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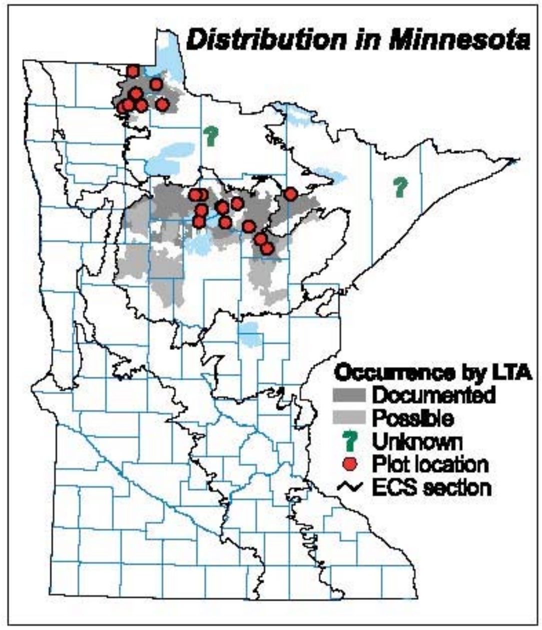
FDn12 – Dry-Sand Pine Woodland

Natural Disturbance Regime, Stand Dynamics, and Tree Behavior

Introduction and Management Highlights

Northern Dry-Sand Pine Woodlands (FDn12) are an occasional fire-dependent community found mostly within the Northern Minnesota Drift and Lake Plain and Northern Minnesota and Ontario Peatlands ecological Sections of Minnesota. Detailed descriptions of this community are presented in the DNR Field Guides to Native Plant Communities of Minnesota.



The range of FDn12 woodlands in Minnesota (shaded) and distribution of releve samples (red dots).

Commercial Trees

As a commercial forest, FDn12 sites offer a limited selection of crop trees and possible structural conditions. Jack and red pine are the only trees ranked as excellent choices as crop trees by virtue of their frequent occurrence and high cover when present on FDn12 sites (see Suitability Tables). Quaking aspen, white spruce, and balsam fir are ranked as good crop trees, and stands can be managed to perpetuate these trees as co-dominants, especially when present or with evidence of former presence (e.g. stumps) in a particular stand.

Among these species, jack pine, red pine, and white spruce were the dominant native trees that have occupied FDn12 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)**. Quaking aspen was also native to FDn12 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 aspen and balsam fir than was usual. Past history and land use as also encouraged the ingress of species that were not significant in native MHn35 stands such as bur and red oak. The increased abundance of quaking aspen and balsam fir complicates our interpretations and the use of natural regeneration models as silvicultural strategies.

Natural Silvicultural Approaches

In the historic landscape, most FDn12 stands (61%) 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 FDn12 sites. Jack pine, red pine, and quaking aspen are all considered open regeneration strategists on FDn12 sites and should respond positively to these management strategies.

About 17% of the native landscape was occupied by transitioning FDn12 woodlands between 55 and 75 years old **(PLS-1)**. At this time, senescence of initial-cohort jack pines created regeneration and recruitment opportunities for trees in single- and multiple-tree gaps. We believe that most of the transition was accomplished by the death of initial-cohort jack pines and release of initial-cohort red pines. The corresponding silvicultural practice is selective thinning of jack pine assuming adequate abundance of red pine to release. The major regenerative event during the transition was the ingress of white spruce and some balsam fir in gaps. According to our interpretation (see Tree Behavior), balsam fir would respond more positively to larger gaps that could be approximated with variants of shelterwooding. White spruce should respond more positively to smaller gaps approximated by variants of selective harvesting. Both species should respond to the strategy of group selection and release above advance regeneration or plantings.

Just about 22% of the FDn12 landscape was mature and very old woodland estimated to be over 75 years of age **(PLS-1)**. Our vision of these older woodlands is that the canopy was dominated by red pines that were reasonably young and able hold the site for perhaps another 100 years barring any catastrophic disturbance. The dynamics of mature and very old FDn12 woodlands was in the understory, and there seem to be two divergent successions. Older FDn12 stands affected by surface fires on a rotation of about 50 years pushed stands towards pine dominance and multi-cohort structures. Our analysis of the behavior of jack and red pine on these sites (see Tree Behavior) suggests that these species need rather open conditions to establish cohorts and recruit to tree heights. Thus partial harvesting strategies like patch cutting and variants of seed-tree harvests would best match the strategy of maintaining older FDn12 stands as surface fires once did. The alternative succession to mixed pine and spruce woodlands most likely happened in patches of FDn12 habitat that escaped surface fires. Gaps in the pine canopy, both large and small, provided the opportunity for white spruce establishment and recruitment. Variants of shelterwooding and group selection would approximate the level of canopy opening that favored white spruce.

Management Concerns

Most FDn12 communities occur on level, coarse-textured sand and gravel of outwash plains. In these situations, there is little concern of soil-compaction. Only when the soil surface is saturated and above frost is there a chance of rutting. It is also common to find the FDn12 community on the sandy, shallow-water deposits of glacial lakes, particularly in the Northern Minnesota & Ontario Peatlands ecological Section of the state. When dry, there is little risk of compaction on these lake deposits because the size of the sand grains is very uniform. Because these sands tend to be fine and are often layered, they hold soil water longer than outwash. Also, the glacial-lake landscape has high water tables. Both of these situations delay soil drainage, and drying times to avoid rutting are longer in the spring and following summer rains than on outwash. Occasionally FDn12 communities occur on sandy inclusions of stagnation moraines. In our experience, these are just local deposits of outwash with the same, low potential for compaction and rutting.

The landscape balance of growth-stages and stand ages for the FDn12 community is not much different than it was historically **(PLS/FIA-1)**. Compositional changes are more of a concern. Most obvious is the replacement of jack and red pine with quaking aspen. Clones of aspen now occur on some FDn12 sites where it once only seeded in after severe fires. Aspen's aggressive vegetative response to logging on these sites complicates strategies for managing pine without some control of the aspen suckers. Balsam fir has also made significant gains in these woodlands because of fire suppression. The presence of understory fir diminishes silvicultural strategies aimed at creating second-cohorts of pine, and it adds greatly to fire risk. The quality of both aspen and fir in FDn12 woodlands is poor. Treatments designed to increase pine and diminish quaking aspen and balsam fir, e.g. prescribed burning, would most likely increase the commercial value of FDn12 sites and improve ecological function.

Natural Disturbance Regime

Natural rotation of catastrophic and maintenance disturbances were calculated from Public Land Survey (PLS) records at 2,341 corners within the primary range of the FDn12 community. At these corners, there were 5,913 bearing trees comprising the species that one commonly finds in FDn12 woodlands.

The PLS field notes described about 9% of the FDn12 landscape as recovering from stand-regenerating fire. Nearly all such records were of burned-over lands with some references to scattered pine timber, and post-fire thickets. From these data, a rotation of 170 years was calculated for stand-replacing fire.

Elsewhere in the FDn12 landscape, the surveyors described lands as windthrown lacking suitable-sized trees for scribing. Such corners were encountered at about 2% of the time, yielding an estimated rotation of 610 years for windthrow.

Far more common at FDn12 sites were references to what we have interpreted as some kind of partial canopy loss, without any explicit mention of fire or windthrow. Most references were to sparse forest or scattered pine timber with distances to bearing trees that were intermediate between the distances for burned/windthrown lands and what is typical for fully stocked pine woodlands. About 9% of the survey corners were described as such, resulting in a calculated rotation of 50 years for disturbances that maintained early and mid-successional trees on FDn12 sites. That more corners were described as burned (130) compared to windthrown (57) suggests that surface fires were the more prevalent cause of partial canopy loss.

Natural Rotations of Disturbance in FDn12 Forests Graphic	
	Banner text over photo
Catastrophic fire photograph	**170 years**
Catastrophic windthrow photograph	**610 years**
Partial Canopy Loss, photograph	**50 years**

Compared to other northern fire-dependent communities (FDn), FDn12 rotations of stand-regenerating disturbances are similar in that the fire rotation exceeds the longevity of most initial cohort species and windthrow was unimportant. Natural stand dynamics involved at least a couple of tree generations and succession of species. FDn12 shows the succession of jack to red to white pines commonly observed throughout northeastern Minnesota. Unlike other FDn communities, the rotation of 50 years for surface fire is extremely short and more similar to fire-dependent communities of the central floristic region (FDc). The obvious connection between FDn12 and FDc communities is their affinity for deep, sandy, somewhat excessively drained soils, in flat landscapes. These conditions must have promoted surface fire more so than the till-derived soils and rugged topography where we find the other FDn communities. Surface fires were apparently effective in maintaining pine and early-successional hardwoods as there is little evidence that FDn12 sites ever escaped disturbance long enough for shade-tolerant species to exert dominance.

Natural Stand Dynamics & Growth-stages

Following stand-regenerating fire or very rarely windstorms, the overall pattern of compositional change in FDn12 communities is for lots if initial change, which then decelerates as the stand becomes older **(PLS-4)**. This pattern is common for communities where fire favors a few pioneer species and is capable of eliminating late-successional species sensitive to fire. For FDn12, jack pine, red pine, and quaking aspen are the species that benefit greatly from fire because they compete poorly with later-successional species under a canopy. Balsam fir and white spruce were the shade-tolerant species that were eliminated by fire, but gained importance during fire-free intervals. Because FDn12 sites were so prone to fire (see Natural Disturbance Regime) they rarely, if ever, achieved a mature state where most of the trees were late-successional species.

FDn12 sites are woodland because the absolute density of trees allows substantial sunlight to reach the forest floor and sustain sun-loving herbs and graminoids. However, its pattern of density change throughout the course of stand maturation is typical of forest where trees are more densely packed in young stands and spacing increases due to canopy competition and self-thinning. In young and transitioning FDn12 woodlands (<75 years) the mean distance of bearing trees to their corners was about 40 feet, substantially greater than the 20-foot mean distances common in true northern forests. In mature and very old FDn12 woodlands, the mean distance of bearing trees to their corners was 33-37 feet. This is still substantially lower tree density than in true forest, but considerably tighter that what is typical of central fire-dependent forests.

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

Young Growth-stage: approximately 0-55 years

About 61% of the FDn12 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 monotypic (61%) than mixed (39%), which is typical of fire-dependent communities like FDn12 that occur on flat landforms. Monotypic conditions were most often represented by survey corners where all bearing trees were jack pine. Red pine and quaking aspen where the other trees to sometimes occur as the only species at a survey corner. At survey corners with mixed composition, jack pine was still the most cited species, and it was usually mixed with red pine, quaking aspen, and sometimes paper birch.

Fire was by far the most likely event to create a young FDn12 forest. Nearly all of the survey corners described as burned were attended by jack or red pine, which together accounted for 96% of the trees in recovering stands **(PLS-3)**. Fire-sensitive species like balsam fir and white spruce were nearly absent. For this reason, we believe that fires on FDn12 sites were intense, and effective at eliminating shade-tolerant conifers. Young stands recovering from windthrow were negligible and wind had no differential effect on composition in comparison to fire that can't be attributed to chance.

The ability of jack and red pine to dominate young FDn12 forests is a consequence of their persistence in the mature and old growth-stages. Both species have just fair ability to establish seedlings under a canopy **(R-2)** and cannot maintain their local populations without some disturbance. We believe that surface fires promoted successive cohorts of these pines, leaving enough trees that the surveyors would not have described them as catastrophically burned. Both red and jack pine responded very well to maintenance-scale disturbances (PLS-3). Quaking aspen maintained a small presence in older forests as well, yet it showed almost no change in relative abundance following disturbance. The poor performance of quaking aspen in young FDn12 forests suggests to us that aspen did not naturally have extensive clones on FDn12 sites and that it was a poorer competitor than the pines at seeding-in on burned, sandy sites.

Transitional Stage: approximately 55-75 years
About 17% of the historic FDn12 landscape was forest undergoing considerable compositional change as stands approached maturity (PLS-1). Stands in this stage were more often mixed (65%) than monotypic (35%). Monotypic conditions were represented mostly by survey corners where all bearing trees were jack pine, and much less often by red pine. Mixed conditions were most often corners with jack and red pine at about equal abundance. Quaking aspen and paper birch were the most frequently referenced deciduous trees to occur with the pines.

The transition stage is driven almost entirely by the behavior of jack and red pine. Initial-cohort jack pines decline throughout the period (PLS-1, PLS-2). Jack pine's relative abundance plummets from 69% in age-class 50 to just 13% in age-class 80. The 56% fall in jack pine abundance is mirrored by a 42% rise in red pine over the same age-classes. Because the sum of jack and red pine abundance is rather constant throughout the transition stage, and because red pine does not show especially good regeneration beyond the 50-year age-class (PLS-5), we believe that this transition had more to do with differential mortality than replacement by regeneration. That is, we believe that young FDn12 forests were fully stocked with jack and red pine in the early post-disturbance years and had about as many established pines as the site could support. The transition stage matches the natural rotation of jack pine in this community, and the compositional change could be attributed to jack pines senescing and dying naturally while the longer-lived red pines remained. This idea though requires species able to regenerate in large-gaps left as the jack pines decline – here quaking aspen, paper birch, white pine, and white spruce – to not respond more strongly than red pine in filling available canopy space. In this case, these species responded to the decline of jack pine to the extent that it was measurable (PLS-1), but far less than we often observe when the declining canopy is quaking aspen. The alternative hypothesis is that 55-75 year-old jack and red pines could be differentially affected by some destructive agent. Because these pines share so many diseases and pests, we favor the idea that surface fires might have played a role in transitioning FDn12 sites from jack pine dominance to red pine. It is easy to envision creeping surface fires killing the thin-barked jack pines and leaving the thick-barked, fire-resistant red pines. This is confirmed by the common field observation that scarred trees in FDn12 forests are almost always the red pines. This idea though requires that 55-75 year-old stands be more susceptible to surface fires than younger and older stands. Apart from the vision of transitioning forests having lots of dead and down initial-cohort jack pines, there is no particular reason to believe that stand age was correlated with the probability of a surface fire. Most ecological research in the FDn12 region suggests that climatic events are far more related the frequency of wildfires than fuel conditions. Frequency though is not intensity, and it remains possible that downed jack pines provided fuel loads that were just right for a surface fire to kill the remainder of the jack pine cohort and leave red pines. We have concluded that the transition stage is initiated by the natural decline of initial-cohort jack pines and that FDn12 forests could depart on quite different successional paths at this stage depending upon whether they were or were not affected by surface fires.

Mature Growth-stage: approximately 75-195 years
About 20% of the historic FDn12 landscape was mature forest where the rate of successional change slowed considerably (PLS-4). Stands in this stage were more likely to be mixed (79%) than monotypic (21%). For the first time, it was far more likely for monotypic corners to be attended by all red pine than all jack pine. Most mixed corners were jack and red pine. Also important was white pine, paper birch, white spruce, and some quaking aspen.

The mature growth-stage of FDn12 forests represents an extended, mid-successional period. It is perceived as a stable episode mostly because the dominant, red pine, shows modest change in relative abundance **(PLS-2)**. We envision this as a time when the local populations of red pine were well-established and likely to live a full life in spite of events like surface fires. Considerable change was probably going on, but it occurred mostly in the understory. In general, this period marks the end of significant regeneration opportunities for most FDn12 trees and marks the beginning of significant white spruce regeneration starting in 70-year age-class and becoming quite good after 90 years **(PLS-5)**. Thus, stands able to avoid surface fire were probably developing understories enriched in white spruce and probably some balsam fir that would ultimately succeed the red pines. In other cases, white pines established in the 40-60 year age-classes were coming in among the older red pines. Here, succession to very old forest probably involved white pines outliving the initial-cohort red pines. More often though the mature red pines were subtended by second-cohort jack pines. The rotation of surface fires was estimated to be 50 years on FDn12 sites (see Natural Disturbance Regime). Few 75-195 year-old stands by chance were unaffected by surface fires. Such fires were pre-requisite for the persistence of jack pine, allowing them to so strongly dominate young FDn12 forests when catastrophic fires eventually occurred. We believe that apart from sharing a supercanopy of old red pines, mature FDn12 forests would have seemed quite different with regard to their mid-canopies and successional trajectories. Only fires truncated the succession. Most likely the stands enriched in spruce and fire were likely to catastrophically burn, and those more often affected by surface fires could rotate several cohorts of jack pine beneath the older red and white pines.

Very Old Growth-stage: approximately >195 years

Just 2% of the historic FDn12 landscape was very old forest **(PLS-1)**. Stands in this stage were more often mixed (95%) than monotypic (5%). Monotypic conditions were represented entirely by survey corners where all trees were red pine. Mixtures of red pine, jack pine, white pine, and white spruce were most common. There was some quaking aspen and paper birch in very old forests, but the trend for FDn12 forests is clearly towards total dominance of conifers.

On FDn12 sites, succession to white spruce as the ultimate climax tree is not at all certain. On richer and moister sites this is the logical conclusion, but FDn12 sites are poor and droughty. Virtually all of the very old survey corners were placed in this category due to very large-diameter white and red pine and not white spruce. We believe that red and white pines could hold FDn12 sites over white spruce until catastrophic fires ultimately rotated the entire FDn12 landscape.

Growth Stage Key

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

Young Forests	•
Transitional Forests	•
Mature Forests	•
Old Forests	•

Tree Behavior

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

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

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

To this end, we have performed analyses using Public Land Survey records, FIA subplots, and releves to answer three very basic questions as to how trees behave in their community context:

- Suitability – for each NPC Class, how often and in what abundance do we see certain tree species in stands where there has been no obvious effort to silviculturally alter abundance or remove competition?
- Succession – for each NPC Class, what was the natural reaction to fire and windthrow and how did the different species succeed one another?
- Regeneration strategies – for each common species within a NPC Class, what were/are the natural windows of opportunity for regeneration throughout the course of succession?

Jack Pine

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

Suitability

FDn12 sites provide ***excellent habitat*** for jack pine trees. The perfect ***suitability rating*** of 5.0 for jack pine is influenced mostly by its very high presence (83%) as trees on these sites in modern forests **(R-1)**. When present, jack pine is an important dominant tree, contributing 44% mean cover in mature stands. The ranking is perfect, because no other tree or plant has a higher presence and cover on FDn12 sites as sampled by releves. Northern fire-dependent forests in general offer fair-to-excellent habitat for jack pine trees (see Suitability Tables). Jack pine is favored on the poorer and drier communities, and FDn12 and FDn32 provide the best options for growing jack pine.

Young Growth-stage: 0-55 years

Historically, jack pine was the overwhelming dominant in young FDn12 stands recovering from any disturbance, but especially after fire **(PLS-1, PLS-2)**. Young jack pines represented 66% of the trees at survey corners described as burned, which is by far more than any other tree. Jack pine was also the leading species following windthrow, representing 62% of the trees at such survey corners. However, windthrow was a far less significant than fire in regenerating FDn12 forests. Jack pine's dominance in the young growth-stage and its leading abundance following fire and windthrow is why we consider it to be an ***early successional*** species on FDn12 sites. Half of all young FDn12 survey corners were attended by all jack pine; just 4% of the young survey corners were monotypic red pine. Small-diameter jack pine regeneration coming in among larger trees was abundant for the first 15 years **(PLS-5)**, and jack pine regeneration was common until about the 50-year age-class. Overwhelmingly, jack pine preferred to come in among other jack pines. We interpret this as jack pine showing excellent ability to establish seedlings in the post-fire years and to then effectively recruit into under-stocked areas of burned stands.

Transition: 55-75 years

Natural succession, or transitioning of young FDn12 forests was driven by the steady loss of initial-cohort jack pine leaving longer-lived red pine **(PLS-1)**. We estimate that this decline started at about age 60 and continued to about age 80 when jack pine abundance stabilized at about 20% relative abundance **(PLS-2)**. The jack pine establishment window lasted only until about age 50 **(PLS-5)**, meaning that we did not detect significant establishment or recruitment in transitioning FDn12 forests and suspect that second cohorts of jack pine could not develop without further disturbance. During the transition period, jack pine was present at most survey corners (~62%) and almost half of those were still pure jack pine. It is possible that there was limited jack pine establishment and recruitment to bearing-tree size (~4" dbh) because it was the only species present in monotypic pockets. When present as smaller diameter trees, young jack pine were coming in under other jack pine in 73% of the cases. We interpret this as some replacement of itself in gaps created by surface fires because jack pine show just modest ability to recruit seedlings under a canopy that could be released due to the demise of overtopping trees **(R-2)**. Although surface fires provided some opportunity for jack pine regeneration, opening some of the mostly serotinous cones, we believe that it was the main source of jack pine mortality during this period favoring the fire-resistant red pines.

Mature and Very Old Growth-stages: 75-195 years and older

In mature FDn12 stands the relative abundance of jack pine stabilizes at about 20% and it persists into the very old growth-stage **(PLS-1, PLS-2)**. Although much diminished from earlier growth-stages, jack pine was still an important co-dominant or dominant trees. If jack pine's continued dominance required regeneration and recruitment, then we must assume that jack pine has secondary strategies for behaving like a mid-successional species able to respond to fine-scale or maintenance disturbances. Jack pine's limited ability to establish and recruit seedlings in modern FDn12 forests diminishes the possibility of it responding to fine-scale disturbance **(R-2)**. Most likely, the primary limitation to establishing seedlings is the tendency of jack pine to have mostly closed, serotinous cones in on FDn12 sites. Unusually warm weather can open some cones, especially on older, senescent branches; however, seedfall followed by establishment, and recruitment was inadequate to sustain 20% relative abundance of jack pine in older forests. This leaves only the likelihood that jack pine responded very favorably to surface fires, which is obvious in its reaction to burned over lands and high presence at survey corners affected by maintenance disturbance **(PLS-3)**. Unlike the transition stage, jack pine in mature forests was coming in mostly under red pine. In other cases jack pine was coming in under larger diameter jack pine, suggesting that there were multiple cohorts of jack pine among the older red pines.

Regeneration Strategy

Jack pine's primary regenerative strategy on FDn12 sites is to dominate ***open habitat*** after stand-regenerating fire. In the historic PLS data this interpretation is supported by: (1) the fact that 71% of the bearing trees in young stands were jack pine **(PLS-1)**, (2) jack pine represented by far, the largest proportion of bearing trees at burned and windthrown corners **(PLS-3)**, (3) jack pine's peak regeneration was in the post-disturbance window with it's absolute peak being the initial age-class **(PLS-5)**. The limited ability of jack pine to regenerate under a canopy in modern forests supports strongly the idea that rather open conditions are required for natural regeneration **(R-2)**.

Historic Change in Abundance

Today, jack pine is far less abundant on FDn12 sites than it was historically **(PLS-FIA-1)**. Most noticeable is the decline in young forests where jack pine historically was 71% of the bearing trees and now jack pines account for just 36% of the FIA trees. Mature FDn12 forests now have about 16% relative abundance compared to the historic condition of 22%. There are no modern, very old (>195 years) FDn12 forests for comparison. We believe that the loss of jack pine is a consequence of regenerating most FDn12 stands by logging and artificial regeneration rather than fire. Conversion to red pine is not an issue, as red pine too, has diminished presence in young FDn12 forests. Quaking aspen is the obvious benefactor of the decline of both jack and red pine, which suggests that some FDn12 sites are being coppiced for aspen and likely, some plantations fail because of aspen competition without fire.

Red Pine

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

Suitability
FDn12 sites provide ***excellent habitat*** for red pine trees. The ***suitability rating*** of 4.9 for red pine is influenced mostly by its presence (48%) as trees on these sites in modern forests **(R-1)**. When present, red pine is an important co-dominant or dominant tree, contributing 32% mean cover in mature stands. This ranking is second, behind jack pine on FDn12 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 FDn12 stands recovering mostly from fire **(PLS-1)**. Young red pines represented 30% of the trees at survey corners described as burned, second only to jack pine **(PLS-3)**. Our interpretation is that red pines were initial-cohort trees on FDn12 sites, but were much less successful than jack pine. Red pine showed similar abundance at windthrown corners (31%), but windthrow was such an infrequent event that it wasn't an important means of establishing red pine on FDn12 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 and was continuously present until the 70-year age-class **(PLS-5)**. In most cases, red pine regeneration was coming in under other red pines or under jack pine. For these reasons, we believe that the young growth-stage offered a good window of opportunity for red pines to increase their abundance relative to jack pine, which shows high, but declining establishment as young FDn12 woodlands age.

Transition: 55-75 years
As stands transitioned to mature conditions red pine increased greatly in abundance, presumably because of its ability to outlive initial cohort jack pine **(PLS-1, PLS-2)**. Also, it seems that the decline of the initial-cohort jack pine released some red pine seedlings established during the young growth-stage. Although most 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 FDn12 habitat tended to be more monotypic as jack pines died, leaving only the longer-lived red pines. Small-diameter red pine regeneration is present at low levels in the 50-70 year age-classes **(PLS-5)**. We believe that there was limited establishment and recruitment of red pine in response to the breakup of the initial-cohort, jack pine canopy. At this time, young red pines were mostly coming in among larger red pines, but often they were still replacing jack pine.

Mature Growth-stage: 75-195 years
Red pine had peak abundance as a co-dominant or dominant tree in mature stands (75-195 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 (rarely) very old-aged **(PLS-1, PLS-2)**. The trend of FDn12 stands to become monotypic continued from the transition stage and was most evident in the mature growth-stage, where nearly 20% 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 70 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. 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 jack pine. 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 shorter trees like jack pine and younger red pines.

Very Old Growth-stage: >195 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 species like white pine and white spruce **(PLS-1, PLS-2)**. The most common condition in the old growth-stage was for the canopy to be mixed red pine, white pine, and white spruce over what must have been second- or third-cohort jack pine that was persisting due to surface fires. We did not detect small-diameter red pine regeneration beyond 70-years, well short of the very old growth-stage **(PLS-5)**, and it was far more common for red pine bearing trees to be the largest tree at the corners. Thus, we attribute the persistence of red pine in these very old stands to it longevity more so than replacement.

Regeneration Strategy

Red pine's primary regenerative strategy on FDn12 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 FDn12 stands **(PLS-1)**, (2) it was abundant at burned and windthrown corners, second only to jack pine **(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 FDn12 woodlands suggests also that red pine needs open habitat to reproduce because it has only fair ability to establish seedlings beneath a canopy **(R-2)**.

Historic Change in Abundance

Today, red pine is in some peril on FDn12 sites. The far lower percentage of sapling stands versus pole stands of red pine in the FIA data would suggest less success or effort regenerating FDn12 stands with red pine over the past 30 years **(FIA-1)**. Historically, the relative abundance of red pine in young FDn12 forests was 16% compared to just 5% today **(PLS/FIA-1)**. More startling, is the loss of red pine in mature stands where its modern abundance of 4% 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, mostly because aspen and the fire-sensitive balsam fir seem to be the benefactors of modern disturbances to FDn12 forests.

Quaking (Big-toothed) Aspen

- ***good 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. Both species were so infrequent in the releve sampling of FDn12 forests that it is hard to predict the true ratio of their occurrence, but there is more quaking aspen than big-toothed aspen in this dataset. The FIA sampling shows that the ratio is overwhelmingly in favor of quaking aspen with 260 trees compared to just 4 big-toothed aspen trees. We consider quaking and big-toothed aspen to be ecologically equivalent for most silvicultural considerations, and we present below the account for quaking aspen.

Suitability

FDn12 sites provide ***good habitat*** for quaking aspen trees. The ***suitability rating*** of 3.5 is the result of balanced presence (13%) and mean cover when present (16%, **R-1**). This ranking is third among trees common on FDn12 sites. As long as the soils are deep (not FDn22), northern fire-dependent forests in general offer good-to-excellent habitat for quaking aspen (see Suitability Tables). Of these communities, FDn12 is least desirable because these sites are much drier and poorer than other FDn communities.

Young Growth-stage: 0-55 years

Historically, aspen was an occasional tree in young FDn12 stands with 4% relative abundance **(PLS-1)**. Young aspen represented 4% of the trees at survey corners described as burned, which is much lower than one would expect given aspen's pioneering behavior in other communities **(PLS-3)**. Aspen was more abundant following windthrow, representing 6% of the trees at such survey corners. It is possible that windthrow favored aspen more than fire, but windthrow was so uncommon (~1%) that just a few trees account for the slight difference. Quaking aspen had its peak abundance of about 10% in the 30- and 40-year age classes, but when averaged across growth-stages it had a persistent background abundance of 4% **(PLS-1)**. Because of its early peak among age-classes, we consider quaking aspen and ***early successional*** tree on FDn12 sites **(PLS-2)**. Small-diameter quaking aspen regeneration was common throughout the young growth-stage and very abundant until the 30-year age-class **(PLS-5)**. This was quaking aspen's best opportunity to regenerate and increase its abundance relative to the dominant pines after a major disturbance. As young stands neared the transition stage, aspen was increasingly subordinate, meaning that other trees were growing faster or that the aspen regeneration was dying before reaching diameters comparable to the canopy trees. This trend and the very modest abundance following fires suggests to us that these were seed-origin trees and that FDn12 sites were not underpinned by extensive clonal rootstocks. In most habitats, aspen clones are significant competitors with pines and the absence of clones on FDn12 might explain the historic success of both jack and red pine on these sites.

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

Aspen played no important dynamic role in transitioning, mature, or very old FDn12 stands. Aspen persisted at about 3-4% relative abundance in these older growth-stages **(PLS-1)**. If persistence required regeneration and recruitment, then we must assume that aspen has secondary strategies for behaving like a mid- or late-successional species able to respond to fine-scale or maintenance disturbances. The ability of aspen to establish seedlings or suckers on FDn12 sites is good **(R-2)**. Its regenerant and seedling indices (3.0-3.2) are in line with species that show success in large gaps and not requiring totally open conditions. Quaking aspen's sapling index though is just fair, suggesting that recruitment to heights over 2m doesn't happen without a sizeable gap forming over the advance regeneration. In modern forests, the seedling-sized aspen are believed to be mostly suckers. Historically though, we believe that most aspen persisted in old FDn12 woodlands by establishing seed-origin trees where surface fires created large enough opening for them to establish and then recruit seedlings to sapling and tree-sized individuals.

Regeneration Strategies

Aspen's primary regenerative strategy on FDn12 sites was to seed into ***open habitat*** after stand-regenerating fire. In the historic PLS data this interpretation is supported by: (1) the fact that aspen's peak relative abundance was in the initial age-classes **(PLS-2)**, and (2) aspen's peak regeneration was in the post-disturbance window **(PLS-5)** with it's absolute peak being the initial age-class. The high percent of aspen as poles in pole stands (situation 22) in the FIA data **(FIA-1)** is also characteristic of species that regenerate effectively in the open, but it was surprising to see such low abundance of aspen saplings in sapling stands (situation 11).

The releve sampling of mature FDn12 forests suggests, however, that aspen is able to function also as a ***large-gap strategist*** with good establishment as seedlings in the understory strata **(R-2)**. Modest abundance of aspen in subordinate situations (12, 23, 13) at FIA plots support also the idea that aspen can regenerate in large gaps **(FIA-1)**. We believe that the large-gap behavior is associated with the development of larger aspen clones in modern forests, and that the "seedlings" are mostly suckers subsidized by a parent tree.

Historic Change in Abundance

Today, aspen is a dominant tree on many FDn12 sites **(PLS/FIA-1)**. Aspen's gains are evident in both the young and mature growth-stages where modern abundance is roughly 6-7 times greater (22-28% abundance) than it was historically. This number is inflated by eliminating many (but not all) plantations from the FIA sampling; however, it is widely recognized that planting efforts have not "kept up" with the conversion to aspen. Young, reasonably natural FDn12 sites are now often aspen-dominated. Our interpretation is that suppressing fires has allowed aspen clones to spread across FDn12 sites. Where aspen once relied on seeding into burned sites, it now out-competes jack and red pine when coppiced.

White Spruce

- ***good habitat suitability rating***
- ***late-successional***
- ***small-gap (large-gap) regeneration strategist***
- ***regeneration window at >70 years***

Suitability

FDn12 sites provide ***good habitat*** for white spruce trees. The ***suitability rating*** of 3.3 for white spruce is the result of balanced presence (13%) and mean cover when present (14%, **R-1**). This ranking is fourth among trees common on FDn12 sites. Northern fire-dependent communities in general are not good habitat for white spruce (see Suitability Tables). Only FDn43 offers excellent habitat, and FDn12 is a distant second providing just good chances to raise white spruce as a crop tree.

Young Growth-stage: 0-55 years

Historically, white spruce was present in just trace amounts in young FDn12 stands **(PLS-1, PLS-2)**. Young spruce represented just 1% of the trees at survey corners described as burned, well behind fire-tolerant species like jack pine, quaking aspen, and red pine **(PLS-3)**. Nonetheless, the presence of any white spruce on burned lands is surprising given its sensitivity to fire. One would guess that fire-sensitive trees like spruce would be substantially more abundant at windthrown corners, but white spruce represented just 1% of the trees at windthrown survey corners. Because of spruce's affinity for wetter habitats included in the FDn12 landscape, we believe that the few, small-diameter spruce showing up in post-burn situations were coming from unburned wetlands near burned survey corners. White spruce regeneration was not observed coming in among larger trees during the initial post-fire years **(PLS-5)**. Our interpretation is that white spruce were absent from the actual burned patches of FDn12.

Transition: 55-75 years

As stands transitioned to mature conditions white spruce increased ever so slightly in abundance **(PLS-1)**. This increase is very modest, but it is the beginning of a trend that will continue through old-growth where white spruce was an important co-dominant tree **(PLS-2)**. Small-diameter, white spruce regeneration coming in among larger trees was first detected in the 50-year age-class **(PLS-5)**. In fact, all of the white spruce detected at this time were small-diameter trees, which is typical of new colonization. A common anecdote among Minnesota foresters is that balsam fir serves as a nurse crop for white spruce. This comes mostly from observations in modern forests where it is far more common (2-3 times in our releves) to have fir in stands without spruce than to have white spruce without any fir. Remarkably, this seems even more true in the historic data where ingress of spruce always follows an initial pulse or fir abundance. On FDn12 sites though, the fir pulse is muted and far less significant that observed in moister and richer plant communities. It seems far more likely that white spruce and balsam fir were independently responding to the same stand conditions during the transition stage. The most likely condition was that some time had passed since the last fire, and that white spruce and balsam fir were able to spread from wet inclusions onto the drier portions of FDn12 sites.

Mature Growth-stage: 75-195 years

In the mature growth-stage, white spruce abundance was increasing steadily from about 5% relative abundance to as much as 30% relative abundance in some age-classes **(PLS-2)**. Throughout this episode, white spruce occurred only at survey corners of mixed composition and was more often, by far, the smaller tree at the corner. This is typical of an ingressing species developing a bank of understory seedlings and saplings. Small-diameter white spruce regeneration was coming in among larger trees abundantly in age-classes spanning the mature growth-stage, suggesting good establishment and recruitment in the ingress window **(PLS-5)**. At this time, spruce regeneration was coming in mostly under old jack pine and large-diameter red pine, and not at all under balsam fir. This favors the idea that spruce was responding more to gaps in the canopy than being nursed by balsam fir. The cause of such openings is problematic.

While it is easy to envision gaps forming under the last of the initial-cohort jack pines, we know that surface fires played a role in gap formation selecting for fire-resistant red and white pines and regenerating some patches of second- or third-cohort jack pine. It is hard to imagine mature stands with a developing understory of white spruce not being susceptible to surface fires. Yet our landscape summary of FDn12 sites shows white spruce being consistently more abundant as bearing tree diameters increase and as our estimates of stand age go up. Our best guess is that at the stand scale, surface fires created patches of mature forest on FDn12 sites that were quite different with regard to understory trees. Where surface fires had occurred, FDn12 stands were pine-dominated and were characterized by large-diameter red and white pines with much younger, early-successional species like jack pine, quaking aspen, and some paper birch below. Where surface fires skipped, FDn12 stands had an overstory of large-diameter pines, but would have appeared to be well on their way to being succeeded by white spruce.

Very Old Growth-stage: >195 years

In the very old growth-stage white spruce was an important co-dominant and sometimes dominant tree, occurring almost always at survey corners of mixed composition. At 14% relative abundance, it was about as abundant as white pine but still trailed red and jack pine as the more common trees on very old FDn12 sites **(PLS-1)**. White spruce's importance in the old growth-stage is the main reason that we consider it to be a ***late-successional*** species on FDn12 sites, even though it had greater abundance in some of the mature (but still late-successional) age-classes. Small-diameter, white spruce regeneration coming in among larger trees represented over 16% of all bearing trees at corners older than 190 years, providing excellent regeneration and recruitment opportunities **(PLS-5)**. Even at this old growth-stage, white spruce was still more often the smaller tree at a survey corner and was replacing larger-diameter pines, especially what must have been second-cohort jack pine. Unlike most climax forest species, white spruce never demonstrated a preference for reproducing under itself. Our interpretation is that very old FDn12 sites would eventually be affected by surface fires (rotation ~50 years) and that white spruce was constantly trying to replace young pine cohorts among some very large-diameter red and white pine.

Regeneration Strategies

White spruce's primary regenerative strategy on FDn12 sites was to develop a bank of seedlings and to then recruit saplings in ***small-gaps***. It was successful at doing this under any other tree, but it was most successful replacing jack pine and red pine on FDn12 sites. In the historic PLS data this interpretation is supported by: (1) the fact that white spruce abundance peaks in the mature and old growth-stages when we assume a full canopy and lower strata **(PLS-1, PLS-2)**, (2) it is most abundant at survey corners in a mature, undisturbed condition **(PLS-3)**, and (3) its best recruitment window is an ingress window **(PLS-5)**. The fairly high percentage of white spruce seedlings in the FIA data (situations 12 and 13) is also characteristic of species successful in small gaps **(FIA-1)**.

In modern forests, white spruce shows just fair ability to establish seedlings under a canopy **(R-2)**. Established seedlings have a good chance though of recruiting to sapling and tree sizes. The indices in the regenerating layer are more in line with species that need ***large-gaps*** for establishment. Spruce's 19% presence as poles in tree stands (situation 23) high for small-gap species and more aligned with trees that do well in larger gaps **(FIA-1)**. Our interpretation is that white spruce functioned well as a large gap strategist in fire-regenerated FDn12 forests because of the effect of fire on reducing brush and because jack and red pine canopies are rarely tight. In modern forests, where brush cover is higher and where quaking aspen is much more important, it seems that gap formation helps to improve recruitment and especially establishment of white spruce.

Historic Change in Abundance

Today white spruce is about as abundant as it ever was historically, but its distribution among growth-stages is quite different **(PLS/FIA-1)**. Today, it is more common in young FDn12 forests, accounting for 4% of the trees, whereas it was present only in trace amounts naturally. We attribute this to the fact that fire is no longer the main means of re-initiating these forests. In mature forests, white spruce now represents about 4% of the trees at a time when it naturally started to ingress at about age 75, but increased substantially and averaged 7% relative abundance. Historically white spruce was most important in very old FDn12 forests, but there are now no modern stands of that age for comparison.

Balsam Fir

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

Suitability

FDn12 sites provide ***good habitat*** for balsam fir trees. The ***suitability rating*** of 3.0 for balsam fir is influenced mostly by its presence (17%) as trees on these sites in modern forests **(R-1)**. When present, balsam fir is a minor co-dominant tree, contributing 9% mean cover in mature stands. The ranking is fifth among trees common on FDn12 sites as sampled by releves. As long as the soils are fairly deep (not FDn22), northern fire-dependent forests (FDn) offer good-to-excellent habitat for balsam fir (see Suitability Tables). Balsam fir is favored on the richer or moister FDn communities and has its poorest performance on FDn12 sites compared to FDn33, FDn32, and especially FDn43.

Young Growth-stage: 0-55 years

Historically, balsam fir was a minor tree in young FDn12 stands **(PLS-1, PLS-2)**. Young firs were not present at all at survey corners described as burned, windthrown, or having suffered partial canopy loss due to maintenance disturbances **(PLS-3)**. Fire was by far the most frequent disturbance in FDn12 forests, and we believe that it was extremely effective in eliminating fir trees and all advance regeneration. Because of balsam fir's affinity for wetter habitats included in the FDn12 landscape, we believe that seed sources were usually present, and that fir was able to start re-colonizing burned FDn12 sites fairly soon after fires. Small-diameter balsam fir regeneration was first detected in the 30-year age class and it increased dramatically to peak at 40 years **(PLS-5)**. In fact, the presence of fir in the young growth-stage was entirely as small-diameter regeneration, which is typical of an invading species. When present, it was most often coming in among larger jack pines. Post-fire thickets of pine and quaking aspen were probably fine habitat for young seed-origin firs, particularly at the stage where the groundlayer is suppressed and the initial-cohort trees start to self-thin. Supporting this argument is the excellent performance of balsam fir seedlings under a canopy in modern FDn12 forests **(R-2)**. The closing years of the young growth-stage offered the best window of opportunity for initial ingress and recruitment of balsam fir.

Transition: 55-75 years

The transition to mature conditions is mostly the consequence of the steady loss of initial-cohort jack pine leaving longer-lived red pine **(PLS-1)**. By the beginning of the transition stage, the pulse of fir regeneration **(PLS-2)** concluded and apparently resulted in recruitment of very few trees. For most of the transition stage, balsam fir was little more than a mid-canopy tree similar to ironwood in northern hardwood stands. The inability of fir to reach tree heights is common on droughty sites throughout northern Minnesota, and recruitment doesn't improve until water tables are within reach of their roots (~10 feet). We are uncertain if fir played an ecological role in transitioning FDn12 forests. As often observed, ingress of white spruce followed the fir pulse; however, the benefit to white spruce must have been indirect as little spruce regeneration was observed coming in among fir bearing trees. As living fuel, balsam fir could have helped to intensify surface fires. To accelerate the natural transition to red pine, such fires would have had to differentially affect the pines, killing more jack pine and leaving more red pine. To us, this seems unlikely, if not contradictory, to the role of ladder fuels in similar ecosystems. Perhaps, fir's muted attempts at regeneration and recruitment throughout the transition stage were functionally benign. Because of its slow growth and because of its susceptibility to surface fires, there simply weren't many balsam firs in 55-75 year old stands with appropriate diameters for use as bearing trees.

Mature Growth-stage: 75-195 years

In the mature growth-stage balsam fir abundance stabilized at about 1% **(PLS-1, PLS-2)**. Balsam fir's relative abundance in the mature growth-stage is the result of ingress and recruitment between the 30 and 60-years age-classes in the young growth-stage **(PLS-5)**. Continued regeneration was not observed in the mature growth-stage. However, almost all fir bearing trees were the smallest tree at the survey corners, suggesting renewed attempts at recruitment. As was the case in the young growth-stage, smaller diameter firs were coming in among what now must have been second-cohort jack pine established after surface fires. It would seem that fir's regenerative attempts followed cohorts of jack pine on FDn12 sites, but always lagged behind jack pine's ability to achieve tree-sized diameters.

Very Old Growth-stage: >195 years
In the very old growth-stage, balsam fir was a minor tree, occurring always at survey corners of mixed composition. At 3% relative abundance, it was the least of all other late-successional trees on very old FDn12 sites **(PLS-1)**. Yet, this stage was the "peak" of fir presence on FDn12 sites and for that reason we consider fir to be a ***late-successional*** species. Small-diameter balsam fir regeneration coming in among larger trees was not detected beyond the 60-year age-class **(PLS-5)**. In mature and very old FDn12 forests balsam firs still tended to be the smaller tree at survey corners, suggesting some regeneration and recruitment in spite of the lack of documentation in the PLS records. As before, smaller diameter firs were coming in beneath larger jack pine. Apart from the "spruce-fir" association in other habitats and in the literature, on FDn12 sites it seems clear that regenerative attempts of fir tracked cohorts of jack pine far more than heralding the ingress and late-successional success of white spruce.

Regeneration Strategy
Balsam fir's primary regenerative strategy on FDn12 sites is to build a bank of seedlings in the groundlayer and to then recruit saplings in ***small-gaps***. It was successful at doing this under jack pine more than any other tree. If the initial-cohort of jack pine is any measure, the ingress of balsam fir happened early and well-before the senescence of jack pine and the formation of large canopy gaps. In the historic PLS data this interpretation is supported by: (1) the fact that balsam fir abundance is steady throughout the older growth-stages where we assume a full canopy **(PLS-1, PLS-2)** and, (2) it is most abundant at survey corners in mature, undisturbed conditions **(PLS-3)**. The high percentage of balsam fir seedlings in the FIA data (situations 12 and 13) is also characteristic of species successful in small gaps **(FIA-1)**. Most significant though, is its unequalled ability to establish and recruit seedlings under a canopy in modern stands **(R-2)**. Today, no other FDn12 tree has the regenerative ability of balsam fir under a canopy.

Historic Change in Abundance
Today populations of balsam fir have exploded in FDn12 forests compared to its historic abundance **(PLS/FIA-1)**. We believe that this is a consequence of fire suppression and fir's obvious abilities to function as a shade-tolerant, small-gap strategist. The increase in fir is obvious in the young growth-stage where it now represents 16% of the young trees in FIA samples compared to just 1% historically. We believe that post-fire FDn12 stands started naturally with almost no balsam fir, whereas now they have significant initial presence after logging. The disparity in fir abundance is even greater in mature FDn12 forests where historically it was just 1% of the trees, but now is 19% of the FIA trees. In these older forests though, tree-sized firs are usually smaller than other species and do not contribute much to stand volumes. In the releve samples of mature forests, balsam fir had peak cover in the understory or subcanopy in 82% of the cases. This is evident also in Tables **R-1** and **R-2**, where it has far greater presence as regeneration (65%) compared to its presence as a tree (17%). The increase in tree abundance in modern stands brings with it substantial amounts of understory fir, perhaps because stands no longer start from "scratch" as they did after intense fires. Fir abundance in the understory now offers a competitive challenge for less tolerant crop trees.

(PLS-1) Historic Abundance of FDn12 Trees in Natural Growth-stages

Table values are relative abundance (%) of Public Land Survey (PLS) bearing trees at corners modeled to represent the FDn12 community by growth-stage. Growth-stages are periods of compositional stability during stand maturation. Arrows indicate periods of compositional change during which tree abundances increase or decrease substantially. Yellow, green, and purple shading groups trees with abundance peaks in the same growth-stage. Percents on the bottom row represent a snapshot of the balance of growth-stages across the landscape *ca.* 1846 and 1908 AD.

Dominant Trees	Forest Growth Stages in Years				
	0 - 55	55 - 75	75 - 195	~ 195	> 195
	Young	T1	Mature		Very Old
Jack Pine	**71%**	||	**22%**	)	**22%**
Quaking (Big-toothed) Aspen	**4%**	)	**4%**	)	**4%**
Red Pine	**16%**	⌉⌉	**50%**	||	**24%**
Paper Birch	**3%**	⌉	**6%**	⌉	**9%**
White Pine	**3%**	⌉	**5%**	⌉⌉	**15%**
Balsam Fir	**1%**	)	**1%**	⌉	**3%**
White Spruce	**–**	⌉⌉	**7%**	⌉⌉	**14%**
Miscellaneous	**2%**		**5%**		**9%**
Percent of Community in Growth Stage in Presettlement Landscape	**61%**	**17%**	**20%**		**2%**

PLS-1

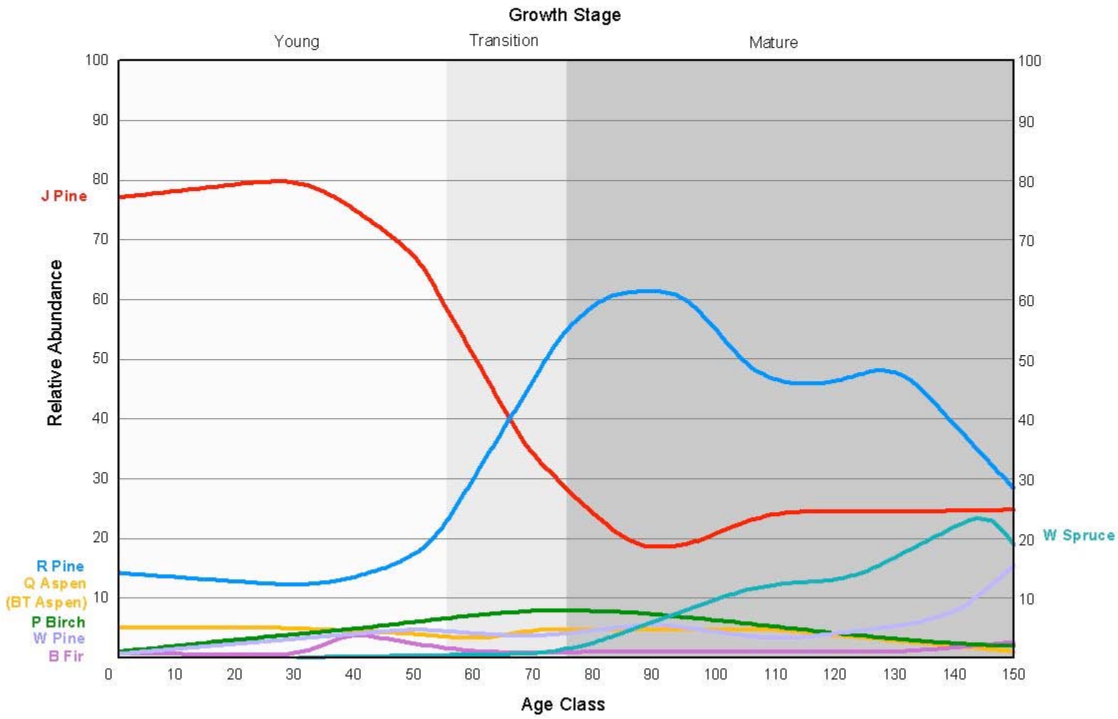
Trees included in Table PLS-1 are species with greater than 3% relative abundance in at least one growth-stage. Species that are now abundant in FDn12 woodlands, but were rare historically appear in Table **PLS/FIA-1**.

The PLS surveyors did not consistently distinguish the more prevalent quaking aspen from big-toothed aspen on FDn12 sites.

Public Land Survey linked text

(PLS-2) Abundance of trees throughout succession in FDn12

Caption: Graphed for the different species of FDn12 trees is their relative abundance (%) as PLS bearing trees by age class. The data were initially smoothed from adjacent classes and then by visually fitting lines to illustrate general trends.



Documentation for Figure PLS-2

**Public Land Survey linked text

(PLS-3) Historic Abundance of FDn12 Trees Following Disturbance

Table values are raw counts and (percentage) of Public Land Survey (PLS) bearing trees at survey corners likely to represent FDn12 woodlands. The columns represent our interpretation of disturbance at the survey corners. Trees in parentheses are minor species that occur in modern forests but couldn't be separated from more common trees because the surveyors did not distinguish them in their field notes. Shading associates trees that peak in the same disturbance category.

Tree	Burned		Windthrown		Maintenance		Mature	
Jack pine	**262**	**66%**	**44**	**62%**	**302**	**57%**	**2417**	**57%**
Quaking (Big-toothed) aspen	**14**	**4%**	**4**	**6%**	**29**	**5%**	**188**	**4%**
Red pine	**118**	**30%**	**22**	**31%**	**196**	**37%**	**1436**	**34%**
White spruce	**4**	**1%**	**1**	**1%**	**4**	**1%**	**139**	**3%**
Balsam fir	**1**	**0%**	**0**	**0%**	**1**	**0%**	**80**	**2%**
Total **%of grand total, 5262**	**399**	**8%**	**71**	**1%**	**532**	**10%**	**4260**	**81%**

PLS-3

Table PLS-3 includes only trees ranked as having excellent, good, or fair suitability for FDn12 sites. Tree sums will not match the totals in the Natural Disturbance Regime text, because trees of poorer suitability were included in that analysis.

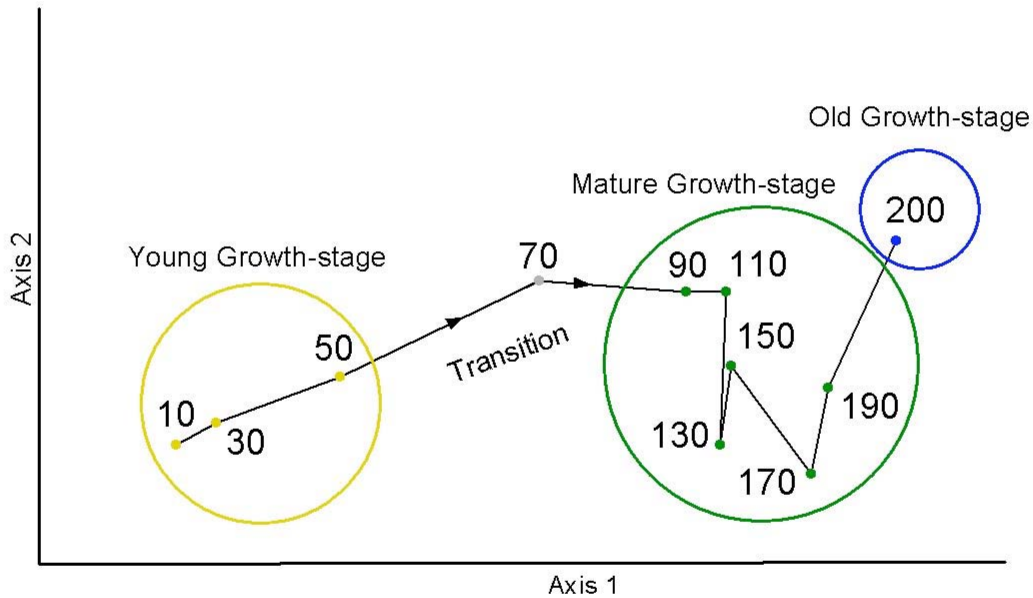
PLS survey corners were assigned to four disturbance categories:

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

Public Land Survey linked text

(PLS-4) Ordination of Historic FDn12 Age-classes

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



PLS-4

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

(PLS-5) Historic Windows of Recruitment for FDn12 Trees

Windows of recruitment are stretches of contiguous age classes where Public Land Survey (PLS) trees recruit to acceptable bearing tree size (~4" dbh) in the presence of trees twice their diameter. We interpret this as their establishment in response to canopy conditions that change during the course of natural stand maturation. The table presents species' peak recruitment window and comparative success in post-disturbance, gap, and ingress windows.

Initial Cohort	Species	Peak years	P-D 0-30 years	G-1 30-90 years	I-1 90-190 years	G-2 >190 years
Yes	Jack Pine	0-50	Excellent	Poor to 60	--	--
Yes	Quaking Aspen	0-30	Good	Poor to 60	--	--
Yes	Red Pine	0-30	Good	Poor to 70	--	--
Minor	White Pine	40	--	Poor 40-60	--	--
Minor	Paper Birch	30-60	Some	Good to 80	--	--
No	Balsam Fir	40	--	Good to 60	--	--
No	White Spruce	150	--	Fair after 50	Good	--

Recruitment windows from ordination PLS-4:

- P-D: post-disturbance filling of understocked areas, 10-30 years
- G-1: gap filling during decline of initial-cohort jack pine, red pine and quaking aspen, 30-90 years
- I-1: ingress of seedlings under canopy of red pine, jack pine, and some quaking aspen and paper birch, 90-190 years
- G-2: gap filling during decline of red pine, about 190 years

-- : No trees were recorded as < half the diameter of the largest bearing tree. A property of PLS data is that diameter variation among bearing trees at the same corner decreases with increasing diameter. Corners estimated to be older than about 100 years only rarely have subordinate bearing trees and should not be taken to mean that small diameter trees didn't occur at all.

Shading: light yellow = trees with peak regeneration immediately after disturbance; **gold =** trees with peak regeneration later in the P-D window; **light green** = trees with peak regeneration in gaps formed during the decline of the initial cohort; **purple** = trees with peak regeneration by ingress under a mature canopy or by filling small gaps in old forests

PLS-5

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

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

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

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

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

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

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

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

(R-1) Suitability ratings of trees on FDn12 sites

This table presents an index of suitability for trees in FDn12 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 FDn12			
Tree	**Percent Presence as Tree**	**Mean Percent Cover When Present**	**Suitability Index***
Jack pine (Pinus banksiana)	**83**	**44**	**5.0**
Red pine (Pinus resinosa)	**48**	**32**	**4.9**
Quaking aspen (Populus tremuloides)	**13**	**16**	**3.5**
White spruce (Picea glauca)	**13**	**14**	**3.3**
Balsam fir (Abies balsamea)	**17**	**9**	**3.0**
*Suitability ratings: **excellent**, **good**, **fair**			

R-1

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

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

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

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

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

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

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

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

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

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

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

(R-2) Natural Regeneration and Recruitment of Trees in Mature FDn12 Stands

This table presents an index of regeneration for FDn12 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 FDn12 communities. Changes in the index values from one stratum to another can be used to estimate regenerative bottlenecks, whether establishment (R-index) or recruitment (SE-, SA-, or T-indices).

Natural regeneration indices for germinants, seedlings, saplings, and trees common in the canopy of Northern Dry-Sand Pine Woodland – FDn12					
Trees in understory	**% presence R, SE, SA**	**R-index**	**SE-index**	**SA-index**	**T-index**
Balsam fir (Abies balsamea)	**65**	**4.2**	**4.2**	**3.7**	**3.0**
Red pine (Pinus resinosa)	**48**	**2.7**	**2.7**	**4.0**	**4.8**
Jack pine (Pinus banksiana)	**39**	**2.2**	**2.3**	**3.7**	**5.0**
Quaking aspen (Populus tremuloides)	**22**	**3.0**	**3.2**	**2.7**	**3.5**
White spruce (Picea glauca)	**22**	**2.7**	**2.2**	**3.0**	**3.3**

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

% presence: the percent of 23 FDn12 sample plots with that species present under 10m (33 feet) tall (R, SE, SA layers)
R-index: index of representation as true seedling or under 10cm (4 inches) tall
SE-index: index of representation as seedlings over 10cm and under 2m (0.3-6.6 feet) tall
SA-index: index of representation as saplings 2-10m (6.6-33 feet) tall
T-index: index of representation as a tree >10m (33 feet) tall
All indexes: equally weight (1) presence, (2) mean cover when present, and (3) mean number of reported strata, the frequency distributions of which are segmented equally by area into 5 classes.

R-2

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

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

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

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

(FIA-1) Structural Situations of Trees in Mature FDn12 Stands

This table presents percentages of structural situations for trees as recorded in Forest Inventory Analysis (FIA) subplots that we modeled to be samples FDn12 forests. The purpose of the table is to provide a general impression of how often a species is seen certain regenerative situations: canopy of a regenerating forest (situations 11, 22), in the subcanopy (situations 12, 23), or in the seedling bank below a remote canopy (situation 13). The situation of trees in older stands at tree height (33) provide no insight about regeneration. Species are ordered by the sum of their percents in 12 and 13 situations, which generally ranks them as would shade-tolerance ratings. The total number of trees counted for each species is presented to provide a sense of reliability.

Species	Tree Count	Structural Situations					
		11	22	12	23	13	33
Jack pine	187	23%	37%	10%	11%	1%	18%
Quaking aspen	135	1%	42%	12%	13%	6%	27%
Red pine	25	8%	40%	8%	8%	16%	20%
White spruce	31	3%	29%	23%	19%	6%	19%
Balsam fir	111	8%	13%	37%	24%	14%	4%

Canopy Situations

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

Subcanopy Situations

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

Understory Situation (remote canopy)

- **13 =** Saplings under trees

FIA linked text

(PLS/FIA-1) Abundance of FDn12 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 FDn12 community and estimated to fall within the young, mature, and old growth-stages. Arrows indicate increase or decrease between historic growth-stages only and for the more common trees. Green shading and text was used for the historic PLS data and blue was used for the FIA data. Percents on the bottom row allow comparison of the balance of growth-stages across the pre-settlement landscape (*ca.* 1846-1908 AD) and the modern landscape (*ca.* 1990 AD).

Dominant Trees	Forest Growth Stages in Years								
	0 - 55		55 - 75		75 - 195		~ 195	> 195	
	Young		T1		Mature		T2	Old	
Jack Pine	71%	36%	||		22%	16%	)	22%	0%
Quaking (Bigtooth) Aspen	4%	28%	)		4%	22%	)	4%	0%
Red Pine	16%	5%	]]		50%	4%	||	24%	0%
Paper Birch	3%	6%	]		6%	15%	]	9%	0%
Balsam Fir	1%	16%	)		1%	19%	]	3%	0%
White Pine	3%	0%	]		5%	3%	]]	15%	0%
White Spruce	–	4%	]]		7%	4%	]]	14%	0%
Bur Oak	–	2%			–	6%		0%	0%
Red Oak	–	1%			1%	5%		1%	0%
Miscellaneous	2%	2%			4%	6%		8%	0%
Percent of Community in Growth Stage in Presettlement and Modern Landscapes	61%	59%	17%	24%	20%	17%		2%	0%

Natural growth-stage analysis and landscape summary of historic conditions is based upon the analysis of 2,341 Public Land Survey records for section and quarter-section corners. Comparable modern conditions were summarized from 479 FIA subplots that were modeled to be FDn12 sites.

Public Land Survey linked text
FIA linked text

Silviculture Systems for FDn12: No arrow - least favorable, ⇧ Favorable, ⇧⇧ Very Favorable

	Silviculture Systems	Clearcut	Patch Cutting	Group Seedtree	Dispersed Seedtree	Uniform Shelterwood	Group Shelterwood	Irregular Shelterwood	Group Selection	Strip Selection	Single Tree Selection
	Regeneration Strategy										
Quaking Aspen	Open (Large-gap)										
Balsam Fir	Small-gap										
Jack Pine	Open										
White Spruce	Small-gap (Large)										
Red Pine	Open										

Forest Health

Jack Pine

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

WATCHOUTS!

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

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

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

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

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

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

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

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.

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.

White Spruce

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Spruce budworm	“	“
Yellow-headed spruce sawfly	Seedlings and saplings	Topkill, mortality
White pine weevil	Seedlings to pole-sized	Forking, multi-stemmed
Spruce decline	Pole-sized and larger	Growth loss, mortality
Spruce beetle	“	Mortality
Stem decay	“	Volume loss

WATCHOUTS!

• Both white pine weevil and yellow-headed spruce sawfly damage can be prevented by planting/ regenerating seedlings under a light overstory until the seedlings are at least 12-20 feet tall.

• Inspect young, open-grown plantations in early June for YHSS larvae. Use contact insecticides on seedlings with active feeding. Repeat inspection in mid to late June.

• In northeast and north central counties, presalvage/ salvage stands as budworm defoliation starts to cause topkill in the dominant trees.

• Along the North Shore, salvage spruce beetle-caused mortality. Contact the RFHS for more information about prevention, timing and sanitation.

• If a white spruce plantation does not respond to its first commercial thinning or mortality losses increase, it may be declining. Contact the RSS or the RFHS for more information.

• 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 roots and stem, dead branches, and dead or broken tops.

Balsam Fir

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Spruce budworm	“	“
Stem decay	“	Volume loss

WATCHOUTS!

• In northeast and north central counties, use a rotation age of 45-50 years and presalvage/ salvage stands as budworm defoliation starts to cause topkill in the dominant trees. Promote mixed species in regeneration.

• Discriminate against balsam fir regeneration in white spruce stands and in areas where budworm outbreaks are common.

• 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 roots and stem, dead branches, and dead or broken tops.

FDn12 - Acceptable Operating Season to Minimize Compaction and Rutting

Primary Soils | **Secondary Soils** | **Not Applicable**

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

Plants below indicate wetter inclusions in FDn12 that are more susceptible to compaction and rutting. They are listed in descending order of presence.

Balsam fir (C) (*Abies balsamea*)
Woodland horsetail (*Equisetum sylvaticum*)
Mountain maple (*Acer spicatum*)
Side-flowering aster (*Aster lateriflorus*)
Tamarack (U) (*Larix laricina*)
Palmate sweet coltsfoot (*Petasites frigidus*)
American elm (U) (*Ulmus americana*)
Highbush cranberry (*Viburnum trilobum*)

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

Foot Notes

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

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

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

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

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

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

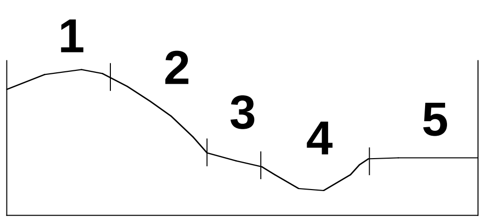
   Poor – water saturation occurs within 10 inches of the surface for most of the growing season

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

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

4. Landscape Position

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



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

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

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

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

   W Winter – the ground is snow covered or partially frozen

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

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

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

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

Public Land Survey linked text

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

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

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

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

Modern Forest linked text

Releve Samples

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

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

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

For more information on the releve method and NPC Classification:

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

FIA Samples

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

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

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

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

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

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

Link to the USFS website, north central