recruitment windows were defined from ordinations of age-classes (PLS-4) that illustrate rates of compositional change. Windows are strings of contiguous age-classes where the rate of change is either consistently high or low.

Post-disturbance windows (P-D) are strings of contiguous age classes that start at age zero and during which we observe little compositional change.

For windows showing lots of compositional change (G-1, G-2) we assume gap-filling because canopy species are declining and being replaced by subordinate trees of another species.

Mid- and late-successional windows showing little compositional change (I-1, I-2) represent episodes of seral stability and subordinate trees are assumed to have established themselves by ingress under a canopy.

After setting post-disturbance, gap, and ingress windows from the ordinations, we calculated how often trees are were found in a subordinate condition during those episodes. A tree was considered subordinate when its diameter was less than half that of the largest tree at a PLS corner. Our assumption is that subordinate trees are younger than the larger diameter trees and that they could not have been established in response to a stand-regenerating disturbance.

Initial-cohort trees that rarely show diameter subordination are true pioneers that regenerate almost entirely in response to stand conditions after catastrophic fire, wind, or flooding.

Initial-cohort trees that show diameter subordination are presumed to have some regenerative ability under stand conditions not associated with the stand-initiating disturbance. For initial-cohort species in forest classes, such windows represent and a shift in regenerative strategy, e.g. from post-disturbance sprouting to seeding into understocked areas. For initial-cohort woodland species, such windows represent a persistent strategy in naturally long windows of recruitment where trees are replacing brush or grass.

For species not in the initial cohort, the windows define the timing of a tree's ability to ingress beneath a canopy or to fill gaps created when canopy species senesce. Ingress or gap-filling windows can end or continue indefinitely depending upon species' reaction to stand maturation processes that result in smaller gaps, deepening shade, increasingly organic seedbeds, and increased likelihood of infection by diseases or pests.

(R-1) Suitability ratings of trees on MHc26 sites

This table presents an index of suitability for trees in MHc26 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 MHc26			
Tree	**Percent Presence**	**Mean Percent Cover When Present**	**Suitability Index***
Northern red oak (Quercus rubra)	**81**	**35**	**5.0**
Quaking aspen (Populus tremuloides)	**41**	**21**	**4.7**
Paper birch (Betula papyrifera)	**58**	**14**	**4.7**
Red maple (Acer rubrum)	**44**	**14**	**4.5**
Basswood (Tilia americana)	**45**	**13**	**4.5**
Sugar maple (Acer saccharum)	**29**	**16**	**4.3**
Bur oak (Quercus macrocarpa)	**28**	**17**	**4.3**
Big-toothed aspen (Populus grandidentata)	**25**	**18**	**4.2**
White pine (Pinus strobus)	**10**	**19**	**3.5**
Red pine (Pinus resinosa)	**10**	**20**	**3.4**
White oak (Quercus alba)	**9**	**15**	**2.9**
Green ash (Fraxinus pennsylvanica)	**12**	**7**	**2.3**
Ironwood (Ostrya virginiana)	**10**	**8**	**2.1**

*Suitability ratings: **excellent**, **good**, **fair**

R-1

Suitability ratings indicate our interpretation of likely success of natural regeneration and growth to crop tree status with little silvicultural manipulation. Statewide suitability tables are available at: link to Tree Tables Field Version.pdf.

What we know of the behavior of trees and their suitability for sites is based upon a classification[1] of thousands of vegetation (releve) plots in Minnesota's native forests. The classification is purely empirical, based upon the occurrence and abundance of all vascular plants in these plots. For the purpose of land management, we have identified 52 basic forest Classes that are not only vegetationally different, but also have interpretable differences in parent material, landform, soil texture, soil moisture regime, and hydrology. The premise of this approach is that the NPC classification has captured the "realized" niche[2] of our trees and provides a field tool for recognizing the physical and competitive environment of forest sites.

The releve plots come from stands of trees older than 40 years through old-growth. The majority of sampled stands are 60 to 80 years old, and most plots were collected over the past 10 years. This means that we are most often observing tree success that reflects regeneration conditions *ca.* 1930-1960 and survival conditions since that time. We are assuming that most of the site conditions important to trees are the same now as then, or at least within their range of natural variability[3]. Thus, predictions of suitability from this table should always be considered in light of modern conditions that depart from past reference conditions.

A second consideration is that our sample plots were of natural forests. Here natural means that the vegetation is mostly composed of native plants and that enduring effects of human activity are not obvious. Most stands sampled have been logged and many grazed. We are assuming that current stand composition includes most of the plants and other trees with which a tree has coexisted in the past. The effect of these plants on the tree species under consideration may be mutualistic or competitive. Also, the effect of these plants on individual trees can change as the tree undergoes physiological changes as it matures. Altering the effects of these plants to benefit certain trees at the appropriate times during their maturation is the essence of silviculture. Because we sampled natural stands with little evidence of manipulation, high ratings imply little need for silvicultural intervention or tending. Conversely, trees with low ratings for certain NPCs will require intensive silvicultural effort.

For this analysis we created a very simple index to estimate suitability. This index is the product of percent presence and percent cover when present. For example, there are 256 sample plots of Northern Mesic Hardwood Forest (MHn35). Basswood trees over ten meters tall (~33 feet) occur in 164 of these plots, thus its percent presence as a tree is (164/256)*100= 64.1%. The mean cover of basswood trees on those 164 plots is 15.0%. Thus, its index is 64.1*15.0=962.

To communicate our estimates of suitability, we ranked the indices of plants that often occur (>5% presence) in a community and divided that ranking into 5 equal parts to create five suitability classes: excellent, good, fair, poor, and not suitable. Continuing the example above, 113 plants were ranked for MHn35 and basswood had the 8^{th} highest ranking, placing it in the excellent class along with 22 other plants.

To estimate relative suitability, we simply expressed the rank order of a tree's index among all of the trees that occur in that community. In the above example, sugar maple was the only tree with a higher index than basswood, thus basswood's rank is 2.

1. **Minnesota Department of Natural Resources** (2003). Field Guide to the Native Plant Communities of Minnesota: the Laurentian Mixed forest Province. Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program. MNDNR St. Paul, MN.

2. **Oliver, C.D. and B. C. Larson.** 1996. Forest Stand Dynamics, update edition. John Wiley & Sons, Inc.

3. **Landres, P.B., P. Morgan, and F.J. Swanson.** 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9:1179-1188.

4. **Forest Inventory & Analysis Plots** 1977, 1990, 2002. North Central Research Station, 1992 Folwell Ave, St. Paul, MN 55108

(R-2) Natural Regeneration and Recruitment of Trees in Mature MHc26 Stands

This table presents an index of regeneration for MHc26 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 MHc26 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 germinants, seedlings, saplings, and trees common in the canopy of Central Dry-Mesic Oak-Aspen Forest – MHc26					
Trees in understory	**% presence R, SE, SA**	**R-index**	**SE-index**	**SA-index**	**T-index**
Northern red oak (Quercus	**85**	**4.7**	**4.7**	**4.0**	**5.0**
Red maple (Acer rubrum)	**83**	**4.8**	**4.8**	**5.0**	**4.3**
Sugar maple (Acer saccharum)	**71**	**5.0**	**4.8**	**5.0**	**3.8**
Ironwood (Ostrya virginiana)	**70**	**4.5**	**4.5**	**4.7**	**2.3**
Basswood (Tilia americana)	**64**	**4.0**	**4.0**	**4.3**	**4.3**
Quaking aspen (Populus	**50**	**3.7**	**3.3**	**3.0**	**4.5**
Green ash (Fraxinus	**47**	**3.8**	**3.8**	**3.0**	**2.5**
Paper birch (Betula papyrifera)	**32**	**1.7**	**1.5**	**2.8**	**4.8**
Bur oak (Quercus macrocarpa)	**28**	**2.7**	**2.5**	**2.8**	**4.0**
Big-toothed aspen (Populus	**21**	**2.3**	**2.2**	**2.3**	**4.3**
White pine (Pinus strobus)	**15**	**3.3**	**2.7**	**1.7**	**3.3**
White oak (Quercus alba)	**10**	**2.5**	**2.0**	**1.8**	**3.3**
Red pine (Pinus resinosa)	**3**	**0.7**	**0.7**	**1.8**	**3.5**

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

% presence: the percent of 156 MHc26 sample plots with that species present under 10m (33 feet) tall (R, SE, SA layers)
R-index: index of representation as true seedling or under 10cm (4 inches) tall
SE-index: index of representation as seedlings over 10cm and under 2m (0.3-6.6 feet) tall
SA-index: index of representation as saplings 2-10m (6.6-33 feet) tall
T-index: index of representation as a tree >10m (33 feet) 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.

R-2

The releve method of sampling forest vegetation describes explicitly how trees occur at different heights. We modified raw releve samples by interpreting the occurrence of trees in four standard height strata: germinants 0-10cm tall, seedlings 10cm-2m tall, saplings 2-10m tall, and trees taller than 10m.

The releve samples all come from forests with an established canopy, so this dataset documents the presence and cover of trees in strata that have formed during the process of stand maturation, i.e. understory development.

We created an index to measure roughly the regenerative success of a tree in each stratum. The index is the product of (1) percent presence in that stratum for all releves classified as that community, (2) mean percent cover of that species when present in a stratum, and (3) the mean number of different strata reported in the releves when that species is present.

The indices for all trees were ranked, the range was then scaled to range between zero and 5. The index ratings of excellent, good, fair, poor, and not-applicable are the 5 whole number segments of the index.

(FIA-1) Structural Situations of Trees in Mature MHc26 Stands

This table presents percentages of structural situations for trees as recorded in Forest Inventory Analysis (FIA) subplots that we modeled to be samples MHc26 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
White Pine	6	-	-	-	-	-	100%
Red Pine	1	-	-	-	-	-	100%
White Oak	18	-	-	-	11%	-	89%
Red Oak	539	1%	6%	1%	20%	2%	70%
Paper Birch	276	4%	22%	5%	36%	5%	27%
Bur Oak	95	3%	14%	2%	31%	11%	40%
Quaking Aspen	737	29%	11%	13%	7%	14%	26%
Green Ash	39	8%	10%	5%	26%	28%	23%
Basswood	390	2%	8%	16%	18%	18%	37%
Red Maple	408	7%	11%	14%	31%	28%	9%
Bigtooth Aspen	69	22%	1%	26%	4%	25%	22%
Sugar Maple	392	4%	15%	16%	17%	39%	10%

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

FIA linked text

(PLS/FIA-1) Abundance of MHc26 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 MHc26 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 - 35		35 - 55	55 - 135		~ 135	> 135	
	Young		T1	Mature		T2	Old	
Quaking (Big-toothed) Aspen	**76%**	**50%**	ǀǀ	**22%**	**19%**	⌉	**26%**	**1%**
Paper Birch	**13%**	**4%**	⌉⌉	**40%**	**11%**	ǀǀ	**20%**	**2%**
Red Oak	**4%**	**5%**	⌉	**12%**	**22%**	ǀ	**11%**	**29%**
Red Maple	**1%**	**12%**	⌉	**5%**	**11%**	ǀ	**2%**	**4%**
Bur and White Oak	**–**	**1%**	⌉	**5%**	**4%**	ǀ	**4%**	**14%**
White Pine	**–**	**0%**	⌉	**2%**	**0%**	⌉	**10%**	**0%**
White Spruce	**–**	**1%**	⌉	**2%**	**0%**	⌉	**12%**	**0%**
Basswood	**1%**	**6%**		**3%**	**10%**		**3%**	**14%**
Sugar Maple	**0%**	**13%**		**0%**	**14%**		**0%**	**17%**
Green (Black) Ash	**--**	**0%**		**1%**	**1%**		**0%**	**3%**
Ironwood	**--**	**6%**		**1%**	**5%**		**2%**	**4%**
Miscellaneous	**5%**	**2%**		**7%**	**3%**		**10%**	**12%**
Percent of Community in Growth Stage in Presettlement and Modern Landscapes	**21%**	**13%**	**31%** **21%**	**45%**	**64%**		**3%**	**1%**

Natural growth-stage analysis and landscape summary of historic conditions is based upon the analysis of 3,649 Public Land Survey records for section and quarter-section corners. Comparable modern conditions were summarized from 2,525 FIA subplots that were modeled to be MHc26 sites.

Public Land Survey linked text
FIA linked text

Silviculture Systems for MHc26: No arrow - least favorable, ⇧ Favorable, ⇧⇧ Very Favorable

	Silviculture Systems	Clearcut	Patch Cutting	Group Seedtree	Dispersed Seedtree	Uniform Shelterwood	Group Shelterwood	Irregular Shelterwood	Group Selection	Strip Selection	Single Tree Selection
	Regeneration Strategy										
Northern Red oak	Large-gap (Small-gap)		⇧	⇧	⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧	⇧
Red Maple	Large-gap (Small-gap)		⇧	⇧	⇧	⇧⇧	⇧	⇧⇧	⇧⇧	⇧	⇧
Sugar Maple	Small-gap							⇧	⇧⇧	⇧⇧	⇧⇧
Basswood	Small-gap (Large-gap)		⇧	⇧		⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧
Quaking Aspen	Open (Large-gap)	⇧⇧	⇧⇧	⇧⇧	⇧⇧		⇧				
Green Ash	Large-gap		⇧	⇧	⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧	
Paper Birch	Large-gap (Open)	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧			
Bur Oak	Large-gap		⇧	⇧⇧	⇧	⇧	⇧⇧	⇧			
Big-toothed Aspen	Open (Large-gap)	⇧⇧	⇧⇧	⇧⇧	⇧⇧		⇧				
White Pine	Large-gap		⇧	⇧	⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧	
White Oak	Large-gap		⇧	⇧	⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧	
Red Pine	Open	⇧⇧									

Forest Health Considerations

Northern Red Oak

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Oak wilt	"	"
Defoliators (FTC, GM, etc.)	"	Predispose to mortality
Deer/ rodent browse	Seedlings and saplings	Mortality, topkill
Two-lined chestnut borer	Pole-sized and larger	Mortality
Stem decay	"	Volume loss

WATCHOUTS!

• Protect seedlings and saplings from browse damage.

• Avoid thinning oaks 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 two-lined chestnut borers and *Armillaria* root disease.

• If oak wilt is known to occur within one mile of the stand, prevent overland spread of oak wilt by not allowing thinning, harvesting, trail building, pruning or other activities that wound oaks from April 1st to July 15th.

• If oak wilt is present in this stand, several precautionary steps must be made prior to thinning or harvest. Please contact your Regional Forest Health Specialist for assistance.

• 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.

Quaking Aspen

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Forest tent caterpillar	"	Defoliation
Hypoxylon canker	Pole-sized and larger	Topkill and mortality
Saperda borer	"	Mortality
Stem decay = white trunk rot	"	Volume loss

WATCHOUTS!

• In over-mature stands, prolonged defoliation will accelerate mortality.

• Harvest during the winter to ensure adequate regeneration.

• To estimate the basal area of a stand affected by white trunk rot, determine the basal area with conks then multiply that number by 1.9.

• Trees along stand edges, openings and trees in low-density stands are more likely to be infected with Hypoxylon canker and infested with Saperda borer.

• 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.

Big-toothed Aspen

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Forest tent caterpillar	"	Defoliation
Hypoxylon canker	Pole-sized and larger	Topkill and mortality
Saperda borer	"	Mortality
Stem decay = white trunk rot	"	Volume loss

WATCHOUTS!

• In over-mature stands, prolonged defoliation will accelerate mortality.

• Harvest during the winter to ensure adequate regeneration.

• Trees along stand edges, openings and trees in low-density stands are more likely to be infected with *Hypoxylon* canker and infested with *Saperda* borer. Note that big-toothed aspen is five times more resistant to *Hypoxylon* canker than trembling aspen.

• 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.

Red and 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.

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.

MHc26 - 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 MHc26 that are more susceptible to compaction and rutting. They are listed in descending order of presence.

- Lady fern (*Athyrium filix-femina*)
- Virginia creeper (*Parthenocissus spp.*)
- Mountain maple (*Acer spicatum*)
- Black ash (U) (*Fraxinus nigra*)
- Side-flowering aster (*Aster lateriflorus*)
- Green ash (C) (*Fraxinus pennsylvanica*)
- Nannyberry (*Viburnum lentago*)
- American elm (U) (*Ulmus americana*)
- Jack-in-the-pulpit (*Arisaema triphyllum*)
- Graceful sedge (*Carex gracillima*)

(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

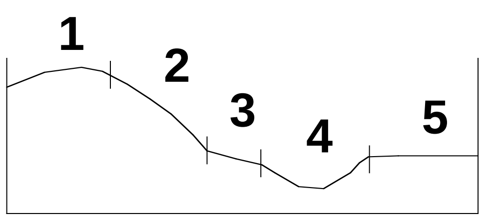
   Poor – water saturation occurs within 10 inches of the surface for most of the growing season

   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 linked text

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-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-1)** or graphic form **(PLS-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 linked text

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 **(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 **(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 **(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 **(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

Modern Forest linked text

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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 **(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 **(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