MHs38

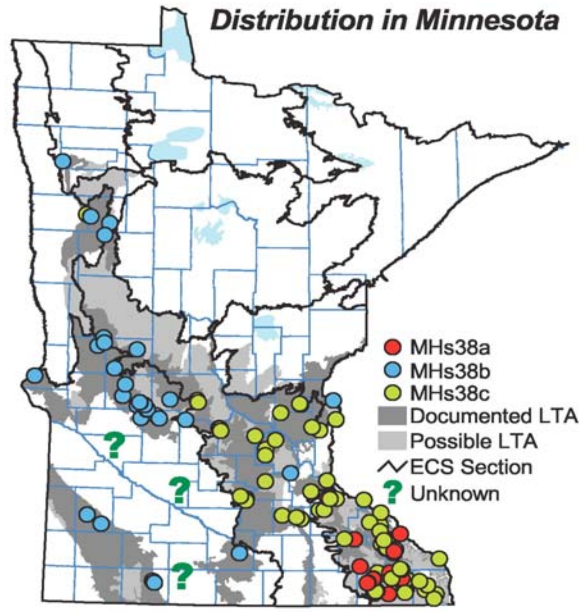
∞ Public Land Survey linked text

∞ Modern Forest linked text

MHs38 – Southern Mesic Oak-Basswood Forest

Natural Disturbance Regime, Stand Dynamics, and Tree Behavior

Summary and Management Highlights



The range of MHs38 forests in Minnesota (shaded) and distribution of releve samples (red, blue, and green dots).

Southern Mesic Oak-Basswood Forests (MHs38) are a common hardwood community found mostly within the Eastern Broadleaf Forest ecological Province of Minnesota. Outliers occur in fire-protected habitats throughout the Prairie Parkland ecological Province. Detailed descriptions of this community are presented in the DNR Field Guides to Native Plant Communities of Minnesota.

Commercial Trees

As a commercial forest, MHs38 sites offer a wide selection of hardwood crop trees, but few possible structural conditions if management is to favor the natural condition of mature, multi-layered, mesic-hardwood forest. Northern red oak, sugar maple, basswood, bur oak, green ash, white oak, white pine, and American elm are all ranked as excellent choices as crop trees by virtue of their frequent occurrence and high cover when present on MHs38 sites (see Suitability Tables). Bitternut hickory is ranked as a good crop tree, 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. Paper birch, hackberry, box elder, white ash, 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.

Among these species, northern red oak, basswood, American elm, sugar maple, and bur oak were the dominant native trees that have occupied MHs38 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)**. Big-toothed aspen, red elm, and white oak are likewise native to MHs38 sites but occurred naturally at lower abundance. The consequence of fire suppression, commercial logging, and settlement in the past century has been to promote much more big-toothed aspen and sugar maple than was usual. Past history and land use as also encouraged the ingress of species that were not significant in native MHs38 stands such as red maple, paper birch, green ash, and great expansion of ironwood in the understory of young stands. The increased abundance of these sugar maple, green ash, and ironwood in particular complicate our interpretations and the use of natural regeneration models as silvicultural strategies to manage oak.

Natural Silvicultural Approaches

In the historic landscape most MHs38 forests (58%) were mature and older than 75 years **(PLS-1)**. In this growth-stage most MHn38 trees maintained their presence by developing banks of seedlings that would recruit to trees in canopy gaps. Wind and surface fires killed or toppled canopy trees to create gaps in the canopy ranging from the size of a single tree crown to about an acre. 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, and basswood over all others on MHs38 sites. Group selection or some variants of shelterwooding would favor species like green ash and bitternut hickory which recruit better in larger gaps.

In the historic landscape, about 35% of the MHs38 forests were transitioning between the young and mature growth-stages (PLS-1). Roughly these were stands 35-75 years old. Towards the end of the transition, senescence of initial-cohort trees (mostly big-toothed aspen) created some regeneration opportunities for trees ranging from single-tree gaps to large gaps up to an acre. Several silvicultural systems could be used to approximate the natural loss of initial-cohort trees and regeneration typical of transitioning MHs38 forests. Selective harvesting matches best the small-gap mortality pattern, and on MHs38 sites would favor sugar maple, American elm, and basswood. Shelterwood variants or group selection match best with trees like white pine, bur oak, green ash, and bitternut hickory, which are predominantly large-gap strategists on MHs38 sites. The early part of the transition was also a time where shade-tolerant trees eventually overtopped what we envision as brushy growth of ironwood and stunted oak. The silvicultural approximation of this would be the non-commercial removal of poorly-formed trees or undesirable species over an existing bank of shade-tolerant seedlings.

A small proportion (7%) of native MHs38 stands were young forest <35 years old (PLS-1). Surface fires and disease probably worked in concert to weaken MHs38 trees to the point where stands were susceptible to catastrophic windthrow. Severe surface fires too, probably affected MHs38 forests to the point where there were nothing but small-diameter trees available to reference survey corners. We doubt very much that very young MHs38 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 MHs38 stand would be to favor red oak, which is the only MHs38 tree with the primary strategy of regenerating in open conditions. Such treatment would probably also regenerate some basswood and American elm as they are secondarily open strategists on these sites. Historically red oak was “positioned” to re-colonize MHs38 sites because it dominated the advance regeneration. We believe that chronic surface fires “cleansed” MHs38 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 MHs38 sites for canopy removal with the expectation of red oak dominance in the new young stand.

Management Concerns

MHs38 communities are common 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. Field monitoring of current soil moisture conditions is required on unfrozen ground. The MHs38 community is also common on till plains. In this setting the soils loamy and derived from fine-textured till. Soil compaction is a risk on these sites. Firm, clayey subsoil horizons perch water and have the effect of extending the drying period. These horizons also promote surface saturation in the spring and after major rains, which increases greatly the risk of rutting. Field monitoring of current soil moisture conditions is required on unfrozen ground. Rarely, MHs38 forests occur on sandy and gravelly flow-tills in stagnation moraines. Often the flow tills buried ice blocks and the general landscape is beset with closed depressions and lakes. The risk of compaction and rutting are generally low, but the slopes are subject to erosions. Field inspection to confirm the gravelly and sandy texture should precede summer operations.

The landscape balance of growth-stages and stand ages for the MHs38 community is not much different than it was historically (PLS/FIA-1). We believe that wildlife populations are probably reacting to MHs38 habitat as they always have apart from imparting coarser-scale patches and loss of forest lands to agricultural development. Compositional changes are more of a concern.

Most obvious is the loss red oak, especially in the young growth stage. Sugar maple is the benefactor of oak's demise and it appears that sugar maple will eventually dominate these sites if management practices are not modified to favor red oak. Most important are non-commercial treatments aimed at favoring advance regeneration of oak over the banks of shade-tolerant seedlings.

Natural Disturbance Regime

Natural rotation of catastrophic and maintenance disturbances were calculated from Public Land Survey (PLS) records at 4,869 corners within the primary range of the MHs38 community. At these corners, there were 12,276 bearing trees that one commonly finds in MHs38 forests.

Natural Rotations of Disturbance in MHs38 Forests Graphic	
	Banner text over photo
Catastrophic fire photograph	**1,100 years**
Catastrophic windthrow photograph	**360 years**
Partial Canopy Loss, photograph	**35 years**

The PLS field notes described about 1% of the MHs38 landscape as recovering from stand-regenerating fire. Burned-over lands, openings, and thickets were about equally used to describe the effect of fire on this community. From these data, a rotation of 1,100 years was calculated for stand-replacing fire.

Elsewhere in the MHs38 landscape, the surveyors described lands without suitable-sized trees for scribing as sparse forest or scattered timber without any mention of fire. Such corners were encountered at about 4% of the time, and we have assumed that wind was the proximal cause of tree mortality. We have estimated from these data a rotation of 360 years for windthrow.

Far more common at MHs38 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, scattered timer, openings, thickets, and oak barrens with distances to bearing trees that were intermediate between the distances for burned/windthrown lands and what is typical for fully stocked mesic hardwood forests. About 15% of the survey corners were described as such, resulting in a calculated rotation of 35 years for disturbances that maintained early and mid-successional trees on MHs38 sites. That more corners were described as burned (22) compared to windthrown (5) suggests that surface fires were the more prevalent cause of partial canopy loss, but the converse seems to be the case for stand-regenerating disturbance (see below).

Compared to other mesic hardwood (MH) communities in Minnesota, MHs38 rotations of catastrophic disturbance are similar in that they exceed the longevity of any initial cohort species. This means that natural stand dynamics will usually involve a few generations of trees and a shift from large regeneration gaps to small ones as stands mature. The rotation of 1,100 years for catastrophic fire is typical of southern MH forests (MHs) and suggests that fire wasn't an important agent of stand regeneration. The rotation of 360 years for catastrophic windthrow is also typical of southern and northwestern MH communities. The greater importance of wind than fire as a catastrophic event is an important distinction between MHs communities and MH forests in the central (MHc) and northern (MHn) floristic regions where windthrow was not important. The rotation of 35 years for maintenance disturbances is short and typical of MHs communities but not MHn or most MHc forests. The fact that MHs38 forests were embedded in a fire-prone landscape and that oaks were a significant component suggests to us that surface fires were and important agent of moderate disturbance, even though the surveyors rarely described such forests as burned.

Natural Stand Dynamics & Growth-stages

Following stand-regenerating fire or windstorms, the overall pattern of compositional change in MHs38 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 is involved in stand-initiation rather than wind, in spite of the fact that we calculated a shorter rotation of windthrow (see Natural Disturbance Regime). The effect of fire is to favor one or two pioneer species and to eliminate late-successional species sensitive to fire. In pre-settlement times red oak and big-toothed aspen were the species that benefited greatly from fire because they competed poorly with fire-intolerant species like sugar maple on these sites in later growth-stages.

Views and Summaries for MHs38 sidebar	
PLS-1	**Summary of historic growth-stages:** relative abundance of bearing trees
PLS-2	**View line-graph of historic change:** bearing tree abundance across age-classes
PLS-3	**Summary of historic disturbance:** abundance of bearing trees at burned, windthrown or disturbed sites
PLS-4	**View historic rates of change:** ordination of bearing tree age-classes
PLS-5	**Summary of historic regeneration:** Species ratings regarding their ability to regenerate after disturbance, in gaps, and beneath a canopy
R-1	**Summary of tree suitability for a Native Plant Community:** Species ratings based upon modern forests
R-2	**Summary of understory recruitment in modern forests:** indices of species' success in the understory
FIA-1	**Summary of regeneration in modern forests:** FIA trees in multiple-cohort situations
PLS/FIA-1	**Summary of differences between modern and pre-settlement forests:** relative abundance of bearing trees and FIA trees by growth-stage.

MHs38 sites, and other southern mesic hardwood communities reacted to fire more like woodland than forest. Following stand-regenerating events, tree density is initially sparse and tightens gradually in the course of maturation. Our interpretation is that the initial reaction of MHs38 stands to fire was to form thicket-like growth that was a mixture of trees, stunted oak, sub-trees like ironwood, and tall shrubs. Thus, a considerable amount of post-disturbance growing-space was occupied by woody plants not likely to become trees. In the young growth-stage (0-35 years), the mean distance of a bearing tree to its corner was 36 feet. This initial spacing is sparse in comparison to the usual 20 feet for northern hardwood forests, but it is far short of the 50-60 feet typical of southern fire-dependent woodlands where we often suspect prairie-like openings after fire. In the transition (35-75 years) the mean distance of bearing trees to MHs38 survey corners is 34 feet. This small increase in density (decrease in distance) was accompanied by considerable compositional movement towards shade-tolerant trees. Although it is tempting to ascribe the arrival of shade-tolerant trees to increased tree density, it is far more likely that achieving normal canopy height in the transition allowed seedling banks of shade-tolerant species to develop and recruit some individuals to bearing tree diameters. MHs38 forests older than 75 years had bearing trees 28 feet from their survey corners on average. This distance is actually comparable (slightly longer) to distances seen in older central and northern hardwoods that eventually reach similar density through self-thinning and crown competition.

Young Growth-stage: approximately 0-35 years

About 7% of the MHs38 landscape in pre-settlement times was covered by forests estimated to be under 35 years old **(PLS-1)**. For any forest class in Minnesota, this percentage is very low and indicates that stand-regenerating disturbance was a rare event. In describing very young, burned stands, the surveyors indicated that red oak was overwhelmingly dominant. In our analysis 101 young red oaks were present at burned survey corners compared to just 5 trees each for aspen and basswood, which were the next most common trees **(PLS-3)**. The data for windthrown corners is similar. There were 283 red oaks present at windthrown corners compared to the runner-up, white oak, with just 25 trees. There is no doubt that historically, red oak was uniquely positioned in older stands to overwhelm all other trees trying to regenerate after major disturbances.

We believe that the only way for a single species 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 30 years (see Natural Disturbance Regime) were the primary disturbance in MHs38 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.

It is important to note that a property of southern forests in general (FD and MH systems) is for a chronic level of maintenance disturbance to take precedence over stand-regenerating disturbance. Southern forests lack the obvious punctuation of stand origin and end that we see in northern forests with significant amounts of conifers. We believe that surface fires were linked, via standing dead fuel and wounding/disease, to the likelihood of a following disturbance that the surveyors would have described as catastrophic and resulting in a new hardwood stand.

Transitional Stage: approximately 35-75 years
About 35% of the historic MHs38 landscape was forest undergoing considerable compositional change **(PLS-1, PLS-4)**. Stands in this stage were about 3 times more likely to be mixed than monotypic. Monotypic conditions were represented mostly by survey corners where all bearing trees were red oak and sometimes all basswood. At survey corners with mixed composition, basswood, American elm, ironwood, and red oak were the major species.

The transition stage is driven mostly by a significant decline in red oak and minor losses of big-toothed aspen **(PLS-1, PLS-2)**. All other species increase in relative abundance, especially sugar maple. At ages between 35 and 75 years, it seems highly unlikely that this decline is caused by natural senescence of initial-cohort red oak. Because this transition starts early (35 years) it is possible that transitioning MHs38 stands were still self-thinning and some red oaks were dying due to overstocking in denser patches. However, the spacing of bearing trees at transitioning MHs38 corners was about 34 feet on average, which is too coarse to suspect self-thinning as a major source of mortality. Alternatively, the transition period in MHs38 forests was an episode where “new” growing space for trees became available and favorable for trees other than red oak. Sugar maple, basswood, American elm, ironwood, and bur (white) oak all increase in relative abundance during the transition **(PLS-1, PLS-2)**. Except for the oaks, all of these species are good at establishing and recruiting seedlings in full shade **(R-2)**. Our best guess is that thicket-like growth of shrubs and perhaps trees that wouldn’t have been useful as bearing trees created an environment where shade-tolerant species were successfully invading and recruiting seedlings on MHs38 sites about 35 to 75 years following a stand-regenerating disturbance. Ironwood is a particularly good candidate for nursing along shade-tolerant trees because thickets of ironwood were described by the surveyors, mentioned in historic descriptions and early studies of the nearby Big Woods, and it seems to play the same role today.

Mature Growth-stage: approximately >75 years
About 58% of the historic MHs38 landscape was mature forest where the rate of successional change slowed greatly **(PLS-1)**. Stands in this stage were far more likely to be mixed than monotypic. Patches of pure red oak, sugar maple, bur (white) oak, and basswood were most common. Nearly all mixed corners involved American (red) elm, basswood, and sugar maple.

The most striking feature of mature MHs38 forests is that they were so evenly mixed **(PLS-1)**. 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 **(PLS-5)**, mature MHs38 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 MHs38 stands in roughly equal amounts. Our interpretation is that chronic maintenance disturbance, mostly surface fires, created a fine-scale mosaic of hardwoods throughout the MHs38 landscape.

Elm and ash were favored in any depression that would hold snowmelt; more exposed areas favored the persistence of red, bur, and white oaks; and anything in-between was sugar maple and basswood.

Growth Stage Key

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

Young Forests	∞
Transitional Forests	∞
Mature Forests	∞
Old Forests	∞

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?

Northern Red Oak

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

Suitability
MHs38 sites provide ***excellent habitat*** for red oak trees. The perfect ***suitability rating*** of 5.0 for red oak is influenced mostly by its very high presence (60%) as trees on these sites in modern forests **(R-1)**. When present, red oak is an important co-dominant and sometimes dominant tree, contributing 39% mean cover in mature stands. The ranking is perfect, because no other tree or plant has higher presence and cover on MHs38 sites as sampled by releves. Southern mesic hardwood communities in general offer excellent habitat for red oak, especially the better drained communities (see Suitability Tables). Among these, MHs38 and MHs37 offer the best opportunity for growing red oak.

Young Growth-stage: 0-35 years
Historically, red oak was the overwhelming dominant in young MHs38 stands recovering from stand-regenerating disturbance **(PLS-1, PLS-2)**. Young red oaks represented 82% of the trees at survey corners described as burned, which is by far more than any other tree **(PLS-3)**. Red oak was also the leading species following windthrow, representing 84% of the trees at such survey corners. Its dominance in the young growth-stage and its leading abundance following fire and windthrow is why we consider red oak to be an ***early successional*** species on MHs38 sites. Small-diameter red oak regeneration was abundant in the post-disturbance window **(PLS-5)**. This is typical of early successional species, and we interpret this as red oak showing excellent ability to stump sprout, to establish seed-origin trees, and to recruit surviving advance regeneration into under-stocked areas of burned or windthrown stands.

The immediate success of red oak following stand-regenerating disturbance in historic forests doesn’t match our management experience in modern forests. Today the seedling bank in MHs38 forests is dominated by shade-tolerant species like sugar maple, ironwood, and basswood. Although red oak is usually present in the seedling bank (55%, **R-2**), canopy removal now results in release of the seedling bank to create young, mixed hardwood stands where red oak is but a minor player. We believe that surface fires were the primary maintenance disturbance on MHs38 sites, in spite of the fact that windthrow was mentioned more often than fire as the stand-regenerating event. We envision such fires as eliminating sugar maple and ironwood from the seedling bank and creating red oak seedlings with significant rootstocks and caliper. Such red oaks were then ready to respond to any level of canopy release, whether caused by wind or fire.

Transition: 35-75 years
As stands transitioned to mature conditions, there was a steady loss of initial-cohort red oak, and its replacement by shade-tolerant hardwoods **(PLS-1)**. We estimate that this decline started at about age 40 and continued to about age 90 when red oak abundance stabilized at about 10% relative abundance **(PLS-2)**. In most cases, red oak was the larger tree at survey corners falling within the transition period, which is consistent with the idea that it was in the initial-cohort. Although losing ground, there was some regeneration and recruitment of red oak until about age 50 **(PLS-5)**. In most cases, red oak regeneration was coming in under larger-diameter red oaks, or under quaking aspen. We interpret this as limited replacement of itself or beneath shade-intolerant species in large-gaps as some of the initial-cohort trees started to senesce, particularly the aspen. During the transition, red oak was present at most survey corners and about 17% were still pure red oak. It is possible that red oak establishment and recruitment to bearing-tree size (~4” dbh) at this stage was often the consequence of it being the only species present in monotypic pockets.

Mature Growth-stage: >75 years

In mature MHs38 stands the relative abundance of red oak stabilizes at about 13% **(PLS-1, PLS-2)**. Although much diminished from earlier growth-stages, 13% abundance is still high for an initial-cohort species. Although red oak is long-lived on MHs38 sites, we believe that persistence must have required some regeneration and recruitment. Thus, we assume that red oak has secondary strategies for behaving like a mid- or late-successional species able to respond to fine-scale or maintenance disturbances. Small-diameter red oak regeneration was not detected in the mature growth-stage, but it was often the smaller tree at corners because of the seedlings established in the preceding G-1 gap window **(PLS-5)**. As the smaller tree at a survey corner, red oak was usually coming in under itself or other oaks. A significant amount of red oak was coming through American elm, and there was some coming through or persisting beneath shade-tolerant hardwoods like sugar maple and basswood. The excellent-to-fair ability of red oak to recruit seedlings under the canopy in modern MHs38 forests **(R-2)** suggests that it can develop a seedling bank that might take advantage of canopy gaps. We believe that red oak persisted in mature MHs38 forests mostly because of surface fires. It is likely that such fires "trained" the bank of red oak seedlings to allocate more resources to root growth rather than stem growth and that trained seedlings were likely to out-compete even sugar maples in canopy openings.

Regeneration Strategies

Red oak's primary regenerative strategy on MHs38 sites is to dominate ***open habitat*** after stand-regenerating disturbance. Any agent or scale of disturbance resulted in red oak regeneration when it was present **(PLS-3)**. In the historic PLS data this interpretation is supported by: (1) the fact that 64% of the bearing trees in young stands were red oak **(PLS-1)**, (2) red oak represented by far, the largest proportion of bearing trees at burned and windthrown corners **(PLS-3)**, and (3) red oak's peak regeneration was in the post-disturbance window **(PLS-5)**.

The releve sampling of mature MHs38 forests suggests, however, that red oak is able to function also as a ***large-gap*** strategist with excellent-to-fair establishment and recruitment in the understory strata **(R-2)**. The R-, SE- and SA-indices decline steadily suggesting that establishment isn't much of a problem, but recruitment is increasingly difficult as trees try to reach heights greater than 2m. Events like surface fires may have helped create large enough canopy gaps for those seedlings to get past this recruitment bottleneck. The high percent of red oak poles among trees (situation 23) is typical of species that do well in large-gaps **(FIA-1)**. The persistence of red oak in the mature growth-stages is also consistent with the idea of it functioning as a large-gap strategist in older pre-settlement forests. It is likely that red oak was successful enough in the understory to have enough advance regeneration to quickly dominate MHs38 sites after fire or windthrow.

Historic Change in Abundance

Today, red oak remains an important and often dominant tree on MHs38 sites **(PLS/FIA-1)**. The modern abundance though is distributed quite differently among the growth-stages. Modern young stands have far less red oak in them, falling from 64% in pre-settlement times to just 11% now. Old stands, have almost twice as much red oak in them than they did naturally. The species increasing at the expense of red oak are sugar maple, ironwood, white oak, and aspen. Our interpretation is that red oak responded very positively to stand conditions in the mid-1900s that were not natural nor the current situation. It seems that the future of red oak is to become a minor co-dominant on MHs38 sites as mature stands are re-initiated.

Sugar Maple

- ***excellent habitat suitability rating***
- ***late-successional***
- ***small-gap regeneration strategist***
- ***regeneration window at 40-70 years***

Suitability

MHs38 sites provide ***excellent habitat*** for sugar maple trees. The ***suitability rating*** of 4.9 for sugar maple is influenced mostly by its high presence (59%) as trees on these sites in modern forests **(R-1)**. When present, sugar maple is an important dominant or co-dominant tree, contributing 40% mean cover in mature stands. The ranking is second, tied with basswood and slightly less than the index for red oak on MHs38 sites as sampled by releves. All southern mesic hardwood communities offer excellent habitat for sugar maple (see Suitability Tables).

Young Growth-stage: 0-35 years

Historically, sugar maple was a nearly absent from young MHs38 stands **(PLS-1, PLS-2)**. Young sugar maples were not recorded at survey corners described as burned **(PLS-3)**. This result is consistent with its well-known sensitivity to fire. Just a single sugar maple tree was recorded at windthrown survey corner. 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 MHs38 forests **(PLS/FIA-1)**. Small-diameter sugar maple regeneration coming in among larger trees was present at low abundance and increased considerably during the post-disturbance window **(PLS-5)**. Today, canopy removal immediately releases the pervasive bank of maple seedlings common in older MHn38 stands. The fact that sugar maple didn't react immediately 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 MHs38 stands to fire was to form thicket-like growth that was a mixture of trees, stunted oak, sub-trees like ironwood, and tall shrubs. At some point, this re-growth reached a height and degree of canopy closure that favored the establishment and recruitment of shade-tolerants like sugar maple.

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 for the life of the stand until sugar maples were dominant **(PLS-2)**. Small-diameter sugar maple regeneration was abundant in the G-1 gap window corresponding with the transition stage **(PLS-5)**. In most cases, young sugar maples were coming in under American 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. We also believe that sugar maple had continued success establishing seed-origin maples under a canopy. 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). This interpretation is also supported by the fact that sugar maple bearing trees at transitioning survey corners were mostly the smaller-diameter tree, ready to replace its larger neighbor.

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. Surprisingly, using our restrictive half-diameter rule, small-diameter sugar maple regeneration was not detected during 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 80 years. When sugar maple was the smallest tree, a significant amount was still coming through

American elm. For the first time though, it was mostly subordinate to itself. We interpret this as sugar maple demonstrating its ability to dominate mature MHs38 sites as it was successful in all strata and beneath itself.

Regeneration Strategy

Sugar maple's primary regenerative strategy on MHs38 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. A remarkable amount of sugar maple seemed to get its start under American elm. 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)**, and (2) its peak abundance, by far, was at survey corners showing no canopy loss or disturbance **(PLS-3)**. The high percent of sugar maples in subordinate canopy situations (12, 13, 23) in the FIA data **(FIA-1)** is also a characteristic of species that tend to regenerate best in small gaps. The releve sampling of mature MHs38 forests shows that sugar maple is unequalled at establishing and recruiting individuals in all understory strata, eventually resulting in canopy dominance **(R-2)**.

Historic Change in Abundance

Today, sugar maple remains an important and often dominant tree on MHs38 sites **(PLS/FIA-1)**. Sugar maple is incredibly more abundant today in young forests (21%) compared to almost nothing historically (1%). This is almost certainly due to the lack of surface fires that favored the establishment of an oak seedling bank over that of sugar maple. In mature forests sampled by FIA plots, sugar maple is now considerably less abundant (14%) than it was historically (30%). However sugar maple is pervasive in mature forests sampled by releves, with 59% presence as a tree **(R-1)** and 70% presence in the understory **(R-2)**. Sugar maple is doing well in the mature, undisturbed forests preferentially sampled by releves, whereas they have lost ground in the average stand. We don't know why, but it is almost certainly tied to the same disturbance events in the mid-1900's that strongly favored oaks (see Red Oak). The reaction of MHs38 sites to grazing and drought in the 1930's might be worth investigating.

Basswood

- ***excellent habitat suitability rating***
- ***late-successional***
- ***small-gap (open) regeneration strategist***
- ***regeneration window at 0-30 years***

Suitability

MHs38 sites provide ***excellent habitat*** for basswood trees. The ***suitability rating*** of 4.9 for basswood is influenced mostly by its very high presence (82%) as trees on these sites in modern forests **(R-1)**. When present, basswood is an important co-dominant tree, contributing 22% mean cover in mature stands. The ranking is second, tied with sugar maple and slightly less than the index for red oak on MHs38 sites as sampled by releves. All southern mesic hardwood communities offer excellent habitat for basswood (see Suitability Tables).

Young Growth-stage: 0-35 years

Historically, basswood was an important component of young MHs38 stands **(PLS-1, PLS-2)**. Young basswood represented 4% of the trees at survey corners described as burned **(PLS-3)**. This result is consistent with its well-known ability to sprout when fire or another agent kills the main stem. Basswood was significantly less successful at windthrown corners where it represented just 1% of the trees present. Small-diameter basswood regeneration coming in among larger trees was abundant in the post-disturbance window **(PLS-5)**. Our interpretation is that a substantial bank of basswood seedlings and stump sprouts were available to re-colonize MHs38 stands following removal of the canopy.

Transition: 35-75 years

As stands transitioned to mature conditions basswood increased in abundance **(PLS-1)**. We estimate that this increase started immediately after disturbance and continued for the life of the stand until basswoods were important co-dominants in old stands **(PLS-2)**. Small-diameter, basswood regeneration was common in the G-1 gap window that corresponds with the transition **(PLS-5)**. In most cases, young basswoods were coming in under other basswood or American elm. We interpret this as good success at establishment and recruitment of seed-origin basswood during the transition and the release of seedlings established during the young growth-stage. The interpretation of continued establishment 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 as subordinate seedlings (situations 12, 13, 23).

Mature Growth-stage: >75 years

Basswood had its peak presence as a canopy co-dominant in mature stands, which is why we consider basswood a ***late-successional*** species – able to replace about any tree other than sugar maple as stands aged **(PLS-1, PLS-2)**. Its steady increase in relative abundance is the result of previous good establishment and recruitment beginning immediately and lasting through the 70-year age-class **(PLS-5)**. High survivorship of those basswood carried it through the mature growth-stage. In the mature growth-stage, basswood showed balanced presence as the largest or smallest tree at a survey corners. This is typical of trees with an extended window of recruitment success, which in basswood's case spanned 70 years. When basswood was the smallest tree at a survey corner, a significant amount was still coming through American elm. For the first time though, it was often subordinate to itself. We interpret this as basswood demonstrating its eventual late-successional importance on MHs38 sites as it was successful in all strata of mature forests and was able to replace itself.

Regeneration Strategies

Basswood's primary regenerative strategy on MHs38 sites is to develop a bank of seedlings capable of recruiting in ***small-gaps***. Basswoods were successful at this beneath most other trees, including itself. A remarkable amount of basswood seemed to get its start under American elm. In the historic PLS data the small-gap interpretation is supported by: (1) the fact that basswood abundance peaks in the mature growth-stage **(PLS-1, PLS-2)**, and (2) it is most abundant by far, at survey corners showing no canopy loss or disturbance **(PLS-3)**. The high percent of basswood in subordinate canopy situations (12, 13, 23) in the FIA data **(FIA-1)** is also a characteristic of species that tend to regenerate best in gaps. The releve sampling of mature MHs38 forests shows that basswood excels at establishing and recruiting individuals in all understory strata, eventually resulting in canopy importance **(R-2)**.

It is important to note that basswood, unlike sugar maple, showed significant success immediately after disturbance. Its peak opportunity for establishment and recruitment was in the post-disturbance window **(PLS-5)**. We believe that a component of this regeneration was basswood acting like an ***open*** regeneration strategist by sprouting after fire had destroyed the main stems and surrounding stand. The amount of young basswood and its consistent presence in the young growth stage argues against all of this regeneration being sprouts. It is possible that most of this was advance regeneration and that basswood seedlings tolerated mild surface fires as did red oak and they were released by the stand-regenerating event. Alternatively, it is possible that the open environment resulted in the establishment of some seed-origin trees.

Historic Change in Abundance

Today, basswood remains an important and often dominant tree on MHs38 sites **(PLS/FIA-1)**. It shows almost no change in abundance in any growth-stage. Basswood's 54% presence as trees at FIA subplots is considerably lower than its 82% presence in the releves **(R-1)**. Also, its 54% presence as regeneration at FIA subplots is similarly lower than its 84% presence in releves **(R-2)**. Apparently basswood had made some gains in undisturbed MHs38 stands sampled by releves that is not reflected in the average FIA stand.

Bur and White Oak

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

Identification Problems

The PLS surveyors referenced both white oak and bur oak as witness trees. In some cases, individual surveyors used both terms and we believe they were distinguishing the species. More often white oak was used in a generic sense and included bur oak, making it impossible to segregate the species in our analyses. MHs38 releve samples show that for plots with either oak present: 4% have both species present; 46% are white oak without bur oak; 50% are bur oak without white oak. In spite of the lack of coincidence in the releve data, we believe that they are sufficiently similar for most silvicultural considerations.

Suitability

MHs38 sites provide ***excellent habitat*** for **bur oak** trees. The ***suitability rating*** of 4.8 for bur oak is influenced mostly by its presence (33%) as trees on these sites in modern forests **(R-1)**. When present, bur oak is an important co-dominant tree, contributing 23% mean cover in mature stands. The ranking is fourth, following northern red oak, sugar maple, and basswood on MHs38 sites. Southern mesic hardwood communities in general offer excellent habitat for bur oak (see Suitability Tables). Among these, MHs38 and MHs49 offer the best opportunities for growing bur oak.

The ***excellent suitability rating*** of 4.6 for **white oak** is based upon its 30% presence and 17% mean cover when present **(R-1)**. This ranking is sixth, tied with white pine and following northern red oak, sugar maple, basswood, bur oak, and green ash on MHc26 sites. Only the driest and poorer southern mesic hardwood communities are good habitat for white oak, including MHs37 and MHs38 (see Suitability Tables).

Young Growth-stage: 0-35 years

Historically, bur and white oaks were infrequent as bearing trees in young MHs38 stands with small-diameter trees **(PLS-1,PLS-2)**. These young oaks represented 5% of the trees at survey corners described as burned, well behind the dominant red oaks but better represented than any other trees common on MHs38 sites **(PLS-3)**. Bur and white oaks represented 8% of the trees at corners affected by stand-regenerating wind, also well behind red oak and again at greater abundance than the remaining species. Windthrow was slightly more favorable for the establishment of bur and white oak, but still their reaction to windthrow was modest compared to red oak. Small-diameter, bur and white oak regeneration was not detected coming in among larger trees in the post-disturbance window **(PLS-5)**. Our interpretation is that some bur and white oaks got their start on MHs38 sites in response to fire and windthrow.

Transition: 35-75 years

As stands transitioned to mature conditions bur and white oaks increased substantially in abundance **(PLS-1)**. We estimate that this increase started at low abundance following disturbance until it peaked at about age 80 **(PLS-2)**. Bur and white oak regeneration was recorded for the first time during the transition as smaller diameter trees coming in among larger ones in the G-1 gap window **(PLS-5)**. In most cases, bur and white oak regeneration was coming in under red oak and sometimes under themselves, but not at all among the shade-tolerant trees like sugar maple and basswood, which were increasing dramatically during the transition stage. Our interpretation is that succession from red oak to bur and white oaks was limited to just the portions of MHs38 habitat where it was adjacent to communities more likely to burn or experience surface fires. Neither bur or white oak show much ability to regenerate under a canopy **(R-2)** and they couldn't have been important in transitioning MHs38 stands that were well on their way to being dominated by sugar maple and basswood. Apparently, surface fires burning through MHs38 stands created the large-gaps that favored recruitment of bur and white oak.

Mature Growth-stage: >75 years

In the mature growth-stage bur and white oaks become about as abundant (12%) as they will ever be in the course of stand maturation **(PLS-1)**. The ability of bur and white oak to decisively replace the initial-cohort red oaks is why we consider them to be a ***mid-successional*** species, although they remain important in the older growth-stages. Their increase in relative abundance is mostly the result of good establishment and recruitment during the transition stage **(PLS-5)** followed by high survivorship. Regeneration during the mature growth-stage was poor, and this is the primary reason that we can't consider them to be late-successional species. Bur and white oak regeneration coming in among larger trees was detected only in the 80-year age-class of mature forests **(PLS-5)**. In most cases, bur and white oak regeneration was still coming in only under red oak or themselves. We interpret this as modest, but continued success of recruiting seed-origin trees in response to surface fires that created large gaps and eliminated sugar maple.

Regeneration Strategy

The primary regenerative strategy bur and white oak on MHs38 sites is to fill ***large-gaps***. They were most successful at this when gaps formed in the canopy of initial-cohort red oak. In the historic PLS data this interpretation is supported by: (1) the fact that bur and white oak abundance rises sharply in response to the decline of the initial cohort species **(PLS-1, PLS-2)**, (2) they were most abundant at survey corners showing partial canopy loss **(PLS-3)**, and they showed peak establishment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**. The high percent of bur oak poles under trees (situation 23) in the FIA data **(FIA-1)** is also a characteristic of species that tend to regenerate best in large gaps. White oak's absence in this category is probably a consequence of low sample numbers. The releve sampling of mature MHs38 forests is consistent with the idea that bur and red oak need considerable sunlight for regeneration. If anything, the indices for these oaks in the regenerating strata are more in line with open regeneration strategists **(R-2)**.

Historic Change in Abundance

Today, bur and white oak remain important co-dominants in older MHs38 stands **(PLS/FIA-1)**. Their relative abundance by growth-stage in modern forests is virtually identical to that calculated for pre-settlement stands. Their presence in releves is similar to their presence at FIA subplots.

Green (White) Ash

- ***excellent habitat suitability rating for green ash***
- ***fair habitat suitability rating for white ash***
- ***late-successional***
- ***large-gap (small-gap) regeneration strategist***
- ***regeneration window at 60-100 years***

Identification Problems

The PLS surveyors did not distinguish between green and white ash. Nearly all references were just to "ash." Black ash is quite uncommon on MHs38 sites and was not a likely bearing tree in this case. Thus, interpretations of PLS data for the more common green ash should always be done knowing that some of these trees were likely white ash. MHs38 releve samples show that for plots with ash present: 2% have both species present; 15% are white ash without green ash; 83% are green ash without white ash.

Suitability

MHs38 sites provide ***excellent habitat*** for **green ash** trees. The ***suitability rating*** of 4.7 for green ash is influenced mostly by its presence (36%) as trees on these sites in modern forests **(R-1)**. When present, green ash is an occasional co-dominant tree, contributing 17% mean cover in mature stands. This ranking is fifth, following northern red oak, sugar maple, basswood, and bur oak on MHs38 sites. Green ash has been invading southern mesic hardwood forests since settlement of the area and has been most successful on MHs38 sites (see Suitability Tables).

MHs38 sites provide just ***fair habitat*** for **white ash**. The ***suitability rating*** of 2.1 for white ash is based upon its 7% presence and 9% mean cover when present **(R-1)**. This ranking is 13th among trees common on MHs38 sites. MHs38 is the only southern mesic hardwood community where white ash occurs often enough to have a suitability rating (see Suitability Tables).

Young Growth-stage: 0-35 years

Historically, ash were essentially absent from young MHs38 stands **(PLS/FIA-1)**. Young ashes were not recorded at burned or windthrown survey corners **(PLS-3)**. Small-diameter ash regeneration coming in among larger trees was not detected in the post-disturbance window **(PLS-5)**. Our interpretation is that ash were either killed by the stand-regenerating event or it was not present as advance regeneration. Given the success of green ash in ruderal habitats throughout the southern mesic hardwood region and after modern logging, we favor the idea of fire being the historic event that kept ash populations low.

Transition: 35-75 years

As stands transitioned to mature conditions ash increased ever so slightly in abundance **(PLS/FIA-1)**. Small-diameter ash regeneration coming in among larger trees was first detected in the 60-year age-class of the transition **(PLS-5)**. The abundance of ash regeneration was very low in comparison to other trees. At this time all ash bearing trees were the smallest tree at survey corners, and most were coming through basswood or elm. Our interpretation is that the transition stage offers the first suitable habitat for ash seedlings in the course of stand maturation. Although green ash and white ash have good ability to establish seedlings, recruitment to tree-sized individuals seems to require more sunlight than is available under a full canopy **(R-2)**. Perhaps MHs38 stands during the transition period were starting to experience some mortality of initial-cohort elms and basswood that created openings of adequate size to release ash seedlings.

Mature Growth-stage: >75 years

Historically, ash had its peak presence as a minor co-dominant in mature stands, which is why we consider it a ***late-successional*** species **(PLS/FIA-1)**. Its steady increase in relative abundance is the result of modest establishment and recruitment in the transition period. Small-diameter ash regeneration was present at low abundance until the 100-year age-class **(PLS-5)**. We interpret this as ash establishing a modest seedling bank early in the mature growth-stage as it does in modern stands where it is commonly (41%) present as seedlings. Recruitment though was unlikely without some kind of opening above green or white ash seedlings **(R-2)**.

Regeneration Strategies

Ash's primary regenerative strategy on MHc26 sites is develop a bank of seedlings that can fill canopy gaps. We are uncertain about the size of the gaps needed. The PLS data argue for ash's ability to fill ***small-gaps*** because ash: (1) has peak abundance in the mature growth-stage **(PLS/FIA-1)**, (2) was present most often at survey corners classified as mature and not recently disturbed **(PLS-3)**, and (3) ash showed at least some regeneration in the ingress window **(PLS-5)**.

Modern data suggest that ash is successful in more open habitats. The high abundance of green ash in the canopy of young stands (situations 11, 22) sampled by FIA plots is typical of trees that do well in the open **(FIA-1)**. However, green ash is also common in subordinate situations (12, 23, 13), which is typical of trees that can recruit in to large or small gaps. The abundance of green ash in all regenerative situations is high on FIA plots because so little actually reaches tree status (situation 33). From this it would seem that whatever constitutes average treatment of MHs38 sites is resulting in a lot of ash regeneration, but not many trees. To some extent, the releve sampling of ecologically intact MHs38 sites supports this conclusion. Both green ash and white ash show slightly greater presence as regeneration **(R-2)** than as trees **(R-1)**, but not nearly as much as is suggested by the FIA data. Both species show good ability to establish seedlings, but these seedlings are having substantial difficulty achieving heights greater than 2m. Our interpretation is that ***large-gaps*** would help ash through this recruitment bottleneck on MHs38 sites that are ecologically similar to historic stands.

Historic Change in Abundance

Today, green and white ash are substantially more abundant than they were historically **(PLS/FIA-1)**. This is most evident in the young growth-stage where these trees have 7% relative abundance compared to just 1% historically. We favor the idea that the ash seedling bank is a legacy of logged stands, whereas they were eliminated by fire historically. The abundance of ash is similar between historic and modern times in mature MHs38 forests. The presence of green ash in releves is about twice that as reported at FIA subplots, suggesting that ash has made greater gains in the less-disturbed stands preferentially sampled by releves. The FIA crews reported just a single mature white ash at subplots modeled to be MHs38 forest. It is possible that white ash is favored in undisturbed habitats but more likely, the FIA crews has as much trouble telling green and white ash apart as did the surveyors.

White Pine

- ***excellent habitat suitability rating***
- ***mid-successional***
- ***large-gap regeneration strategist***
- ***unknown regeneration window***

Suitability

MHs38 sites provide ***excellent habitat*** for white pine trees. The ***suitability rating*** of 4.6 for white pine is influenced most by very high mean cover when present (42%) as trees on these sites in modern forests **(R-1)**. The presence of white pine trees, however, is low (12%). This ranking is sixth, sited with white oak and following northern red oak, sugar maple, basswood, bur oak, and green (white) ash on MHs38 sites. Southern mesic hardwood forests in general do not provide habitat for white pine, and MHs38 sites offer the best chance (see Suitability Tables).

Historic Change in Abundance and Interpretation Problems

White pine is essentially absent from the historic PLS records for survey corners most likely to represent MHs38 sites. This is quite surprising given its ability to actually dominate the canopy of some modern stands. Equally surprising is the fact that when white pine is present today, it is often as large, supercanopy trees that we could envision as being present at the time of the Public Land Survey. Because white pine has a much higher affinity for fire-dependent forests, especially FDs27, it is possible that our methods excluded lots of survey corners with white pine bearing trees from being classified as potentially MHs38 sites. The co-occurrence though of almost any mesic hardwood tree like sugar maple though would have brought such corners back into the mesic hardwood system because sugar maple's affinity for MHs38 sites is far higher than white pine's affinity for FDs27 sites. From this, we have concluded that large white pines on MHs38 sites post-date the Public Land Survey and that white pine was but a minor component of these sites historically.

The FIA data suggest also that white pine is not an important component of MHs38 forests. Because we used the same probability tables in classifying PLS corners as we did for FIA subplots, the same methodological concerns apply. Just three individual white pine trees were captured in our analysis of FIA subplots **(FIA-1)** likely to represent MHs38 stands. From this, we have concluded that white pine is not a significant component of the average MHs38 forest.

This leaves us with the uncomfortable fact that white pine is often present (12%) and commonly dominant (42% mean cover) on our releve samples of MHs38 forests **(R-1)**. It is significant that our three samplings of Minnesota's forests represent different eras. The townships in the Blufflands subsection of the state, where white pine occurs in MHs38 communities, were among the first surveyed. The PLS records reflect the condition of MHs38 sites between *ca.* 1850 and 1870 AD, when apparently there was very little white pine. The FIA sampling represents MHs38 forests with little white pine from about 1977 until the present. The releve sampling is biased, representing little-disturbed stands that, given the size of the white pines, were probably established at some time in the early-to-mid-1900's. We believe that white pine expanded its small, local populations on MHs38 sites in response to disturbances typical of early land use that were not "natural" or characteristic of modern times. Grazing, selective harvesting of high-quality trees, and slope erosion are all disturbance agents that probably peaked at that time and could have favored a burst of white pine regeneration. It may be significant that white pine and red oak show strong positive association where their ranges overlap in central Minnesota. Red oak seems to have similarly responded to conditions of the early 1900's (see Red Oak).

Successional Position and Regeneration Strategy

Our interpretation of the behavior of white pine is limited to our releve sampling **(R-2)**. We believe that it was probably a ***mid-successional*** tree, because of its affinity for habitats disturbed more often than calculated for MHs38, but following the initial response of oaks and aspen. Its presence in very old stands suggests the behavior of a late-successional species, but we feel that its longevity more than regeneration success carried into older growth-stages. Its behavior in the understory of modern stands shows regeneration indices of success typical of species that do best in ***large-gaps***. Establishment under a canopy is not much of a problem, but regenerant survival to produce healthy seedlings seems to be a problem that we believe would improve with greater amounts of sunlight. There are no data for interpreting a ***natural window of establishment***.

American (Red) Elm

- ***excellent habitat suitability rating for American elm***
- ***poor habitat suitability rating for red elm***
- ***late-successional***
- ***small-gap (open) regeneration strategist***
- ***regeneration window at 0-40 years***

Identification Problems
The PLS surveyors did not distinguish between American and red (slippery) elm. Thus, interpretations of PLS data for the more common American elm should always be done knowing that some of these trees were likely red elm. MHs38 releve samples show that for plots with elm present: 17% have both species present; 26% are red elm without American elm; 57% are American elm without red elm. We consider American elm and red elm to be ecologically equivalent for most silvicultural considerations.

Suitability
MHs38 sites provide ***excellent habitat*** for **American elm** trees. The ***suitability rating*** of 4.0 for American elm is influenced mostly by its presence (27%) as trees on these sites in modern forests **(R-1)**. When present, American elm is a minor co-dominant tree, contributing 8% mean cover in mature stands. The ranking is eighth, following northern red oak, sugar maple, basswood, bur oak, green ash, white oak, and white pine on MHs38 sites. Southern mesic hardwood communities in general offer excellent habitat for American elm (see Suitability Tables). Among these, MHs38 has the lowest suitability rating, but it is still considered excellent.

MHs38 sites provide ***poor habitat*** for **red elm** trees. The ***suitability rating*** of 2.0 for red elm is the consequence of 16% presence and 1% mean cover when present. The ranking is 14th among trees common on MHs38 sites. In general, southern mesic hardwood forests (MHs) are excellent habitat for red elm, with the exception of MHs38 sites (see Suitability Tables). Its presence in MHs38 communities is comparable to other MHs communities, but its cover is exceedingly low for unknown reasons.

Young Growth-stage: 0-35 years
Historically, American elm was an important component of young MHs38 stands **(PLS-1, PLS-2)**. Young elms represented 2% of the trees at survey corners described as burned **(PLS-3)**. Elm was more successful at windthrown corners where it represented 4% of the trees present. Small-diameter, elm regeneration coming in among larger trees was abundant in the post-disturbance window **(PLS-5)**. Our interpretation is that a substantial bank of elm seedlings were available to re-colonize MHs38 stands following removal of the canopy. We believe also that elms were successful in establishing seed-origin trees in the open.

Transition: 35-75 years
As stands transitioned to mature conditions American elm increased in abundance **(PLS-1)**. We estimate that this increase started immediately after disturbance and continued for the life of the stand until elms were important co-dominants in old stands **(PLS-2)**. Small-diameter elm regeneration was abundant in the G-1 gap window corresponding with the transition **(PLS-5)**. In most cases, young elms were coming in under basswood, other elms, red oak, and sometimes under aspen. We interpret this as good success at establishment and recruitment of seed-origin elms during the transition and some release of elm seedlings established during the young growth-stage. This interpretation is supported by elm's good 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
American elm had its peak presence as a canopy co-dominant in mature stands, which is why we consider basswood a ***late-successional*** species – able to replace about any tree as stands aged **(PLS-1, PLS-2)**. Its steady increase in relative abundance is the result of good establishment and

recruitment beginning immediately and lasting at least until the 80-year age-class **(PLS-5)**. The survivorship of established elms must have been high. At this time elms were usually the largest tree at survey corners, but there were plenty of corners where it was the smallest tree. This diameter variation is typical of trees that have a long window (80 years) of regenerative success. When elm was the smallest tree at a survey corner, a significant amount was replacing itself. It was common also for elm to be coming in under basswood, sugar maple, and red oak. We interpret this as elm demonstrating its late-successional importance on MHs38 sites as it was consistently present in all strata of a mature forest and able to replace itself.

Regeneration Strategies

American elm's primary regenerative strategy on MHs38 sites is to develop a bank of seedlings capable of recruiting in ***small-gaps***. Elms were successful at this beneath most other species, including itself. In the historic PLS data this interpretation is supported by: (1) the fact that elm abundance peaks in the mature growth-stage **(PLS-1, PLS-2)**, and (2) it is most abundant by far, at survey corners showing no canopy loss or disturbance **(PLS-3)**. The high percent of elm in subordinate canopy situations (12, 13, 23) in the FIA data **(FIA-1)** is also a characteristic of species that tend to regenerate best in small gaps. The releve sampling of mature MHs38 forests shows that American elm is good at establishing and recruiting individuals in all regenerating strata, eventually resulting in canopy importance **(R-2)**.

It is important to note that American elm, unlike sugar maple, showed significant success immediately after disturbance. Its peak opportunity for establishment and recruitment was in the post-disturbance window **(PLS-5)**. It seems likely that most of this was advance regeneration and that elm seedlings tolerated mild surface fires as did red oak and they were released by the stand-regenerating event. In the ***open***, elm seedlings must have responded vigorously in comparison to competing oak and basswood. As long as elm regeneration was present, it probably responded to almost any level of canopy removal, but it seemed to have a greater competitive edge over other MHs38 trees in small gaps.

Historic Change in Abundance

Today, the abundance of elm is considerably less than it was historically, with relative abundance of about 3% in all growth-stages **(PLS/FIA-1)**. The decline from 13% in mature pre-settlement forests 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. Red oak is the only other species to show significant decline in the young growth-stage, and in that case we attributed lower success to the lack of surface fires that favored oak seedlings over fire-sensitive trees like sugar maple. Given elm's late-successional, small-gap behavior on MHs38 sites, it seems quite unlikely that they would benefit directly from surface fires. It seems far more likely that surface fires burning through MHs38 stands would have skipped the wetter inclusions where elm is favored in this community. Perhaps, burned-through MHs38 stands were especially good seeding habitat for American elm, and such habitat is now mostly absent.

Bitternut Hickory

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

Suitability

MHs38 sites provide ***good habitat*** for bitternut hickory trees. The ***suitability rating*** of 3.3 for bitternut hickory is influenced mostly by its presence (18%) as trees on these sites in modern forests **(R-1)**. When present, bitternut hickory is a minor co-dominant tree, contributing just 8% mean cover in mature stands. The ranking is ninth among trees common on MHs38 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, MHs38 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 MHs38 stands with about 3% 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 MHs38 survey corners. 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 MHs38 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 MHs38 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 6% relative abundance at age 60 is real because it occurs in the most populated age-classes. Because hickory peaks during this transition, we consider it to be a ***mid-successional*** species on MHs38 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 the normal snow depth **(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 bitternut hickory trees were in decline, and recruitment seems to not have happened often past about age 80 **(PLS-5)**. When hickory was recorded, it now was almost exclusively subordinate to the neighboring bearing trees. At this stage, small hickories were beneath elm, sugar maple, basswood, and some red oak. In modern mature MHs38 forests, bitternut hickory is disproportionally abundant as regeneration (50%, **R-2**) compared to its presence as a tree (18%, **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 MHs38 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 MHs38 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, (2) they were present at survey corners showing partial canopy loss **(PLS-3)**, and (3) they showed peak establishment 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.

The releve sampling of mature MHs38 forests shows that bitternut hickories also show some characteristics of trees that fill ***small-gaps***. Most obvious is their ability to maintain a bank of seedlings as they are usually present (50%) in MHs38 forests and have high recruitment indices for regenerants and seedlings **(R-2)**. Bitternut hickory has the highest presence as seedlings under a mature canopy (situation 13) in the FIA sampling of MHs38 stands, which is characteristic of small-gap strategists **(FIA-1)**. Unlike sugar maple, basswood, elm and other small-gap trees, 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 10m.

Historic Change in Abundance

Today, bitternut hickory is about as abundant as it ever was (PLS/FIA-1). The greatest departure is in the young growth-stage where historically it had 3% relative abundance and now has just 1%. Sugar maple is now abundant in young MHs38 forests, and most likely able to out-compete hickory in the gaps. The presence of bitternut hickory is far greater in the releves than FIA data. It has 18% presence as a tree in releves compared to just 1% at FIA subplots. Bitternut seedlings have a remarkable presence of 50% compared to just 4% in the FIA subplots, mostly because few seedlings achieve the minimum 1" diameter required for inclusion in the FIA data that we used. It seems that bitternut hickory is doing better in the undisturbed releves stands.

(PLS-1) Historic Abundance of MHs38 Trees in Natural Growth-stages

Table values are relative abundance (%) of Public Land Survey (PLS) bearing trees at corners modeled to represent the MHs38 community by growth-stage. Growth-stages are periods of compositional stability during stand maturation. Arrows indicate periods of compositional change during which tree abundances increase or decrease substantially. Yellow, green, and purple shading groups trees with abundance peaks in the same growth-stage. Percents on the bottom row represent a snapshot of the balance of growth-stages across the landscape *ca.* 1846 and 1908 AD.

Dominant Trees	Forest Growth Stages in Years		
	0 - 35	35 - 75	> 75
	Young	T1	Mature
Red Oak	**64%**		**13%**
Big-toothed (Quaking) Aspen	**5%**		**–**
Basswood	**12%**		**18%**
American (Red) Elm	**7%**		**14%**
Ironwood	**4%**		**14%**
Sugar Maple	**1%**		**30%**
Bur & White Oak	**–**		**12%**
Miscellaneous	**7%**		**7%**
Percent of Community in Growth Stage in Presettlement Landscape	**7%**	**35%**	**58%**

PLS-1

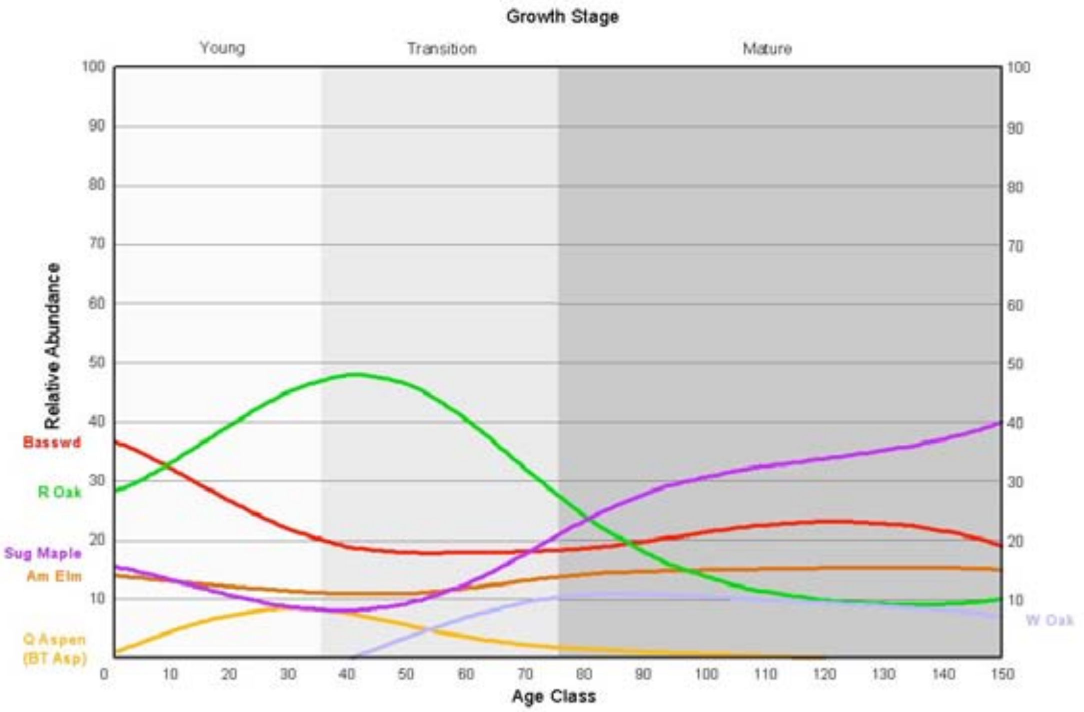
Trees included in Table PLS-1 are species with greater than 3% relative abundance in at least one growth-stage. Species that are now abundant in MHs38 forests, but were rare historically appear in Table **PLS/FIA-1**.

On MHs38 sites the PLS surveyors did not consistently distinguish the more prevalent big-toothed aspen from quaking aspen, the more prevalent American from red elm, and white from bur oak, which have similar abundance.

Public Land Survey linked text

(PLS-2) Abundance of trees throughout succession in MHs38

Caption: Graphed for the different species of MHs38 trees is their relative abundance (%) as PLS bearing trees by age class. The data were initially smoothed from adjacent classes and then by visually fitting lines to illustrate general trends.



Documentation for Figure PLS-2

**Public Land Survey linked text

(PLS-3) Historic Abundance of MHs38 Trees Following Disturbance

Table values are raw counts and (percentage) of Public Land Survey (PLS) bearing trees at survey corners likely to represent MHs38 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	
Big-toothed (Quaking) aspen	5	4%	7	2%	43	3%	194	2%
Paper birch	2	2%	1	0%	11	1%	42	0%
Box elder	1	1%	0	0%	0	0%	3	0%
Northern red oak	101	82%	283	84%	1167	72%	1993	20%
Bur & White oak	6	5%	27	8%	244	15%	857	9%
Sugar maple	0	0%	1	0%	31	2%	2114	21%
Basswood	5	4%	4	1%	50	3%	2146	21%
American (Red) elm	2	2%	12	4%	45	3%	1527	15%
Ironwood	1	1%	0	0%	10	1%	706	7%
Green (White) ash	0	0%	0	0%	17	1%	209	2%
Bitternut hickory	0	0%	0	0%	10	1%	236	2%
White pine	0	0%	0	0%	0	0%	1	0%
Hackberry	0	0%	0	0%	0	0%	27	0%
Total (% of grand total, 12141)	123	1%	335	2.8%	1628	13%	10055	83%

PLS-3
Table PLS-3 includes only trees ranked as having excellent, good, or fair suitability for MHs38 sites. Tree sums will not match the totals in the Natural Disturbance Regime text, because trees of poorer suitability were included in that analysis.

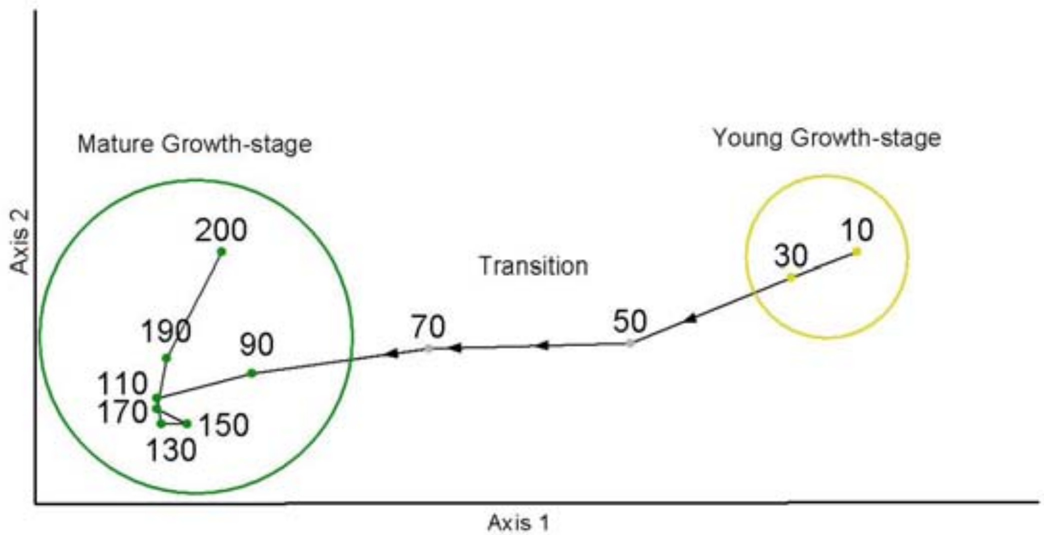
PLS survey corners were assigned to four disturbance categories:

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

Public Land Survey linked text

(PLS-4) Ordination of Historic MHs38 Age-classes

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



PLS-4
For each PLS survey corner we estimated stand age based on the diameter of the largest tree. The corners were placed into 20-year age-classes for this analysis. We used coarse age-classes mostly because the surveyors tended to estimate diameters coarsely in even inches. For each age-class the relative abundance of each bearing tree type was calculated and used to characterize and ordinate the age-classes. Detrended Correspondence Analysis provided the smoothest ordinations, meaning that the age-classes tend to sequentially track across the ordination plot. There is always some subjectivity and uncertainty in placing the seams between growth-stages and transitions in these diagrams. When uncertain, we placed seams that match process transitions (self-thinning to density-independent mortality, ingress of shade-tolerants, etc.) described in more general models of stand dynamics in silvicultural literature.

(PLS-5) Historic Windows of Recruitment for MHs38 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 yrs	G-1 30-90 yrs	I-1 >90 yrs
Yes	Big-toothed Aspen[1]	0-30	Excellent	Good to 40	--
Yes	Hackberry	0-30	Fair	Poor to 50	--
Yes	Basswood	0-30	Excellent	Good to 70	--
Yes	American Elm[5]	0-40	Excellent	Good to 80	--
Yes	Red Oak	0-50	Excellent	Good to 70	--
Yes	Ironwood	0-150	Good	Excellent	Excellent
Minor	Sugar Maple	40-70	Fair	Good to 80	--
No	Box Elder	40-50	--	Poor 40 to 50	--
No	Paper Birch	40-60	--	Poor 40 to 60	--
No	Bur & White Oak[4]	50-60	--	Fair 50 to 80	--
No	Bitternut Hickory	50-60	--	Fair 50 to 80	--
No	Green Ash[2]	60-100	--	Poor	Poor to 100
No	White Pine[3]	120	--	--	Poor at 120

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 and quaking aspen, 30-90 years
- **I-1:** ingress of seedlings under canopy of sugar maple mixed with basswood, red oak, elm, and ironwood, >90 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; **gold =** trees with peak regeneration later in the P-D window; **light green** = trees with peak regeneration in gaps formed during the decline of the initial cohort; **purple** = trees with peak regeneration by ingress under a mature canopy or by filling small gaps in old forests

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. Green ash bearing trees couldn't be segregated from white ash in the PLS notes for this community. The green ash data probably include some white, which we consider ecologically similar to green ash.
3. White pine appears in old modern stands but was not present in the PLS data. The interpretation presented here is based upon FIA data for just a few trees and is unreliable.
4. Bur & White Oak bearing trees couldn't be segregated in the PLS notes for this community. They have roughly equal presence in modern forests and are ecologically similar.
5. American elm bearing trees couldn't be segregated from red (slippery) in the PLS notes for this community. The American data probably include some red elm, which we consider ecologically similar to American elm.

PLS-5

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

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

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

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

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

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

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

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

(R-1) Suitability ratings of trees on MHs38 sites

This table presents an index of suitability for trees in MHs38 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 MHs38

Tree	Percent Presence as Tree	Mean Percent Cover When Present	Suitability Index*
Northern red oak (Quercus rubra)	60	39	5.0
Sugar maple (Acer saccharum)	59	40	4.9
Basswood (Tilia americana)	82	22	4.9
Bur oak (Quercus macrocarpa)	33	23	4.8
Green ash (Fraxinus pennsylvanica)	36	17	4.7
White oak (Quercus alba)	30	17	4.6
White pine (Pinus strobus)	12	42	4.6
American elm (Ulmus americana)	27	8	4.0
Bitternut hickory (Carya cordiformis)	18	8	3.3
Paper birch (Betula papyrifera)	20	4	2.3
Hackberry (Celtis occidentalis)	5	12	2.3
Box elder (Acer negundo)	8	8	2.2
White ash (Fraxinus americana)	7	9	2.1
Big-toothed aspen (Populus grandidentata)	8	8	2.1

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

R-1

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

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

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

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

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

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

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

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

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

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

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

(R-2) Natural Regeneration and Recruitment of Trees in Mature MHs38 Stands

This table presents an index of regeneration for MHs38 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 MHs38 communities. Changes in the index values from one stratum to another can be used to estimate regenerative bottlenecks, whether establishment (R-index) or recruitment (SE-, SA-, or T-indices).

Natural regeneration indices for germinants, seedlings, saplings, and trees common in the canopy of Southern Mesic Oak-Basswood Forest – MHs38					
Trees in understory	**% presence R, SE, SA**	**R-index**	**SE-index**	**SA-index**	**T-index**
Ironwood (Ostrya virginiana)	**90**	**4.3**	**4.8**	**5.0**	**4.0**
Basswood (Tilia americana)	**84**	**4.7**	**4.7**	**4.3**	**4.8**
Sugar maple (Acer saccharum)	**70**	**5.0**	**5.0**	**5.0**	**5.0**
Northern red oak (Quercus rubra)	**55**	**4.3**	**3.8**	**2.7**	**5.0**
Bitternut hickory (Carya cordiformis)	**50**	**4.3**	**4.3**	**3.7**	**3.0**
Green ash (Fraxinus pennsylvanica)	**41**	**3.3**	**3.8**	**2.8**	**4.3**
American elm (Ulmus americana)	**38**	**3.8**	**3.7**	**3.3**	**3.5**
Box elder (Acer negundo)	**34**	**2.0**	**2.3**	**2.2**	**2.3**
Hackberry (Celtis occidentalis)	**28**	**2.7**	**2.8**	**3.0**	**2.3**
Bur oak (Quercus macrocarpa)	**23**	**1.7**	**1.8**	**1.8**	**4.3**
White oak (Quercus alba)	**13**	**2.2**	**2.0**	**2.0**	**4.3**
White ash (Fraxinus americana)	**13**	**3.2**	**3.8**	**2.8**	**2.5**
White pine (Pinus strobus)	**9**	**3.3**	**2.7**	**3.2**	**4.0**
Paper birch (Betula papyrifera)	**7**	**0.8**	**0.7**	**1.7**	**3.3**
Big-toothed aspen (Populus grandidentata)	**5**	**1.0**	**0.8**	**1.0**	**3.0**

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

% presence: the percent of 128 MHs38 sample plots with that species present under 10m (33 feet) tall (R, SE, SA layers)
R-index: index of representation as true seedling or under 10cm (4 inches) tall
SE-index: index of representation as seedlings over 10cm and under 2m (0.3-6.6 feet) tall
SA-index: index of representation as saplings 2-10m (6.6-33 feet) tall
T-index: index of representation as a tree >10m (33 feet) tall
All indexes: equally weight (1) presence, (2) mean cover when present, and (3) mean number of reported strata, the frequency distributions of which are segmented equally by area into 5 classes.

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

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

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

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

(FIA-1) Structural Situations of Trees in Mature MHs38 Stands

This table presents percentages of structural situations for trees as recorded in Forest Inventory Analysis (FIA) subplots that we modeled to be samples MHs38 forests. The purpose of the table is to provide a general impression of how often a species is seen certain regenerative situations: canopy of a regenerating forest (situations 11, 22), in the subcanopy (situations 12, 23), or in the seedling bank below a remote canopy (situation 13). The situation of trees in older stands at tree height (33) provide no insight about regeneration. Species are ordered by the sum of their percents in 12 and 13 situations, which generally ranks them as would shade-tolerance ratings. The total number of trees counted for each species is presented to provide a sense of reliability.

Species	Tree Count	Structural Situations					
		11	22	12	23	13	33
White pine	3	-	-	-	67%	-	33%
White ash	1	-	100%	-	-	-	-
Northern red oak	570	2%	9%	-	18%	2%	70%
White oak	17	-	6%	-	-	6%	88%
Bur oak	214	1%	5%	2%	25%	4%	63%
Paper birch	79	8%	25%	8%	19%	1%	39%
Big-toothed aspen	65	6%	17%	18%	12%	5%	42%
Box elder	16	19%	6%	25%	38%	-	12%
Basswood	386	5%	3%	7%	18%	21%	50%
Green ash	36	22%	11%	14%	11%	19%	22%
Sugar maple	316	6%	4%	11%	15%	26%	39%
American elm	39	3%	10%	10%	13%	41%	23%
Bitternut hickory	9	11%	-	-	33%	56%	-
Hackberry	7	-	-	-	14%	86%	-

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

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

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

FIA linked text

(PLS/FIA-1) Abundance of MHs38 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 MHs38 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	64%	11%			13%	25%
Big-toothed (Quaking) Aspen	5%	17%			–	5%
Basswood	12%	11%			18%	17%
American (Red) Elm	7%	3%			13%	3%
Ironwood	4%	10%			13%	10%
Sugar Maple	1%	21%			30%	14%
Bur & White Oak	–	3%			12%	12%
Red Maple	0%	4%			0%	2%
Paper Birch	2%	5%			--	3%
Green (White) Ash	1%	7%			2%	2%
Bitternut Hickory	3%	1%			1%	0%
Miscellaneous	1%	7%			0%	7%
Percent of Community in Growth Stage in Presettlement and Modern Landscapes	7%	8%	35%	39%	58%	53%

Natural growth-stage analysis and landscape summary of historic conditions is based upon the analysis of 4,869 Public Land Survey records for section and quarter-section corners. Comparable modern conditions were summarized from 1,712 FIA subplots that were modeled to be MHs38 sites.

Public Land Survey linked text
FIA linked text

Silviculture Systems for MHs38: No arrow - least favorable, ⇧ Favorable, ⇧⇧ Very Favorable

	Silviculture Systems	Clearcut	Patch Cutting	Group Seedtree	Dispersed Seedtree	Uniform Shelterwood	Group Shelterwood	Irregular Shelterwood	Group Selection	Strip Selection	Single Tree Selection
	Regeneration Strategy										
N. Red Oak	Open (large-gap)										
Sugar Maple	Small-gap										
Basswood	Small-gap (open)										
White Oak	Large-gap										
Green Ash	Large-gap (small-gap)										
White Pine	Large-gap										
American Elm	Small-gap (open)										
Bitternut Hickory	Large-gap (small-gap)										

Forest Health

Northern Red Oak

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

WATCHOUTS!

∞ Protect seedlings and saplings from browse damage.

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

∞ Maintain optimal stocking in high-value stands to avoid mortality losses due to two-lined chestnut borers and Armillaria root disease.

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

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

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

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.

White Pine

Agent	Growth stage	Concern/ Effect
White pine blister rust	All stages	Mortality
Armillaria root disease	"	"
Deer/ rodent browse	Seedlings and saplings	Mortality, topkill
White pine weevil	"	Topkill, forking
White pine blister rust	Pole-sized and larger	Topkill, branch death
Stem decay	"	Volume loss

WATCHOUTS!

∞ Protect seedlings and saplings from browse damage.

∞ Always regenerate/ plant white pine under an overstory to avoid losses from white pine blister rust and white pine weevil.

∞ For cross-pollination, parent trees must be within 200 feet of each other.

∞ In the northern half of the state, natural and artificial regeneration are very likely to develop blister rust cankers and die if they are not pathologically pruned from the time of establishment until there is 9 feet of clear stem.

∞ Pole-sized and larger trees will survive for a long time with multiple blister rust infections in their crowns. Do not be too hasty in harvesting them because they are good seed sources.

∞ 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.

MHs38 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	Acceptable Operating Season [5]: 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 MHs38 that are more susceptible to compaction and rutting. They are listed in descending order of presence.

Virginia creeper (*Parthenocissus spp.*)
Virginia waterleaf (*Hydrophyllum virginianum*)
Lady fern (*Athyrium filix-femina*)
Jack-in-the-pulpit (*Arisaema triphyllum*)
White avens (*Geum canadense*)
American elm (U) (*Ulmus americana*)
Kidney-leaved buttercup (*Ranunculus abortivus*)
Charming sedge (*Carex blanda*)
Box elder (U) (*Acer negundo*)
Wood nettle (*Laportea canadensis*)

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

Foot Notes

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

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

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

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

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

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

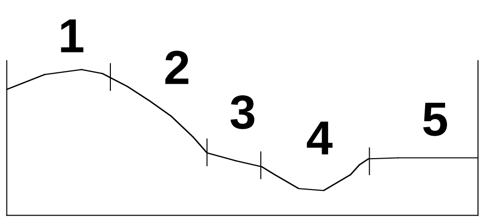
   Poor – water saturation occurs within 10 inches of the surface for most of the growing season

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

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

4. Landscape Position

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



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

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

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

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

   W Winter – the ground is snow covered or partially frozen

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

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

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

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

Public Land Survey linked text

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

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

By ordinating age-classes (PLS 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 linked text

Releve Samples

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

First, releves were used as a means of determining just how well adapted the different species of trees are to living with other plants in the NPC and to important soil characteristics like drainage and water-holding capacity. Based upon how often we find certain trees in a community and how abundant it is when we do find it, we created an Index of Suitability for trees (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