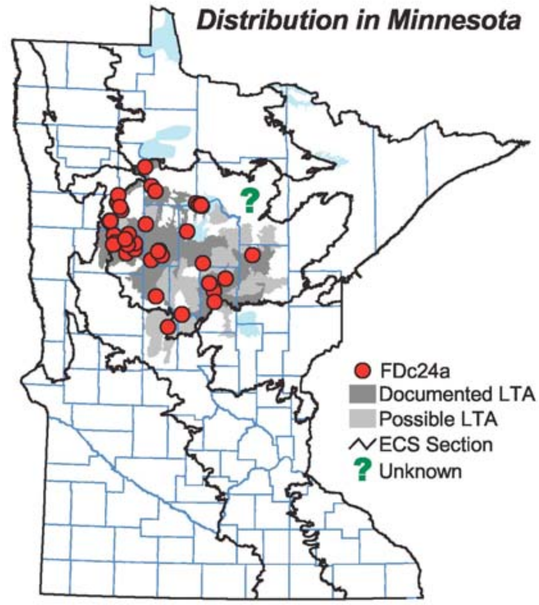
FDc24

FDc24 – Central Rich Dry Pine Woodland

Natural Disturbance Regime, Stand Dynamics, and Tree Behavior

Introduction and Management Highlights

Central Rich Dry Pine Woodlands (FDc24) are a common fire-dependent community in the Northern Minnesota Drift and Lake Plain ecological Section of Minnesota. Detailed descriptions of this community are presented in the DNR Field Guides to Native Plant Communities of Minnesota.



The range of FDc24 forests in Minnesota (shaded) and distribution of releve samples (red dots).

Commercial Trees and Opportunities

As a commercial woodland, FDc24 sites offer a very limited selection of crop trees and incredible variety of possible structural conditions. Jack pine, red pine, quaking aspen and bur oak are all ranked as trees with excellent suitability for FDc24 sites by virtue of their frequent occurrence and high cover when present on FDc24 sites (see Suitability Tables). Quaking aspen though produces poor-quality pulp on sites this dry, and bur oak does not produce logs commercial interest in the present market. Paper birch and red oak are ranked as having good suitability, and stands can be managed to perpetuate these trees as co-dominants. Birch though, is short-lived on FDc24 sites, and red oak does not produce useable logs.

All of these trees are native to the FDc24 community and have occupied these sites for about a millennium, replacing what was prairie and brushland that thrived in the drier climate of times past (~8,000-1,500 B.P.). For trees, this is not a long period for adaptation through successive generations to the current physical conditions of FDc24 sites. Most likely, FDc24 sites with native jack pine, red pine, and quaking aspen are harboring genotypes adapted to the forecast global warming. The consequence of fire suppression, commercial logging, and settlement in the past century has been to promote much more quaking aspen than was usual **(PLS/FIA-1)**. Both jack pine and red pine are in peril on these sites because artificial planting has been much less successful than fire in regenerating these pines.

Although our interest is in silviculture, it is clear that FDc24 sites offer management opportunities apart from wood products. In circumstances where wood production is a secondary goal, FDc24 sites offer an excellent opportunity to provide habitat for “prairie” plants and habitat for wildlife adapted to prairie-brushland. Both prairie and prairie-brushlands have been nearly eliminated from Minnesota’s landscape due to agricultural development, and FDc24 sites could at least temporally provide “lifeboat” habitat. Because of their prairie heritage, FDc24 have rich soils. This presents silvicultural obstacles, most relating to competition, that make it difficult to fully stock these sites with pine within a few years of harvest. However, the growth of established pines is very good. In our limited experience, there are not great differences in yield between stands that go through the naturally slow process of replacing native prairie-brushland with jack pine or plantations that suffer incredible thinning due to the stressful nature of FDc24 sites.

Natural Silvicultural Approaches

In the historic landscape, most FDc24 woodlands (71%) were in the young growth-stage **(PLS-1)**. Roughly these woodlands were under 55 years old, meaning that succession rarely proceeded beyond the life expectancy of the dominant jack pines. At this time fires, whether intense stand-initiating ones or milder surface fires, created lots of open and large-gap habitat for regeneration of jack pine, red pine, and quaking aspen. Silvicultural systems approximating these disturbances include clear-cutting, clear-cutting with reserves, patch cutting, and some variants of seed-tree harvests. According to our interpretations (see Tree Behavior), paper birch and red pine are the main species that require the entirely open habitat approximated by variants of clear-cutting. Jack pine and quaking aspen should perform well in the open or in large gaps. Clear-cutting, patch cutting, and some seed-tree systems might work for these species if reducing grass and brush competition accompanies the treatment. The large-gap strategies of patch cutting and some seed-tree systems should result in recruitment of larger bur and red oak stems, and could possibly improve acorn production.

About 18% of the historic landscape was in transition between the young and mature growth-stages **(PLS-1)**. At this time, senescence of the initial-cohort jack pines or their death due to surface fires created regeneration opportunities for trees in gaps ranging from single-tree gaps to very large gaps up to a few acres. Several silvicultural systems could be used to approximate the natural loss of initial-cohort trees and regeneration typical of transitioning FDc24 forests. Selective harvesting matches best the small-gap mortality pattern, but no FDc24 trees are small-gap strategists other than perhaps red oak. Large gap systems such as patch cutting, variants of seed-tree harvesting, and some variants of shelterwooding are the likely candidates for moving mixed jack and red pine FDc24 woodlands towards greater abundance of red pine. Usually, these strategies would be aimed at the dual goal of capturing the impending mortality of the jack pines and regenerating second-cohorts of jack and red pine.

Mature and old FDc24 woodlands covered about 11% of the historic landscape **(PLS-1)**. Our vision of these woodlands is a skeletal presence of red pine standing above one to several cohorts of younger jack pine dating to surface fires. The mean diameter of red pines at survey corners older than 75 years was 20 inches with many trees exceeding 30 inches. FDc24 sites are quite able to grow large-diameter red pines at sparse spacing. These woodlands were maintained by frequent surface fires that created openings and large-gaps for pine regeneration and probably selected for scattered red pines that were getting large enough to resist surface fires. The silvicultural equivalent of these surface fires is thinning from below and systems that create gaps in the red pine canopy. Patch cutting, variants of seed-tree harvesting, and some variants of shelterwooding are the likely candidates for creating the regeneration openings for jack or red pine. These systems would follow thinnings from below aimed at getting some advance regeneration of red pine. The actual silvicultural system used would be an adaptive reaction to the success or failure of the thinnings to create advance regeneration.

Management Concerns

Most FDc24 communities occur on level, coarse-textured sand and gravel of outwash plains. In these situations, there is little concern of soil-compaction. Only when the soil surface is saturated and above frost is there a chance of rutting. Rarely FDc24 communities occur on sandy inclusions of stagnation moraines. In our experience, these are just local deposits of outwash with the same, low potential for compaction and rutting.

The landscape balance of growth-stages and stand ages for the FDc24 community is not much different than it was historically **(PLS/FIA-1)**. Today, there is slightly less young forest (<55 years) and slightly more transitioning forest (55-75 years) than in pre-settlement times. Today's young woodlands though, do not resemble the prairie-like conditions of the past because agricultural weeds (e.g. bluegrass) dominate logged sites. Compositional changes are more of a concern. Most obvious is the loss of jack and red pine as the dominants, especially in the young-growth stage. There are basically no examples of young, fire-regenerated, prairie-like FDc24 woodlands. Quaking aspen has replaced the pines. Although quaking aspen is a native FDc24 tree, it never occurred at such high abundance. The effect of modern management has been to allow aspen to develop extensive clonal rootstocks on FDc24 sites, whereas we believe that its historic presence was the result of seeding in on burned sites. Deterring aspen, now able to respond vegetatively to canopy removal, presents a silvicultural challenge to our attempts to restore jack and red pine.

Natural Disturbance Regime

Natural rotation of catastrophic and maintenance disturbances were calculated from Public Land Survey (PLS) records at 2,667 corners within the primary range of the FDc24 community. At these corners, there were 7,223 bearing trees that one commonly finds in FDc24 woodlands.

Natural Rotations of Disturbance in FDc24 Forests Graphic	
	Banner text over photo
Catastrophic fire photograph	**130 years**
Catastrophic windthrow photograph	**2,210 years**
Partial Canopy Loss, photograph	**30 years**

The PLS field notes described about 12% of the FDc24 landscape as recovering from stand-regenerating fire. Most records were of burned-over lands with some references to post-fire thickets, scattered oak or pine timber, and sparsely stocked forest. From these data, a rotation of 130 years was calculated for stand-replacing fire.

Elsewhere in the FDc24 landscape, the surveyors described lands as windthrown and without suitable-sized trees for scribing. Such corners were encountered at about 1% of the time, yielding an estimated rotation of 2,210 years for windthrow.

Far more common on FDc24 sites were references to what we have interpreted as some kind of partial canopy loss, without any explicit mention of fire or windthrow. Most references were to scattered pine or oak timber, thickets, or sparse forest with distances to bearing trees that were intermediate between the distances for burned/windthrown lands and what is typical of pine forests. About 18% of the survey corners were described as such, resulting in a calculated rotation of 30 years for disturbances that maintained early and mid-successional trees on FDc24 sites. That far more corners were described as burned (159) compared to windthrown (19) suggests that surface fires were the more prevalent cause of partial canopy loss.

Rotations of catastrophic and maintenance disturbance for FDc24 are similar to all other central communities where jack pine is the dominant tree. Wind played virtually no role in regenerating these communities. The rotation of about 130 years for catastrophic fire is about twice the expected longevity of jack pine in this region of Minnesota, yet jack pine remained the dominant tree in substantially older forests. From this, we conclude that surface fires on about a 30-year rotation maintained local populations of jack pine and the woodland physiognomy on FDc24 sites. This regime is rather similar to southern and northwestern oak-aspen FD woodlands where surface fires were about 5 times as likely as stand-regenerating fire. This contrasts with northern fire-dependent pineries where surface fires were only about twice as likely or about as common as catastrophic fire. This chronic level of surface fire probably explains also physiological differences of jack pines between the central and northern floristic regions. The central trees live about half as long, mature earlier, and have lightly serotinous cones capable of shedding seed in response to surface fire or just warm summer conditions.

Natural Stand Dynamics & Growth-stages

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

Following stand-regenerating fire, the overall pattern of change in prairie-like woodlands such as FDc24 involves both compositional succession and structural maturation. Unlike true forests, compositional succession in woodlands involves "canopy" dominants that are not trees, which makes reconstruction from tree databases like the PLS survey notes more difficult to interpret. The surveyors described prairie openings, brush, and brushy forms of trees like oak and aspen. From our releves, Pennsylvania sedge and bracken would have been the most likely herbaceous plants to have dominated post-fire FDc24 sites. American and beaked hazelnut are the most likely shrubs to have occupied treeless areas. Jack pine strongly dominated the FDc24 patches regenerating to trees **(PLS-1, PLS-2)**, so much so that there was not much initial compositional change due to trees **(PLS-4)**. The brushy, prairie-like vegetation must have been nearly impenetrable to trees other than jack pine. By age 50, patches of FDc24 were nearing forest structure and other patches were little modified from the post-fire years. Because shade was beginning to play a role in the forest-like patches, there was limited ingress of red and less often white pine. The resulting mixed pinery showed very little compositional movement as chronic surface fires maintained a mixed composition and assured continued presence of jack pine.

Structural maturation is all about shade and chance. Prairie-like woodlands in Minnesota occur on soils and in climatic regions that will ultimately will support forest vegetation if not disturbed. Shade, that is the eventual formation of a tree canopy, will eventually subordinate the prairie grasses, Pennsylvania sedge, bracken, and shrubs. Historically, the chance occurrence of surface fires rarely allowed succession to a growth-stage that a forester would describe as fully stocked pine forest. Young and transitioning FDc24 woodlands <75 years old were more tightly packed with trees than older stands. However, the mean distances of bearing trees to their corners was about 50 feet, which is not even close to the 20-foot means typical of true forests. The variance of bearing tree distances is incredibly high for these younger growth-stages, which suggests patchy distribution rather than orchard-like spacing of trees. Our vision of young FDc24 sites is that of scattered patches where the regenerating jack pines were at forest-like density separated by patches of brush and prairie with a few scattered jack pines. The density of jack and red pine in the mature and second transition FDc24 stands dropped dramatically as indicated by increasing mean distance of larger-diameter pines to survey corners. At this time, the mean distance of a pine bearing tree to the corresponding corner was nearly 80 feet. This increase in spacing has nothing to do with canopy competition; rather we believe that the chronic surface fires favored the survival of larger-diameter trees with remote crowns and removal of smaller-diameter, shorter trees. Even in the very old growth-stage the mean distance of woodland bearing trees to survey corners was 46 feet, just beginning to approach the 30 foot mean distances typical of central fire-dependent forests. The FDc24 community was woodland in all growth-stages because chronic surface fires killed mature trees, removed pine regeneration, and stunted the growth of oaks.

It is important to note that our field experience with modern FDc24 communities doesn't entirely match our interpretation of the PLS survey notes. Though declared failures, many of our planting efforts match exactly our concept of naturally sparse stocking of pine, with grasses and brush dominating much of the site. However, there are examples where FDc24 stands burned intensely on the Bemidji Sand Plain and the Park Rapids Sand Plain since the 1950's resulting in good natural regeneration of both jack and red pine. Our best guess is that fire suppression allowed for the formation of jack pine forest that structurally would support crown fire. In that case, central jack pines behaved much like our northern jack pine communities, with a strong initial-cohort of jack pine.

Young Growth-stage: approximately 0-55 years
About 71% of the FDc24 landscape in pre-settlement times was covered by woodlands estimated to be under 55 years old **(PLS-1)**. Post-fire woodlands were patches of prairie, brushland, and trees. The treed areas were essentially monotypic and dominated by jack pine. There were some references to initial-cohort red pine, quaking aspen, and possibly white pine **(PLS-1, PLS-2)**. In describing these very young, burned woodlands the surveyors indicated that the pines were dominant and aspen, paper birch, and bur oak were widely scattered if present at all. Young stands recovering from windthrow were negligible and wind had no differential effect on composition in comparison to fire **(PLS-3)**.

The ability of jack pine to dominate young FDc24 woodlands is in part a consequence of its persistence in the mature growth-stage. Jack pines were abundant in older stands and prepared to re-establish themselves. By as early as age 15 years, jack pine in these habitats is sexually mature, holding at least a few-years' production of seed in serotinous cones and with older cones opening and shedding seed to help fill in brushy or grassy gaps between trees. Because FDc24 sites are so fire-prone (see Natural Disturbance Regime) it is entirely likely that some fires passed through young woodlands at a time when only jack pine trees were capable of reproducing by seed, giving jack pine a considerable edge over red and white pine.

Transitional Stage: approximately 55-75 years
About 18% of the historic FDc24 landscape was woodland undergoing compositional change **(PLS-4)**. About half of the stands in this stage were monotypic jack pine, and a few were pure aspen. At survey corners with mixed composition, jack pine is still the most cited species and it was mixed with red pine and aspen **(PLS-1, PLS-2)**. Bur oak and white pine were minor contributors to mixed, transitioning stands.

Species' succession during the transition stage was driven mostly by the decline in jack pine as the dominant species **(PLS-2)**. We interpret this as the decline of initial-cohort jack pine and replacement by other species, particularly red pine. This idea is supported mostly by our experience in this community where significant stand-level mortality of jack pine is observed as early as 30 years and peaks at about age 40-50. The fact that significant compositional change is delayed until about age 50 invites the argument that jack pine in some way "prepared" FDc24 sites for invasion by other species at about 50 years. It seems possible that trees like red and white pine had greater chances of regenerating under the remote canopy of senescing jack pine than they did under the proximal canopy of American hazelnut and bracken.

This being woodland, though, it is important to consider the alternative that doesn't require mortality and replacement of initial-cohort trees. It is possible that FDc24 sites, even up to 50 years after catastrophic fire, were continuing to recruit trees to brushy or grassy gaps and that jack pine's ability to fill these gaps decreases with stand age while red pine's ability increases. This idea brings into question the validity of standard forestry concepts like stand-age and initial-cohort when describing woodlands. The idea of a long, post-fire recruitment window is partially supported by our experience in cut-over FDc24 stands. Annual-ring counts on the remaining stumps usually show a range of tree ages within a window of 15 to 30 years. From this we assume that jack pine's response to logging *ca.* 1950-1970 AD was to slowly, but certainly stock FDc24 sites no later than age 30. This regeneration window is much longer in comparison to more synchronous establishment of jack pine in northern FD communities, but not approaching 50 years as suggested by natural dynamic changes **(PLS-4)**. Logging though, is not catastrophic fire, and a natural 50-year stocking window remains a possibility.

For jack pine and quaking aspen, the abundance of young regeneration peaks immediately after fire and declines slowly throughout the young growth-stage and transition **(PLS-5)**. That is, the ratio of small-diameter regeneration to tree-sized individuals gradually declines. This pattern is quite consistent with the idea of jack pine and quaking aspen gradually filling the prairie or brushy openings but not regenerating beneath themselves. Red pines were simply present as small-diameter trees at low abundance until age 50, which is characteristic of an initial-cohort tree with a long episode of suppression. Something happened during the transition to release the red pines as they quickly increase in relative abundance. We do not believe that this increase was supported through the gradual process of establishment and recruitment. Rather, we favor the idea that red pines became dominant by outliving jack pines, whether the mortality of jack pine was natural senescence or whether surface fires selectively removed the jack pines. The fact that tree density declines significantly at the close of the transition favors our hypothesis.

Mature Growth-stage: approximately 75-155 years
About 10% of the historic FDc24 landscape was mature woodland where the rate of successional change slowed greatly **(PLS-4, PLS-2)**. Stands in this stage were far more likely to be mixed than monotypic. Patches of pure jack pine or aspen were the most common monotypic conditions. Nearly all mixed corners involved some combination of jack, red, or white pine with occasional references to quaking aspen, red oak, and bur oak.

The most striking feature of mature FDc24 woodlands is that they were still dominated by jack and red pine. Neither species is normally considered late-successional or shade-tolerant, yet they were able to “hold” sites indefinitely without the benefit of catastrophic disturbance **(PLS-1, PLS-2)**. We believe that surface fires were responsible for creating somewhat open conditions allowing the persistence of pine on these sites. We calculated a rotation of 30 years for surface fire, meaning that by the time a stand reached the mature growth-stage, it had probably experienced a surface fire and would likely experience 2-3 more while in the mature growth-stage. Because red pines survive surface fires more so than jack pine, it is entirely possible that such fires were the selective agent to favor red pine over jack pine during the preceding transition stage. Because jack pine is short-lived in this community, surface fires must have provided some opportunity for regeneration. It is surprising to not see jack pines at diameters less than half that of the largest trees at mature survey corners, which is our method for detecting regeneration beyond stand-regenerating events **(PLS-5)**. It is significant though, that 45% of all mature FDc24 corners were limited to a mixture of jack and red pine. The most common condition was for red pines to be the larger tree. Also common were mixtures of red and jack pine of similar diameter. There were virtually no cases where jack pine bearing trees had significantly larger diameters than attending red pine. Our conclusion is that mature woodlands were patches of FDc24 habitat with a skeletal presence of large red pines, perhaps 10-30 trees per acre. About the veteran red pines were one to several cohorts of younger jack pine dating to surface fires.

Second Transition Stage (155-195 years) and Very Old Growth-stage (>195 years)
Almost none of the historic FDc24 landscape was in secondary transition or the very old growth-stage (~1%, **PLS-1**). The central concept is that on FDc24 sites with the good fortune to avoid fire, white pine would eventually replace the senescent old red pines. Our evaluation of very old PLS corners was convincing that extremely large and very old white pines were here-and-there on the historic FDc24 landscape. These trees and any of their progeny are simply gone from the stands that remain in today’s FDc24 woodlands **(PLS/FIA-1)**.

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?

Jack Pine

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

Suitability

FDc24 sites provide ***excellent habitat*** for jack pine trees. The perfect ***suitability rating*** of 5.0 for jack pine is influenced mostly by its very high presence (84%) as trees on these sites in modern forests **(R-1)**. When present, jack pine is an important dominant tree, contributing 46% mean cover in mature stands. The ranking is perfect, because no other tree or plant has a higher presence and cover on FDc24 sites as sampled by releves. In general, central fire-dependent woodland and forest communities offer good-to-excellent habitat for jack pine (see Suitability Tables). Jack pine is the premier species on the drier sites (FDc12, FDc23, FDc24).

Young Growth-stage: 0-55 years

Historically, jack pine was the overwhelming dominant in young FDc24 stands recovering from any disturbance but especially so after fire **(PLS-1, PLS-2)**. Young jack pines represented 80% of the trees at survey corners described as burned, which is by far more than any other tree **(PLS-3)**. Jack pine was also the leading species following windthrow, representing 74% of the trees at such survey corners; however, windthrow was not an important means of re-initiating FDc24 woodlands in comparison to fire. Jack pine's dominance in the young growth-stage and its leading abundance following fire and windthrow is why we consider it to be an ***early successional*** species on FDc24 sites. Small-diameter jack pine regeneration coming in among larger trees was abundant in the post-disturbance years until about age 40 **(PLS-5)**. In nearly all cases, the jack pine regeneration was coming in among larger jack pines. Looking at just trees is a bit misleading in that bearing tree density in young FDc24 stands was about half of what we calculate for fully stocked pine forests, and the variance is much larger than the mean. We interpret this as jack pine showing excellent ability to recruit into burned stands that probably were patches of jack pine regeneration at forest-like density separated by openings of prairie and hazel brush. Jack pine was clearly the only tree able to recruit into the prairie openings, taking as long as 40-50 years to achieve a more uniform distribution of trees across large expanses of FDc24 habitat.

Transition: 55-75 years

Transitioning of young FDc24 woodlands was driven by the steady loss of initial-cohort jack pine leaving longer-lived red pine **(PLS-1)**. We estimate that this decline started at about age 50 and continued to about age 90 when jack pine abundance stabilized at about 50% relative abundance **(PLS-2)**. The jack pine establishment window extends into the transitional growth-stage until about age 60, offering just poor chances for jack pine to establish seedlings without some kind of further disturbance **(PLS-5)**. During the transition period, jack pine was present at most survey corners (~75%) and two-thirds of those were still pure jack pine. It is possible that limited jack pine establishment and recruitment to bearing-tree size (~4" dbh) during the transition was the consequence of it being the only species present in monotypic pockets. When present as smaller diameter trees, young jack pine were coming in under other jack pine in 75% of the cases. We interpret this as limited replacement of itself in gaps created by surface fires because jack pine show no ability to recruit seedlings under a canopy that could be released due to the demise of overtopping trees **(R-2)**. It is important to remember that prairie was part of the FDc24 landscape during the transition and prairie openings were likely ignition sources for fires that could spread into the adjacent pines. Although surface fires provided some opportunity for jack pine regeneration, we believe that it was the main source of jack pine mortality during this period favoring more resistant red pines.

Mature, Second Transition, and Very Old Growth-stages: 75-155 years, 155-195 years and older

In mature FDc24 stands the relative abundance of jack pine stabilizes at about 50% and it persists into the following transition and very old growth-stages **(PLS-1, PLS-2)**. Although diminished from earlier growth-stages, jack pine is still the dominant tree. If jack pine's continued dominance required regeneration and recruitment, then we must assume that jack pine has secondary strategies for behaving like a mid-successional species able to respond to fine-scale or maintenance disturbances. Jack pine's inability to establish and recruit seedlings in modern FDc24 woodlands eliminates the possibility of it responding to fine-scale disturbance **(R-2)**. This leaves only the likelihood that jack pine responded very favorably to surface fires, which is obvious in its reaction to burned over lands and partial canopy loss in the survey notes **(PLS-3)**. Unlike the transition stage, jack pine in mature woodlands was coming in mostly under red pines. However, it was still common for jack pine to come in under larger diameter jack pine, suggesting that there were multiple cohorts of jack pine among the older red pines.

Regeneration Strategies

Jack pine's primary regenerative strategy on FDc24 sites is to dominate ***open habitat*** after stand-regenerating fire. In the historic PLS data this interpretation is supported by: (1) the fact that 88% of the bearing trees in young stands were jack pine **(PLS-1)**, (2) jack pine represented by far, the largest proportion of bearing trees at burned and windthrown corners **(PLS-3)**, (3) jack pine's peak regeneration was in the post-disturbance window with it's absolute peak being the initial age-class **(PLS-5)**. The inability of jack pine to regenerate under a canopy in modern forests supports strongly the idea that open conditions are required for natural regeneration **(R-2)**.

Diameter variation among bearing trees on FDc24 sites is impressive. It is a property of all growth-stages, but especially during the first 50 years when as often as not, young jack pines occurred in the presence of a tree with twice their diameter. Variation in distance to bearing trees was also impressive on FDc24 sites. We estimated that 18% of all survey corners were samples of woodlands with substantial loss of canopy trees because of long distances to bearing trees **(PLS-3)**. Percentages this high are a property of woodlands in comparison to closed-canopy forest. From this, it seems inconceivable that jack pine didn't possess the abilities of a ***large-gap*** regeneration strategist, able to establish several cohorts of young trees following surface fires by the time FDc24 sites reached maturity. Yet the near absence of jack pine regeneration in modern examples of mature forests is real **(R-2)**. This has nothing to do with canopy closure due to fire suppression as the canopy of modern FDc24 woodlands is sparse, and these stands have some of the lowest yields of jack pine in the state. It is also true that we no longer see significant diameter variation among jack pine in modern FDc24 woodlands. Surely, something must be different between historic FDc24 woodlands and our modern sampling of them as it affects jack pine reproduction. The dense shrub layer of modern FDc24 stands is the most obvious condition that detrimentally affects jack pine reproduction. Also, the tendency of the competing grass component of these stands to shift from native bunch grasses to sod-forming species might also explain the lack of jack pine seedlings.

Historic Change in Abundance

Today, jack pine is in peril on FDc24 sites. Releve samples of these woodlands show very little regeneration in mature stands **(R-2)**. About 94% of all FIA samples were of trees in mature stands. No young jack pines were recorded in sapling or pole stands in the FIA data. Planting jack pine on FDc24 sites results in some regeneration, but most plantations are considered failures with regard to survivorship and stocking levels.

Quaking (Big-toothed) Aspen

- ***excellent habitat suitability rating for quaking aspen***
- ***very poor habitat suitability rating for big-toothed aspen***
- ***early successional***
- ***open (large-gap) regeneration strategist***
- ***regeneration window at 0-30 years***

Identification Problems

The PLS surveyors did not distinguish between quaking and big-toothed aspen. Thus, interpretations of PLS data for the more common quaking aspen should always be done knowing that some of these trees were likely big-toothed aspen. FDc24 releve samples show that for plots with aspen present: 7% have both species present; 7% are big-toothed aspen without quaking aspen; 86% are quaking aspen without big-toothed aspen. We consider quaking and big-toothed aspen to be ecologically equivalent for most silvicultural considerations.

Suitability

FDc24 sites provide ***excellent habitat*** for quaking aspen trees. The ***suitability rating*** of 4.5 for quaking aspen is influenced mostly by its very high presence (30%) as trees on these sites in modern forests **(R-1)**. When present, quaking aspen is an important co-dominant and sometimes dominant tree, contributing 23% mean cover in mature stands. This ranking is second, following jack pine on FDc24 sites. Except for FDc12, central fire-dependent communities offer good-to-excellent habitat for quaking aspen (see Suitability Tables). Among these, FDc24 provides the best aspen habitat.

FDc24 sites are ***very poor habitat*** for big-toothed aspen and a ***suitability rating*** was not calculated because its presence is under 5%. When present, it accounts for just 3% mean cover on releve plots.

Young Growth-stage: 0-55 years

Historically, aspen was an occasional tree in young FDc24 stands with 4% relative abundance **(PLS-1)**. Young aspen were represented just 2% of the trees at survey corners described as burned, which is much lower than one would expect given aspen's pioneering behavior in other communities **(PLS-3)**. Aspen was more abundant following windthrow, representing 10% of the trees at such survey corners. It is possible that windthrow favored aspen more than fire, but windthrow was so uncommon (<1%) that just a few trees account for the 8% difference. When viewed across age-classes, aspen was most abundant following disturbance and declined slowly as stands matured, which is why we consider it to be ***early successional*** on FDc24 sites **(PLS-2)**. Small-diameter aspen regeneration was common following disturbance until the 30-year age-class **(PLS-5)**. As young stands neared the transition stage, these small aspen trees were increasingly subordinate to other species, meaning that other trees were growing faster or that the aspen regeneration was dying before reaching diameters comparable to the canopy trees. This trend and the very modest abundance following fires suggests to us that these were seed-origin trees and that FDc24 sites were not underpinned by extensive clonal rootstocks. In most habitats, aspen clones are significant competitors with pines and the absence of clones on FDc24 might explain the historic success of both jack and red pine on these sites.

Transition, Mature, Second Transition and Old Growth-stages: 55-75 years, 75-155 years, 155-195 years, and older

Aspen played no important dynamic role in transitioning, mature, or old FDc24 stands. Aspen persisted at about 3-4% relative abundance in these older growth-stages **(PLS-1, PLS-2)**. If persistence required regeneration and recruitment, then we must assume that aspen has secondary strategies for behaving like a mid- or late-successional species able to respond to fine-scale or maintenance disturbances. The ability of aspen to recruit seedlings or suckers through all height strata in modern FDc24 forests suggests that it can persist under a regime of fine-scale disturbance on FDc24 sites **(R-2)**. Its regeneration indices (3.3-4.0) though are more in line with species that benefit from maintenance disturbances like surface fires that tend to create larger gaps. For this reason, we believe that aspen persisted in mature and old FDc24 forests mostly because of surface fires.

Regeneration Strategies
Aspen's primary regenerative strategy on FDc24 sites was to seed into ***open habitat*** after stand-regenerating fire. In the historic PLS data this interpretation is supported by: (1) the fact that aspen's peak relative abundance was in the initial age-classes **(PLS-1, PLS-2)**, and (2) aspen's peak regeneration was in the post-disturbance window **(PLS-5)** with it's absolute peak being the initial age-class. The high percent of aspen as saplings in sapling stands (situation 11) in the FIA data **(FIA-1)** is also characteristic of species that regenerate effectively in the open.

The releve sampling of mature FDc24 forests suggests, however, that aspen is able to function also as a ***large-gap strategist*** with good establishment and recruitment in the understory strata **(R-2)**. Modest abundance of aspen in subordinate situations (12, 23, 13) at FIA plots support also the idea that aspen can regenerate in large gaps **(FIA-1)**. The rotation of 30 years for maintenance disturbances (see above) would suggest that by the time FDc24 forests reached maturity (~75 years) they would have experienced a couple of surface fires or similar events that result in partial canopy loss. Throughout the mature growth-stage (75-155 years), it was likely that surface fires burned through FDc24 stands with such little effect on the canopy trees that we didn't recognize them as regenerated. We did, however detect considerable thinning of the canopy, and 18% maintenance disturbance **(PLS-3)** is high and characteristic of woodlands. Such events clearly favor trees that depend mostly on ***large-gaps*** for regeneration. Although this is a secondary strategy for aspen, we believe that such disturbances were the main reason that aspen persisted in the mature and old growth-stage on FDc24 sites.

Historic Change in Abundance
Today, aspen dominates almost all FDc24 sites in all growth-stages **(PLS/FIA-1)**. Incredibly, a tree with such modest historic presence (3-4%) has come to represent over 80% of the trees that now grow on FDc24 sites. This number is inflated by eliminating many (but not all) plantations from the FIA sampling; however, it is widely recognized that planting efforts have not "kept up" with the conversion to aspen. Young, reasonably natural FDc24 sites are now almost all aspen-dominated. Our interpretation is that suppressing the chronic fire regime has allowed aspen clones to spread across FDc24 sites. Where aspen once relied on seeding into burned sites, it now out-competes jack and red pine when coppiced.

Red Pine

- ***excellent habitat suitability rating***
- ***mid-successional***
- ***open regeneration strategist***
- ***regeneration window at 0-20 years***

Suitability

FDc24 sites provide ***excellent habitat*** for red pine trees. The ***suitability rating*** of 4.3 for red pine is influenced mostly by its presence (30%) as trees on these sites in modern forests **(R-1)**. When present, red pine is an important co-dominant, contributing 19% mean cover in mature stands. This ranking is third, behind jack pine and quaking aspen on FDc24 sites as sampled by releves. In general, central fire-dependent woodland communities offer fair-to-excellent habitat for red pine (see Suitability Tables).

Young Growth-stage: 0-55 years

Historically, red pine was an occasional tree in young FDc24 stands recovering mostly from fire **(PLS-1)**. Young red pines represented 16% of the trees at survey corners described as burned, a distant second to jack pine **(PLS-3)**. Our interpretation is that red pines were initial-cohort trees on FDc24 sites, but were much less successful than jack pine. Red pine showed similar abundance at windthrown corners, but windthrow was an infrequent event and not an important means of regeneration for red pine on FDc24 sites. Because the abundance of red pine increases during the young growth stage we believe that it had some ability to recruit into under-stocked areas of burned stands **(PLS-2)**. Because red pine bearing trees occur in subordinate diameter classes throughout the young growth-stage it seems that the young growth-stage offered just a fair window of opportunity from 0-20 years for red pines to increase their abundance relative to jack pine, which shows high, but decreasing establishment in young FDc24 woodlands **(PLS-5)**.

Transition: 55-75 years

As stands transitioned to mature conditions red pine increased in abundance, presumably because of its ability to outlive initial cohort jack pine **(PLS-1, PLS-2)**. Also, it seems that the decline of the initial-cohort jack pine released some red pine seedlings established during the young growth-stage. Throughout the transition stage, red pines occurred only at survey corners of mixed composition often as the bearing tree with smaller diameter. Usually, red pines were subordinate trees coming through jack pine, but nearly as often, they were coming through other red pines.

Mature Growth-stage: 75-155 years

Red pine had peak presence as a co-dominant in mixed mature stands, which is why we consider red pine a ***mid-successional*** species – able to replace initial cohort trees but dropping in relative abundance as stands became (rarely) old-aged **(PLS-1, PLS-2)**. There were no red pine bearing trees smaller than half the diameter of the largest trees at survey corners estimated to be older than 70 years, which suggests to us that there was little regeneration beyond this point **(PLS-5)**. At this point there is a reversal of diameter subordination between the pines with red pines more often the larger tree than jack pine. It seems possible that at about this time, red pines reached a stature, tall and with thick bark, where they became rather impervious to the common surface fires and that the selective pressure of surface fires was to kill shorter trees like jack pine and younger red pines.

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

Upon rare occasion, stands would transition to very old forests. During the transition, the relative abundance of red pine decreases as it is replaced with white pine **(PLS-1)**. The most common condition in the second transition and old growth-stage was for the canopy to be mixed red and white pine over what must have been second- or third-cohort jack pine. There were no subordinate red pine trees throughout these periods to suggest regeneration. We interpret the persistence of red pine in these old stands to its longevity.

Regeneration Strategy
Red pine's primary regenerative strategy on FDc24 sites is to seed into ***open habitat*** after stand-regenerating disturbance. It was equally able to do so after fire or windthrow **(PLS-3)**. In the historic PLS data this interpretation is supported by: (1) red pine's modest abundance in young FDc24 stands **(PLS-1)**, (2) it was reasonably abundant at burned and windthrown corners **(PLS-3)**, and (3) its peak regeneration was in the post-disturbance window **(PLS-5)** with it's absolute peak being the initial age-class. The modest percent of red pine as poles in pole stands (situation 22) in the FIA data **(FIA-1)** is also characteristic of species that regenerate effectively in the open. The releve sampling of mature FDc24 woodlands suggests also that red pine needs open habitat to reproduce because it seems incapable of establishing and recruiting seedlings beneath a canopy **(R-2)**.

Historic Change in Abundance
Today, red pine is in peril as natural stands on FDc24 sites. Releve samples of these woodlands show very little natural regeneration **(R-2)**. About 93% of all FIA samples were of older trees in mature stands, and no young red pines were recorded in, sapling stands. Planting red on FDc24 sites results in some regeneration, and that was most successful about 20-30 years ago because there are at least some red pine pole stands (situation 22) in today's forests **(FIA-1)**. More recently, a substantial amount of our plantations are considered failures with regard to survivorship and stocking levels. We attribute the decline of red pine to the lack of mature seed trees and the lack of frequent surface fires, which historically provided many regeneration opportunities during the lifetime of mature red pines.

Bur Oak

- ***excellent habitat suitability rating***
- ***mid-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 30-80 years***

Suitability
FDc24 sites provide ***excellent habitat*** for bur oak trees. The ***suitability rating*** of 4.1 for bur oak is influenced equally by its presence (23%) as trees on these sites in modern forests and its 20% mean cover when present **(R-1)**. The ranking is fourth, behind jack pine, quaking aspen, and red pine. Although the habitat is excellent for bur oak, they do not produce logs of commercial interest on FDc24 sites. Except for FDc12, central fire-dependent woodlands provide good-to-excellent habitat for bur oak (see Suitability Tables).

Young Growth-stage: 0-55 years
Historically, bur oak was present as a tree in just trace amounts in young FDc24 stands recovering mostly from fire **(PLS/FIA-1)**. Young bur oaks represented just 1% of the trees at survey corners described as burned, far behind jack and red pine **(PLS-3)**. Bur oaks were not present at windthrown FDc24 corners. Our interpretation is that bur oaks were always present on FDc24 sites but following fire, they tended to exhibit their "grub" growth-form and didn't provide stems suitable for bearing trees. Small-diameter bur oak regeneration was detected in the young growth-stage, but at low amounts **(PLS-5)**. In fact, all bur oak bearing trees were small-diameter regeneration in this stage. Our interpretation is that nearly all of the bur oak bearing trees recorded in young FDc24 forests were grub sprouts.

Transition: 55-75 years
Bur oak peaks in relative abundance at about 5% in the 70- and 80-year age-classes at the seam between the transition and mature growth-stages. The peak is short-lived and when averaged across whole growth-stages amounts to just 1% of the trees **(PLS/FIA-1)**. Because of this peak, we consider bur oak a ***mid-successional*** tree on FDc24 sites. Small-diameter bur oak regeneration is consistently present in stands 30-80 years old **(PLS-5)**, but the transition represents the first episode where there seems to be recruitment to bearing tree size (~4" dbh). The simplest explanation is that it might take 70-80 years for bur oak sprouts to grow to 4-5 inch diameters. Alternatively, these could be vigorous, seed-origin trees established during the transition and released as stands naturally thinned in the mature growth-stage (see Stand Dynamics).

Mature, Second Transition, and Very Old Growth-stages: 75-155 yrs, 155-195 yrs, and older
Bur oak played no important dynamic role in mature, second transition, or very old FDc24 stands. Bur oak persisted at about 1% relative abundance in these older growth-stages **(PLS/FIA-1)**. If persistence required regeneration and recruitment, then we must assume that bur oak has secondary strategies for behaving like a mid- or late-successional species able to respond to fine-scale or maintenance disturbances. The regenerative ability of bur oak in the understory of modern FDc24 woodlands suggests that it can persist under a regime of fine-scale disturbance on FDc24 sites **(R-2)**. Amazingly, its regeneration indices (4.0-4.5) are excellent and in line with species that bank seedlings and recruit into small-gaps. However, all of that excellent regeneration is infrequently translated into but oak trees taller than 10m (33 feet). In our combined field experience, we cannot recall ever seeing FDc24 bur oaks of comparable heights to the dominant pines, quaking aspen, or paper birch. Our interpretation is that bur oak persisted in older FDc24 stands as grub sprouts of varying size, giving the illusion of steady establishment and recruitment. We do believe that some seed-origin trees were recruited at the beginning of the mature growth-stage, but they didn't have long to wait until surface fires killed them or started the grub-forming process.

Regeneration Strategy

On FDc24 sites, bur oak's strategy is to never die. Bur oaks develop massive rootstocks and care little about the number or size of the stems feeding the rootstock. Our methods of studying establishment are poorly suited to a tree with this "attitude." Our methods do address stem recruitment and bur oak shows the character of a tree that recruits in ***large-gaps***. In the historic PLS data this conclusion is supported by (1) the fact that most bur oaks recruited to bearing tree size when tree density drops naturally at the beginning of the mature growth-stage, (2) bur oaks had their highest presence at survey corners showing partial canopy loss **(PLS-3)**, and (3) recruitment was most consistent in a gap window (G-1, **PLS-5**) rather than the post-disturbance or ingress windows. Its high presence as poles in tree stands (situation 23) is also consistent with species that do well in large gaps **(FIA-1)**. However, most of the FIA bur oaks were poles and this is what we believe is the natural stagnation of its growth on FDc24 sites. In modern stands, its regeneration indices are more in line with small-gap recruiters **(R-2)**, but differs from them in having a recruitment bottleneck to tree heights (>10m).

Historic Change in Abundance

Today, bur oak is slightly more abundant than it was historically in all FDc24 growth-stages **(PLS/FIA-1)**. We believe that the density of bur oak rootstocks on these sites have been stable for centuries. Ring counts show that grubs can survive for hundreds of years. Though complicated by the translocation of carbon compounds in their rays, radiocarbon dates of core wood from grubs suggest that survival could approach millennia. These old grubs seem to care little if fire or logging removes their stems. In modern times, site preparation for pine plantations may have provided some seeding opportunities for bur oak and explain the modest increase in bur oak. Alternatively, FDc24 sites occur in regions of Minnesota where policy has been to leave masting species like oaks for deer habitat.

Paper Birch

- ***good habitat suitability rating***
- ***early-successional***
- ***open regeneration strategist***
- ***regeneration window at 0-30 years***

Suitability

FDc24 sites provide ***good habitat*** for paper birch trees. The ***suitability rating*** of 3.5 for paper birch is influenced mostly by its presence (25%) as trees on these sites in modern forests **(R-1)**. When present, paper birch is an occasional co-dominant contributing 12% mean cover in mature stands. The ranking is fifth among trees common on MHc26 sites sampled by releves. Except for FDc12, central fire-dependent woodlands offer fair-to-excellent habitat for paper birch (see Suitability Tables). Paper birch's performance increases as these sites get moister and richer, favoring FDc25 and FDc34 communities.

Young Growth-stage: 0-55 years

Historically, paper birch was an infrequent tree in young FDc24 stands with just 1% relative abundance **(PLS/FIA-1)**. Young paper birch represented just 1% of the trees at survey corners described as burned **(PLS-3)**, which is much lower than one would expect given paper birch's pioneering behavior in other communities. Paper birch was not recorded at windthrown FDc24 corners. When viewed across age-classes, paper birch was most abundant following disturbance and declined slowly as stands matured, which is why we consider it to be ***early successional*** on FDc24 sites. Small-diameter paper birch regeneration was common following disturbance until the 30-year age-class **(PLS-5)**. We believe that the regenerating birch in young FDc24 stands was a combination of stump sprouts and seed-origin trees.

Transition: 55-75 years

Paper birch abundance seems to decline slightly throughout the transition, but its abundance still rounds to 1% in most age-classes under 155 years **(PLS/FIA-1)**. The sample numbers are low and possibly unreliable. Small-diameter paper birch regeneration is consistently present in stands 0-70 years old **(PLS-5)**, but there was little recruitment to larger diameters. We have noticed that birch is short-lived on prairie soils such as those on FDc24 sites. In landscapes with a mosaic of forest and prairie soils, paper birch has a strong affinity for forest soils and clearly avoids the prairie soils. In the FIA sampling, very few birch attain diameters over 10 inches on FDc24 sites. Almost always, paper birch in transitioning FDc24 stands were of smaller diameter than adjacent pines. Our interpretation is that birch was constantly trying to invade the understocked FDc24 woodlands, but most trees died shortly after they became large enough to be bearing trees.

Mature, Second Transition and Very Old Growth-stages: 75-155 years, 155-195 years, and older

Paper birch played no important dynamic role in mature, second transition, or old FDc24 stands. Paper birch persisted at about 1% relative abundance in these older growth-stages **(PLS/FIA-1)**. The ability of paper birch to establish seedlings is poor-to-fair in modern FDc24 forests **(R-2)**, but this might be enough to account for 1% abundance. More likely, paper birch persisted in older FDc24 stands because surface fires created seedbeds and large enough openings for limited establishment and recruitment.

Regeneration Strategy

Paper birch's primary regenerative strategy on FDc24 sites was to sprout or to seed into ***open habitat*** after stand-regenerating fire. In the historic PLS data this interpretation is supported by: (1) the fact that paper birch's peak relative abundance (though slight) was in the initial age-classes, (2) it was present at burned survey corners **(PLS-3)**, and (3) paper birch's peak recruitment was in the post-disturbance window **(PLS-5)** with it's absolute peak being the initial age-class. The high percent of paper birch as poles in pole stands (situation 22) in the FIA data could be interpreted as characteristic of an open strategist, but just 6 trees contributed to that analysis and the data are unreliable **(FIA-1)**. The releve sampling of mature FDc24 forests shows that paper birch has poor-to-fair ability to establishment and recruitment seedlings under a canopy **(R-2)**. Its regenerant and seedling indices (1.7-2.3) are quite in line with trees that need open conditions to establish seedlings.

Historic Change in Abundance

Today, paper birch is about as abundant as it ever was on FDc24 sites in all growth-stages **(PLS/FIA-1)**. Given its low abundance and presence as bearing trees and as FIA trees, its 25% presence as a tree **(R-1)** and 30% presence as regeneration **(R-2)** in the releves is surprising. Apparently paper birch has made greater gains in undisturbed and older FDc24 stands than in the average FIA stand.

Northern Red Oak

- ***good habitat suitability rating***
- ***mid-successional***
- ***large-gap (small-gap) regeneration strategist***
- ***regeneration window at 30-40 years***

Suitability

FDc24 sites provide ***good habitat*** for red oak trees. The ***suitability rating*** of 3.5 for red oak is influenced mostly by its presence (18%) as trees on these sites in modern forests **(R-1)**. When present, red oak is a co-dominant tree, contributing 12% mean cover in mature stands. The ranking is fifth, behind all others considered ecologically important on FDc24 sites as sampled by releves. Although the habitat is good for red oak, they do not produce logs of much commercial interest on FDc24 sites. Except for FDc12, central fire-dependent woodlands offer good-to-excellent habitat for red oak (see Suitability Tables). The FDc34 community is by far the best central fire-dependent community for red oak of commercial interest.

Young Growth-stage: 0-55 years

Historically, red oak was present a minor tree with 1% relative abundance in young FDc24 stands recovering mostly from fire **(PLS/FIA-1)**. Young red oaks were not recorded at survey corners described as burned or windthrown **(PLS-3)**. Small-diameter red oak regeneration was present at low abundance throughout the post-disturbance window, lasting until stands were age 60 **(PLS-5)**. In fact, nearly all red oak bearing trees were small-diameter regeneration in this stage. Our interpretation is that most of the red oak bearing trees recorded in young FDc24 woodlands were grub sprouts. If new, seed-origin red oaks were established, it happened near the end of the young growth-stage at about age 40-50.

Transition: 55-75 years

Red oak was present more often as a tree in the transition, but never achieved more than trivial abundance (~1%). Small-diameter red oak regeneration was essentially absent, restricted to the 60-year age-class comprising just a few small-diameter red oak bearing trees **(PLS-5)**. Our interpretation is that there was no red oak regeneration during the transition, nor was there significant mortality of the post-disturbance sprouts. Established red oaks simply lived through the transition with little gain or loss.

Mature Growth-stage: 75-155 years

Red oak abundance "peaks" at 2% during the mature growth-stage **(PLS/FIA-1)**. More accurately, red oak was consistently present between age 30 and age 130 with slightly higher abundance in the age-classes falling in the mature growth-stage. For this reason, we consider red oak to be ***mid-successional*** on FDc24 sites. The regenerative ability of red oak in the understory of modern FDc24 woodlands would suggest that its 100-year persistence could have been accomplished by regeneration and recruitment. Amazingly, its regenerant and seedling indices (4.2-4.3) are excellent and typical of trees able to bank seedlings **(R-2)**. It is clear though, that in spite of all that excellent establishment, red oak has problems recruiting seedlings to heights over 2m and even greater problems recruiting to tree heights over 10m. In our combined field experience, we cannot recall ever seeing FDc24 red oaks of comparable heights to the dominant pines, quaking aspen, or paper birch. Our interpretation is that red oak persisted in older FDc24 stands as grub sprouts of varying size, giving the illusion of steady establishment and recruitment. Some seed-origin trees, established late in the young growth-stage may have contributed to red oak's abundance in the mature growth-stage, but by this time it was likely that surface fires had killed the new oaks or initiated the grub-forming process.

Second Transition, and Very Old Growth-stages: 155-195 yrs and older

Red oak played no important dynamic role in second transition or very old FDc24 stands. Just 5 red oak trees were the total sample in the second transition and no red oaks were recorded at survey corners representing very old FDc24 stands **(PLS/FIA-1)**. No small-diameter red oak regeneration was recorded in FDc24 woodlands this old **(PLS-5)**. We seriously doubt that red oaks were ever totally absent from FDc24 sites. Most likely, in stands this old, there were too many good trees to select as bearing trees in comparison to the twisted, contorted, small-diameter boles of red oaks.

Regeneration Strategy

On FDc24 sites, red oak's strategy is to never die. Red oaks develop massive rootstocks and care little about the number or size of the stems feeding the rootstock. Our methods of studying establishment are poorly suited to a tree with this "attitude." Our methods do address stem recruitment and red oak shows the character of a tree that recruits in ***large-gaps***. In the historic PLS data this conclusion is supported by (1) the fact that most red oaks recruited to bearing tree size when tree density drops naturally at the beginning of the mature growth-stage, and (2) red oaks had their highest presence at survey corners showing partial canopy loss **(PLS-3)**. In modern stands, its regenerant and seedling regeneration indices (4.2-4.2) are similar to those of small-gap strategists, but its sapling and tree indices (3.8-3.0) are typical of large-gap strategists, needing more sunlight to move seedlings into the sub-canopy **(R-2)**.

Historic Change in Abundance

Today, red oak is slightly less abundant than it was historically in all FDc24 growth-stages **(PLS/FIA-1)**. We believe that the density of red oak rootstocks on these sites have been stable for centuries. Ring counts show that grubs can survive for hundreds of years. Though complicated by the translocation of carbon compounds in their rays, radiocarbon dates of core wood from grubs suggest that survival could approach millennia. These old grubs seem to care little if fire or logging removes their stems.

In both the historic PLS records and in the FIA sampling, red oak is a trivial FDc24 species. Its presence (18%) and abundance (12% mean cover) in the releve samples **(R-1)** is quite remarkable for a tree nearly missing from the FIA inventory. Even more astounding is its 77% presence in the regenerating layers of the releve samples **(R-2)**. It would seem that red oak has been highly favored in unmanaged stands preferentially sampled by releves, and it is poised to take over FDc24 sites if left unmanaged or unburned. More likely is the idea that red oaks rarely formed trunks desirable for use as bearing trees, and most red oak regeneration on these sites is under an inch in diameter and therefore did not contribute to our FIA dataset.

(PLS-1) Historic Abundance of FDc24 Trees in Natural Growth-stages

Table values are relative abundance (%) of Public Land Survey (PLS) bearing trees at corners modeled to represent the FDc24 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.

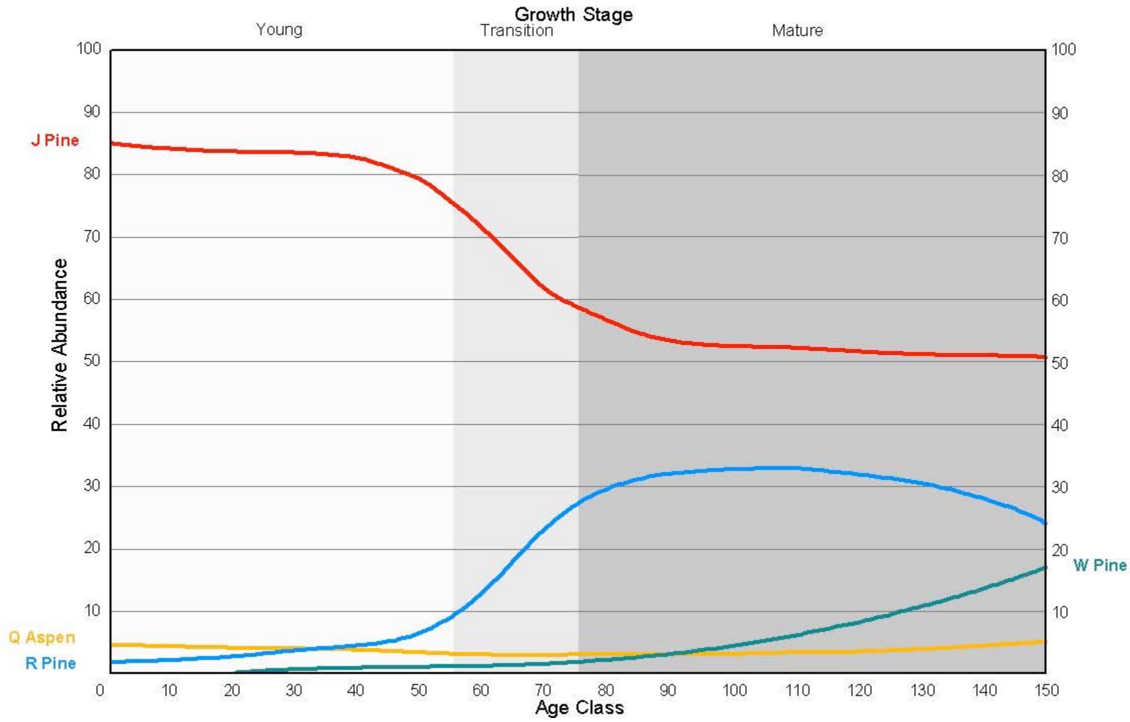
Dominant Trees	Forest Growth Stages in Years				
	0 - 55	55 - 75	75 - 155	155 - 195	> 195
	Young	T1	Mature	T2	Very Old
Jack Pine	**88%**	↓↓	**58%**	↓	**51%**
Red Pine	**4%**	↑↑	**31%**	↓↓	**8%**
Quaking (Big-toothed) Aspen	**4%**	↓	**3%**	↑	**6%**
White Pine	**1%**	↑	**2%**	↑↑	**24%**
Miscellaneous	**3%**		**5%**		**11%**
Percent of Community in Growth Stage in Presettlement Landscape	**71%**	**18%**	**10%**	**1%**	**–**

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 FDc24 woodlands, but were rare historically appear in Table **PLS/FIA-1**.

Public Land Survey linked text

(PLS-2) Abundance of trees throughout succession in FDc24

Caption: Graphed for the different species of FDc24 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 FDc24 Trees Following Disturbance

Table values are raw counts and (percentage) of Public Land Survey (PLS) bearing trees at survey corners likely to represent FDc24 woodlands. 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	
Red pine	**116**	**16%**	**5**	**16%**	**193**	**15%**	**435**	**9%**
Quaking (Big-toothed) aspen	**15**	**2%**	**3**	**10%**	**59**	**5%**	**180**	**4%**
Bur oak	**10**	**1%**	**0**	**0%**	**26**	**2%**	**56**	**1%**
Northern red oak	**0**	**0%**	**0**	**0%**	**10**	**1%**	**24**	**0%**
Jack pine	**593**	**80%**	**23**	**74%**	**1000**	**77%**	**4208**	**86%**
Paper birch	**9**	**1%**	**0**	**0%**	**15**	**1%**	**74**	**1%**
Total (% of grand total, 7054)	**743**	**11%**	**31**	**0.4%**	**1303**	**18%**	**4977**	**71%**

PLS-3

Table PLS-3 includes only trees ranked as having excellent, good, or fair suitability for FDc24 sites. Tree sums will not match the totals in the Natural Disturbance Regime text, because trees of poorer suitability were included in that analysis.

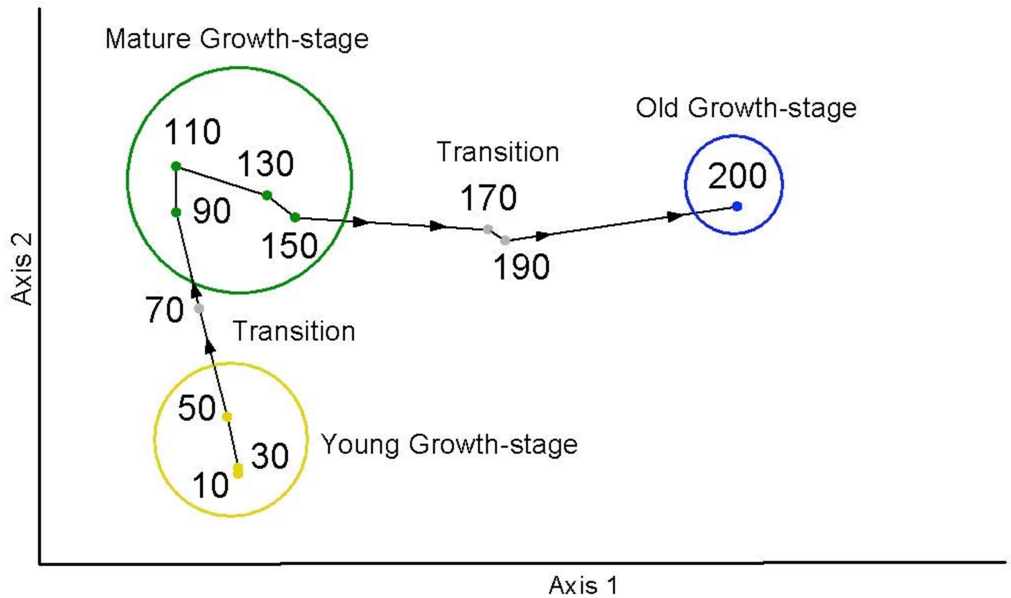
PLS survey corners were assigned to four disturbance categories:

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 FDc24 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 FDc24 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 0-50 years	G-1 50-90 years	I-1 90-150 years	G-2 150-200 years	I-2 >200 years
Yes	Red Pine	0-20	Fair	Poor to 70	--	--	--
Yes	Quaking Aspen[1]	0-30	Good	Poor to 60	--	--	--
Minor	Paper Birch	0-30	Fair to 30	Fair to 70	--	--	--
Yes	Jack Pine	0-40	Excellent	Poor to 60	--	--	--
No	Red Oak	30-40	Fair	Poor to 60	--	--	--
Minor	Bur Oak	30-80	Fair	Fair to 80	--	--	--
No	White Pine	40	Poor 40-50	--	--	--	--

Recruitment windows from ordination PLS-4:

- **P-D:** very slow post-disturbance filling of understocked areas, 10-50 years
- **G-1:** gap filling during decline of initial-cohort jack pine and quaking aspen, 50-90 years
- **I-1:** ingress of seedlings under a canopy of jack pine and red pine, 90-150 years
- **G-2:** gap filling during decline of red pine and second-cohort jack pine, 150-200 years
- **I-2:** ingress of seedlings under a canopy of jack pine, white pine, red pine, and quaking aspen.

-- : 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.

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

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 FDc24 sites

This table presents an index of suitability for trees in FDc24 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 FDc24			
Tree	**Percent Presence as Tree**	**Mean Percent Cover When Present**	**Suitability Index***
Jack pine (Pinus banksiana)	**84**	**46**	**5.0**
Quaking aspen (Populus tremuloides)	**30**	**23**	**4.5**
Red pine (Pinus resinosa)	**30**	**19**	**4.3**
Bur oak (Quercus macrocarpa)	**23**	**20**	**4.1**
Paper birch (Betula papyrifera)	**25**	**12**	**3.8**
Northern red oak (Quercus rubra)	**18**	**12**	**3.6**
*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 FDc24 Stands

This table presents an index of regeneration for FDc24 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 FDc24 communities. Changes in the index values from one stratum to another can be used to estimate regenerative bottlenecks, whether establishment (R-index) or recruitment (SE-, SA-, or T-indices).

Natural regeneration indices for germinants, seedlings, saplings, and trees common in the canopy of Central Rich Dry Pine Woodland – FDc24					
Trees in understory	**% presence R, SE, SA**	**R-index**	**SE-index**	**SA-index**	**T-index**
Northern red oak (Quercus rubra)	**77**	**4.2**	**4.3**	**3.8**	**3.0**
Bur oak (Quercus macrocarpa)	**73**	**4.0**	**4.5**	**4.5**	**3.5**
Quaking aspen (Populus tremuloides)	**48**	**3.3**	**4.0**	**4.0**	**4.3**
Paper birch (Betula papyrifera)	**30**	**1.7**	**2.3**	**3.0**	**3.8**
Red pine (Pinus resinosa)	**14**	**0.8**	**0.8**	**1.8**	**4.3**
Jack pine (Pinus banksiana)	**11**	**0.3**	**0.3**	**2.2**	**5.0**

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

% presence: the percent of 44 FDc24 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 FDc24 Stands

This table presents percentages of structural situations for trees as recorded in Forest Inventory Analysis (FIA) subplots that we modeled to be samples FDc24 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
Jack pine	17	-	-	-	6%	-	94%
Red pine	14	-	7%	-		-	93%
Bur oak	26	8%	42%	15%	19%	-	15%
Paper birch	6	-	50%	-	-	17%	33%
Quaking aspen	704	58%	4%	23%	3%	8%	3%

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 FDc24 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 FDc24 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 - 55		55 - 75		75 - 155		155-195		> 195	
	Young		T1		Mature		T2		Very Old	
Jack Pine	88%	1%			58%	7%			51%	3%
Red Pine	4%	1%			31%	1%			8%	5%
Quaking Aspen	4%	87%			3%	81%			6%	76%
White Pine	1%	0%			2%	0%			24%	0%
Balsam Fir	--	1%			--	2%			0%	3%
Red Maple	--	2%			0%	3%			0%	0%
Paper Birch	1%	2%			1%	3%			1%	1%
Bur Oak	--	2%			1%	3%			2%	6%
Red Oak	1%	0%			2%	0%			0%	0%
Basswood	0%	1%			0%	0%			0%	3%
Miscellaneous	2%	3%			4%	0%			8%	3%
Percent of Community in Growth Stage in Presettlement and Modern Landscapes	71%	64%	18%	25%	10%	11%	1%	0%	--	0%

Natural growth-stage analysis and landscape summary of historic conditions is based upon the analysis of 2,667 Public Land Survey records for section and quarter-section corners. Comparable modern conditions were summarized from 456 FIA subplots that were modeled to be FDc24 sites.

Public Land Survey linked text
FIA linked text

Silviculture Systems for FDc24: No arrow - least favorable, ⇧ Favorable, ⇧⇧ Very Favorable

	Silviculture Systems	Clearcut	Patch Cutting	Group Seedtree	Dispersed Seedtree	Uniform Shelterwood	Group Shelterwood	Irregular Shelterwood	Group Selection	Strip Selection	Single Tree Selection
	Regeneration Strategy										
Northern Red oak	Large-gap (Small-gap)		⇧	⇧	⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧	⇧
Quaking Aspen	Open (Large-gap)	⇧⇧	⇧⇧	⇧⇧	⇧⇧		⇧				
Paper Birch	Large-gap (Open)	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧⇧	⇧			
Bur Oak	Large-gap		⇧	⇧⇧	⇧	⇧	⇧⇧	⇧			
Jack Pine	Open (Large-gap)	⇧⇧									
Red Pine	Open	⇧⇧									

Forest Health

Jack Pine

Agent	Growth stage	Concern/ Effect
Jack pine budworm	All stages	Mortality
Armillaria root disease	“	“
Diplodia blight & canker	Regeneration	Mortality
Gall rust	“	“
Root collar weevil	“	“
White pine weevil	“	Topkill, forking
Bark beetles	Pole-sized and larger	Mortality
Stem decay = red rot	“	Volume loss
Stem rusts	“	Volume loss/ growth reduction

WATCHOUTS!

• In the northwest and west-central counties, jack pine budworm is a cyclic problem that causes significant topkill and mortality. Stands older than 50 years are at high risk for mortality due to budworm outbreaks. Use a 45 to 50 year rotation age in these areas to prevent adverse stand impacts from jack pine budworm.

• Elsewhere, jack pine budworm outbreaks are infrequent, so rotation ages can be much higher but should be based on pathological rotation age.

• Open-grown stands, characterized by wolfy jack pines, create conditions suitable for jack pine budworm build-up. Harvesting and regenerating these types of stands should be a priority. Maintain optimally stocked stands, between 70 and 100 sq ft of basal area.

• Susceptibility of mature and over-mature stands to bark beetles is high when droughty weather and/or jack pine budworm defoliation occur.

• Avoid creating pine slash and fresh cut products in or adjacent to red and jack pine stands from February 1 to September 1 in order to prevent the buildup of bark beetles and mortality losses due to their subsequent attack of standing, live pines.

• When planning intermediate 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, rust cankers, dead branches, and dead or broken tops.

• Regeneration growing below red pine overstory trees may not survive due to the accumulation of *Diplodia* infections.

Quaking Aspen

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

WATCHOUTS!

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

• Harvest during the winter to ensure adequate regeneration.

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

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

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

Red Pine

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Diplodia blight & canker	Regeneration	Mortality
Sirococcus shoot blight	“	“
Bark beetles	Pole-sized and larger	Mortality
Red pine pocket mortality	“	“
Stem decay	“	Volume loss

WATCHOUTS!

• Avoid creating pine slash and storing fresh cut products inside or adjacent to red and jack pine stands from February 1 to September 1 in order to prevent the buildup of bark beetle populations and mortality losses due to their subsequent attack of residual pines.

• 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.

• Natural and artificial regeneration growing below red pine overstory trees may not survive due to the accumulation of *Diplodia* and *Sirococcus* infections. Seedlings and saplings within 1 chain of red pine overstory trees are also likely to be heavily infected.

Paper Birch

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

WATCHOUTS!

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

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

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

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

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

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

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

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.

FDc24 - Acceptable Operating Season to Minimize Compaction and Rutting

Primary Soils	Secondary Soils	Not Applicable

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

Plants below indicate wetter inclusions in FDc24 that are more susceptible to compaction and rutting.

Virginia creeper (*Parthenocissus spp.*)
Lady fern (*Athyrium filix-femina*)
Fringed Loosestrife (*Lysimachia ciliata*)
Box elder (U) (*Acer negundo*)
Black ash (U) (*Fraxinus nigra*)

Highbush cranberry (*Viburnum trilobum*)
Mountain maple (*Acer spicatum*)
Side-flowering aster (*Aster lateriflorus*)
Green ash (C) (*Fraxinus pennsylvanica*)
Yellow avens (*Geum aleppicum*)

(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

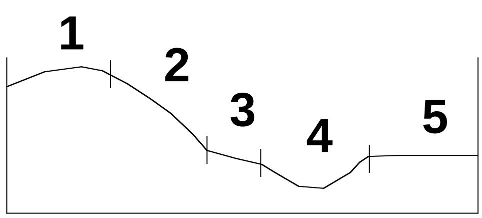
   Poor – water saturation occurs within 10 inches of the surface for most of the growing season

   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