FDc34

FDc34 – Central Dry-Mesic Pine-Hardwood Forest

Natural Disturbance Regime, Stand Dynamics, and Tree Behavior

Summary and Management Highlights

Central Dry-Mesic Pine-Hardwood Forests (FDc34) are a common community found almost entirely within the Northern Minnesota Drift and Lake Plains Section of Minnesota (Figure 1). Detailed descriptions of this community are presented in the DNR Field Guides to Native Plant Communities of Minnesota.

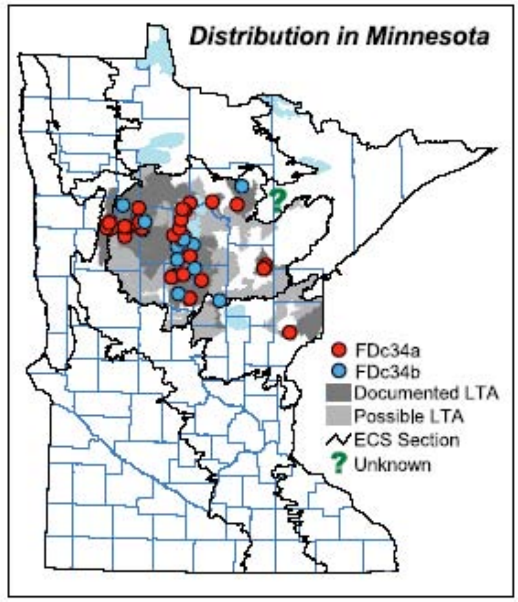


Figure 1. The range of FDc34 forests in Minnesota (shaded) and distribution of releve samples (red and blue dots).

Commercial Trees and Management Opportunities

As a commercial forest, FDc34 sites offer a wide selection of crop trees and possible structural conditions. Red pine, white pine, quaking aspen, northern red oak, paper birch, and red maple are all ranked as excellent choices as crop trees by virtue of their frequent occurrence and high cover when present on FDc34 sites (see Suitability Tables). Bur oak, big-toothed aspen, and jack pine are ranked as good crop trees, and stands can be managed to perpetuate these trees as co-dominants, especially when present or with evidence of former presence (e.g. stumps) in a particular stand. Basswood is ranked as just a fair choice of crop tree, but stands can be managed to maintain their presence as minor trees for purposes other than timber production.

Among these species, red pine, white pine, jack pine, and quaking aspen, were the dominant native trees that have occupied FDc34 sites for a long time and have had the opportunity through successive generations to adapt to physical conditions typical of these sites **(PLS/FIA-1)**. Red oak, paper birch, and white spruce are likewise native to FDc34 sites but occurred naturally at lower abundance. The consequence of fire suppression, commercial logging, and settlement in the past century has been to promote much more quaking and big-toothed aspen than was usual. Past history and land use as also encouraged the ingress of species that were not significant in native FDc34 stands such as red maple and bur oak. The increased abundance of these trees and the loss the pine seed-source complicates our interpretations and the use of natural regeneration models as silvicultural strategies.

Natural Silvicultural Approaches

In the historic landscape, most FDc34 stands (47%) were young and under the age of 55 years **(PLS-1)**. Nearly all of these forests resulted from catastrophic fires that killed most canopy trees and created young forests with clear dates of origin. Clear-cutting and clear-cutting with reserves are the silvicultural systems that best match the canopy loss and regeneration opportunities typical of young FDc34 sites. Jack pine, red pine, and quaking aspen are all considered open regeneration strategists on FDc34 sites and should respond positively to these management strategies.

About 31% of the native landscape was occupied by transitioning FDc34 forests between 55 and 95 years old **(PLS-1)**. At this time, senescence or fire-injury of initial-cohort jack pine and aspen created regeneration and recruitment opportunities for trees in gaps. We believe that surface fires played a major role in creating these gaps – causing synchronous decline of canopy trees, reduced thickness of duff on the forest floor, and release of fire-resistant pines and oak. A variety of two- or three-step silvicultural systems might match what must have been highly variable patterns of canopy removal and species oriented selection. Just looking at the pattern of supercanopy pines in mature and old FDc34 forests, the pattern of partial retention spanned the entire range of systems described as seed-tree, shelterwood, or group selection. Regardless of pattern, the fundamental idea of a system designed to mimic transitioning FDc34 forests should be aimed at modest regeneration of aspen and jack pine, release of red pine or red oak, and ingress of white pine.

About 13% of the FDc34 landscape was mature forest estimated to be between 95 and 135 years of age **(PLS-1)**. Our vision of these mature forests is that the canopy was dominated by red pines that were reasonably vigorous and able hold the site until natural senescence set in (~135 years) and initiated the second transition. During this period, the "action" was in the understory as surface fires had the varying effects of: cleansing the understory of brush and advance regeneration, regenerating some small patches of aspen and jack pine, and creating seedbeds that favored ingress of white pine and maybe even some white spruce. Silvicultural systems like coppicing with standards would fit the idea of managing aspen on a short rotation beneath larger, intolerant pines. Although normally, the coppiced species is shade-tolerant, quaking aspen shows good success beneath red pine **(R-2)**. Otherwise, group selection matches our vision of the usual scale of gap formation that maintained mature FDc34 forests.

In the historic FDc34 landscape about 3% of the forest was transitioning to very old forest dominated by white pine **(PLS-1)**. Senescence and loss of individual or groups of aging red pines was the hallmark of this period. Silvicultural thinning of red pine from above coupled with the release or establishment of white pine below is the natural strategy. Irregular shelterwood or perhaps natural or nurse tree shelterwood over existing regeneration, might approximate the natural process. Selective harvesting of red pine to release or provide planting space for white pine would also fit.

About 6% of the historic FDc34 landscape was very old forest estimated to have trees older than 175 years **(PLS-1)**. Selective systems aimed at removal of the veteran pines over advance regeneration is the natural strategy. According to the FIA data **(PLS/FIA-1)** managing FDc34 stands in this way is no longer an opportunity. Stands even approximating the very old composition and structure of FDc34 sites should probably be conserved. Management should focus on their perpetuation and their ability to produce upon occasion very large diameter, high-quality white pine lumber.

Management Concerns

FDc34 communities occur on medium textured soils often enough to have legitimate concerns about heavy equipment compacting or rutting the soil. This community occurs primarily on stagnation moraines where the core parent material is loamy and compactable. However, during glacial stagnation the material on the ice surface is usually sorted to some degree by surface meltwater moving material to topographic lows on ice sheet. The result is to deposit a cap or blanket of parent material that is highly variable with regard to texture and degree of sorting over the more uniform till of the moraine's core. The other feature of stagnation moraines is hummocky topography where most of the land surface is sloped, often steeply. Thus, erosion is a significant concern as well. Consequently at the stand scale, susceptibility to compaction, rutting, and erosion varies over short distances and foresters must locate skid trails and manage traffic patterns based upon their understanding of the interaction of several contributing factors. Most important are: surface texture, stoniness, soil drainage, slope, slope position, and length of slope above. These interactions are summarized to some degree on our tabular guides to Acceptable Operating Season to Minimize Compaction. In our experience, local places to avoid with heavy equipment will have some plants or trees typical of communities more mesic or wetter than is typical of the FDc34 community. We especially like lady fern as a consistent indicator of areas to avoid in this situation.

The landscape balance of growth-stages and stand ages for the FDc34 community is considerably younger than it was historically. Today, there is 9-11% more forest in the young growth-stage and first transition **(PLS/FIA-1)**. The loss of mature forest is significant, as today just 2% of the FIA subplots were estimated to be between 95 and 135 years old. The FIA sampling also returned no plots where we calculated that trees were older than 135 years. To our knowledge, essentially all old FDc34 forest is limited to Itasca State Park and some protected portions of the Chippewa National Forest.

Compositional changes are also alarming. Most obvious is the loss of all pine species, especially in the young growth-stage. Together jack, red, and white pine accounted for 50% of all trees in young FDc34 forests, and today we have estimated that there is 1% jack pine and no red or white pine in naturally regenerated stands **(PLS/FIA-1)**. It would seem that all regeneration of pine on FDc34 sites has been artificial for at least the past 50 or 60 years. This too, is alarming in that failure rates in pine plantations on FDc34 sites is now very high due to deer depredation and disease issues. Quaking and big-toothed aspen are the obvious benefactors of modern forest management on these sites. It seems that coppicing aspen has been the easiest and most often applied silvicultural strategy. Another consequence of this approach is the expansion of red maple and possibly bur oak. The ingress of red maple is more significant in that it adds a shade-tolerant species to the mix of successful trees on FDc34 sites, where historically all trees were somewhat intolerant. This may complicate our interpretations of tree behavior based upon historic data.

The ease of managing FDc34 sites for coppiced aspen has obviously contributed to the imbalance of age classes and composition between historic and modern times. However, the suppression of chronic surface fires has probably had a greater effect on the whole ecosystem. FDc34 sites are quite rich in comparison to other FDc or FDn communities. Without frequent fire, the tendency is to succeed rather rapidly to more mesic vegetation and stands begin to resemble the MHc26 community. There are few if any silvicultural treatments that can replace surface fires. Restoration is an obvious need, but it will require serious commitment to the use of prescribed fire and patience regarding attempts to naturally regenerate pine. Such efforts may be worthy, as the FDc34 community has great potential to rapidly produce large red and white pine timber.

Natural Disturbance Regime

Natural rotation of catastrophic and maintenance disturbances were calculated from Public Land Survey (PLS) records at 4,688 corners within the primary range of the FDc34 community. At these corners, there were 11,194 bearing trees comprising the species that one commonly finds in FDc34 forests.

Natural Rotations of Disturbance in FDc34 Forests Graphic	
	Banner text over photo
Catastrophic fire photograph	**110 years**
Catastrophic windthrow photograph	**1,050 years**
Partial Canopy Loss, photograph	**30 years**

The PLS field notes described about 13% of the FDc34 landscape as recovering from stand-regenerating fire. Most such records were of burned-over lands, but common also were descriptions of scattered pine, scattered timber, and pine thickets. From these data, a rotation of 110 years was calculated for stand-replacing fire.

Elsewhere in the FDc34 landscape, the surveyors described lands as windthrown and lacking suitable-sized trees for scribing. Such corners were encountered at about 1% of the time, yielding an estimated rotation of 1,050 years for windthrow.

Far more common at FDc34 sites were references to what we have interpreted as some kind of partial canopy loss, without any explicit mention of fire or windthrow. Most references were to sparse forest, scattered pine, scattered timber, and sometimes openings with distances to bearing trees that were intermediate between the distances for burned/windthrown lands and what is typical for fully stocked pine forests. About 17% 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 FDc34 sites. That more corners were described as burned (342) compared to windthrown (63) suggests that surface fires were the more prevalent cause of partial canopy loss.

Rotations of catastrophic and maintenance disturbance for FDc34 are similar to all other central communities where pines are the dominant trees. The rotation of about 110 years for catastrophic fire is nearly four times that of the 30 year rotation off surface fires. This chronic level of surface fire allowed early-successional trees like jack pine and quaking aspen to persist at modest abundance in growth-stages far older then their life-expectancy. More important, the surface fires brought along successive cohorts of both red and white pine that allowed these trees to indefinitely occupy FDc34 sites. This regime contrasts with northern fire-dependent pineries where surface fires were only about twice as likely or about as common as catastrophic fire. Across the FDc floristic region, cyclic drought would seem to explain the high frequency of surface fire. However, eastern outliers of FDc34 forests occur well within the FDn floristic region, and virtually all occurrences are associated with waterways and lakeshores where Indians imposed a regime of frequent surface fire around their settlements.

Natural Stand Dynamics & Growth-stages

Following stand-regenerating fire or very rarely windstorms, the overall pattern of compositional change in FDc34 communities is to rather steadily succeed from short-lived initial-cohort trees to very long-lived conifers **(PLS-4)**. The rate of compositional change accelerates during episodes of rather synchronous mortality of trees in the same cohort. The most rapid period of change was between ages 55 and 95 as initial-cohort aspen and jack pine died. A second period of accelerated change from about 135-175 years is associated with the death of red pines that could be initial-cohort trees. FDc34 forests were so frequently affected by surface fires that the full set of common species have some ability to contribute to the initial-cohort and some ability to persist in old growth-stages. Thus, succession doesn't entirely involve turnover from intolerant pioneers to tolerant late-successional trees. We believe that succession to red pine and eventually white pine is mostly a consequence of the pine's longevity and their superior ability to survive surface fires in comparison to the other species.

The FDc34 community is the only FDc community considered to be true forest as all others are woodland. It is similar to forests in that early in its development it achieves tree densities that vary little throughout the course of stand maturation. The distances to bearing trees for all stages of development range between 44 and 51 feet. However, these distances are nearly double that typical of comparable FDn forests. Also, the variance of tree distances are greater in relation to their means for FDc34 than comparable FDn forests. This suggests not only wider spacing, but patchier distribution. Distances to trees during compositional transitions (~51 feet) are longer than the more stable growth-stages, which is consistent with the idea of the loss of canopy trees initiating episodes of replacement by other species.

Young Growth-stage: 0-55 years
Nearly half (47%) of the FDc34 landscape in pre-settlement times was covered by forests estimated to be under 55 years old **(PLS-1)**. Stands in this stage were more often mixed (64%) than monotypic, which is typical of fire-dependent communities like FDc34 that occur on rugged topography with habitats that vary over short distances. Monotypic conditions were represented mostly by survey corners where all bearing trees were quaking aspen. Less common were survey corners of pure red pine, jack pine, or white pine. At survey corners with mixed composition, jack pine and aspen were the most cited species, but red pine was common as well. In describing young, burned stands the surveyors indicated that in addition to jack pine, quaking aspen, and red pine, the initial-cohort included white pine, oak, and some paper birch as well **(PLS-3)**.

All of the initial-cohort species are well adapted to re-colonizing after catastrophic fire. The vegetative strategies of aspen and oak are as evident as the seeding strategies of the pines on FDc34 sites. FDc communities in general occur in a zone of transition were vegetative response to fire is dominant towards the prairie/forest border to the west and where re-colonization by seed is more important to the northeast. It is broadly true that vegetative regeneration, especially that of quaking aspen, is favored on finer-textured soils where we believe it is easier for trees to maintain healthy rootstocks. FDc34 soils are notoriously complex at a fine scale, regarding the thickness of a sandy/gravelly cap over fine-textured till. We believe that this created a complex response of vegetation after catastrophic fires where suckering aspen was favored where the cap is thin or absent, and seed-origin pines were favored where the cap was thicker (appx. >7 feet).

The ability of quaking and big-toothed aspen to dominate young FDc34 forests is most likely a consequence of their persistence in the mature and old growth-stages. For a pioneer species, quaking aspen show surprisingly good success in maintaining a presence in older forests by establishing seedlings or suckers and recruiting some to mid- and full-canopy heights **(R-2)**. Big-toothed aspen is far less capable of persisting in mature forests by filling canopy gaps. Apparently quaking aspen was successful enough at maintaining clone rootstocks and scattered seed trees so that they could rapidly repopulate burned areas, even if the burned stand had reached the older growth-stages. Other initial-cohort trees like jack pine, red pine, white pine, paper birch, and oak also maintained a significant presence in older stands and were prepared to re-colonize following fires. White pine, paper birch, and oak are similar to quaking aspen in that regeneration and recruitment in the older growth-stages seems possible. Both red and jack pine have very poor ability to establish and recruit seedlings in mature stands, due most likely to the usual presence of subcanopy hardwoods and low light levels on the forest floor. The persistence of red pine in older forests could be attributed to its longevity on FDc34 sites. Jack pine must have persisted in larger openings created by surface fires.

An alternative hypothesis for hardwood dominance of regenerating patches of FDc34 habitat is that these patches were burned at least twice in short succession. Catastrophic fires may have usually resulted in good regeneration of jack and red pine, but if burned again before the pines reach sexual maturity, the seed source is lost thus favoring colonization of trees capable of long-distance seeding like quaking and big-toothed aspen. The general correlation of aspen with slightly “richer” soil conditions (shallow to till, incipient Bt horizons) on FDc34 sites leads us to believe that most aspen regeneration was vegetative and restricted to places where aspen could maintain extensive rootstocks. For the past 2,000-4,000 years pedogenic processes, most notably the formation of subsoil horizons able to perch water, has favored the expansion of hardwoods on moraines that probably were once solid FDc34 pine forests. Double burning probably wasn’t the usual cause of aspen dominance in young FDc34 forests, but it could have played and important role in the initial establishment of FDc34 patches where the soil conditions had just become favorable for the persistence of hardwoods.

Perhaps most interesting is the seeming lack of any fire-sensitive trees in the historic FDc34 landscape **(PLS-1)**. Today, FDc34 forests occur on stagnation moraines where fire-sensitive hardwoods are included throughout the moraines in the more mesic habitats. This is evident on FDc34 sites today as having much more red maple in young forests than was usual **(PLS/FIA-1)**. Also, it is possible that some MHc26 forests were formerly FDc34 sites, which have picked up more sugar maple, basswood, and ironwood since settlement (see **PLS/FIA-1** for MHc26). We believe that historically, chronic surface fires (~30-year rotation) eliminated most fire-sensitive trees on these moraines and prevented them from being an important component of young FDc34 forests.

Transition: 55-95 years

About 31% of the historic FDc34 landscape was forest undergoing considerable compositional change as stands approached maturity **(PLS-1)**. Stands in this stage were far more likely to be mixed (80%) than monotypic (20%). Monotypic conditions were represented mostly by survey corners where all bearing trees were red pine, and much less often by quaking aspen or oak. At survey corners with mixed composition, red pine was still the most cited species and it was mixed most often with quaking aspen, jack pine, white pine, paper birch, and oak. It seems possible that during the transition, surveyors may have preferentially selected red pine bearing trees because decline in the initial-cohort hardwoods and jack pine was evident.

The transition stage is driven mostly by the steady decline of initial-cohort aspen and jack pine. The relative abundance of aspen falls sharply from about 60% of all trees in the 30-year age class to under 5% in the 80-year age class **(PLS-2)**. Initial-cohort jack pine persist longer than aspen, but its relative abundance drops to background levels (~5-10%) at the close of the transition period. Red pine seems to be the immediate benefactor of the demise of initial-cohort trees. Its relative abundance mirrors the loss of aspen and jack pine, rising sharply from about 20% to 80% between the 40- and 100-year age classes. The simplest explanation is that initial-cohort red pines just outlived both aspen and jack pine. However, its peak abundance of 80% seems too high to have not included at least some recruitment of second-cohort trees. White pine shows the same pattern of increase during the transition, but at abundances of about half that of red pine **(PLS-1)**. It is important to remember that by the close of the transition stage, it is quite likely that stands were affected by one or two surface fires. It is entirely possible that red pine dominance at about age 100 years, was the result of the fact that 50-100 year-old red pines were more likely to survive surface fires than aspen, jack pine, paper birch, and red oak. Such fires must have provided some opportunity for the establishment of red and white pine at the expense of initial-cohort trees, particularly the hardwoods.

Mature Growth-stage: 95-135 years
About 31% of the historic FDc34 landscape was mature forest where the rate of successional change slowed slightly **(PLS-1, PLS-4)**. Stands in this stage were far more likely to be mixed (72%) than monotypic. Patches of pure aspen or pure paper birch were most common, but there were patches of solid red and white pine as well. Mixed corners were most often combinations of quaking aspen, paper birch, balsam fir, or white pine.

The most striking feature of mature FDc34 forests is that they were still dominated by rather intolerant trees. Red pine is especially intolerant in mature FDc34 forests **(R-2)**, yet it was able to "hold" sites indefinitely without the benefit of catastrophic disturbance **(PLS-1, PLS-2)**. We believe that surface fires were responsible for maintaining rather open conditions that allowed intolerant and mid-tolerant trees to persist on these sites during the older growth-stages. 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 2-3 surface fires and would likely experience a couple more while in the mature growth-stage. It is entirely possible that succession towards red and white pine dominance during the transition is related to the tendency of these pines to survive surface fires more so than other species – and that stability in the following the mature growth-stage is related mostly to dominance of just a couple species and their longevity. The notion of surface fires winnowing FDc34 forests and leaving the fire-resistant pines is supported by several of our observations. First, tree density as estimated from bearing tree distances was about a quarter of that of comparable FD communities where we see shade-driven succession. Second, we detected almost no recruitment of trees in the I-1, window that corresponds with the mature growth-stage **(PLS-5)**. That is, surface fires probably maintained park-like understory conditions with little brush or advance regeneration of smaller-diameter trees that we would have ascribed to recruitment. Finally, the historic dominants of the mature growth-stage show modest or poor ability to establish and recruit seedlings beneath a canopy (**R-2; FIA-1**, situation 13). Our best guess is that mature FDn34 forest was a coarse-scale perception across the moraines where this community is extensive. Most likely old, super-canopy pines in groves or scattered above younger forests would have dominated the view from a fire tower. Points like PLS survey corners were far more likely to sample patches of similar diameter trees representing cohorts dating to the last surface fire – i.e. young patches yet to be winnowed by subsequent fires (47% young forest, **PLS-1**). Ideas like deepening duff layers and the formation of multiple strata as stands mature seem to have no application in describing succession in FDc34 forests. Mature FDc34 landscapes were maintained by surface fires, most likely as a mosaic of stand-scale (5 to 50-acre) patches.

Second Transition: 135-175 years
About 3% of the historic FDc34 landscape was forest undergoing considerable compositional change as it approached old age **(PLS-1)**. Stands in this stage were almost always of mixed composition (80%). Monotypic conditions were represented mostly by survey corners where all bearing trees were red pine or white pine. Mixed survey corners involved either red or white pine in combination with other trees. For the most part, early-successional trees like aspen, birch, and jack pine were present at the same corner with an old, veteran pine. For the first time, there was some presence of moderately tolerant trees like white spruce and elm.

The second transition was driven mostly by the behavior of red pine, because it was the most abundant tree in the mature growth-stage. After peaking in the mature growth-stage at about 80% relative abundance, red pine declines to about 20% relative abundance in the 150-year age-class **(PLS-2)**. We believe that this decline was caused by the death of initial-cohort red pines and their replacement by advance regeneration of white pine. Most likely, the old red pines were supercanopy trees replaced by rather mature white pines as we did not detect any recruitment of small-diameter trees in these old growth-stages **(PLS-5)**. The near loss of jack pine is also a driving factor of the second transition **(PLS-1)**. Unlike red pine, it seems impossible that these were initial-cohort trees. The big decline of initial-cohort jack pine is between the 50- and 90-year age classes where its relative abundance falls sharply from about 25% to 5% relative abundance. Thus, we doubt that jack pine lives much longer than 80-90 years on FDc34 sites. Surface fires might have been successful in establishing second-cohort jack pines as long as the supercanopy was red pine during the mature growth-stage. The eventual replacement of red pine with white pine may have created forest floor conditions that were too shaded for jack pine, in spite of surface fires creating adequate seedbeds.

Old Growth-stage: >175 years

About 6% of the historic FDc34 landscape was old forest **(PLS-1)**. Stands in this stage were mixed about 84% of the time. Monotypic conditions were represented almost entirely by survey corners where all trees were white pine. Mixed survey corners involved white pine occurring with other trees such as red pine, white spruce, paper birch, and quaking aspen. This result is due mostly to the fact that white pine was about the only species available that could achieve great age and cause us to estimate stand age in excess of 200 years. White spruce, American elm, and northern white cedar are trees within the range of the FDc34 community that can also achieve great diameter and presumed old age. Apparently these species were too sensitive to the chronic surface-fire regime typical of the FDc34 community.

FDc communities in general share the pine cover-types with FDn communities but not the fire-sensitive species of older growth-stages. Other than the modest occurrence of some white spruce in the old growth-stage, the FDc34 community never included other fire-sensitive conifers or mesic hardwoods. In addition to the lack of shade-tolerant, late-successional species, we believe that “old” FDc34 sites lacked other amenities that we usually ascribe to forests that have escaped disturbance for some time. Thick duff layers, nurse logs and other coarse woody debris, and complex understory stratification were probably kept in check or eliminated by surface fires. Opportunities for establishment favored ruderal species, and recruitment favored tolerance of fire more so than low light. Our vision of “old” FDc34 forest is the skeletal or grove-like presence of white pines that had become so tall and large as to be impervious to surface fires. Among these veteran white pines were patches of FDc34 forest in almost any stage of development.

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?

Red Pine

- ***excellent habitat suitability rating***
- ***mid-successional***
- ***open regeneration strategist***
- ***regeneration window at 0-30 years***

Suitability

FDc34 sites provide ***excellent habitat*** for red pine trees. The ***suitability rating*** of 4.9 for red pine is influenced mostly by its presence (52%) as trees on these sites in modern forests **(R-1)**. When present, red pine is an important co-dominant or dominant tree, contributing 37% mean cover in mature stands. This ranking is the highest for any tree on FDc34 sites as sampled by releves. Northern fire-dependent forests in general offer excellent habitat for red pine trees (see Suitability Tables).

Young Growth-stage: 0-55 years

Historically, red pine was an important tree in young FDc34 stands recovering mostly from fire. Young red pines represented 25% of the trees at young survey corners, second only to aspen **(PLS-1)**. At survey corners described as recently burned, red pines represented 36% of the bearing trees, which is greater abundance than any other tree **(PLS-3)**. Our interpretation is that red pines could be dominant initial-cohort trees on FDc34 sites, especially on drier and poorer soils where seeding of pines seemed favored over sprouting of hardwoods. Red pine showed similar abundance at windthrown corners (33%), but windthrow was such an infrequent event that it wasn't an important means of establishing red pine on FDc34 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)**. Small-diameter red pine regeneration is most abundant in the post-disturbance window immediately after disturbance and was important until about age 30 **(PLS-5)**. After 30 years, low levels of recruiting red pine were detected until the close of the young growth-stage. In most cases, red pine regeneration was coming in under other red pines or under jack pine. Other than just a few instances of red pine coming in among larger aspen, it seems that red pine never filled growing space where hardwoods had a good start.

Transition: 55-95 years

As stands transitioned to mature conditions red pine increased greatly in abundance, presumably because of its ability to outlive and overtop initial-cohort jack pine and aspen **(PLS-1, PLS-2)**. At this stage, red pine was about four-times as likely to be the largest tree at a corner rather than the smallest tree. Although most transition survey corners with red pines were of mixed composition, the proportion of pure red pine corners actually increased during the transition. Our interpretation is that patches of FDc34 habitat tended to be more monotypic as surface fires killed older jack pines and possibly some aspen while leaving the more fire-resistant red pines. Small-diameter red pine regeneration is present at low levels up to the 60-year age-classes **(PLS-5)**. We believe that there was limited establishment and recruitment of red pine in response to the death of the initial-cohort jack pines. At this time, young red pines were mostly coming in among larger red pines, but often they were still replacing jack pine. Only rarely, were small-diameter red pines seemingly replacing larger aspen or paper birch.

Mature Growth-stage: 95-135 years

Red pine had peak abundance as a co-dominant or dominant tree in mature stands (95-105 years), 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 old-aged **(PLS-1, PLS-2)**. The trend of FDc34 stands to become monotypic continued from the transition stage and was most evident in the mature growth-stage, where nearly 24% of the survey corners were attended by all red pines. There were no red pine bearing trees smaller than half the diameter of the largest trees at survey corners estimated to be older than 60 years, which suggests to us that there was little regeneration beyond this point **(PLS-5)**. When red pines were the smaller tree at a corner, they now are almost always under larger red pines (95%). Starting in the transition stage, but most evident in the mature stage is the tendency of red pines to be the larger diameter tree when it co-occurred with other species. It was ten times more likely for red pines to be the largest tree at a corner than it was for them to be smaller than another species. It seems possible that at about this time, red pines reached a stature, where they became rather impervious to surface fires and that the selective pressure of surface fires was to kill advance regeneration of nearly all trees, including small red pines.

Second Transition: 135-175 years
As stands transitioned to old conditions red pine decreased in abundance, presumably because initial-cohort red pines were starting to senesce and die **(PLS-1)**. Small-diameter red pine regeneration coming in among larger trees was not detected during this second transition stage **(PLS-5)**. Although it was still most common for red pines to be the largest bearing tree at a corner, it was now the smallest bearing tree at about a third of the survey corners compared to just a tenth in the mature growth-stage. Now, it was about equally common for the smaller-diameter pine bearing trees to be next to larger red pines or white pines. This pattern is consistent with the idea that the oldest and largest red pines were dying, leaving smaller second- or third-cohort red pines beneath initial-cohort white pines and the remnant population of initial-cohort red pines.

Very Old Growth-stage: >175 years
Upon rare occasion, stands would transition to very old forests. The relative abundance of red pine in very old forests was about half of its abundance in mature forests, losing ground to white pine **(PLS-1)**. The most common condition in the old growth-stage was for a supercanopy of initial-cohort white pine to tower above a canopy of red and white pines that probably date to more recent surface fires. We believe that red pine abundance drops relative to white pine in very old FDc34 forests because it doesn't live as long as white pine and because white pine is far better at developing advance regeneration under a canopy **(R-2)**.

Regeneration Strategy
Red pine's primary regenerative strategy on FDc34 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 substantial abundance in young FDc34 stands **(PLS-1)**, (2) it was the most abundant bearing tree 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 high 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 FDc34 woodlands suggests also that red pine needs open habitat to reproduce because it has essentially no ability to establish seedlings beneath a canopy **(R-2)**.

Historic Change in Abundance
Today, red pine is in peril on FDc34 sites. The absence of sapling stands versus pole stands of red pine in the FIA data would suggest less success or effort regenerating FDc34 stands with red pine over the past 30 years **(FIA-1)**. Historically, the relative abundance of red pine in young FDc34 forests was 25% compared to none today **(PLS/FIA-1)**. Equally startling, is the loss of red pine in mature stands where its modern abundance of 10% is dwarfed by its historic dominance at 50% relative abundance. We attribute this decline to logging and stand re-initiation without using fire as a management tool, which strongly favors aspen on FDc34 sites. Essentially all young red pine on FDc34 sites is now in plantation.

White Pine

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

Suitability

FDc34 sites provide ***excellent habitat*** for white pine trees. The ***suitability rating*** of 4.9 for white pine is influenced mostly by its presence (47%) as trees on these sites in modern forests **(R-1)**. When present, white pine is an important co-dominant and sometimes dominant tree, contributing 32% mean cover in mature stands. The ranking is nearly perfect, and just slightly poorer than that of red pine on FDc34 sites as sampled by releves. The FDc34 community provides the only important habitat for white pine among FDc communities because red pine and jack pine are favored in the poorer FDc woodlands.

Young Growth-stage: 0-55 years

Historically, white pine was an important tree in young FDc34 stands **(PLS-1)**. Young white pines represented 15% of the trees at survey corners described as burned, following only red pine and quaking aspen **(PLS-3)**. Our interpretation is that some white pines got their start on FDc34 sites by seeding on mineral soil exposed by hot fires. White pines represented 26% of the trees at corners affected by stand-regenerating wind, substantially more than following fire. Although windthrow was not an important means of regenerating FDc34 forests, the improved performance of white pine following wind would suggest that there was significant advance regeneration able to react to canopy removal. White pine regeneration coming in among larger trees was detectable throughout the 0-40 year post-fire window **(PLS-5)**. We interpret this as white pine having fair success filling under-stocked areas of the regenerating stand later in the young growth-stage **(PLS-2)**. Most often, subordinate white pines were coming in under larger white pines, but it was common to see them beneath larger red pines, aspen, and paper birch.

Transition: 55-95 years

As stands transitioned to mature conditions white pine increased slightly in abundance **(PLS-1)**. We estimate that this increase started at low abundance following disturbance and continued throughout the successional cycle into old-growth conditions **(PLS-2)**. Small-diameter white pine regeneration coming in among larger trees was present following disturbance, peaking in the 40-year age class **(PLS-5)**. To some extent, these recruiting white pines seemed to be replacing aspen, paper birch, and jack pine in natural decline during the transition. The slight increase in white pine abundance during the transition is probably related to this success. More often, small-diameter white pines were beneath larger red or white pines. We believe that the effect of surface fires was to winnow stands in transition and favor the thicker-barked pines. At this time, 55-95 year-old red pines seemed more resistant than white pine, but that relationship will change to favor white pine in the later growth-stages. Enough young white pines were surviving surface fires during the transition to eventually outlive or replace red pines in older growth-stages.

Mature Growth-stage: 95-135 years

In the mature growth-stage white pine makes substantial gains in abundance relative to red pine **(PLS-1, PLS-2)**. The abundance of white pine rises from about 20% to 40% during this period, averaging 22% of all trees. At this time, it was more common for white pines to be the largest tree at a survey corner, dominant over other species of trees. We believe that these were initial-cohort white pines. It was almost as common for white pines to be the smallest tree at a corner, and in nearly all cases they were beneath larger-diameter red pines. We attribute this to good survival of white pines established near the close of the young growth-stage beneath a canopy of red pine. Small-diameter white pine regeneration was not detected in the historic data **(PLS-5)** during this growth-stage, but in modern forests where surface fires has not recently affected the site it is especially abundant compared to red pine **(R-2)**. We doubt that the significant increase in white pine during the mature growth-stage and extending into old-growth was accomplished without at least some establishment and recruitment because that is clearly its competitive edge over red pine in today's mature forests.

Second Transition: 135-175 years

As stands transitioned to old conditions white pine replaced red pines as the dominant tree on FDc34 sites **(PLS-1)**. Small-diameter, white pine regeneration coming in among larger trees was not detected during this second transition stage **(PLS-5)**, but this is the case for all species based upon our stringent rules for recruitment. At this stage it was about six-times more likely that white pines were the largest tree at a survey corner, which is an indication of its dominance in the canopy. When it was the smallest tree, almost all occurrences were of smaller trees being beneath larger white pines. About 7% of all survey corners estimated to be this old were pure white pine, double that of the mature growth-stage.

Very Old Growth-stage: >175 years

In the old growth-stage white pine dominated FDc34 sites. At 54% relative abundance, it was by far the most common tree **(PLS-1)**. This result is at least partially due to the fact that white pine is about the only common MHn34 tree to achieve diameters where we would estimate a survey corner to be older than 175 years. However, among the trees of the very old growth-stage (aspen, paper birch, and red pine), white pine is at least equally tolerant and adept at establishing and recruiting seedlings beneath a canopy **(R-2)**. For this reason, we consider white pine to be a ***late-successional*** species on these sites historically. The general lack of late-successional, shade-tolerant trees is testimony to the effectiveness of surface fires. At least some of the dominance of white pine in the very old growth-stage is due to its superior ability to survive fires and live a long time.

Regeneration Strategies

White pine's primary regenerative strategy on FDc34 sites is to fill ***large-gaps***. It is most successful at this beneath pines, but also did well when gaps formed within the declining canopy of initial-cohort quaking aspen and paper birch. In the historic PLS data this interpretation is supported by the fact that white pine abundance rises steadily in response to the decline of the initial cohort species in both the first and second transitions **(PLS-1, PLS-2)**. The recruitment indices (3.3-3.8) in **Table R-2** are also most in-line with species that tend to do well in large-gaps. In modern forests sampled with FIA plots, white pine's tendency to do well in subordinate situations (12 and 13, **FIA-1**) suggests that it has some ability to fill ***small-gaps*** as well. Significant influx of red maple and brush has occurred on FDc34 sites in historic times due to fire suppression, and these species probably compromise white pine's historic ability to fill small-gaps.

Historic Change in Abundance

Today, white pine is mostly gone from the FDc34 landscape, accounting for less than 2% of the trees at FIA subplots in any growth-stage **(PLS/FIA-1)**. Young FIA plots recorded no white pine in a naturally regenerated forest. The releve sampling paints a slightly better picture of white pine's current status. White pine has fairly high presence as a tree (47%, **R-1**)) and similar presence (41%, **R-2**) in the understory. The releve sampling is biased, favoring ecologically intact remnants of FDc34 forests. However, the presence of white pine was not a deciding factor in plot location. Outside of Itasca State Park, most of the 59 releve plots were on sites previously logged and still available for commercial interests. Regardless of the data source, it is widely accepted that white pine populations on FDc34 sites have declined to the point where restoration efforts are warranted.

Quaking and Big-toothed Aspen

- ***excellent habitat suitability rating***
- ***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. FDc34 releve samples show that for plots with aspen present: 4% have both species present; 25% are big-toothed aspen without quaking aspen; 71% are quaking aspen without big-toothed aspen. We consider quaking and big-toothed aspen to be ecologically equivalent for most silvicultural considerations.

Suitability
FDc34 sites provide ***excellent habitat*** for **quaking aspen** trees. The ***suitability rating*** of 4.7 for quaking aspen is influenced mostly by its high presence (36%) 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 third, following red and white pine on FDc34 sites. In general the richer FDc communities FDc24, FDc25, and FDc34 offer excellent habitat for quaking aspen (see Suitability Tables).

FDc34 sites offer ***good habitat*** for **big-toothed aspen**. The ***suitability rating*** of 3.3 for big-toothed aspen is based upon its 14% presence and 14% mean cover when present **(R-1)**. This ranking is eighth, following red pine, white pine, quaking aspen, northern red oak, paper birch, red maple, and bur oak on FDc34 sites. Big-toothed aspen is restricted to the richer FDc25 and FDc34 communities (see Suitability Tables), with FDc25 offering better opportunities.

Young Growth-stage: 0-55 years
Historically, aspen was an important dominant in young FDc34 stands recovering mostly from stand-regenerating fire **(PLS-1, PLS-2)**. Young aspen represented 22% of the trees at survey corners described as burned, which is second only to red pine **(PLS-3)**. Aspen was also an important species following windthrow, representing 25% of the trees at such survey corners. Young FDc34 corners with aspen trees present were more often mixed in composition (62%), but often (38%) all of the bearing trees were aspen. Its dominance in the young growth-stage and its high abundance following fire and windthrow is why we consider quaking and big-toothed aspen to be an ***early successional*** species on FDc34 sites. Small-diameter, aspen regeneration was most often observed coming in among larger trees in the 0-30 year post-disturbance window **(PLS-5)**. This is typical of early successional species, and we interpret this as aspen showing excellent ability to recruit into under-stocked areas of burned stands. The presence of smaller diameter aspen could be due natural variation among suckers that are more-or-less connected to parent rootstocks, but it is more likely that seed-origin trees were the smaller ones filling in among the suckers.

Transition: 55-95 years
Transitioning of young FDc34 forests was driven in-part by the steady loss of initial-cohort aspen leaving longer-lived red and white pine **(PLS-1)**. We estimate that this decline started at about age 30, and continued until the 80-year age-class where its relative abundance stabilized at about 5% **(PLS-2)**. Small-diameter aspen regeneration was detectable only in the initial age-classes of the transition 60 **(PLS-5)**. Aspen regeneration was beneath just about any other tree, but most cases were of aspen beneath red pine. Fewer references placed aspen beneath red oak, white pine, and larger aspen. During the young growth-stage it was fairly common for aspen to be the only species at a survey corner and often it was the largest bearing tree. By the close of the transition, the situation was reversed and throughout the remainder of the successional cycle, aspen remained a subordinate species in a mixed understory.

Mature, Second Transition, and Very Old Growth-stages: 95-135 years, 135-175 years, and older

By the close of the first transition aspen was a minor component of FDc34 forests and had little influence on stand dynamics. The relative abundance of aspen was stable during these periods at about 5-7% **(PLS-1)**. Small-diameter quaking aspen regeneration coming in among larger trees was not detected in these older growth-stages **(PLS-5)**, but some regeneration and recruitment must have happened for it to maintain its modest presence and to contribute so significantly after major disturbances. The pattern of it being the smaller tree at survey corners and in mixture with other species continued from the first transition. This behavior seems odd for a tree usually described as very intolerant and often regenerating in rather pure patches. It is important though that in its usual context, i.e. beneath red and white pines in mature FDc34 forests, quaking aspen has good success recruiting seedlings to taller strata **(R-2)**. Also important is the fact that historically, FDc34 forests had rather low density of canopy trees. We estimate that the density of pines in this community was just about a quarter of that for pine cover-types in the northern floristic region. Apparently there was enough light and regeneration opportunities to maintain aspen at low abundance in the older growth-stages.

We are uneasy about our interpretation of aspen's successional role in FDc34 forests in that it requires a varying response to fire – strongly favored after catastrophic fire (see Young Growth-stage) yet substantially diminished by surface fires in order to favor red and white pine in older growth-stages. Suckering in aspen is sufficiently complicated to envision different responses to fire intensity. Basically, an aspen clone is in a hormonal war whereby the branch tips produce a hormone (auxin) that inhibits suckering versus the root tips which produce a hormone (cytokinin) that promotes suckering – with the bulk of the older tree tissues being at the mercy of youthful, hormonal direction. Hot fires that destroy both the downward transport of auxins in the phloem and upward transport of cytokinins in the xyelm (similar to harvesting) leave the root system enriched in cytokinins and elicit a strong suckering response. Mild fires that inhibit or perhaps just weaken the downward transport of auxin but leave the xylem transport system in place (similar to girdling) tend to result in poor suckering. It is important to remember that the primary difference between stand-regenerating fire and surface fires is the amount of residual canopy. High soil temperatures promote cytokinin production and sucker production. It could just be that the soil-temperature threshold that initiates suckering lies between the warmer soil temperatures of a stand without canopy trees and cooler soil temperatures typical of a stand with an intact canopy. Alternatively, we may have just underestimated aspen's ability to seed into open habitat and failed to appreciate the amount of seed-origin aspen in young FDc34 forests.

Regeneration Strategies

Aspen's primary regenerative strategy on FDc34 sites is to dominate ***open habitat*** after stand-regenerating fires. In the historic PLS data this interpretation is supported by: (1) the fact that 31% of the bearing trees in young stands were aspen **(PLS-1)**, (2) aspen represented a large proportion of bearing trees at burned and windthrown corners **(PLS-3)**, and (3) aspen's peak regeneration was in the post-disturbance window **(PLS-5)** with it's absolute peak being the initial age-class **(PLS-2)**. The high percent of quaking and big-toothed aspen as initial-cohort trees in young forests (situation 11) in the FIA data **(FIA-1)** is also characteristic of species that regenerate effectively in the open.

The releve sampling of mature FDc34 forests suggests, however, that quaking aspen is able to function also as a ***large-gap strategist*** with good establishment and recruitment in the understory strata **(R-2)**. Its regeneration indices (3.0-3.8) are in line with large-gap strategists. Here, the data for big-toothed aspen departs from that of quaking aspen in that it seems far less able (regeneration indices 1.7-2.8) to establish and recruit seedlings in the understory. In the FIA data, both species show modest abilities in subordinate situations (12, 23, 13, **FIA-1**), which is also typical of large-gap strategists.

Historic Change in Abundance

Today, aspen has essentially replaced red pine and white pine on FDc34 sites **(PLS/FIA-1)**. Most (71%) young FDc34 stands are dominated by aspen, which is a significant increase over the historic condition where aspen accounted for 31% of the trees in young stands. Aspen is now far more important at 29% relative abundance in mature forests compared to its 5% relative abundance in historic stands. Outside of Itasca State Park, there are not any examples of old FDc34 forests sampled by FIA plots. Our interpretation is that the ease of coppicing aspen on FDc34 sites coupled with difficulties in plantation approaches for pine have led to the expansion of aspen populations on these sites. Currently there is a high failure rate (>50%) for establishing pine at expected density on FDc34 sites.

Northern Red Oak

- ***excellent habitat suitability rating***
- ***mid- (early-) successional***
- ***large-gap (open) regeneration strategist***
- ***regeneration window at 30-40 years***

Suitability
FDc34 sites provide ***excellent habitat*** for red oak trees. The ***suitability rating*** of 4.6 for red oak is influenced mostly by its high presence (36%) as trees on these sites in modern forests **(R-1)**. When present, red oak is an important co-dominant tree, contributing 22% mean cover in mature stands. The ranking is fourth behind red pine, white pine, and aspen on FDc34 sites as sampled by releves. Central fire-dependent communities in general offer good-to-excellent habitat for red oak within its native range (see Suitability Tables). Among these, FDc34 offers the best opportunity for red oak.

Young Growth-stage: 0-55 years
Historically, red oak was an important tree (7% relative abundance) in young FDc34 stands recovering from stand-regenerating disturbance **(PLS-1, PLS-2)**. Young red oaks represented 10% of the trees at survey corners described as burned, which is substantially behind the pines and aspen **(PLS-3)**. Red oak was nearly absent from survey corners affected by windthrow. However, windthrow was not an important means of regenerating FDc34 forests. Young FDc34 corners with red oak trees present were more often mixed (78%) than monotypic (22%). Small-diameter, red oak regeneration coming in among larger trees was limited initially but peaked in the 30- and 40-year age classes **(PLS-5)**. We interpret this as slow-growing stump sprouts in the initial-cohort and as seed-origin trees showing some success under a self-thinning canopy of aspen, jack pine, and larger red oaks. Because red oak has high presence in the young growth-stage and was common at disturbed survey corners, we consider it to be secondarily an ***early successional*** species on FDc34 sites (but see Transition Stage below).

Transition: 55-95 years
As stands transitioned to mature conditions red oak generally decreased in abundance **(PLS-1)**. However, the young and transition growth-stages are long, and averaging the relative abundance of red oak masks a definite peak of red oak abundance between the 60 and 80 year age-classes **(PLS-2)**. Because of this peak, it is fair to ascribe ***mid-successional*** behavior to red oak on FDc34 sites. We believe that some of this peak was the consequence of red oaks established in the young growth-stage just outliving initial-cohort quaking aspen, jack pine, and paper birch. Small-diameter, red oak regeneration was still detectable in the early years of the transition stage and young red oaks were coming in among larger trees up until about age 70 **(PLS-5)**. In most cases, red oak regeneration was coming up among larger red oaks, suggesting that some oak-dominated inclusions formed at this time on FDc34 sites. Otherwise, it was common for young red oaks to be coming in among larger red pines and aspen. We interpret this as limited success at establishment and recruitment of seed-origin oak under a partial canopy of initial-cohort trees. Also, it seems likely that the collapse of the initial-cohort aspen released red oak seedlings established during the young growth-stage.

Mature, Second Transition, and Very Old Growth-stages: 95-135 years, 135-175 years, and older
By the close of the first transition red oak was a minor component of FDc34 forests and had little influence on stand dynamics. The relative abundance of red oak was stable during these periods at about 3-4% **(PLS-1, PLS-2)**. Small-diameter red oak regeneration was not detected during the mature growth-stage, whereas it was steadily present until age 70 **(PLS-5)**. At this time, red oaks were more common as the smaller tree at survey corners. We interpret this as red oak having limited success recruiting advance regeneration, though no red oak bearing trees met our half-diameter rule for **Table PLS-5**. Red oak's consistently good performance in regenerating strata in modern forests supports the idea that red oak could maintain modest presence in mature stands

by regeneration and recruitment **(R-2)**. When red oak was the smaller tree at a survey corner, there was a tendency for the larger trees to be red or white pine. Our best guess is that maintenance surface-fires affected some patches of FDc34 habitat in a way that promoted limited opportunities for red oak beneath a supercanopy of red and white pine trees unaffected by surface fires.

Regeneration Strategies

Red oak's primary regenerative strategy on FDc34 sites is to fill ***large-gaps***. It was most successful at this when gaps were forming within a declining canopy of initial-cohort quaking aspen, jack pine, and paper birch. In the historic PLS data this interpretation is supported by: (1) the fact that red oak abundance peaks in response to the decline of the initial cohort species **(PLS-2)**, (2) it is abundant at survey corners showing partial canopy loss **(PLS-3)**, and it shows measurable establishment in a gap window **(PLS-5)**. The fairly high percent of red oak as a subordinate under an proximal canopy (situations 12 and 23) in the FIA data **(FIA-1)** is also a characteristic of species that tend to regenerate best in large gaps. The releve sampling of mature FDc34 forests shows that red oak has some success beneath a canopy. Its indices of regeneration (3.5-3.8) under a canopy are typical of a large-gap strategist. It is important to note though that red oak was most abundant in both young and transitioning FDc34 forests **(PLS-1)**. Impressive also is the fact that red oak presence at burned survey corners is comparable to that of jack pine. Red oak clearly has regenerative strategies that allow it to perform in ***open habitat***. Our interpretation is that the best opportunity for seed-origin oaks was in large-gaps, and stump sprouts served as a reliable mechanism to re-colonizing FDc34 forests destroyed by fire.

Historic Change in Abundance

Today, it seems that red oak on FDc34 sites is in some peril. The decline in red oak is most evident in the young growth-stage as it now represents just 2% of the FIA trees as compared to 7% of the bearing trees **(PLS/FIA-1)**. There is, however, substantially more red oak in mature FDc34 forests (12%) than there was historically (3%). An examination of the age-class data shows that the point in time where there is consistently more or less red oak now than historically is at age 80. Our interpretation is that red oak has done better than they did historically in unmanaged stands and poorly where, most likely, FDc34 stands have been managed for quaking aspen. The fairly high presence of red oak trees **(R-1)** and especially its high presence in the understory **(R-2)** in the little-disturbed stands sampled by releves supports this idea. Our general impression is that red oak would benefit from silvicultural attention when FDc34 stands are regenerated and that there should be plenty of opportunities to do so.

Paper Birch

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

Suitability

FDc34 sites provide ***excellent habitat*** for paper birch trees. The ***suitability rating*** of 4.5 for paper birch is influenced mostly by its high presence (43%) as trees on these sites in modern forests **(R-1)**. When present, paper birch is an important co-dominant tree, contributing 15% mean cover in mature stands. The ranking is fifth behind red pine, white pine, quaking aspen, and northern red oak on FDc34 sites as sampled by releves. Only the richer, FDc communities (FDc25, FDc34) offer excellent habitat for paper birch, (see Suitability Tables).

Young Growth-stage: 0-55 years

Historically, paper birch was an occasional tree (6% relative abundance) in young FDc34 stands recovering from stand-regenerating disturbance **(PLS-1, PLS-2)**. Young paper birch represented just 2% of the trees at survey corners described as burned **(PLS-3)**. Paper birch was seemingly more important following windthrow representing 5% of the trees such survey corners; however the data are sparse and windthrow was not an important means of regenerating FDc34 forests. Because of its peak abundance of 7% in undisturbed forest, we believe that regenerating paper birch was favored in the more mesic patches of FDc34 forests where surface fires were less intense or less frequent. Young FDc34 corners with paper birch trees present were entirely of mixed composition, and it was far more common for birch to be the smaller tree at the survey corner. Because paper birch was about as abundant as it would ever be in the young growth-stage we consider it to be mostly an ***early successional*** species on FDc34 sites. Small-diameter, paper birch regeneration was most often observed coming in among larger trees in the post-disturbance window **(PLS-5)**. Most birch regeneration was coming in beneath jack pine, quaking aspen, and larger paper birch. We interpret paper birch's regenerative success in the post-disturbance years as it showing some ability to recruit into under-stocked areas of burned or windthrown stands.

Transition: 55-95 years

Transitioning of young FDc34 forests was driven by the steady loss of initial-cohort aspen and jack pine early in the stage, beneath which there was some paper birch **(PLS-1)**. The relative abundance of paper birch actually rises slightly throughout the young growth stage and up to the 70 year age class of the transition **(PLS-2)**. After 70 years, the abundance of paper birch declines to base levels of about 4-6% that were persistent throughout the remainder of the successional cycle. Because paper birch has peak presence in the 60-70 year age classes, it has some characteristics of ***mid-successional*** trees. Small-diameter, paper birch regeneration was coming in among larger trees throughout the transition **(PLS-5)**. It was most successful coming in beneath the pines, and was far less likely to be beneath hardwoods. We interpret this as paper birch having some success at establishing and recruiting seedlings after surface fires beneath older pines that don't cast as much shade as hardwoods.

Mature, Second Transition, and Very Old Growth-stages: 95-135 years, 135-175 years, and older

By the close of the first transition paper birch was a minor component of FDc34 forests and had little influence on stand dynamics. The relative abundance of paper birch was stable during these periods at about 4-6% **(PLS-1)**. Small-diameter paper birch regeneration was not detected beyond the 100-year age-class of the mature growth-stage **(PLS-5)**. However, among the common FDc34 trees, paper birch had the strongest and longest record of recruitment throughout the transition. Paper birch was almost always the smallest diameter bearing tree at corners of mixed composition. Apparently, paper birch was able to establish and recruit enough seedlings to persist in the older growth stages, and was poised to expand its local populations after the more severe fires. In modern forests, paper birch is not especially good at establishment beneath a canopy, but saplings have a fairly good chance of reaching tree height **(R-2)**. We believe that today, birch's establishment is hindered by the lack of mineral soil seedbeds, which would not have been a problem historically as stands experienced surface fires about every 30 years.

Regeneration Strategies
Paper birch's primary regenerative strategy on FDc34 sites is to re-populate ***open habitat*** after stand-regenerating disturbance. It was not especially successful at doing this after fires, suggesting that stump sprouting was its main strategy **(PLS-3)**. Although the data are sparse, it seemed to perform better after windthrow, suggesting that canopy removal could have released a modest amount of birch advance regeneration. In the historic PLS data birch's open regeneratoin strategy is supported by: (1) the fact that paper birch was the most abundant tree in young forests **(PLS-1)**, and (2) paper birch'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 paper birch as poles in pole stands (situation 22) in the FIA data is also characteristic of species that regenerate effectively in the open but its low percentage as saplings in sapling stands (situation 11) suggests that it is not as effective in the open as quaking aspen **(FIA-1)**. Most likely this is the consequence of most modern stands being regenerated by clear-cut logging rather than fire or windthrow. Paper birch's fair regenerant and seedling indices (2.0) in modern stands sampled by releves is also very consistent with the idea that it prefers open habitat **(R-2)**.

The persistence of paper birch in older stands and its ability to replace some initial-cohort aspen and jack pine is the main reason to suspect that paper birch has some regenerative ability in ***large gaps***. This idea is supported by the long, 100-year regeneration window **(PLS-5)**. The high percentage of paper birch poles in tree stands (situation 23) is particularly characteristic of trees that are successful at recruiting in large gaps **(FIA-1)**. In more mesic habitats paper birch ultimately loses to small-gap specialists like sugar maple, but this rarely happened in FDc34 landscapes because maintenance surface fires were effective in eliminating shade-tolerant, fire-sensitive species. The recent expansion of red maple on FDc34 sites **(PLS/FIA-1)** may now diminish paper birch's large-gap abilities and discourage our inclination to prescribe large-gap silvicultural systems to favor paper birch.

Historic Change in Abundance
Today, paper birch is slightly more abundant than it was historically on FDc34 sites. This is most evident in the young growth-stage where it now represents about 10% of the trees compared to 6% historically **(PLS/FIA-1)**. In the mature growth-stage, it is now 7% of the trees as compared to 4% historically. There were no old FDc34 forests sampled by FIA plots, where historically paper birch was a steady component at 6% relative abundance. It would seem that coppicing FDc34 sites has favors paper birch a bit more so than the historic fires, but not nearly as much as it favors aspen. This pattern seems similar in the releve samples of older and not recently managed FDc34 stands. Its presence in both the canopy **(R-1)** and understory **(R-2)** seem higher than expected given our vision of the historic forests. Our best guess is that fire suppression has contributed to the loss of pines and birch populations have expanded slightly as the old pines eventually die.

Red Maple

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

Identification Problems

The PLS surveyors did not distinguish between red and sugar maple. FDc34 releve samples show that for plots with maples present: 5% have both species present, and 95% are red maple without sugar maple. Red maple is so much more common on modern FDc34 sites that it is probably safe to assume that surveyor references to "maple" were red maple.

Suitability

FDc34 sites provide ***excellent habitat*** for red maple trees. The ***suitability rating*** of 4.3 for red maple is influenced mostly by its presence (33%) as trees on these sites in modern forests **(R-1)**. When present, red maple is a minor co-dominant tree, contributing 14% mean cover in mature stands. This ranking is sixth among trees common on FDc34 sites, following red pine, white pine, quaking aspen, northern red oak, and paper birch. Only the richer FDc communities (FDc25, FDc34) provide habitat for red maple, and FDc34 sites offer the only viable commercial opportunities.

Young Growth-stage: 0-55 years

Historically, red maple was present in just trace amounts (~1%) in young FDc34 stands recovering mostly from fire **(PLS/FIA-1,PLS-2, PLS-3)**. Red maple did not appear as a bearing tree often enough at young survey corners to evaluate its historic ecological behavior in the post-fire years. Small-diameter red maple regeneration appears at low, but measurable amounts in the 20- and 30-year age classes and peaks in the 40- and 50-year age classes **(PLS-5)**. Our interpretation is that the initial small-diameter trees were advance regeneration in older forests that were missed by stand regenerating fire. We believe that the peak of recruiting red maple was the result of successful establishment under self-thinning aspen.

Transition: 55-95 years

As stands entered the transition period red maple abundance peaks at 2% relative abundance in the 40- and 50-year age-classes **(PLS-2)**. This short-lived peak is the main evidence that red maple was a ***mid-successional*** tree – able to replace initial-cohort trees and declining in abundance in later growth-stages. Small-diameter red maple regeneration coming in among larger trees had its peak abundance in the 40-50 year age-classes as well **(PLS-5)**. At this time red maples were always the smallest tree at survey corners, which is typical of a species colonizing a site well after the stand-regenerating event. Though the sample size is small, it seems that small-diameter red maples could come in under about any other species including, red pine, white pine, red oak, or paper birch. Our interpretation is that red maple was able to seed into young, self-thinning FDc34 stands and that it enjoyed limited success recruiting to tree status as the initial-cohort canopy achieved greater height. That is, red maple took on the role of a subcanopy tree as it was living among species that were too intolerant to do so.

Mature, Second Transition, and Very Old Growth-stages: 95-135 years, 135-175 years, and older

By the close of the first transition red maple was a minor component of FDc34 forests and had little influence on stand dynamics. The relative abundance of red maple was stable during these periods at about 1-2% **(PLS/FIA-1)**. Small-diameter red maple regeneration was not detected during the in these later growth-stages **(PLS-5)**. At this time, red maples were always the smaller tree at survey corners. We interpret this as red maple having limited success recruiting advance regeneration, though no red maple bearing trees met our half-diameter rule for **Table PLS-5**. Red maple's excellent performance in regenerating strata in modern forests supports the idea that red maple could maintain modest presence in older stands through regeneration and recruitment **(R-**

2)**. When red maple was the smaller tree at a survey corner, there was a tendency for the larger trees to be red or white pine. Our best guess is that red maple had limited success in patches of old forest missed by surface fires.

Regeneration Strategies
Red maple's primary regenerative strategy on FDc34 sites is to fill ***small-gaps***. Be believe that it was most successful at this by establishing seedlings under self-thinning aspen and recruiting into gaps as the initial-cohort aspen started to die. In the historic PLS data the small-gap strategy of red maple is supported by: (1) the fact that red maple first appears as only small diameter trees preceding the decline of the initial-cohort canopy, and (2) it has peak abundance in mature, undisturbed forest **(PLS-3)**. The FIA data show red maple to be especially successful as seedlings below a remote canopy, which is typical of small-gap strategists (situation 13, **FIA-1**). The releve sampling also supports the idea that red maple is a small-gap strategist. Red maple's regeneration indices (4.7-4.8) are excellent and in line with small-gap strategists that are good at banking seedlings under a canopy **(R-2)**.

Red maple also shows some behavior typical of trees that need ***large-gaps*** to for recruitment. In the PLS data it didn't recruit to tree-sized individuals until the breakup of the aspen canopy at about age 40-60 years. In the FIA data, it is well represented as poles beneath a tree canopy (situation 23), which is usually a trait of trees needing larger gaps. In the mature forests that we sampled by releves, the tree index is lower than that of the regenerating layers, meaning that it has some troubles recruiting to heights over 33 feet **(R-2)**. Our best guess is that red maple is highly successful at establishment under low light conditions, but recruitment to tree-sized individuals may require an opening larger than the 1-few tree gaps that we associate with small-gap strategists.

Historic Change in Abundance
Populations of red maple have been expanding in Minnesota. Red maple abundance has at least doubled since pre-settlement times and is most evident in the young and mature growth-stages of FDc34 forests where it has increased from about 1% relative abundance to 8% of the trees today **(PLS/FIA-1)**. Our interpretation is that this is the consequence of fire-suppression, in particular the lack of surface fires that periodically "cleansed" FDc34 stands of maple regeneration. Logging doesn't eradicate maple as did fire, and modern regeneration harvests simply release advance regeneration of red maple. An amazing fact is that 95% of all the red maple references in the FIA data were in regenerating situations (not situation 33, **FIA-1**). The abnormal abundance of red maple on some FDc34 sites may be a hindrance to managing these sites for the large-gap and open regeneration strategists that were more common historically.

Bur Oak

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

Identification Problems

The PLS surveyors did not distinguish between bur and white oak. Most of the range of FDc34 is northwest of the range of white oak, and there were no occurrences of white oak in a releve classified ad FDc34. Thus, it seems safe to assume that all mention of white oak in the PLS data assigned to the FDc34 community were referencing bur oak.

Suitability

FDc34 sites provide ***good habitat*** for bur oak trees. The ***suitability rating*** of 3.8 for bur oak is influenced mostly by its presence (24%) as trees on these sites in modern forests **(R-1)**. When present bur oak is a minor co-dominant, contributing 12% mean cover when present. This ranking is seventh among the common trees on FDc34 sites. Except for FDc12, central fire-dependent communities offer good-to-excellent habitat for bur oak (see Suitability Tables).

Young Growth-stage: 0-55 years

Historically, bur oak was infrequent in young FDc34 stands **(PLS/FIA-1, PLS-2)**. Young bur oaks represented just 2% of the trees at survey corners described as burned, well behind pine, red oak, and aspen **(PLS-3)**. Also, bur oaks were nearly absent (1%) at windthrown corners. Our interpretation is that these few young oaks were stump sprouts among aspen suckers and dense pine regeneration on burned lands. Bur oak bearing trees were not recorded as small-diameter regeneration until the 50-year age-class in the post-disturbance window **(PLS-5)**, suggesting that opportunities for seedling establishment were not associated with stand-regenerating disturbance.

Transition: 55-95 years

As stands transitioned to mature conditions bur oak increased in abundance, peaking at about 4% relative abundance in the 70- and 80-year age classes **(PLS-2)**. Because they were nearly absent in young forests, we interpret this increase to be the consequence of limited success of establishment and recruitment in young FDc34 stands. Although peak recruitment was in the 50-year age-class, small-diameter regeneration was consistently present only during the transition until the 80-year age-class **(PLS-5)**. Apparently large-gaps in the canopy of declining aspen and jack pine provided the right habitat for establishing some seed-origin bur oaks.

Mature, Second Transition, and Very Old Growth-stages: 95-135 years, 135-175 years, and older

By the close of the first transition bur oak was a minor component of FDc34 forests and had little influence on stand dynamics. The relative abundance of bur oak was stable during these periods at about 1-2% **(PLS/FIA-1, PLS-2)**. Small-diameter bur oak regeneration was not detected beyond the 80-year age-class of the transition **(PLS-5)**. Bur oak was the smallest diameter bearing tree at older survey corners, and it was always mixed with other species. Apparently, bur oak was able to establish and recruit enough seedlings during the transition in order to persist in the older growth stages. In modern forests, bur oak has fair-to-good ability to establish and recruit seedlings in the understory **(R-2)**.

Regeneration Strategy

The primary regenerative strategy of bur oak on FDc34 sites to fill ***large-gaps***. It was most successful at this when gaps formed under a declining canopy of initial-cohort quaking aspen. In the historic PLS data this interpretation is supported by: (1) bur oak's peak abundance in response to the decline of the initial-cohort species, (2) the tendency of bur oak to be comparatively important at survey corners showing partial canopy loss **(PLS-3)**, and (3) the consistent presence of small-diameter bur oak regeneration in the G-1 window **(PLS-5)**. The percentage of bur oak poles under trees (situation 23, 13%) in the FIA data **(FIA-1)** is suggestive of a large-gap strategy; however its 14% abundance as saplings in sapling stands suggests that it is adept in the open as well. Bur oak's regeneration indices (2.8-3.2) under the canopy in modern forests are most in line with large-gap species **(R-2)**.

Historic Change in Abundance

The modern abundance of bur oak seems amazingly higher than in historic times on FDc34 sites **(PLS/FIA-1)**. This is evident, only in the mature growth-stage where FIA plots suggest that a quarter of all trees are bur oak in comparison to just 1% historically. The big departure from abundances comparable to bearing trees are in the 90-120 year age classes of the FIA data. There are just 525 trees total in these FIA age-classes, which is a low sample number but not so low as to attribute the increase to chance alone. Red oak also shows substantially greater abundance in the mature growth-stage in modern forests. It seems possible that historically, chronic surface fires resulted in the oaks adopting their "grub" growth-form and were unattractive as bearing trees. After nearly a century of fire protection, some of these stems may have finally achieved enough diameter to be included by prism on the FIA subplots. The frequency of oak trees in releves **(R-1)**, and especially their frequency in the understory **(R-2)** seems to corroborate the FIA perception of oaks being frequent in today's mature FDc34 forests.

Jack Pine

- ***good habitat suitability rating***
- ***early successional***
- ***open regeneration strategist***
- ***regeneration window at 0-50 years***

Suitability

FDc34 sites provide ***good habitat*** for jack pine trees. The ***suitability rating*** of 3.2 for jack pine is influenced mostly by its presence (17%) as trees on these sites in modern forests **(R-1)**. When present, jack pine can be an important tree, contributing 14% mean cover in mature stands. The ranking is ninth among trees common on FDc34 sites. Central fire-dependent forests in general offer excellent habitat for jack pine trees (see Suitability Tables). Among these communities, FDc34 is the poorest choice for jack pine because jack pine is more competitive under drier conditions.

Young Growth-stage: 0-55 years

Historically, jack pine was a common tree in young FDc34 stands recovering mostly from stand-replacing fire **(PLS-1, PLS-2)**. Young jack pines represented 12% of the trees at survey corners described as burned, which is less than the response of red pine, white pine, or aspen. Jack pine was less likely to pioneer on sites affected by windthrow, representing just 6% of the trees present following that disturbance. Jack pine's peak abundance in the young growth-stage and its good abundance following fire is why we consider it to be an ***early successional*** species on FDc34 sites. Amazingly, all jack pine bearing trees occurred at FDc34 corners in mixture with other species such as quaking aspen, red pine, or white pine. In other FDc and FDn communities, it is more common for young jack pine to occur in monoculture. Small-diameter jack pine regeneration coming in among larger trees was abundant throughout the young growth-stage **(PLS-5)**. This too is unusual in that the reaction of jack pine in other FDc and FDn communities seems to be a more punctuated response to stand-replacing fire with the initial age-class showing the most regeneration. Recruitment of jack pine into young FDc34 forests was steady and persistent, and occurred beneath larger jack pine, aspen, and red pine. Our interpretation is that post-disturbance stocking in FDc communities is just a slower process than we expect in FDn communities. It is possible that most jack pine establishment was soon after the fire, but recruitment seemed slow in contrast to the growth of suckering aspen. It is probably significant that the jack pines typical of FDc communities tend to have open cones and are sexually mature and a young age. Thus, they are able to continue to fill growing space as these stands slowly stocked after catastrophic fires.

Transition: 55-95 years

Natural succession, or transitioning of young FDc34 forests was driven in part by the loss of initial-cohort jack pine **(PLS-1)**. Obscured by the growth-stage averaging in Table PLS-1 is the fact that jack pine reached peak abundance in the 50-year age class at about 20%, followed by a sharp decline to under 10% in the 70-year age class **(PLS-2)**. The jack pine establishment window lasted only until about age 60 **(PLS-5)**, meaning that we did not detect significant establishment or recruitment in transitioning FDc34 forests and suspect that second cohorts of jack pine could not develop without canopy-removing disturbance. When jack pines were the smaller diameter trees at survey corners, they were almost exclusively beneath larger jack pines or red pines. Our interpretation is that recruitment early in the transition was limited to situations where the overstory trees cast little shade. This idea is supported by our data from modern forests, where jack pine has almost no ability to establish or recruit seedlings beneath a canopy **(R-2)**.

Mature Growth-stage: 95-135 years

Modest regeneration and recruitment in the transition carried some jack pine into the mature growth-stage **(PLS-1)**. Beyond the close of the mature growth-stage, jack pine abundance was below 2% and would not recover in older growth-stages. Small-diameter jack pine regeneration was not detected in this period **(PLS-5)**. When jack pines were the smaller trees at a survey corner, they were almost entirely beneath red pine (89%). Our interpretation is that jack pines lived longer when overtopped by trees like red pine that don't cast a lot of shade, and that old jack pines tended to die when overtopped by white pine or hardwoods.

Second Transition, and Very Old Growth-stages: 135-175 years, and older
By the close of the mature growth-stage jack pine was a minor component of FDc34 forests and had little influence on stand dynamics. The relative abundance of jack pine was stable during these periods at about 1-2% **(PLS-1)**. Small-diameter jack pine regeneration was not detected in these old forests **(PLS-5)**. There were too few jack pine bearing trees in these old forests to draw any conclusions about behavior. Our interpretation is that surface fires eventually winnowed the thin-barked jack pine from stands and left the more fire-resistant red and white pines. In stands that achieved old age it would seem that when catastrophically burned, jack pine regeneration would have to come from nearby patches of younger forest.

Regeneration Strategy
Jack pine's primary regenerative strategy on FDc34 sites is to establish in ***open habitat*** after stand-regenerating fire. In the historic PLS data this interpretation is supported by: (1) the fact that jack pine's peak abundance is in the young growth-stage **(PLS-1)**, (2) jack pine was most abundant after catastrophic fire **(PLS-3)**, and (3) jack pine's peak regeneration was in the post-disturbance window with it's absolute peak being the initial age-class **(PLS-5, PLS-2)**. 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)**.

Historic Change in Abundance
Today, jack pine is nearly absent from FDc34 sites where it was historically important **(PLS-FIA-1)**. Most noticeable is the near absence of young jack pine forests where historically jack pine accounted for 11% of the regenerating trees. The results are similar for mature FDc34 forests where jack pine now accounts for just 1% of the trees compared to the historic condition of 9%. No FDc34 forests were estimated to be older than 135 years for comparison. We believe that the loss of jack pine is a consequence of regenerating most FDc34 stands by logging and artificial regeneration rather than fire. Conversion to red pine is not an issue, as red pine too is absent from young FDc34 forests. Quaking aspen is the obvious benefactor of the decline of both jack and red pine, which suggests that some FDc34 sites are being coppiced for aspen and likely, some plantations fail because of aspen competition without fire. Jack pine is in peril on FDc34 sites and restoration efforts are warranted.

(PLS-1) Historic Abundance of FDc34 Trees in Natural Growth-stages

Table values are relative abundance (%) of Public Land Survey (PLS) bearing trees at corners modeled to represent the FDc34 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.

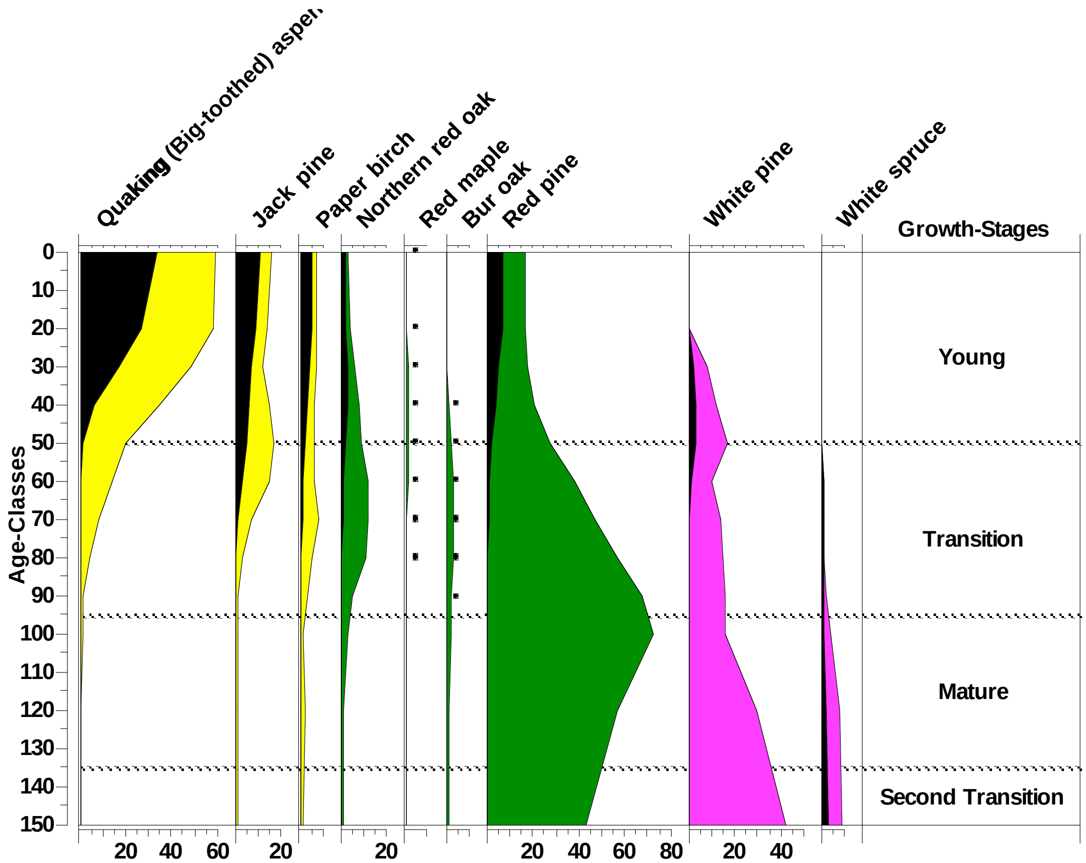
Dominant Trees	**Forest Growth Stages in Years**				
	0 - 55	**55 - 95**	**95 - 135**	**135 - 175**	**> 175**
	Young	**T1**	**Mature**	**T2**	**Very Old**
Quaking (Bigtooth) Aspen[1]	**31%**	| |	**5%**	⌉	**7%**
Jack Pine	**11%**	|	**9%**	| |	**1%**
Red Oak	**7%**	|	**3%**	⌉	**4%**
Paper Birch	**6%**	|	**4%**	⌉	**6%**
Red Pine	**25%**	⌉⌉	**50%**	| |	**15%**
White Spruce	**1%**	⌉	**3%**	/	**3%**
White Pine	**14%**	⌉	**22%**	⌉⌉	**54%**
Miscellaneous	**5%**	|	**4%**	⌉	**10%**
Percent of Community in Growth Stage in Presettlement Landscape	**47%**	**31%**	**13%**	**3%**	**6%**

1. The PLS surveyors did not consistently distinguish the more prevalent quaking aspen from big-toothed aspen on FDc34 sites.

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

(PLS-2) Abundance of trees throughout succession in FDc34

Graphed for the individual species of FDc34 trees is their relative abundance (%) as PLS bearing trees by age class. Species with good-to-excellent suitability have graphs colored as follows: early successional (yellow); mid-successional (green); late-successional (magenta). The data were smoothed from adjacent classes (3-sample moving average). Not shown is the very old growth-stage because of sparse data (see PLS-1). Black insets show the proportion of bearing trees that were small-diameter trees that were presumably recruiting to bearing tree size (~4" dbh, see PLS-5). For infrequent trees, the presence of small-diameter trees is indicated by black dots rather than insets.



FDc34, J.C. Almendinger, April 2008

See linked text on brief methods and silvicultural application for Table PLS-2, file NPC Figures and Tables

(PLS-3) Historic Abundance of FDc34 Trees Following Disturbance

Table values are raw counts and (percentage) of Public Land Survey (PLS) bearing trees at survey corners likely to represent FDc34 forests. The columns represent our interpretation of disturbance at the survey corners. Trees in parentheses are minor species that occur in modern forests but couldn't be separated from more common trees because the surveyors did not distinguish them in their field notes. Shading associates trees that peak in the same disturbance category.

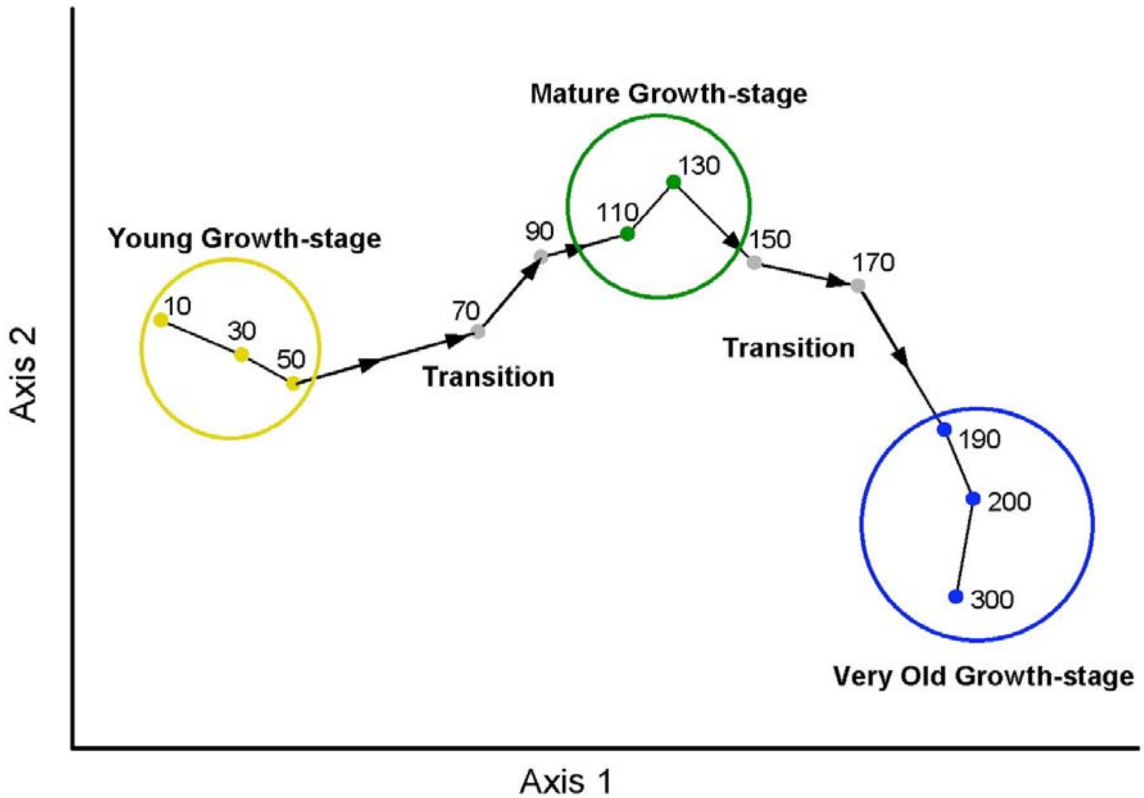
Tree	Burned		Windthrown		Maintenance		Mature	
Jack pine	158	12%	7	6%	224	12%	695	9%
Northern red oak	134	10%	2	2%	149	8%	523	7%
Bur oak	30	2%	1	1%	40	2%	95	1%
White pine	187	15%	30	26%	300	16%	1560	21%
Quaking (Bigtooth) aspen[1]	281	22%	29	25%	388	21%	1317	18%
Basswood	5	0%	1	1%	1	0%	29	0%
Red pine	456	36%	38	33%	674	37%	2711	36%
Paper birch	30	2%	6	5%	54	3%	491	7%
Red maple	1	0%	0	0%	1	0%	105	1%
Total (% of grand total, 10753)	1282	12%	114	1%	1831	17%	7526	70%

1. The PLS surveyors did not consistently distinguish the more prevalent quaking aspen from big-toothed aspen on FDc34 sites.

See linked text on brief methods and silvicultural application for Table PLS-3, file NPC Figures and Tables

(PLS-4) Ordination of Historic FDc34 Age-classes

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



See linked text on brief methods and silvicultural application for Table PLS-1, file NPC Figures and Tables

(PLS-5) Historic Windows of Recruitment for FDc34 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 90-130 years	G-2 130-170 years	I-2 >170 years
Yes	Quaking aspen[1]	0-30	Excellent	Poor to 60	--	--	--
Yes	Red pine	0-30	Good	Fair to 60	--	--	--
Yes	White pine	0-40	Good	Poor to 60	--	--	--
Yes	Paper birch	0-40	Good	Fair	Poor to 100		
Minor	Basswood	0-40	Poor	Poor to 60	--	--	--
Yes	Big-toothed aspen	0-30	Fair	Poor to 80	--	--	--
Yes	Jack pine	0-50	Excellent	Poor to 60	--	--	--
Yes	Northern red oak	30-40	Good	Fair to 70	--	--	--
No	Red maple	40-50	Fair	Poor to 70	--	--	--
No	Bur oak	50	Fair	Poor to 80	--	--	--

Recruitment windows from ordination PLS-4:

- **P-D:** post-disturbance filling of understocked areas, 10-50 years
- **G-1:** gap filling during decline of initial-cohort quaking aspen, red pine, jack pine, and white pine, 50-90 years
- **I-1:** ingress of seedlings under canopy of red pine and white pine, with some decadent jack pine, 90-130 years
- **G-2:** gap filling during decline of red pine and very old jack pine, 120-170 years
- **I-2:** ingress of seedlings under a canopy of white pine and red pine

-- : 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 bigtooth aspen in the PLS notes for this community. The quaking aspen data probably include some bigtooth aspen, which we consider ecologically similar to quaking aspen.

See linked text on brief methods and silvicultural application for Table PLS-5, file NPC Figures and Tables

(R-1) Suitability Ratings of Trees on FDc34 Sites

This table presents an index of suitability for trees in FDc34 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 FDc34

Tree	Percent Presence as Tree	Mean Percent Cover When Present	Suitability Index*
Red pine (Pinus resinosa)	52	37	4.9
White pine (Pinus strobus)	47	32	4.9
Quaking aspen (Populus tremuloides)	36	23	4.7
Northern red oak (Quercus rubra)	36	22	4.6
Paper birch (Betula papyrifera)	43	15	4.5
Red maple (Acer rubrum)	33	14	4.3
Bur oak (Quercus macrocarpa)	24	12	3.8
Big-toothed aspen (Populus grandidentata)	14	14	3.3
Jack pine (Pinus banksiana)	17	10	3.2
Basswood (Tilia americana)	9	10	2.2

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

See linked text on brief methods and silvicultural application for Table R-1, file NPC Figures and Tables

(R-2) Natural Regeneration and Recruitment of Trees in Mature FDc34 Stands

This table presents an index of regeneration for FDc34 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 FDc34 communities. Changes in the index values from one stratum to another can be used to estimate regenerative bottlenecks, whether establishment (R-index) or recruitment (SE-, SA-, or T-indices).

Natural regeneration indices for regenerants, seedlings, saplings, and trees common in the canopy of Central Dry-Mesic Pine-Hardwood Forest – FDc34					
Trees in understory	**% presence R, SE, SA**	**R-index**	**SE-index**	**SA-index**	**T-index**
Red maple (Acer rubrum)	**79**	**4.8**	**4.8**	**4.7**	**3.8**
Northern red oak (Quercus rubra)	**62**	**3.5**	**3.5**	**3.8**	**4.3**
Bur oak (Quercus macrocarpa)	**57**	**3.2**	**2.8**	**3.2**	**3.3**
Paper birch (Betula papyrifera)	**52**	**2.0**	**2.0**	**3.7**	**4.3**
Quaking aspen (Populus	**47**	**3.8**	**3.7**	**3.0**	**4.5**
White pine (Pinus strobus)	**41**	**3.8**	**3.3**	**3.5**	**4.8**
Basswood (Tilia americana)	**24**	**1.5**	**2.0**	**2.5**	**2.5**
Big-toothed aspen (Populus	**12**	**1.7**	**1.7**	**2.8**	**3.5**
Red pine (Pinus resinosa)	**9**	**0.3**	**0.7**	**1.5**	**4.8**
Jack pine (Pinus banksiana)	**1**	**0.3**	**0.3**	**0.3**	**3.8**

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

% presence: the percent of 58 FDc34 sample plots with that species present under 10m tall (R, SE, SA layers)
R-index: index of representation as true seedling or under 10cm tall
SE-index: index of representation as seedlings under 2m tall
SA-index: index of representation as saplings 2- 10m tall
T-index: index of representation as a tree >10m tall
All indexes: equally weight (1) presence, (2) mean cover-when-present, and (3) mean number of reported strata, the frequency distributions of which are segmented equally by area into 5 classes.

See linked text on brief methods and silvicultural application for Table R-2, file NPC Figures and Tables

(FIA-1) Structural Situations of Trees in Mature FDc34 Stands

This table presents percentages of structural situations for trees as recorded in Forest Inventory Analysis (FIA) subplots that we modeled to be samples FDc34 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
Red maple	293	7%	14%	16%	28%	31%	5%
Northern red oak	67	0%	30%	13%	10%	9%	37%
Paper birch	311	6%	36%	11%	20%	10%	17%
White pine	12	0%	17%	25%	8%	8%	42%
Bur oak	64	14%	27%	11%	13%	0%	36%
Quaking aspen	1998	45%	12%	14%	5%	12%	12%
Big-toothed aspen	26	54%	0%	19%	12%	4%	12%
Basswood	16	38%	25%	13%	6%	0%	19%
Red pine	8	0%	75%	0%	0%	0%	25%
Jack pine	4	0%	0%	0%	0%	0%	100%

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

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

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

See linked text on brief methods and silvicultural application for Table FIA-1, file NPC Figures and Tables

(PLS/FIA-1) Abundance of FDc34 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 FDc34 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 - 95		95 - 135		135~ 175		> 175	
	Young		T1		Mature		T2		Old	
Quaking Aspen (incl. Bigtooth)	31%	71%	| |		5%	29%	⌉		7%	0%
Jack Pine	11%	1%	|		9%	1%	| |		1%	0%
Red Oak	7%	2%	|		3%	12%	⌉		4%	0%
Red Pine	25%	0%	⌉⌉		50%	10%	| |		15%	0%
Paper Birch	6%	10%	|		4%	7%	⌉		6%	0%
White Spruce	1%	0%	⌉		3%	1%	)		3%	0%
White Pine	14%	0%	⌉		22%	2%	⌉⌉		54%	0%
Red Maple	1%	8%			1%	8%			2%	0%
Bur Oak	1%	2%			1%	25%			2%	0%
Miscellaneous	3%	6%			2%	5%			6%	0%
Percent of Community in Growth Stage in Presettlement and Modern Landscapes	47%	58%	31%	40%	13%	2%	3%	0%	6%	0%

Natural growth-stage analysis and landscape summary of historic conditions is based upon the analysis of 4,684 Public Land Survey records for section and quarter-section corners. Comparable modern conditions were summarized from 1,969 FIA subplots that were modeled to be FDc34 sites.

See linked text on brief methods and silvicultural application for Table PLS/FIA-1, file NPC Figures and Tables

Forest Health Considerations

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.

White Pine

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

WATCHOUTS!

• Protect seedlings and saplings from browse damage.

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

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

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

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

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

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.

Bigtooth Aspen

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

WATCHOUTS!

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

• Harvest during the winter to ensure adequate regeneration.

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

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

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.

Paper Birch

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

WATCHOUTS!

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

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

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

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

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

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

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

Red Maple

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

WATCHOUTS!

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

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

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.

FDc34 - Acceptable Operating Seasons 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 FDc34 that are more susceptible to compaction and rutting. They are listed in descending order of presence.

Mountain maple (*Acer spicatum*)
American elm (U) (*Ulmus americana*)
Virginia creeper (*Parthenocissus spp.*)
Lady fern (*Athyrium filix-femina*)
Alpine enchanter's nightshade (*Circaea alpina*)
Black ash (U) (*Fraxinus nigra*)
Side-flowering aster (*Aster lateriflorus*)
Graceful sedge (*Carex gracillima*)
Aniseroot (*Osmorhiza longistylis*)

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

Foot Notes

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

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

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

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

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

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

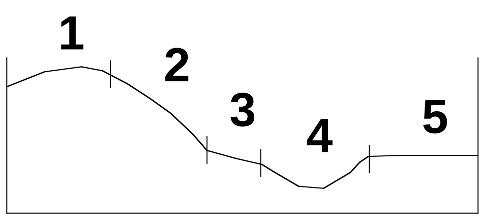
   Poor – water saturation occurs within 10 inches of the surface for most of the growing season

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

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

4. Landscape Position

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



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

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

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

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

   W Winter – the ground is snow covered or partially frozen

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

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

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

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

Public Land Survey

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

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

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

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

Modern Forest

Releve Samples

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

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

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

For more information on the releve method and NPC Classification:

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

FIA Samples

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

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

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

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

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

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

Link to the USFS website, north central