MHs39

MHs39 – Southern Mesic Maple-Basswood Forest

Natural Disturbance Regime, Stand Dynamics, and Tree Behavior

Summary and Management Highlights

In historic times, Southern Mesic Maple-Basswood Forest (MHs39) was a common hardwood community found mostly within the Eastern Broadleaf Forest Province south of Ottertail County. Outliers occur across the North-Central Glaciated Plains Section where rivers and lakes protected mesic forests from prairie wildfires. Outliers to the northeast are associated with shores and peninsulas of major lakes such as Mille Lacs and Leech Lake. (Figure 1). Detailed descriptions of this community are presented in the DNR Field Guides to Native Plant Communities of Minnesota.

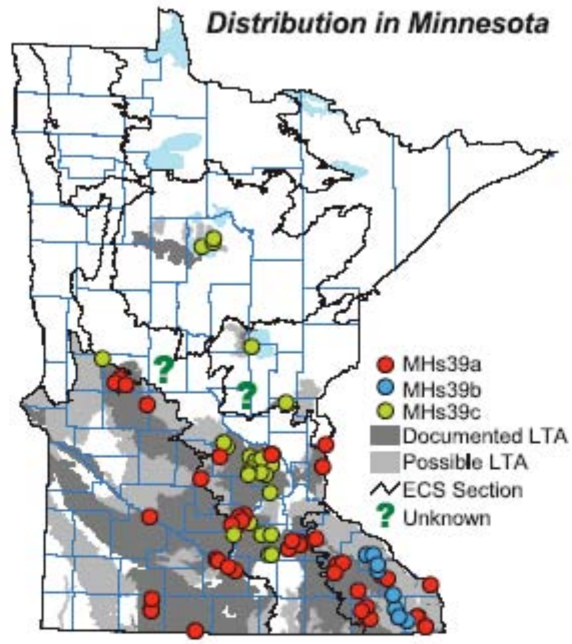


Figure 1. The range of MHs39 forests in Minnesota (shaded) and distribution of releve samples (red, blue, and green dots).

Commercial Trees and Management Opportunities

As a commercial forest, MHs39 sites offer a wide selection of crop trees and possible structural conditions. Sugar maple, basswood, northern red oak, red elm, and American elm are all ranked as excellent choices as crop trees by virtue of their frequent occurrence and high cover when present on MHs39 sites (see Suitability Tables). Bitternut hickory and black ash 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. Green ash, bur oak, white oak, and big-toothed aspen are ranked as just fair choices of crop trees, but stands can be managed to maintain their presence as minor trees for purposes other than timber production.

Among these species, red oak, basswood, big-toothed aspen, red or American elm, and sugar maple were the dominant native trees that have occupied MHs39 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)**. White oak was also native to MHs39 sites but occurred naturally at lower abundance, and is infrequent today. The consequence of fire suppression, commercial logging, and settlement in the past century has been to promote much more sugar maple and ironwood than was usual. Past history and land use as also encouraged the ingress of species that were not significant in native MHs39 stands such as box elder, red maple, paper birch, and green ash. The increased abundance of these trees, especially sugar maple, complicates our interpretations and the use of natural regeneration models as silvicultural strategies.

Natural Silvicultural Approaches

In the historic landscape, most MHs39 forests (50%) were transitioning between the young and mature growth-stages **(PLS-1)**. Roughly these were stands 35-75 years old. Towards the beginning of the transition, senescence of initial-cohort trees (mostly big-toothed aspen) created some recruitment opportunities for trees ranging from single-tree gaps to large gaps up to an acre. Because this happens so early there should be little need for creating regeneration opportunities, thus silvicultural approximation would amount to selectively thinning aspen from above to release crop trees but also maintain enough density of aspen or possibly elm to encourage clear boles.

Otherwise, natural transitioning in MHs39 forests involved the loss of canopy red oak and its replacement. We envision this process as creating a broad range of gap sizes depending upon the agent of mortality. Small-gaps created by the death of diseased trees helped to accelerate succession to mesic hardwoods; large-gaps created by maintenance disturbances resulted in regeneration opportunities for trees typical of young MHs39 forest. The small-gap process matches improvement harvesting, where canopy oaks are gradually removed to release subordinate crop trees. Presumably, cleaning sapling regeneration to select desired crop trees has been done in preparation of canopy removal. The small-gap approach should favor sugar maple, elm, ash, and basswood on MHs39 sites. Shelterwood variants or group selection systems match the scale of the large-gap process where the goal is to regenerate or release mid-tolerant trees. A substantial amount (9%) of transitioning or mature forest showed signs of partial canopy loss that favored less-tolerant hardwoods **(PLS-3)**. Surface fires probably created the large-gap opportunities that favored regeneration of red oak, big-toothed aspen, basswood, and bitternut hickory on these sites.

We believe that American elm played a role in transitioning MHs39 forests from oak cover-type to mesic hardwoods. It occurred more often in mixture with other trees than chance would dictate, appearing to be a cover tree for small-diameter regeneration of shade-tolerant species, especially sugar maple. We honestly don't know if its effect was to create dense, subcanopy shade that eliminated mid-tolerant trees from the groundlayer, or if its soil-enriching litter helped to improve seedbeds for trees like sugar maple. Though we don't understand it, we mention this behavior of elm because it may have practical application. It is possible that in the field, abundant elm is an indicator that natural regeneration opportunities for red oak are declining in favor of sugar maple and basswood. Because Dutch Elm disease kills elms when they reach pole-size, using elm to train crop trees as they did in the past might be a good silvicultural strategy that now doesn't require their removal.

In the historic landscape 46% of the MHs39 forests were mature and older than 75 years **(PLS-1)**. In this growth-stage most MHs39 trees maintained their presence by developing banks of seedlings that would recruit in canopy gaps. Most likely, diseases killed individual trees or groups of trees. Variants of selection harvesting could be used to approximate single-tree or few-tree gaps. These systems would favor small-gap strategists like sugar maple, American elm, red elm, and basswood over all others on MHs39 sites. Group selection or some variants of the shelterwood system would favor species like black ash, bitternut hickory, and possibly red oak which recruit better in larger gaps. In theory, MHs39 forests could be maintained in their mature growth-stage indefinitely with these silvicultural systems.

A small proportion (4%) of native MHs39 stands were young forest <35 years old **(PLS-1)**. Surface fires and disease probably worked in concert to weaken MHs39 trees to the point where stands were susceptible to catastrophic windthrow. Severe surface fires too, probably affected MHs39 forests to the point where there were nothing but small-diameter trees available to reference survey corners. We doubt very much that very young MHs39 stands ever resembled a clear-cut. This community occurs in topographically rough terrain where it is highly unlikely that the effects of fire or wind were uniform. Patch cutting or variants of shelterwooding would best approximate the natural level of canopy removal. The only real reason to re-initiate a MHs39 stand would be to favor red oak or big-toothed aspen, which are the only MHs39 trees with the primary strategy of regenerating in open conditions. Such treatment would probably also regenerate some basswood and American elm as they were also initial-cohort species on these sites.

Historically red oak was "positioned" to re-colonize MHs39 sites because it dominated the advance regeneration. We believe that chronic surface fires "cleansed" MHs39 sites of sugar maple advance regeneration and forced red oak to allocate resources to root growth and caliper more than height. The silvicultural equivalent would most likely involve prescribed burning, underplanting, and monitoring caliper in order to prepare MHs39 sites for canopy removal with the expectation of red oak dominance in the new young stand. It is important to note that our interpretation is a significant departure from previous studies of the Big Woods, which is predominantly MHs39 forest. People have called the Big Woods “asbestos forest” because it didn’t burn and it is a common place to demonstrate gap-phase dynamics where fire has been eliminated from consideration as an influencing agent. Our technique of using landscape summaries of stands in spatially varying stages of development to guess at the temporal dynamics of individual stands may have some shortcomings for the MHs39 forest. It is quite possible that the protected core of the Big Woods and other patches of MHs39 forest never experienced fire, but the edges adjacent to prairie or FDs communities did. That pattern could result in our temporal interpretation. However, it remains a fact that we found very few MHs39 survey corners where all bearing trees were small diameter and included sugar maple – rather they were oak or aspen. Silviculturally, we are confident that manipulation of advance regeneration to kill sugar maple and encourage oak is required if the management goal is to include oak crop trees.

Management Concerns

MHs39 communities occur entirely on medium textured soils where there are legitimate concerns about heavy equipment compacting or rutting the soil (see Acceptable Operating Season to Minimize Compaction tables). On stagnation moraines, this community consistently occurs on till that is of loam texture or finer. Soil compaction is always a concern with these textures. Because of the usual high relief of stagnation moraines, drainage is good, and when dry, the soils may have adequate strength for heavy equipment. Almost always the soils have firm, subsoil horizons which make rutting a serious risk when the upper horizons are saturated. MHs39 communities are also common on till plains, with soils similar to those on stagnation moraines with regard to texture and firm subsoil horizons. Compaction and rutting are always a concern for the same reasons. In this situation, MHs39 sites are less-well drained because the till plains are flatter and require drying periods far longer than on stagnation moraines. MHs39 communities occur occasionally on silt-capped bedrock hills. The surface texture is usually silt loam or loamy very fine-sand, both of which are susceptible to compaction by heavy equipment. Colluvium and rocks are common and can help to alleviate compaction and rutting. The slopes are generally significant and erosion is a concern. Drainage, however, is good and sites can dry to the point where soils are no longer plastic and risk of compaction low. On all of these landforms, field monitoring of current soil-moisture conditions is required.

Today the landscape balance of growth-stages and stand ages for the MHs39 community is similar to its historic condition **(PLS/FIA-1)**, where there was very little young forest in comparison to transitioning or mature forest . At the stand scale, we believe that wildlife populations are probably reacting to MHs39 habitat as they always have, but the once expansive MHs39 landscape has been reduced to just a few remnant stands because of conversion to agricultural fields and development. For this reason, conserving any intact MHs39 stand is ecologically important. Compositional changes are also a concern. Most obvious is the loss of red oak, which is arguably the most valuable species in today’s market. Sugar maple, ironwood, green ash, box elder, paper birch, and red maple are the benefactors of modern conditions because logging does not selectively kill these trees as did natural processes. These mesic hardwoods, particularly in the young growth-stage complicate and diminish our silvicultural ability to manage MHs39 stands for red oak. This community along with the southern mesic hardwood (MHs) communities were the stronghold of red oak habitat in Minnesota and all are suffering from conversion to mesic hardwoods under modern management. If red oak is to remain an important commercial tree, conservation and silvicultural experimentation are essential.

Natural Disturbance Regime

Natural Rotations of Disturbance in MHs39 Forests Graphic	
	Banner text over photo
Catastrophic fire photograph	3,210 years
Catastrophic windthrow photograph	680 years
Partial Canopy Loss, photograph	51 years

Natural rotation of catastrophic and maintenance disturbances were calculated from Public Land Survey (PLS) records at 3,903 corners within the primary range of the MHs39 community. At these corners, there were 10,277 bearing trees comprising the species that one commonly finds in MHs39 forests.

The PLS field notes described <1% of the MHs39 landscape as recovering from stand-regenerating fire. There were no direct references to fire, and just a few records of openings and thickets which we usually attribute to fire damage in hardwood forests. From these data, a rotation of 3,210 years was calculated for stand-replacing fire.

More often in the MHs39 landscape, the surveyors described lands as windthrown and lacking suitable-sized trees for scribing. Such corners were encountered at about 2% of the time, yielding an estimated rotation of 680 years for windthrow. Most references were to scattered timber or some windthrow.

Far more common at MHs39 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 sparse forest or scattered timber with distances to bearing trees that were intermediate between the distances for burned/windthrown lands and what is typical for fully stocked hardwood forests. About 10% of the survey corners were described as such, resulting in a calculated rotation of 51 years for disturbances that maintained some early and mid-successional trees on MHs39 sites. The paucity of direct references to fire and windthrow would suggest that bole-weakening disease affecting clusters of trees (e.g. *Armillaria*, oak wilt) was probably the proximal cause of partial canopy loss.

Rotations of catastrophic disturbance are similar among all MHs communities 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 unifying characteristic of the MHs communities is the short rotation of maintenance disturbances. The rotation of 51 years for MHs39 is intermediate between drier MHs communities with shorter rotations and the wetter MHs49 community with a much longer rotation. The effect of frequent maintenance disturbance is to favor the persistence of oak throughout succession and prevent total dominance of sugar maple, basswood, and elm.

Natural Stand Dynamics

Following stand-regenerating windstorms or very rarely fire, the overall pattern of compositional change in MHs39 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 MHs39 red oak, basswood, quaking aspen, and big-toothed aspen are the species that benefit greatly from windthrow or fire because they compete poorly with shade-tolerant species like sugar maple, basswood, American elm, and perhaps ironwood on MHs39 sites in the absence of disturbance.

Early in the process of stand maturation, MHs39 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, self-thinning and crown competition among canopy trees causes this. Young MHs39 forests under 35 years had mean distance of 17 feet from survey corners to the bearing trees. This is typical of fully stocked hardwood forests of comparable age. Transitioning forests 35-75 years old had bearing trees 28 feet from corners on average; mature forests >75 years had a mean of 34 feet. Compared to other communities, these distances are quite typical of naturally stocked hardwood forest.

Young Growth-stage: 0-35 years
Just 4% of the MHs39 landscape in pre-settlement times was covered by forests estimated to be under 35 years old **(PLS-1)**. There were too few survey corners with a full complement of bearing trees to determine if young MHs39 forests tended to be mixed or monotypic. In describing the few cases (<1%) of very young, burned stands, the surveyors indicated that red oak was by far the dominant initial-cohort tree **(PLS-3)**. Following fire, the surveyors most often described the structure of the forest as openings, thickets, or just burned-over land.

Young stands recovering from windthrow were more common **(PLS-3)**. There was really very little compositional difference between stands recovering from fire or windthrow, except that the dominance of red oak was slightly less pronounced. Most important is the fact that windthrow didn't release advance regeneration of mesic, fire-sensitive trees – meaning that surface fires in older forests must have maintained advance regeneration of oak and mid-tolerants rather than sugar maple, basswood, and ironwood. Elm seemed to benefit more from windthrow than fire. Curiously, the surveyors described the structure of windthrown forest in quite different terms than they did for burned forest. Most often, they described windthrown sites as scattered timber or even sparse forest, which suggests to us that stand-regenerating wind events left a lot of scattered, wind-firm oaks and even mesic hardwoods like basswood and elm **(PLS-1)**.

We believe that the only way for red oak to so strongly dominate young forests was for it to have had similar dominance among the advance regeneration of older forests. It seems incredibly unlikely that disturbances as different as fire and wind would create seedbed conditions that would favor red oak over all other species equally. Our interpretation is that surface fires on a rotation of about 51 years (see Natural Disturbance Regime) were the primary disturbance in MHs39 forests that maintained a bank of young red oak seedlings. This idea is supported by the fact that red oaks dominated also the historic forests where we suspected partial canopy loss due to some maintenance disturbance **(PLS-3)**. Any disturbance seemed to result in red oak regeneration, which included in the initial-cohort some white oak and bur oak as well.

Averaging the age-class data across the young growth-stage **(PLS-1)** masks what we believe was rather immediate occupation of growing space by big-toothed or quaking aspen **(PLS-2)**. In a restrictive analysis with finer age-classes, it seems that aspen could have represented about 15% of the trees barely large enough to blaze and scribe as a bearing tree. Our interpretation is that following fire, young aspen suckers filled the matrix leaving stump-sprouting species like red oak, basswood, and paper birch at the coarser spacing of mature canopy trees. Rapid self-thinning of the aspen suckers and higher survivorship of the stump sprouts caused the impression of modest, post-disturbance regeneration of aspen and red oak dominance.

Transition: 35-75 years
The bulk (50%) of the historic MHs39 landscape was forest undergoing considerable compositional change **(PLS-1, PLS-2, PLS-4)**. Stands in this stage far more likely to be mixed (82%) than monotypic (18%). Monotypic conditions were represented mostly by survey corners where

all bearing trees were red oak (83%), but some pure basswood corners (12%) were starting to appear. Survey corners with mixed composition were most often attended by trees that we think of as fairly shade-tolerant. Basswood, ironwood, and elm were most common. Red oak occurred in mixture about as often as the tolerant trees, but there was little sugar maple at this time. We believe that this is a clear sign, of gradual succession to mesic hardwoods during the transition.

Succession during the transition stage is initiated by a precipitous decline in aspen between the 30- and 40-year age-classes **(PLS-2)**. The immediate benefactor of aspen's decline was red oak, although we show red oak declining during the transition **(PLS-1)**. Averaging across the growth-stages obscures a clear peak in red oak abundance in the 40- and 50-year age-classes where red oaks represented as much as 40% of the trees in transitioning MHs39 forests. Steady decline of red oak between the 50- and 90-year age classes is the event that creates this lengthy transition. Mesic hardwoods like sugar maple, ash, American elm, and ironwood are the benefactors of red oak's delayed decline during the transition.

The early transition of MHs39 from oak and aspen to mesic hardwoods and sugar maple presents a logical conundrum. This community along with most MHs communities have nearly identical disturbance regimes of long catastrophic rotations and chronic levels of maintenance disturbance that is presumed to be surface fire. The presumption of fire is made because any kind of canopy removal – fire, wind, or disease – resulted in oak regeneration with almost no sugar maple or other fire-sensitive trees. To explain this, we envision a seedling bank of oak and little sugar maple that is maintained by surface fire. To explain rapid succession, we envision a seedling bank of shade-tolerant, fire-sensitive trees unmolested by fire – thus the puzzle. What did the understory of MHs39 and similar hardwood communities look like? In the modern forest there is no puzzle. Sugar maple and basswood are the superior competitors in the understory able to bank seedlings **(R-2)**. Canopy removal results in a young stand of these mesic hardwoods, with very little red oak. Thus, it would seem that advance regeneration had to be solidly fire-maintained oak in the past to explain its post-disturbance success. How then did mesic hardwoods ingress and reach diameters that might usually survive light surface fires? One must imagine episodes where patches of MHs39 forests escaped fire long enough to develop a canopy of mesic hardwoods, but fire would soon rectify the situation and favor advance regeneration of oak beneath a sugar maple and basswood canopy (the exact opposite of today's situation). If this happened, we believe that it was most likely during the self-thinning stage of development as tree density on young MHs39 sites was tight (just 22 feet on average to bearing trees). It is easy to envision ingress of sugar maple during self-thinning as it is unequalled in its ability to establish and recruit beneath a canopy on these sites. All of these communities show uncharacteristic peaks of small-diameter sugar maple regeneration very early in succession **(PLS-5)**, thus supporting the idea that self-thinning aspen and oak was prime habitat for young sugar maples. However, the argument also requires self-thinning stands to ward off fire long enough for the hardwoods to reach diameters that might survive surface fires. Were self-thinning stands less likely to burn than older ones? We don't know.

Regardless of this confusion, the actual transition is not hard to understand. It is classic, textbook replacement of rather intolerant trees with shade-tolerant ones. This pattern of replacement fits exactly our observations in modern forests that start the successional cycle enriched in aspen or red oak. Precisely how older red oaks maintained their potency to dominate these sites after historic disturbances is somewhat mysterious if we are forced to envision advance regeneration with but modest presence of red oak as true seedlings.

Mature Growth-stage: >75 years
About 46% of the historic MHs39 landscape was mature forest where the rate of successional change slowed greatly **(PLS-1, PLS-4)**. Stands in this stage were far more likely to be mixed (92%) than monotypic. Nearly all monotypic survey corners were sugar maple, and some were entirely basswood. Mixed conditions were represented by combinations of sugar maple, basswood, ironwood, and American elm. This degree of mixture is a striking feature of mature MHs39 forests. Although it is clear that sugar maple is the dominant species, and it is also clear that it is

unequalled in ability to regenerate and recruit in any stratum (R-2) – mature MHs39 forests were not all sugar maple. Co-dominant species with varying regeneration strategies, varying tolerance of shade, and varying successional position were all present as large trees in mature MHs39 stands in roughly balanced amounts. Our interpretation is that chronic maintenance disturbance, mostly surface fires, created a fine-scale mosaic of hardwoods throughout the MHs39 landscape. Elm was favored in any depression that would hold snowmelt; more exposed areas favored the persistence of oaks; and anything in-between was a mix of sugar maple and basswood.

Tree Behavior

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

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

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

To this end, we have performed analyses using Public Land Survey records, FIA subplots, and releves to answer three very basic questions as to how trees behave in their community context:
- Suitability – for each NPC Class, how often and in what abundance do we see certain tree species in stands where there has been no obvious effort to silviculturally alter abundance or remove competition?
- Succession – for each NPC Class, what was the natural reaction to fire and windthrow and how did the different species succeed one another?
- Regeneration strategies – for each common species within a NPC Class, what were/are the natural windows of opportunity for regeneration throughout the course of succession?

Sugar Maple

- ***excellent habitat suitability rating***
- ***late-successional***
- ***small-gap regeneration strategist***
- ***regeneration window at 0-60 years***

Suitability

MHs39 sites provide ***excellent habitat*** for sugar maple trees. The perfect ***suitability rating*** of 5.0 for sugar maple is influenced mostly by its very high presence (91%) as trees on these sites in modern forests **(R-1)**. When present, sugar maple is an important dominant or co-dominant tree, contributing 54% mean cover in mature stands. The ranking is perfect, because no other tree or plant has a higher presence and cover on MHs39 sites as sampled by releves. All southern mesic hardwood sites (MHs) offer excellent habitat for sugar maple (see Suitability Tables). Among these, MHs39 offers the best opportunity to grow sugar maple trees.

Young Growth-stage: 0-35 years

Historically, at 2% relative abundance sugar maple was a minor tree in young MHs39 stands **(PLS-1, PLS-2)**. Young sugar maples were nearly absent from stands recovering from either catastrophic fire or windthrow **(PLS-3)**. This result is consistent with its well-known sensitivity to fire. Just a single tree was recorded at windthrown survey corners. This result is surprising in that there is no particular reason to think that windthrow would select against sugar maples, and they are now quite common in young MHs39 forests where the canopy has been removed by logging **(PLS/FIA-1)**. Small-diameter sugar maple regeneration coming in among larger trees was present at surprisingly high abundance during the post-disturbance window **(PLS-5)**. Today, canopy removal immediately releases the pervasive bank of maple seedlings common in older MHs39 stands. The fact that sugar maple didn't react immediately to disturbance in the historic record suggests to us that the maple seedling bank was not pervasive or that the regenerating event killed the maple seedlings. We believe that fire accomplished this. Our interpretation is that the reaction of MHs39 stands to fire was to form thicket-like growth that was a mixture of aspen suckers, sprouting trees, sub-trees like ironwood, and possibly tall shrubs. At some point (~self-thinning stage), this re-growth reached a height and degree of canopy closure that favored the establishment and recruitment of shade-tolerant trees like sugar maple. Sugar maple is unequalled among MHs39 trees in its ability to establish and recruit seedlings in the shade **(R-2)**.

Transition: 35-75 years

As stands transitioned to mature conditions sugar maple increased in abundance **(PLS-1)**. We estimate that this increase started during this transition and continued until sugar maples were dominant **(PLS-2)**. Small-diameter sugar maple regeneration was common in the G-1 gap window corresponding with the transition stage **(PLS-5)**. At this time, it was about five-times as likely for sugar maple bearing trees to be the smallest tree at a survey corner than it was for it to be the largest tree. Also, it occurred almost entirely (93%) at corners of mixed composition. This pattern is typical of an invading species. Young sugar maples were coming in under almost any other tree common in MHs39 forests. It was especially common though, beneath initial-cohort elm and basswood. We interpret this as release of seedlings established in the young growth-stage in response to the death of some initial-cohort trees and perhaps in response to a change from thicket-like growth to forest structure. This interpretation is strongly supported by sugar maple's perfect indices of regeneration in modern forests **(R-2)** and its performance on FIA plots **(FIA-1)** were it does well in all subordinate situations (12, 13, 23).

Mature Growth-stage: >75 years

Sugar maple had its peak presence as a canopy dominant or co-dominant in mature stands, which is why we consider sugar maple a ***late-successional*** species – able to replace about any other tree as stands aged **(PLS-1, PLS-2)**. Its steady increase in relative abundance is the result of good establishment and recruitment beginning in the young growth-stage followed by high survivorship. Small-diameter sugar maple regeneration was detected until the 90-year age class of the mature growth-stage **(PLS-5)**. At this time sugar maples were rather balanced as either the largest or smallest tree at survey corners. This is typical of trees with an extended window of recruitment success, which in sugar maple's case spans 90 years. When sugar maple was the smallest tree, a significant amount (40%) was coming in among other sugar maples. Smaller sugar maples were also common among larger-diameter American elm and basswood. There were very few instances of smaller-diameter maples below any species like aspen and red oak that might have been in the initial-cohort. Our interpretation is that by the time MHs39 stands were 75 years old, sugar maple was occupying all strata and could indefinitely replace itself in the absence of fire.

Regeneration Strategy

Sugar maple's primary regenerative strategy on MHs39 sites is to develop a pervasive bank of seedlings capable of recruiting in ***small-gaps***. Sugar maples were successful at this beneath almost any other species of tree, including itself. In the historic PLS data the small-gap interpretation is supported by: (1) the fact that sugar maple is dominant in the mature growth-stage of the community when gaps are usually small **(PLS-1, PLS-2)**, (2) its peak abundance, by far, was at survey corners showing no canopy loss or disturbance **(PLS-3)**, and (3) it had at least some small-diameter regeneration in the I-1 ingress window where trees must have some small-gap ability **(PLS-5)**. The high percent of sugar maple seedlings below poles or trees (situations 12 and 13) in the FIA data **(FIA-1)** is also a characteristic of species that can bank seedlings and recruit into small gaps. The releve sampling of mature MHs39 forests shows that sugar maple is unequalled at establishing and recruiting individuals in all understory strata, eventually resulting in canopy dominance **(R-2)**. This is especially characteristic of a small-gap species.

Historic Change in Abundance

Today, sugar maple is probably about as abundant as it once was, but its growth-stage distribution is different. In mature forest, it has declined in relative abundance from 32% historically to about 17% today **(PLS/FIA-1)**. Its loss seems to be spread evenly among the other trees common on MHs39 sites. The most obvious departure from history is the incredible abundance of sugar maple in today's young stands (21%) in contrast to it's minor presence (2%) historically; obviously sugar maple has replaced red oak in regenerating forests. Sugar maple is especially pervasive in mature forests sampled by releves, with 91% presence as a tree **(R-1)** and 93% presence in the understory **(R-2)**. These presence values seem quite high even when compared with modern forests as sampled by FIA plots. Most likely this is due to our tendency to place releves in the least disturbed forests, many of which are now protected. Our interpretation is that in young forests sugar maple has benefited greatly from the lack of surface fires, which once maintained a healthy bank of seedling-sprout oaks on MHs39 sites. In mature forests, there is a clear distinction between releve data and FIA data. It would seem that when stands are protected they are inclined towards sugar maple dominance. The average stand has less sugar maple than in times past due to some disturbance, which we would guess to be related to the tendency of private MHs39 woodlots to be grazed or used for firewood.

Basswood

- ***excellent habitat suitability rating***
- ***early-successional***
- ***small-gap (large-gap) regeneration strategist***
- ***regeneration window at 0-40 years***

Suitability

MHs39 sites provide ***excellent habitat*** for basswood trees. The ***suitability rating*** of 4.9 for basswood is influenced mostly by its very high presence (90%) as trees on these sites in modern forests **(R-1)**. When present, basswood is an important co-dominant or dominant tree, contributing 20% mean cover in mature stands. The ranking is second, following sugar maple on MHs39 sites as sampled by releves. All southern mesic hardwood communities (MHs) offer excellent habitat for basswood (see Suitability Tables).

Young Growth-stage: 0-35 years

Historically, at 24% relative abundance basswood was an important initial-cohort tree in young MHs39 stands **(PLS-1, PLS-2)**. Young basswood were only rarely recorded at survey corners catastrophically regenerated by windthrow or fire **(PLS-3)**. This result is surprising given basswood's well-known ability to sprout when fire or another agent kills the main stem. Small-diameter, basswood regeneration coming in among larger trees was very abundant in the post-disturbance window, peaking immediately and lasting until the 60-year age-class **(PLS-5)**. In spite of minimal direct association of basswood with major disturbance, our interpretation is that a substantial bank of basswood seedlings and stump sprouts were available to re-colonize MHs39 stands following removal of the canopy by fire or wind. Because basswood shows peak abundance in the young growth-stage, we are forced to conclude that it was an ***early-successional tree***.

Transition: 35-75 years

As stands transitioned to mature conditions basswood decreased slightly in abundance **(PLS-1)**. We estimate that this decrease started in the transition and it continued for the life of the stand until basswoods were subordinate to sugar maple in old stands **(PLS-2)**. At this time it was about twice as common for basswood to be the larger tree at a survey corner as it was to be the smallest one. The larger trees were probably initial-cohort stump sprouts. Small-diameter basswood regeneration was still common early in the transition, but at levels less than in the young growth stage **(PLS-5)**. Young basswoods showed a clear preference (45%) to recruit beneath parent basswoods. Also common, were instances of smaller diameter basswood beneath American elm (17%) and ironwood (10%). We interpret this as good success at establishment and recruitment of seed-origin basswood during the transition under a canopy. This interpretation is supported by basswood's excellent indices of regeneration in modern forests **(R-2)** and its performance on FIA plots **(FIA-1)** were it does well in all subordinate situations (12, 13, 23). Given this level of establishment and recruitment it is hard to imagine that basswood would decline in abundance, but it did so because its good performance didn't match that of sugar maple.

Mature Growth-stage: >75 years

The relative abundance of basswood decreased steadily throughout the mature growth-stage, but at a very slow rate **(PLS-2)**. The average relative abundance for the entire growth stage is 19% **(PLS-1)**, which still allowed for co-dominance with sugar maple, red oak, and American elm. Its steady loss is muted because of good establishment and recruitment for the first 70 years of stand maturation **(PLS-5)** followed by high survivorship as mature, reproducing trees. In mature forests, basswood about equally likely to be the largest tree at a survey corner as it was for it to be the smallest tree. This is typical of a species with a long, preceding recruitment window. We attribute its persistence to its excellent ability to continuously establish and recruit seedlings under a canopy **(R-2)**. At this time, the tendency of basswood to recruit beneath parent basswood was still evident (41%), but smaller trees below American elm (35%), sugar maple (11%), and black ash (8%) were now common situations. Although basswood gradually declined in abundance, it is clear that it had enough late-successional character to persist indefinitely on MHs39 sites in spite of competition with sugar maple.

Regeneration Strategies

On MHs39 sites basswood exhibits regenerative flexibility, which allows it to be ever-present throughout the full course of stand maturation. Basswood sprouts effectively following disturbances that kill the main stem, and it is able to carry its parent tree density into the post-disturbance forest. Its slightly higher abundance in the young growth stage **(PLS-1)** could be the result of it (and red oak) recruiting from both the sprout and seedling pools, whereas sugar maple was to rely on advance regeneration alone. A surprising result was the tendency of young basswoods to recruit beneath parent trees. Perhaps this is just the consequence of having heavy seeds and modest dispersal, but the same could be said of sugar maple and oak in these forests. We believe that basswood was most successful increasing its presence locally by developing a pervasive bank of seedlings that can recruit ***small canopy gaps.*** In the historic PLS data this interpretation is supported by the fact that basswood was far more abundant at mature, undisturbed survey corners where we presume small-gaps **(PLS-3)**. In the FIA data, basswoods peak presence as seedlings beneath trees (situation 13) is the hallmark of a small-gap strategist that banks seedlings **(FIA-1)**. Basswood's excellent ability to establish and recruit seedlings through all understory strata **(R-2)**, is also characteristic of a tree that prefers to recruit in small-gaps.

There is also evidence that basswood was able to capture growing space in ***large-gaps*** as well. In the PLS data, the most compelling argument is that basswood's peak recruitment was immediate after disturbance and that it did well in the G-1 gap window where we presume some large gaps as initial-cohort trees start to die **(PLS-5)**. The immediate response was probably from stump sprouts, but its later success probably followed the loss of groups of red oak to disease or pests. In the FIA data, basswood has high presence as poles in tree stands (situation 23) which we normally associate with large-gap trees **(FIA-1)**. In the releves, its regenerant indices are characteristic of small-gap tree, but barely so **(R-2)**. In reality, basswood probably cared little about gap size or canopy removal, as long as it happened over existing advance regeneration or caused them to sprout.

Historic Change in Abundance

Today, basswood is probably about as abundant as it once was, but its growth-stage distribution is different. In mature forest, has increased slightly in relative abundance from 19% historically to about 23% today **(PLS/FIA-1)**. The most obvious departure from history is in the young growth-stage. In today's stands, basswood abundance is about 13% compared to 24% in the past. Basswood is no longer favored in young forests because logging doesn't diminish sugar maple as did natural disturbance. Although not to the extent of oak, basswood is more tolerant of surface fire than sugar maple. We believe that advance regeneration of basswood was significantly higher than that of sugar maple in fire-influenced forest, which gave it a better chance recruiting after any canopy disturbance than sugar maple. Although diminished from historic times, basswood's excellent ability to maintain advance regeneration **(R-2)** assures its persistence on MHs39 sites.

Northern Red Oak

- ***excellent habitat suitability rating***
- ***early-successional***
- ***large-gap (open) regeneration strategist***
- ***regeneration window at 30-50 years***

Suitability

MHs39 sites provide ***excellent habitat*** for red oak trees. The ***suitability rating*** of 4.8 for red oak is influenced mostly by its high presence (55%) as trees on these sites in modern forests **(R-1)**. When present, red oak is an important co-dominant tree, contributing 16% mean cover in mature stands. The ranking is third, following sugar maple and basswood on MHs39 sites as sampled by releves. Except for the wetter MHs49 community, all southern mesic hardwood communities provide excellent habitat for red oak (see Suitability Tables).

Young Growth-stage: 0-35 years

Historically, at 38% relative abundance northern red oak dominated young MHs39 stands recovering from fire or windthrow **(PLS-1)**. Young red oaks represented 83% of the trees at survey corners described as burned, far ahead of any other tree **(PLS-3)**. Our interpretation is that red oaks got their start on MHs39 sites by sprouting from strong rootstocks that could have had aerial stems of almost any diameter. Similarly, red oak dominated the vegetation following windthrow as it represented 75% of the smaller-diameter trees. Most likely, these were well-established seedling-sprouts that were prepared for release. We believe that the fact that any disturbance – even disturbances as different as fire and wind – resulted in good regeneration of red oak is testimony to its dominance as advance regeneration in older forests, maintained by surface fires. Small-diameter red oak regeneration was abundant throughout the young growth stage **(PLS-5)**. We believe that in the young growth-stage, red oak reclaimed its former abundance in older forests by stump sprouts, and that seedlings and seedling-sprouts were superior to other trees competing for growing space in the open. Because of red oak's success in the young growth-stage, we consider it to be an ***early-successional*** tree on MHs39 sites.

Transition: 35-75 years

As stands started to transition to mature conditions red oak abundance decreased steadily in abundance **(PLS-1)**. We estimate that this decline started at about age 50 and would continue throughout successional cycle **(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 (67%), red oak regeneration was coming in under larger-diameter red oaks, but it was also common to see it among aspen. Small-diameter red oak bearing trees were not common among shade-tolerant hardwoods like basswood and American elm, and there were no cases of it occurring with larger sugar maples. We interpret this as fair success at establishment and recruitment of seed-origin or seedling-sprout oak under a partial canopy of initial-cohort trees, including itself. The decline of red oak and its replacement by tolerant hardwoods is the major contributor to compositional movement and definition of the transition period **(PLS-4)**.

Mature Growth-stage: >75 years

In forests older than 75 years, the relative abundance of red oak continued to decline **(PLS-2)**. Small-diameter red oak regeneration was not detected in the mature growth-stage using our restrictive half-diameter rule **(PLS-5)**, but it had enjoyed steady recruitment in the preceding growth-stages. At this stage it was about twice as likely for red oaks to be the larger tree at a survey corner as it was for them to be the smallest tree. This is typical of a species likely to decline as time goes on, but slowly as there was some replacement of trees by from advance regeneration. When red oak was the smaller tree at a corner, it was still most often beneath larger-diameter red oaks, but cases where it was among larger American elm, basswood, and white oak were common. As was the case during the transition, it was still uncommon for red oak to recruit beneath sugar maple. We interpret this as red oak's modest ability to establish some true seedlings and recruit beneath a canopy as long as the canopy wasn't sugar maple. In modern forests, it shows only fair ability to compete with sugar maple in the understory, but its modest indices exceed greatly those of other oaks **(R-2)**. The ability of red oak to establish or maintain seedlings among more tolerant hardwoods in mature forests was probably a key to its success in the young growth-stage and why bur oak and white oak were not part of the initial-cohort.

Regeneration Strategies

We believe that red oak's primary regenerative strategy on MHs39 sites is to fill ***large-gaps***. It was most successful at this when gaps formed in the canopy of other red oaks, but it was successful beneath most trees other than sugar maple. In the historic PLS data this interpretation is supported by: (1) the fact that red oak is abundant at survey corners showing partial canopy loss **(PLS-3)**, and (2) 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 releves show that red oak has fair regeneration indices (2.0-2.7) beneath a canopy **(R-2)**, and these values are intermediate between trees that recruit well in large-gaps or ***open*** environments. Red oak's peak abundance in the initial-cohort argues also that it was an effective open strategist.

The rotation of 51 years for maintenance disturbances on MHs39 sites would suggest that by the time forests reached the mature growth stage (95 years) they would have experienced at least a couple of events that resulted in partial canopy loss. Such events clearly favor trees like red oak that depend mostly on large-gaps for regeneration. We believe that most of this was surface fire and they were the main reason that red oak persisted into the old growth-stage on MHs39 sites. We believe also that these fires were particularly effective at diminishing the advance regeneration of trees like sugar maple, thus maintaining a high presence of oak seedlings and saplings in older forests and assuring red oak good opportunity to dominate after a canopy-removing catastrophe.

Historic Change in Abundance

Today, it seems that red oak on MHs39 sites is in some peril because it is being replaced by sugar maple. Mature and old forests actually have a bit more red oak than they did historically, but today it is uncommon to see the oak cover-type in young forests. Historically, 38% of the trees in stands under 35 years were red oak, but today they have just 6% relative abundance **(PLS-FIA-1)**. Our interpretation is that the loss of surface fires has resulted in advance regeneration impoverished in oak and enriched in sugar maple – which is released in that ratio by logging the overstory. Learning to silviculturally manipulate the abundance and vigor of advance regeneration of red oak prior to harvest would seem to be the key in reversing red oak's decline. We doubt however that red oak will cease to be a component of future MHs39 forests because it shows high presence even in the least disturbed stands **(R-1, R-2)**. It's ability to recruit some individuals under mature forest conditions is actually fair, but it will consistently lose to ground to sugar maple each rotation.

Red & American Elm

- ***excellent habitat suitability rating***
- ***late-successional***
- ***small-gap (large-gap) regeneration strategists***
- ***regeneration window at >90 years for red elm***
- ***regeneration window at 0-40 years for American elm***

Identification Problems

The PLS surveyors did not distinguish between American and red (slippery) elm. Even today, most foresters have difficulty distinguishing the species, and even the best botanists are bewildered by juveniles. MHs39 releve samples show that for plots with elm present: 34% have both species present; 33% are red elm without American elm; 33% are American elm without red elm. At least some of this perfect balance is the result of taxonomic uncertainty. By providence these species have enough ecological similarity to treat them together, except for what seems to be some difference in their peak regeneration windows.

Suitability

MHs39 sites provide ***excellent habitat*** for **red elm** trees. The suitability rating of 4.6 for red elm is influenced mostly by its presence (35%) as trees on these sites in modern forests **(R-1)**. When present, red elm is a minor canopy tree, contributing 11% mean cover in mature stands. The ranking is fourth, following sugar maple, basswood, and northern red oak on MHs39 sites. Except for MHs38, southern mesic hardwood communities in general offer excellent habitat for red elm (see Suitability Tables). Note that red elm is quite restricted to the southern floristic region in comparison to the broader range of American elm.

MHs39 sites provide ***excellent habitat*** for **American elm** trees. The ***suitability rating*** of 4.4 for American elm is influenced mostly by its presence (35%) as trees on these sites in modern forests **(R-1)**. When present, American elm is a minor canopy tree, contributing 9% mean cover in mature stands. The ranking is fifth, following sugar maple, basswood, northern red oak, and red elm on MHs39 sites. Except for MHs38, southern mesic hardwood communities in general offer excellent habitat for American elm (see Suitability Tables). Note that the range of American elm is substantially broader than that of red elm.

Young Growth-stage: 0-35 years

Historically, at 9% relative abundance elm was an important component of young MHs39 stands **(PLS-1, PLS-2)**. Young elms were absent from survey corners described as burned **(PLS-3)**. Elm was more successful at windthrown corners where it represented 5% of the trees present. Small-diameter, elm regeneration coming in among larger trees was abundant in the post-disturbance window **(PLS-5)**. Based upon FIA data, it seems most likely that initial-cohort elm was mostly American elm. Our interpretation is that a substantial bank of elm seedlings were available to re-colonize MHs39 stands following removal of the canopy. We believe also that American elms were successful in establishing seed-origin trees in the open.

Transition: 35-75 years

As stands transitioned to mature conditions Elm increased slightly in abundance **(PLS-1, PLS-2)**. Small-diameter elm regeneration was lower in the G-1 gap window corresponding with the transition **(PLS-5)**. In most cases, young elms were coming in under parent elms, but it was also common for them to occur with larger basswood, sugar maple, and red oak. During this period, it was about twice as likely for elm to be the largest tree at a survey corner as it was for them to be the smallest tree. Because elm is usually overtopping the shade-tolerant trees it seems to have played a direct role in accelerating succession. Apparently forest floor conditions below American elm, were ideal for the formation of seedling banks of sugar maple, basswood, and red elm. It is possible that elm's role during the transition is was the conversion of rather acid oak humus to base-rich humus that favors the tolerant hardwoods. We attribute elm's success in the transition to its ability to establish and recruit seedlings below initial-cohort oaks. Consistent with this idea is elm's behavior in modern forests where it has good indices of regeneration (R-2) and its performance on FIA plots (FIA-1) were it does well in all subordinate situations (12, 13, 23).

Mature Growth-stage: >75 years
In the mature growth-stage, elm had sustained high presence as a canopy co-dominant, which is why we consider basswood a ***late-successional*** species (PLS-1, PLS-2). Its abundance was maintained by establishment and recruitment of seedlings under a mature canopy, that probably was biased towards American elm in the earlier age-classes and biased towards red elm in the older age-classes (PLS-5). Because of the taxonomic difficulty in identifying juvenile elms we are not certain about a switch from mostly American elm to red elm as stands mature. An advantage that red elm has over American elm is that under dense shade, small red elms can become decumbent and colonies creep along the forest floor until they encounter more favorable light conditions. When red elm colonies encounter substantial light-gaps, they have the ability to produce strong saplings with a good chance of recruiting to at least the subcanopy. During the mature growth-stage, it still was more likely for elms to be the largest tree at a survey corner. Beneath these large elms, was what must have been a very impressive subcanopy of sugar maple as the maples show a strong preference for coming in among elms. In spite of a smaller bank of seedlings than sugar maple, elms were successful enough at replacing themselves to maintain their abundance in mature forests.

Regeneration Strategies
Elm's primary regenerative strategy on MHs39 sites is to develop a bank of seedlings capable of recruiting in gaps of about any size. If we had to guess, we believe that American elm is favored in ***larger-gaps*** and red elm is favored in ***smaller-gaps***. In the PLS data, where we can't distinguish the species but the gap strategy is evident by: (1) elm's high abundance in mature forest where we presume gap dynamics (PLS-1), (2) elm's peak presence at survey corners in mature, undisturbed forest where we presume small-gaps (PLS-3), and (3) the rather constant presence of small-diameter regeneration throughout the gap window and ingress window where we presume large- and small-gaps respectively (PLS-5). In the modern data, we don't see great differences between red and American elms. The very high presence of elms as seedlings in tree stands (situation 13) is a character of small-gap strategists (FIA-1). In the releves, both elms have good indices of regeneration, which we associate with large-gap strategists (R-2).

Historic Change in Abundance
Today, the abundance of elm is considerably less than it was historically (PLS/FIA-1). The decline from 14% in mature pre-settlement forests to 8% today is easily explained by Dutch elm disease, which has significantly depleted large elms from all southern hardwood forests in Minnesota. The paucity of young elms, which are somewhat resistant to Dutch elm disease, is a bit surprising. In young forests, the historic abundance of elm was about 9% and today it is just 5%. Aspen and red oak are the other species to show significant decline in the young growth-stage, and in those cases we attributed lower success to the lack of surface fires that favored oak seedlings and aspen suckers over fire-sensitive trees like sugar maple. Given elm's late-successional, small-gap behavior on MHs39 sites, it seems quite unlikely that they would benefit directly from surface fires. It seems far more likely that surface fires burning through MHs39 stands would have skipped the wetter inclusions where elm is favored in this community. Perhaps, burned-through MHs39 stands were especially good seeding habitat for Elm, and such habitat is now mostly absent. Alternatively, Dutch elm disease has affected American forests for a long time (since ~1930-1940), and the lack of elm in younger forests could just be the effect of having fewer mature seed-trees on the landscape.

Bitternut Hickory

- ***good habitat suitability rating***
- ***mid-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 50-60 years***

Suitability
MHs39 sites provide ***good habitat*** for bitternut hickory trees. The ***suitability rating*** of 3.3 for bitternut hickory is influenced mostly by its presence (25%) as trees on these sites in modern forests **(R-1)**. When present, bitternut hickory is a minor co-dominant tree, contributing just 6% mean cover in mature stands. The ranking is sixth, tied with black ash, among trees common on MHs39 sites as sampled by releves. Southern mesic hardwood communities provide the bulk of habitat available to bitternut hickory as a tree in Minnesota (see Suitability Tables). Among these, MHs39 provides just good habitat, as hickory abundance is higher on richer or wetter hardwood sites.

Young Growth-stage: 0-35 years
Historically, bitternut hickory was infrequent bearing tree in young MHs39 stands with about 1% relative abundance **(PLS/FIA-1)**. All records of hickory were in the 30-year age class. There were no records of hickory at burned or windthrown MHs39 survey corners **(PLS-3)**. We did not detect any hickory as regeneration in the post-disturbance window **(PLS-5)**. From this we conclude that hickory was absent immediately following disturbance, and ingressed into MHs39 forests at about age 30. Because bitternut hickory has excellent ability to establish seedlings under a canopy **(R-2)**, we believe that young hickories got their start as MHs39 stands started to develop a remote canopy at the close of the young growth-stage.

Transition: 35-75 years
As stands transitioned to mature conditions there was a short-lived peak of hickory establishment and recruitment that is lost in the averaging and smoothing of the abundance data **(PLS/FIA-1)**. We believe that this peak, to about 5% relative abundance at age 60 is real because it occurs in the most populated age-classes **(PLS-2)**. Because hickory peaks during this transition, we consider it to be a ***mid-successional*** species on MHs39 sites. Small-diameter, hickory regeneration was most evident in the 50 and 60 year age-classes **(PLS-5)**. In most cases, young hickories were the smallest tree at a survey corner, suggesting that the rise in abundance was from recruitment. In modern stands hickory seedlings are common but have difficulty recruiting to heights much above 2m **(R-2)**. When hickory was the smallest tree it was most often coming through basswood and American elm. Our interpretation is that there was some mortality among initial-cohort basswood and elm at this time and that young hickory seedlings were occasionally able to fill the canopy gaps.

Mature Growth-stage: >75 years
In the mature growth-stage the abundance of bitternut hickory was stable at about 2% **(PLS/FIA-1)**. Small-diameter hickory regeneration was not detected beyond the 80-year age-class **(PLS-5)**, seemingly unable to recruit to bearing tree size. In modern mature MHs39 forests, bitternut hickory is disproportionally abundant as regeneration (75%, **R-2**) compared to its presence as a tree (25%, **R-1**). When present, hickories are usually small-diameter, sub-canopy trees that contribute little to the overall canopy cover. Our interpretation is that hickory is essentially and understory species on MHs39 sites and only infrequently are conditions right for recruiting a few individuals into the canopy. This behavior has been observed for other eastern hardwoods, e.g. black cherry, when they occur near the edge of their range in Minnesota.

Regeneration Strategies
The primary regenerative strategy of bitternut hickory on MHs39 sites is to fill ***large-gaps***. They were most successful at this when gaps formed in the canopy of initial-cohort basswood and American elm. In the historic PLS data this interpretation is supported by: (1) the fact that bitternut

hickory abundance peaks in response to the decline of the initial cohort species **(PLS-2)**, (2) they were present at survey corners showing partial canopy loss **(PLS-3)**, and (3) they showed peak recruitment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**. The high percent of hickory poles under trees (situation 23) in the FIA data **(FIA-1)** is also a characteristic of species that tend to regenerate well in large gaps. In the releve data, bitternut hickory has excellent regenerant and seedling indices (4.3-4.5) which is a small-gap characteristic, but its failings in the sapling layer (3.7) is typical of a tree that needs more light to recruit to tree size **(R-2)**. Unlike sugar maple, basswood, elm and other gap species, bitternut hickory has poor success becoming a tree. There were no tree-sized (>10" dbh) hickories recorded on FIA plots. The releves show slightly better success, but hickory is clearly having problems achieving heights over 2m. We doubt that light is hickory's sole recruitment problem. Others have noticed that few hickories achieve heights greater than the average snow-depth. Presumably its large terminal buds are sensitive to winter desiccation just above the snow and for the same reason, they may be an attractive winter food for some animals.

Historic Change in Abundance

Today, bitternut hickory is about as abundant as it ever was at 1-2% **(PLS/FIA-1)**. The sample sizes in both the FIA and PLS records are too small to draw any real conclusions about population trends. In the modern data, it is an abundant and common component of the seedling layer **(R-2)**. As long as there are a few nut-producing trees in a stand, small hickories will remain a significant component of the groundlayer. If hickory's recruitment problems are linked to snow-cover and winter conditions, it could be a bell-weather species of global warming that would be evident as improved recruitment of hickory to tree status across central and southeastern Minnesota.

Black (Green) Ash

- ***good habitat suitability rating***
- ***late-successional***
- ***large-gap (small-gap) regeneration strategists***
- ***regeneration window at 60-70 years for black ash***

Identification Problems
The PLS surveyors did not distinguish between black and green ash. Thus, interpretations of PLS data for the more common black ash should always be done knowing that some of these trees were likely green ash. MHs39 releve samples show that for plots with ash present: 28% have both species present; 22% are green ash without black ash; 50% are black ash without green ash. There are incidental occurrences of white ash on MHs39 sites, but it is far less frequent than black or green ash. We consider black and green ash to be ecologically similar on MHs39 sites and most silvicultural strategies would work for either species.

Suitability
MHs39 sites provide ***good habitat*** for black ash trees. The ***suitability rating*** of 3.3 for black ash is influenced mostly by its presence (25%) as trees on these sites in modern forests **(R-1)**. When present, black ash is a minor co-dominant tree, contributing 6% mean cover in mature stands. The ranking is sixth, tied with bitternut hickory, among trees common on MHs39 sites as sampled by releves. Southern mesic hardwood communities offer poor-to-excellent habitat (see Suitability Tables). Black ash is favored most on the wetter and richer MHs49 sites.

Young Growth-stage: 0-35 years
Historically, at 1% abundance black ash was an incidental species in young MHs39 stands recovering from stand-regenerating events **(PLS-1)**. No young black ash were recorded at survey corners described as burned or windthrown **(PLS-3)**. Small-diameter black ash regeneration was not detected in the post-disturbance window **(PLS-5)**. Our interpretation is that there was limited advance regeneration of black ash in mature MHs39 forests available to re-colonize sites after significant canopy removal.

Transition: 35-75 years
As stands transitioned to mature conditions black ash increased slightly in relative abundance to about 2%, but this is barely detectable **(PLS-2)**. It is more accurate to say that black ash was consistently represented in age-classes older than 50-years. Small-diameter black ash regeneration was detectable in the G-1 gap window corresponding with the transition stage **(PLS-5)**. At this time black ash occurred only as the smallest tree at survey corners. This is characteristic of an ingressing species, where establishment and recruitment was linked to the structure or composition of transitioning MHs39 forests. It is probably significant that smaller-diameter ash seemed to prefer to recruit beneath larger elms. Both species prefer wetter habitat than MHs39 forests, thus it seems possible that scattered vernal pools within the matrix of MHs39 stands are where elm and some black ash had some success. On the other hand, almost all shade-tolerant trees showed a preference to recruit beneath elm during the transition.

Mature Growth-stage: >75 years
The mature growth-stage represents the time where black ash had consistent abundance at 2% or higher in some age-classes **(PLS/FIA-1, PLS-2)**. For this reason, we consider black ash to be a ***late-successional*** tree on MHs39 sites. Small-diameter black ash regeneration was evident at least until the 100-year age-class of the mature growth-stage **(PLS-5)**, suggesting that it could at least maintain itself in older, well-stratified MHs39 forest. At this time it was about equally likely for black ash to be the largest tree at a survey corner as it was for it to be the smallest one. This is typical of a species that has had some recruitment success for a lengthy period, which for black ash was from about age 40 to age 100. Our interpretation is that black ash was always present in included vernal swales, which are common throughout MHs39 stands. It would seem that black ash had some success coming in under the elm that often occupy or ring these wetlands. In

modern mature forests, black ash shows fair ability to establish seedlings and recruit under a canopy **(R-2)**, which seems to us to be good enough to explain 2-3% abundance in older forests.

Regeneration Strategy

Black ash's primary regenerative strategy on MHs39 sites is develop a bank of seedlings under a closed canopy and then to recruit trees when ***large-gaps*** develop over the advance regeneration. In the historic PLS data the idea that black ash is a large gap strategist is supported by the fact that it responded to gaps during the decline of initial-cohort trees **(PLS-1)**, and (2) its main window of regeneration is the G-1 gap window **(PLS-5)**. In the FIA data **(FIA-1)**, black ash regeneration has its peak presence as poles in tree stands (situation 23), which is a property of large-gap strategists. The releve sampling of MHs39 stands older than about 40 years, shows that black ash just fair ability to develop advance regeneration under a canopy **(R-2)**. Its regeneration indices (2.3-3.0) are most in line with species that need especially large gaps. Because black ash has some affinity for vernal swales and pools within MHs39 forests, prolonged ponding might provide the large-gap opportunities as sugar maple is sensitive to flooding. Historically, such flooding probably had little effect on the surrounding elms, thus requiring black ash to make use of smaller gaps.

Historic Change in Abundance

Today, at 3% relative abundance black ash is about as abundant as it ever was in mature MHs39 forests **(PLS/FIA-1)**. However in young forests, there is much more ash today (7%) than there was historically (1%). Obscured by combining ash in Table **PLS/FIA-1** is the fact that the FIA data show all of the young ash as green ash. This makes sense to us in that green ash is the superior competitor in disturbed forests, which are sampled by FIA plots but not commonly sampled by our releves.

(PLS-1) Historic Abundance of MHs39 Trees in Natural Growth-stages

Table values are relative abundance (%) of Public Land Survey (PLS) bearing trees at corners modeled to represent the MHs39 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 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.

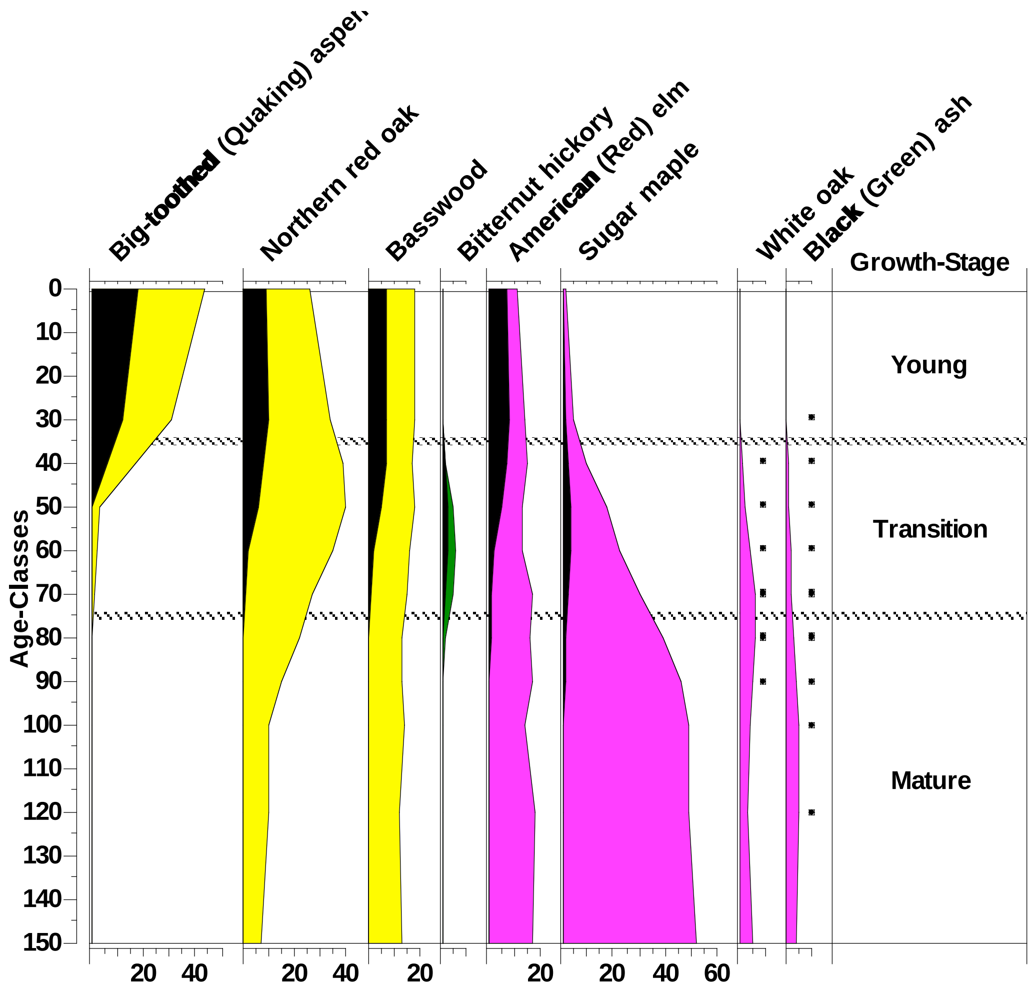
Dominant Trees	Forest Growth Stages in Years		
	0 - 35	35 - 75	> 75
	Young	T1	Mature
Red Oak	**38%**	↓↓	**13%**
Basswood	**24%**	↓	**19%**
Big-toothed (Quaking) Aspen[1]	**15%**	↓↓	**1%**
American (Red) Elm[1]	**9%**	↑	**14%**
White Oak	**–**	↑	**5%**
Ironwood	**6%**	↑	**8%**
Sugar Maple	**2%**	↑↑	**32%**
Miscellaneous	**6%**		**8%**
Percent of Community in Growth Stage in Presettlement Landscape	**4%**	**50%**	**46%**

1. The PLS surveyors did not consistently distinguish the more prevalent big-toothed aspen from quaking aspen, nor did they distinguish American from red elm on MHs39 sites.

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

(PLS-2) Abundance of trees throughout succession in MHs39

Graphed for the individual species of MHs39 trees is their relative abundance (%) as PLS bearing trees by age class. Species with good-to-excellent suitability have graphs colored as follows: early successional (yellow); mid-successional (green); late-successional (magenta). The data were smoothed from adjacent classes (3-sample moving average). Black insets show the proportion of bearing trees that were small-diameter trees that were presumably recruiting to bearing tree size (~4" dbh, see PLS-5). For infrequent trees, the presence of small-diameter trees is indicated by dots.



MHs39, J.C. Almendinger, April 2008

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

(PLS-3) Historic Abundance of MHs39 Trees Following Disturbance

Table values are raw counts and (percentage) of Public Land Survey (PLS) bearing trees at survey corners likely to represent MHs39 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.

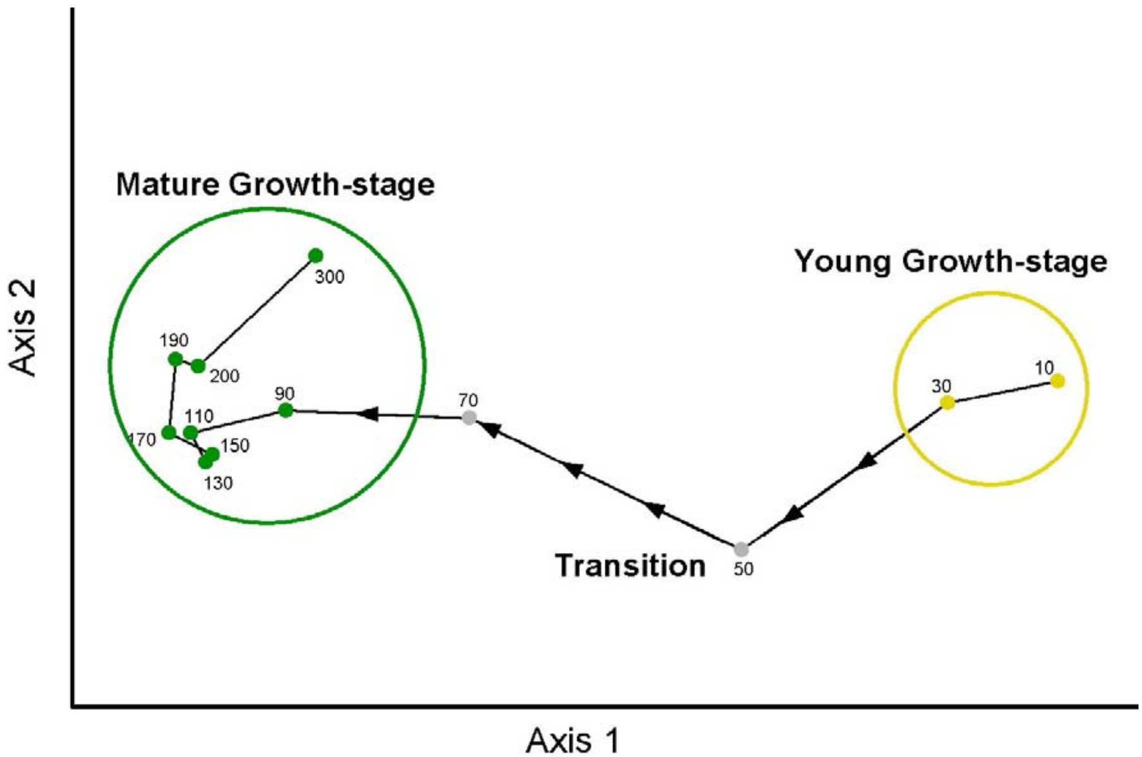
Tree	Burned		Windthrown		Maintenance		Mature	
Northern red oak	29	83%	131	75%	608	68%	1562	17%
White oak	4	11%	20	11%	81	9%	314	3%
Big-toothed (Quaking) aspen[1]	1	3%	6	3%	21	2%	132	1%
Bur oak	1	3%	5	3%	38	4%	116	1%
Sugar maple	0	0%	1	1%	35	4%	2189	24%
Basswood	0	0%	3	2%	48	5%	2090	23%
American (Red) elm[1]	0	0%	8	5%	39	4%	1483	16%
Ironwood	0	0%	0	0%	6	1%	689	8%
Bitternut hickory	0	0%	0	0%	7	1%	234	3%
Black (Green) ash[1]	0	0%	0	0%	15	2%	214	2%
Total (% of grand total, 10095)	35	0%	174	2%	898	9%	9023	89%

1. The PLS surveyors did not consistently distinguish the more prevalent big-toothed aspen from quaking aspen; nor did they distinguish the American elm from red elm; nor did they distinguish black and green ash on MHs39 sites.

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

(PLS-4) Ordination of Historic MHs39 Age-classes

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



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

(PLS-5) Historic Windows of Recruitment for MHs39 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 30-80 years	I-1 >80 years
Yes	Big-toothed aspen1	0-30	Excellent	Poor to 40	--
Yes	American elm	0-40	Excellent	Fair to 80	--
Minor	Green ash[2]	0-40	Fair	Fair	Fair
Yes	Basswood	0-60	Excellent	Good to 70	--
Minor	Sugar maple	0-60	Excellent	Good	Poor to 90
Yes	Northern red oak	30-50	Fair	Excellent to 70	--
No	Bitternut hickory	50-60	--	Good to 80	--
No	Bur oak	50-60	--	Fair	--
No	White oak[2]	50-60	--	Poor	--
No	Black ash	60-70	--	Poor	Poor to 100
Minor	Red elm[2]	>90	Fair	Poor	Fair
Yes	Ironwood	>80	Good	Good	Excellent

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 red oak, basswood, and big-toothed aspen with some American elm and ironwood, 30-80 years
- ☨ **I-1:** ingress of seedlings under canopy of sugar maple, basswood, red oak, and American elm, >80 years

-- : 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. Big-toothed aspen bearing trees couldn't be segregated from quaking aspen in the PLS notes for this community. The big-toothed aspen data probably include some quaking aspen, which we consider ecologically similar to big-toothed aspen.

2. Red elm, green ash, and white oak were inconsistently distinguished from their more abundant counterparts in the PLS notes: American elm, black ash, and bur oak respectively. We reconciled both the PLS and FIA data in these cases to make our best interpretation of windows of recruitment.

See linked text on brief methods and silvicultural application for Table PLS-5, file *Figures_Tables_Documentation*

(R-1) Suitability Ratings of Trees on MHs39 Sites

This table presents an index of suitability for trees in MHs39 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 MHs39

Tree	Percent Presence as Tree	Mean Percent Cover When Present	Suitability Index*
Sugar maple (Acer saccharum)	91	54	5.0
Basswood (Tilia americana)	90	20	4.9
Northern red oak (Quercus rubra)	55	16	4.8
Red elm (Ulmus rubra)	35	11	4.6
American elm (Ulmus americana)	35	9	4.4
Bitternut hickory (Carya cordiformis)	25	6	3.3
Black ash (Fraxinus nigra)	25	6	3.3
Green ash (Fraxinus pennsylvanica)	16	7	2.9
Bur oak (Quercus macrocarpa)	14	8	2.8
White oak (Quercus alba)	10	7	2.2
Big-toothed aspen (Populus grandidentata)	6	10	2.0

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

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

(R-2) Natural Regeneration and Recruitment of Trees in Mature MHs39 Stands

This table presents an index of regeneration for MHs39 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 MHs39 communities. Changes in the index values from one stratum to another can be used to estimate regenerative bottlenecks, whether establishment (R-index) or recruitment (SE-, SA-, or T-indices).

Natural regeneration indices for regenerants, seedlings, saplings, and trees common in the canopy of Southern Mesic Maple-Basswood Forest – MHs39

Trees in understory	% presence R, SE, SA	R-index	SE-index	SA-index	T-index
Sugar maple (Acer saccharum)	93	5.0	5.0	5.0	5.0
Bitternut hickory (Carya	75	4.3	4.5	3.7	3.3
Basswood (Tilia americana)	72	4.0	4.0	4.2	4.8
Ironwood (Ostrya virginiana)	72	3.5	4.0	4.8	3.3
Northern red oak (Quercus	41	2.5	2.7	2.0	4.8
Red elm (Ulmus rubra)	40	3.8	3.7	3.2	4.0
Green ash (Fraxinus	32	2.3	2.8	1.7	3.0
American elm (Ulmus	30	3.7	3.2	3.0	4.0
Black ash (Fraxinus nigra)	22	2.7	3.0	2.3	3.5
Bur oak (Quercus macrocarpa)	5	0.7	0.7	0.5	3.3
White oak (Quercus alba)	2	0.8	0.7	0.7	3.0
Big-toothed aspen (Populus	2	0.3	0.7	0.3	3.0

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

% presence: the percent of 110 MHs39 sample plots with that species present under 10m tall (R, SE, SA layers)
R-index: index of representation as true seedling or under 10cm tall
SE-index: index of representation as seedlings under 2m tall
SA-index: index of representation as saplings 2- 10m tall
T-index: index of representation as a tree >10m tall
All indexes: equally weight (1) presence, (2) mean cover when present, and (3) mean number of reported strata, the frequency distributions of which are segmented equally by area into 5 classes.

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

(FIA-1) Structural Situations of Trees in Mature MHs39 Stands

This table presents percentages of structural situations for trees as recorded in Forest Inventory Analysis (FIA) subplots that we modeled to be samples MHs39 forests. The purpose of the table is to provide a general impression of how often a species is seen certain regenerative situations: canopy of a regenerating forest (situations 11, 22), in the subcanopy (situations 12, 23), or in the seedling bank below a remote canopy (situation 13). The situation of trees in older stands at tree height (33) provide no insight about regeneration. Species are ordered by the sum of their percents in 12 and 13 situations, which generally ranks them as would shade-tolerance ratings. The total number of trees counted for each species is presented to provide a sense of reliability.

Species	Tree Count	Structural Situations					
		11	22	12	23	13	33
Sugar maple	**289**	**9%**	**6%**	**11%**	**15%**	**31%**	**28%**
Ironwood	**173**	**9%**	**3%**	**12%**	**8%**	**65%**	**3%**
Basswood	**426**	**5%**	**1%**	**8%**	**15%**	**19%**	**52%**
Bitternut hickory	**15**	**20%**	**0%**	**0%**	**27%**	**53%**	**0%**
Red elm	**45**	**4%**	**7%**	**2%**	**16%**	**51%**	**20%**
American elm	**30**	**0%**	**10%**	**10%**	**10%**	**50%**	**20%**
Black ash	**24**	**0%**	**13%**	**13%**	**38%**	**25%**	**13%**
Northern red oak	**372**	**3%**	**8%**	**0%**	**24%**	**2%**	**62%**
Green ash	**72**	**8%**	**6%**	**6%**	**15%**	**18%**	**47%**
White oak	**11**	**0%**	**0%**	**0%**	**9%**	**9%**	**82%**
Bur oak	**74**	**1%**	**8%**	**3%**	**11%**	**3%**	**74%**
Big-toothed aspen	**67**	**4%**	**19%**	**18%**	**13%**	**4%**	**40%**

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

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

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

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

(PLS/FIA-1) Abundance of MHs39 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 MHs39 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 - 75		> 75	
	Young		T1		Mature	
Red Oak	38%	6%	||		13%	18%
Basswood	24%	13%	|		19%	23%
Quaking Aspen (incl. Bigtooth)	15%	15%	||		1%	5%
American Elm (incl. Slippery)	9%	5%	⌉		14%	8%
Ironwood	6%	13%	⌉		8%	11%
Sugar Maple	2%	21%	⌉⌉		32%	17%
White Oak	–	0%	⌉		5%	2%
Box Elder	0%	3%			--	1%
Red Maple	0%	3%			0%	1%
Paper Birch	0%	3%			--	2%
Black Ash (incl. Green)	1%	7%			2%	3%
Bur Oak	0%	3%			2%	5%
Bitternut Hickory	1%	2%			2%	0%
Miscellaneous	4%	8%			2%	4%
Percent of Community in Growth Stage in Presettlement and Modern Landscapes	4%	9%	50%	39%	46%	52%

Natural growth-stage analysis and landscape summary of historic conditions is based upon the analysis of 3,903 Public Land Survey records for section and quarter-section corners. Comparable modern conditions were summarized from 1,320 FIA subplots that were modeled to be MHs39 sites.

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

Forest Health

Sugar Maple

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

WATCHOUTS!

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

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

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.

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.

MHs39 - 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 MHs39 that are more susceptible to compaction and rutting. They are listed in descending order of presence.

Virginia waterleaf (*Hydrophyllum virginianum*)
Cleavers (*Galium aparine*)
Wood nettle (*Laportea canadensis*)
Jack-in-the-pulpit (*Arisaema triphyllum*)
Lady fern (*Athyrium filix-femina*)
Virginia creeper (*Parthenocissus spp.*)
Kidney-leaved buttercup (*Ranunculus abortivus*)
White avens (*Geum canadense*)
American elm (C) (*Ulmus americana*)
Hackberry (U) (*Celtis occidentalis*)

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

Foot Notes

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

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

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

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

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

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

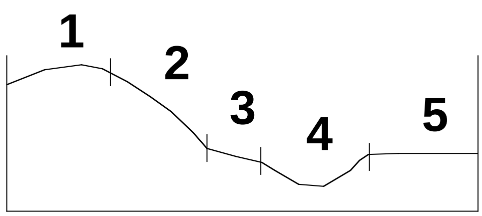
   Poor – water saturation occurs within 10 inches of the surface for most of the growing season

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

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

4. Landscape Position

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



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

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

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

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

   W — Winter – the ground is snow covered or partially frozen

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

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

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

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

Public Land Survey

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

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

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

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

Modern Forest

Releve Samples

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

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

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

For more information on the releve method and NPC Classification:

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

FIA Samples

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

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

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

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

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

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

Link to the USFS website, north central