FPn82

FPn82 – Northern Rich Tamarack Swamp (Western Basin)

Natural Disturbance Regime, Stand Dynamics, and Tree Behavior

Summary and Management Highlights

Northern Rich Tamarack Swamps (FPn82) are a common coniferous community found throughout the Laurentian Mixed Forest Province, and at scattered locations in the Eastern Broadleaf Forest Province north of Stearns County (Figure 1). Detailed descriptions of this community are presented in the DNR Field Guides to Native Plant Communities of Minnesota.

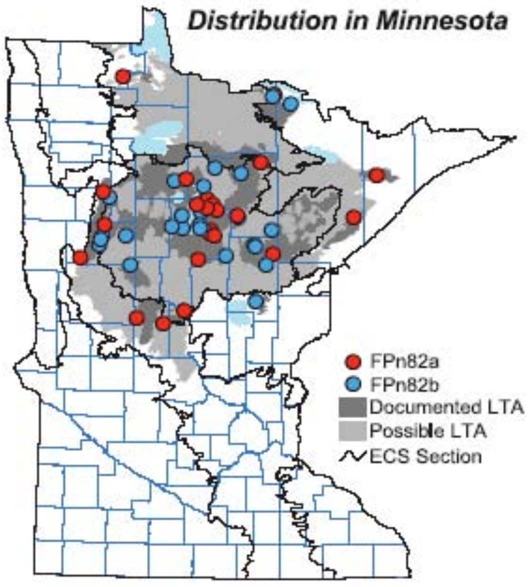


Figure 1. The range of FPn82 forests in Minnesota (shaded) and distribution of releve samples (red and blue dots).

Commercial Trees and Management Opportunities

As a commercial forest, FPn82 sites offer a very limited selection of crop trees and possible structural conditions. Only tamarack and black spruce are ranked as excellent choices as crop trees by virtue of their frequent occurrence and high cover when present on FPn82 sites (see Suitability Tables). White cedar is ranked as a good crop tree and stands can be managed to perpetuate cedar as a co-dominant, especially when present or with evidence of former presence (e.g. stumps) in a particular stand.

All of these species – tamarack, black spruce, and white cedar – were the dominant native trees that have occupied FPn82 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)**. The consequence of fire suppression, commercial logging, settlement, and arguably invasive pests in the past century has been to lose tamarack and promote much more black spruce than was usual. Unlike so many terrestrial forests, there is little ingress of other species that would be considered unnatural or a silvicultural obstacle for managing stands to favor any of the three native trees. All of these swamp conifers are capable of natural regeneration on FPn82 sites regardless of silvicultural system.

Natural Silvicultural Approaches

In the historic landscape, most FPn82 stands (77%) were in the mature growth-stage **(PLS-1, PLS/FIA-1)**. At this time, we believe that the death of canopy trees and their replacement by advance regeneration was mostly the result of species-specific mortality from insects and disease such as larch sawfly, larch beetles, spruce budworm, and dwarf mistletoe. The pattern of this disturbance was probably similar to that of epidemics in other populations, whereby centers of infection spread across the landscape. Thus, silvicultural systems aimed at selective removal from above and expanding in size between frequent entries are good matches with the natural process. Strip shelterwoods perpendicular to the prevailing winds and progressing towards the prevailing winds are generally successful in naturally regenerating tamarack and black spruce in peatlands. The general idea is to have mature, seed-bearing trees upwind and adjacent to recently cut strips. When the harvest strips are stocked, the adjacent strip of mature trees is ready for another entry. Group shelterwood approaches, especially where second and third entries are aimed at expanding the initial gaps (femelschlag) closely match the natural pattern and should result in adequate natural regeneration. We do not recommend selective harvesting for tamarack and black spruce because it is difficult to predict the ability of advance regeneration to respond to release. Small trees may well be young and able to respond to release, or they may be old, stunted individuals. Also, the canopy cover in FPn82 forests is generally sparse, and the removal of individual trees or even groups of trees probably doesn't change the light environment enough to stimulate release of black spruce or tamarack. In the case of cedar, we believe that they are more likely to respond to release as recruitment to heights over 10m seems stifled by overtopping trees **(R-2)**. The natural shelterwood system might benefit white cedar if there is adequate and evenly distributed advance regeneration. Otherwise, release cutting might be beneficial about individual cedars or patches of cedar regeneration. Regardless of the system or species emphasis, it is important to remember that slash and debris above the preserving environment of the saturated peat is a significant source of nutrients for the next generation of trees.

A significant proportion (23%) of native FPn82 stands were young forest <55 years old **(PLS-1, PLS/FIA-1)**. Given that only 4% of FPn82 forests were described as having been recently burned or windthrown **(PLS-3)**, it is clear that destructive agents other than these obvious catastrophes were involved to create so much young, small diameter FPn82 forest. We suspect chronic disease and perhaps following surface fires. What seems clear from the historic records is that young, re-initiated FPn82 stands presented an environment where tamarack was highly successful by seeding into the open areas. Black spruce was less successful, but it was always present in substantial abundance. Cedar seemed to be the loser following catastrophes **(PLS-1)**, although there were some cedars at burned and windthrown corners **(PLS-3)**. Thus, we expect that most silvicultural systems resulting in even-aged forests will favor tamarack and black spruce over cedar. Clear-cutting with reserves, patch cutting, and variants of seed-tree cutting could all approximate the natural pattern of disturbances that created young FPn82 forests. In all cases the reserved species are favored in re-colonizing the harvested areas. Broadcast burning as site preparation is often employed when natural or augmented seeding of black spruce is part of the prescription. Most likely, burning releases mineral nutrients that are normally in short supply on FPn82 sites. The ash and slash are the nutrient capital for the next generation of trees. Burning comes with some risk, and it is debatable as to whether it is a sustainable practice because the natural rotation of fire is far longer (appx. 360 years) than a commercial rotation of tamarack and black spruce (appx. 80 years). Risk increases under dry conditions where burning can flatten the peat surface and diminish the drainage required for good tree growth. We suspect that at least some of the very wet, open peatland communities (OPn92 and possibly OPn81) originated after severe fire in the forested FPn communities like FPn82.

Management Concerns

All FPn82 communities occur on *Sphagnum* peat. Because of the weak organic substrate and poor drainage, the use of heavy equipment is restricted entirely to solidly frozen site conditions. There have been several attempts to use lighter, high-flotation equipment in order to extend the season of operation in Minnesota. Because of the higher nutrient status and modest upwelling groundwater, FPn swamps have a peat mat with far less integrity than APn swamps and bogs. Even "light" equipment tends to break through the living mat into the non-living peat. If ruts or trails fill with water that is open to sunlight and wind, the tendency is to promote decomposition of the side walls and bottom of the rut. This means that such trails will tend to continue to incise into the peat, making them useless for further traffic. On air photographs it is easy to spot past trails that haven't been used in 50 years and researchers believe that the trails of migratory caribou are still evident even though caribou were extirpated from Minnesota in the 1940s. Input of surface runoff from adjacent uplands create a border of rich, soupy peat called a moat, which has no ability to support heavy equipment as the name would suggest.

The landscape balance of growth-stages and stand ages for the FPn82 community has inverted since settlement. Historically, about 77% of the FPn82 forests were mature and today they represent just 40% **(PLS/FIA-1)**. Obviously, the situation is reversed for young forests which accounted for 23% of the historic landscape, but now are extensive (60%). FPn82 swamps can be large and historically they provided some of the most extensive, continuous-canopy, older forest habitat available for animals that prefer uniform, interior habitats. Here, it is important to remember that the 55-year seam between the age-classes is imposed. We see little structural or compositional difference between stands with trees that have achieved most of their height growth. Wildlife concerns are aimed more at the size of management units, where we see commercial logging imposing a pattern of hard, structural edges at a scale substantially finer than our natural vision of very large patches of continuous-canopy swamp. Managing larger stands and retaining trees to facilitate natural regeneration would go a long way towards alleviating concerns about forest interior animals.

Compositional changes are more of a concern. Most obvious is the near reversal of abundance of tamarack and black spruce **(PLS/FIA-1)**. Statewide in all habitats, tamarack populations have plummeted relative to other trees. While the trend is evident in FPn82 forests, tamarack is still and important and abundant tree. The loss of tamarack in wet mineral-soil habitats is nearly complete and more serious. Logging without regeneration is probably the proximal cause of tamarack's demise in the wet-mineral soil environments; however, the decline in peatlands is most likely the result of devastating outbreaks of larch sawfly and possibly larch beetles. In either case, silvicultural attempts to maintain local populations of tamarack are important in all native plant communities. On FPn82 sites, this could be accomplished by leaving some tamarack seed-trees rather than clear-cutting and seeding just black spruce. A similar case can be made for white cedar as most upland cedar has been lost. White cedar populations have increased in some FP communities, but not FPn82. Just allowing some stands to reach maturity and older age-classes might help reverse the situation. Because advance regeneration of white cedar seems fairly common (42% presence in releves, **R-2**), increasing the abundance of cedar trees should be as easy as planning some release cuttings where the regeneration is present.

Natural Disturbance Regime

Natural Rotations of Disturbance in FPn82 Forests Graphic	
	Banner text over photo
Catastrophic fire photograph	**360 years**
Catastrophic windthrow photograph	**430 years**
Partial Canopy Loss, photograph	**77 years**

Natural rotation of catastrophic and maintenance disturbances were calculated from Public Land Survey (PLS) records at 2,840 corners within the primary range of the FPn82 community. At these corners, there were 7,017 bearing trees comprising the species that one commonly finds in FPn82 forests.

The PLS field notes described about 1% of the FPn82 landscape as recovering from stand-regenerating fire. Nearly all such records were of burned-over lands with some references to post-fire thickets. From these data, a rotation of 360 years was calculated for stand-replacing fire using a 5-year recognition window.

Elsewhere in the FPn82 landscape, the surveyors described lands as windthrown and lacking suitable-sized trees for scribing. Such corners were encountered at about 4% of the time, yielding an estimated rotation of 430 years for windthrow, using a 15-year recognition window.

More common at FPn82 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 swamp or some windthrow, with distances to bearing trees that were intermediate between the distances for burned/windthrown lands and what is typical for fully stocked tamarack and black spruce forests on peat. To the surveyors, “swamp” included a broad range of structural conditions from open, wet meadow to forest. About 7% of the survey corners were described as such, resulting in a calculated rotation of 77 years for disturbances that maintained early-successional tamarack on FPn82 sites. That more corners were described as windthrown (47) compared to burned (30) suggests that wind was the more prevalent cause of partial canopy loss. Because peat is a weak substrate it is not surprising that windthrow was prevalent; however, bole-weakening disease (e.g. red-rot and butt rots) probably contributed to the toppling of mature trees in a scattered pattern as well.

There is substantial variety among FPn communities regarding our calculated rotations of catastrophic disturbance. There is some similarity in that rotations of catastrophic fire or windthrow are long (usually >400 years) and exceed the expected longevity of tamarack and black spruce. Our calculations of 360 years for rotation of catastrophic fire and 430 years for stand-regenerating wind for FPn82 forests fall within that general range. FPn82 forests are also similar to the other FPn forests in that disturbances resulting in partial canopy loss were much more likely. The amazing feature of FPn forests, including FPn82, is that disturbance had essentially no effect on stand composition. Other than the slight tendency of old FPn82 forests to have more white cedar and black spruce, tamarack maintained a strong dominance on these sites regardless of the intensity or absence of disturbance. There was no succession, and only the slightest tendency of shade-tolerant black spruce to replace initial-cohort tamarack.

Natural Stand Dynamics

FPn82 forests are among several peatland communities where a particular hydrologic regime translates into dominance of tamarack, in this case mixed with some black spruce and white cedar. The growth of *Sphagnum* mosses has elevated the growing surface to the point where input of groundwater enriched with dissolved mineral salts is far less than in wet forests (WF System) where cedar often dominates, but not to the extreme of ombrotrophic bogs (AP System) where black spruce prevails. Acid to circumneutral surface waters (pH 5.5-7.2) and the waterlogged conditions favor the preservation of organic matter rather than recycling. Under these conditions, which are intermediate as peatlands go, tamarack is by far the most adapted tree and steady dominant.

A critical difference between terrestrial and peatland communities regarding succession and stand dynamics is that the peatland communities are linked by a single process. For the past 6,000 years the climate of Minnesota has favored the expansion and development of wetland forests. The swamping, or paludification, of terrestrial sites has been a rather unidirectional process of peat accumulation, rising water tables, greater predictability of depth to the water table, and increased acidification by *Sphagnum* mosses. Along the way, different species of trees are favored and tend to dominate wetland forests that are at a particular stage of this process. That is, there is an ontogeny of wetland forest types that is evident both spatially and in the temporal reconstructions of vegetation change preserved in the peat strata. FPn82 forests belong to the “mixed-mire pathway” of wetland development, meaning that FPn82 sites tend to succeeded richer FPn swamps and will eventually develop into sparsely forested or open bog where only black spruce occurs in abundance. ***This is significant because the sort-term stand dynamics tend to reflect the long-term ontogeny.*** In this case young FPn82 stands tend to have compositional and structural similarities with the slightly drier FPn72 tamarack swamps and possibly FDn63 cedar swamps. Old FPn82 stands start to resemble APn81 poor swamp forests. Disturbances that re-initiate FPn82 forests can set back this process, but eventually the gains towards bog outweigh the regressions to richer tamarack or cedar swamp.

Thus, the general compositional dynamics of FPn82 forests is for younger stands to be dominated by tamarack more so than mature ones, although tamarack remains the most common tree regardless of age **(PLS-1)**. Throughout succession, the proportion of black spruce and white cedar steadily increase relative to tamarack **(PLS-2)**. The fact that all species are present in the initial cohort and that all are important in very old FPn82 forests means that there is no true succession. The range of movement in ordination space **(PLS-4)** in miniscule in comparison to forests where pioneer species are totally replaced by late-successional trees. There was not enough consistent movement in the ordination for us to confidently assign growth-stages. For any particular stand, the relative abundance of tamarack versus black spruce or cedar probably relates to a historic event. Nuance differences after disturbance that favored one species over the others could account for dominance in any particular stand for quite some time as all are long-lived in this habitat. Species-specific diseases that preferentially remove or leave species could also account for variation in local dominance. For the purpose of discussion, we have arbitrarily set the seam between young and mature FPn82 forests at age 55.

The general structural dynamics of FPn82 forests is a bit more like woodland than that typical of Minnesota’s northern forests. Tree density tends to increase with stand age, suggesting that it takes some time for trees to occupy the available growing space following a disturbance. In young FPn82 stands the average distance of bearing trees to their corners was 33 feet. In mature FPn82 forests the distance of bearing trees to their corners decreases to 26 feet. Stocking in the mature FPn82 forest is rather tight compared to terrestrial coniferous forests and could be the result of stagnation, where stands tend to achieve the condition of having evenly-spaced, similar-diameter, equally competitive trees. However, the tendency of increasing density with stand age is far more pronounced in APn forests than it is in FPn forests.

Young Growth-stage: 0-55 years

About 23% of the FPn82 landscape in pre-settlement times was covered by forests estimated to be under 55 years old **(PLS-1)**. Most often these stands were monotypic (83%). For these survey corners, tamarack was sole species far more often (93%) in comparison to black spruce (7%). About 17% of all survey corners assigned to the young growth-stage were mixtures of tamarack with either black spruce or white cedar.

The surveyors described some young FPn82 forests as having been burned. About 1% of the PLS corners were burned **(PLS-3)**, and fire strongly favored tamarack (76%) over black spruce (14%) or white cedar (9%). The thin-barked, oil rich white cedar is incredibly sensitive to fire, especially in peatlands where even light surface fires burn the organic substrate away from its very shallow roots. We attribute its post-fire presence to its tendency to occur in the wetter, “soupier” microhabitats in FDn82 wetlands that were most likely skipped by fire. Both tamarack and black spruce effectively seed onto burned peat, often to the point of overpopulation. However tamarack consistently overtops black spruce in this situation, and biased selection of the larger trees as bearing trees might explain the apparent preponderance of tamarack in young FPn82 forests **(PLS-1)**. Unlike black spruce, tamarack is able to produce suckers from its extensive, shallow root system. Although consistently mentioned in the silvicultural literature, the importance of tamarack’s ability to reproduce by vegetative means after a fire seems unexplored and probably unimportant silviculturally. The semi-serotinous cones of black spruce allow for significant release of seeds after forest fires, and broadcast burning is a traditional silvicultural method of site preparation for black spruce seeding. Based upon our silvicultural experience one would think that black spruce would be favored in the post-fire environment, but our results show the opposite. Apparently, tamarack is simply more aggressive and efficient at capturing growing space in the open.

Windthrow was more evident to the surveyors than fire, affecting 3% of the PLS corners. Because of the high water table and weak organic substrate it seems likely that windthrow significantly contributed to the regeneration of FPn82 stands. About 87% of the trees at windthrown corners were tamarack compared to 6% black spruce and 7% white cedar **(PLS-3)**. All of these species are well-equipped to regenerate by vegetative means following windthrow. Branch nodes are able to produce adventitious roots from which arise new upright stems or growth of existing branches. Because black spruce tends to hold lower branches longer than tamarack or white cedar, it is not uncommon to see parent spruces surrounded by rings of seedlings where their drooping, lower branches have been “buried” by the growth of *Sphagnum* moss. All of these trees can produce strings of layering seedlings along their windthrown boles.

However, the natural rotations of fire (360 years) and windthrow (430 years) are too long to create the observed balance of growth-stages across the FPn82 landscape **(PLS-1)**. Thus, it seems clear that small-diameter FPn82 stands were initiated by means other than just fire and wind. As is often the fate of monocultures, or near-monocultures like FPn82 forests, outbreaks of disease or pests can have catastrophic consequences over large areas. Outbreaks or larch sawfly since about 1900 have converted thousands of acres of mixed FPn82 stands to spruce cover-type. At this writing, larch beetles are having a similar effect. Although slower to act, ever-expanding (2-10 feet per year) pockets of dwarf mistletoe cause the demise of canopy black spruce and tamarack to regenerate FPn82 forests. The tendency to find white cedar more so in mature woodlands, could be the result of the fact that it has almost no natural pests or diseases in comparison to tamarack and black spruce.

Widely mentioned is the connection between windthrown/diseased timber and fire in forested peatlands. The argument is that dead-and-down spruce and tamarack greatly add to the available fuel for a catastrophic fire, thus increasing greatly the likelihood of that event. Increased intensity in diseased and windthrown timber is our experience in burning peatlands by prescription, but the effect of available fuel on frequency is debatable. Most students of disturbance ecology would argue that severe drought is by far the stronger correlate with fire frequency than available fuel.

Most FPn82 forests tend to occur in large peatlands with incredible amounts of stored water, meaning that severe and sustained drought is required to make them vulnerable to catastrophic fire. Based upon our calculations, such drought and fire was a rare event.

Mature Growth-stage: approximately >55 years

About 77% of the historic FPn82 landscape was mature forest **(PLS-1)**. Stands in this stage were an even balance of monotypic and mixed survey corners. Monotypic conditions were represented mostly by survey corners where all bearing trees were tamarack (88%). At survey corners with mixed composition tamarack was predominant (44%); black spruce was common (21%); but northern white cedar was now much more important at 17% of mixed survey corners than it was in the young growth-stage. It was amazing to see no monotypic cedar corners, suggesting that the cedars were widely spaced and successfully recruiting beneath tamarack or black spruce.

Although FPn82 forests follow the usual trend of mature forests being more mixed than young ones, it is unusual for mature forests to still have nearly half of the survey corners monotypic as is the case for this community (48%). This pattern is restricted to communities where tamarack is the dominant tree in mature forests. This pattern is partially due to the fact that there are just three species are present in most situations. However, other wetland trees able to form young monotypes – black spruce, northern white cedar, and black ash – have mature growth stages that are far more likely to be mixed. Most ecologists believe that mixing is the result of several things that add to the variety of habitats as stands mature: enough time for seeds of most trees to reach the site after a disturbance, a shift from species-specific mortality to age-dependent mortality, the formation of multiple strata of woody plants favoring shade-tolerant species over pioneers, increased abundance and variety of organic seedbeds, and maintenance disturbances that create a variety of sizes of canopy gaps. Mature FPn82 tamarack swamps are lacking in most of these categories: they are remote from the seed sources of many tree species, mortality of canopy trees is attributed mostly to species-specific insects and diseases, they become structurally simple in maturity and sunlight on the forest floor maintains a continuous carpet of mosses, there are no mineral soil seedbeds, and variety in canopy gap size is not important because there is no solid canopy. Several hypothesis might explain the slight tendency of black spruce and white cedar to become more important in older FPn82 forests historically. First, FPn82 forests have at least some shade, which favors black spruce and white cedar over tamarack in the understory. Silvics manuals describe tamarack as totally intolerant; however, our assessment of its ability to develop advance regeneration beneath the usual FPn82 canopy show it to be just slightly less able than black spruce or white cedar **(R-2)**. Also, the fact that tamarack is deciduous might favor understory black spruce and cedar by giving them a slightly longer growing season. Finally, it seems possible that most canopy trees recruit after a major disturbance and succession is just a matter of black spruce outliving tamarack and white cedar outliving both of them. This is the usual explanation for communities where the rotation of catastrophic disturbance is shorter than the life-expectancy of the pioneer trees. Combined, the rotation of catastrophic fire or windthrow on FPn82 sites is estimated to be about 250-300 years. Do most black spruce and some tamarack live that long in these peatlands? Perhaps – field estimates of tree age from FPn82 forests are notoriously poor and usually underestimated, but beneath the microscope there are examples of 300 year-old black spruce and tamarack. Cedar can easily live longer than 300 years.

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?

Tamarack

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

Suitability

FPn82 sites provide ***excellent habitat*** for tamarack trees. The ***suitability ranking*** of 5.0 for tamarack is influenced mostly by its dominating presence (81%) as trees on these sites in modern forests **(R-1)**. When present, tamarack is the dominant tree, contributing 28% mean cover in mature stands. Tamarack has perfect suitability as no other tree or vascular plant has greater presence and abundance. In general, tamarack presence and dominance is a defining character of the FP System regardless of floristic region. Other than a few situations where black spruce is more abundant (FPn71) or where cedar is prevalent (FPn63), all FP communities offer excellent habitat for tamarack (see Suitability Tables).

Young Growth-stage: 0-55 years

Historically, tamarack was dominant in young (0-55 years) FPn82 stands recovering from stand-regenerating disturbance **(PLS-1, PLS-2)**. Young tamarack represented 76% of the trees at survey corners described as burned **(PLS-3)**. Tamarack was also important following windthrow, representing 87% of the trees at such survey corners. Virtually any kind of disturbance favored tamarack over black spruce or white cedar. A high proportion of young FPn82 corners with tamarack trees present were monotypic (77%). Small-diameter, tamarack regeneration was most often observed coming in immediately after disturbance until about age 30 **(PLS-5)**. Nearly all smaller-diameter tamarack were recruiting beneath larger tamarack. We interpret this as tamarack slowly filling all available growing space after a catastrophic disturbance as FPn82 forests seemed slow to stock (see Natural Stand Dynamics).

Mature Growth-stage: >55 years

In the mature growth-stage (>55 years), the abundance of tamarack slowly decreases but it remained the most abundant tree **(PLS-1, PLS-2)**. The tendency of tamarack to steadily decrease as stands age is the reason we consider it to be ***early-successional*** in FPn82 forests. Mature survey corners with tamarack were still more likely to be monotypic (42%), but this is a significant trend towards mixture as compared to the young growth-stage where 77% of the corners were monotypic. Silvics manuals describe tamarack as very intolerant, and beneath any kind of hardwood canopy seedlings are non-existent. Beneath a canopy of older tamarack or black spruce on FPn82 sites, tamarack appears to do rather well at establishing and recruiting seedlings **(R-2)**. We are uncertain as to whether sapling-sized tamarack are usually recruiting seedlings or just stunted, suppressed individuals. Seedling-sized tamarack are common and appear in releves 46% of the time. Tamarack regeneration and recruitment was just fair in the mature growth-stage, but not absent **(PLS-5)**. At this time, small-diameter tamarack were apparently recruiting under older tamarack (82%), but sometimes it was replacing older black spruce (6%) or white cedar (5%).

Regeneration Strategy

Tamarack's primary regenerative strategy on FPn82 sites is to out-compete black spruce or white cedar in the open, post-disturbance environment. It was successful following any type of disturbance, including fire. This is a bit surprising, given black spruce's highly touted abilities following prescribed burning. Our interpretation of tamarack as an ***open regeneration strategist*** is supported by: (1) the tendency of tamarack abundance to decrease as stands age **(PLS-1, PLS-2)**, (2) the high abundance of tamarack at disturbed PLS survey corners **(PLS-3)**, (3) its peak recruitment in the post-disturbance window **(PLS-5)**, and (4) peak presence in canopy situations 11 and 22 in FIA subplots **(FIA-1)**. Most open regeneration strategists are intolerant species, and tamarack is considered highly intolerant in silvics manuals. However, in our releves it shows good ability to establish seedlings, and its seedling and sapling indices (3.7-4.7, **R-2**) are in line with species that recruit in ***large-gaps***. It’s high presence as seedlings in pole stands (situation 12, **FIA-1**) and high presence at survey corners showing partial canopy loss **(PLS-3)**, are also indicative that large-gaps provide adequate light for successful recruitment of tamarack.

Historic Change in Abundance

Today, tamarack seems to be losing its dominant grip on FPn82 sites **(PLS/FIA-1)**. This is most evident in the young growth-stage where tamarack had 80% relative abundance historically, but now it is at 39%. The abundance of tamarack in the more mixed, mature forests is about the same as it was historically. More than any other tree, tamarack has suffered widespread decline in many communities since the PLS surveys. It is debatable if this trend is natural or a consequence of settlement and land management practices. Pollen diagrams and other means of reconstructing the vegetation history of FPn82 and similar peatlands clearly show a recent shift from tamarack to black spruce. Unfortunately, the time resolution of these investigations are not adequate for separating the possibility that the shift to black spruce was a natural response of vegetation to Little Ice Age cooling or the reaction of peatlands to settlement and logging. Better documented are historic outbreaks of larch sawfly, beginning as early as 1900 in Minnesota. Defoliation by these insects left thousands of acres of stressed tamarack to die from prolonged drought (e.g. 1930’s), larch beetle infestations, or disease. Unlike the tamarack in the AP System, site index of tamarack and fairly dense stocking of trees makes FPn82 sites an economical contributor to forest industry. The loss of tamarack in the young growth-stage could easily be the result of the standard practice of clear-cutting FPn82 sites and attempted conversion to black spruce by aerial seeding. This is done for no better reason than it is far easier to collect black spruce seed, and black spruce has historically been the preferred pulp species. However, conversion is rarely complete as even modest retention of tamarack seed trees results in significant regeneration. Our interpretation is that tamarack is such a strong dominant on FPn82 sites that silvicultural systems relying upon tamarack seed trees (not clear-cutting) would be successful – demonstrating that black spruce seeding is superfluous if not contrary to slowing the widespread decline of tamarack.

Black Spruce

- ***excellent habitat suitability rating***
- ***late successional***
- ***small-gap regeneration strategist***
- ***regeneration window at >50 years***

Suitability

FPn82 sites provide ***excellent habitat*** for black spruce trees. The ***suitability ranking*** of 4.6 for black spruce is influenced mostly by its high presence (40%) as trees on these sites in modern forests **(R-1)**. When present, black spruce is an important co-dominant tree, contributing 14% mean cover in mature stands. The ranking is second behind tamarack on FPn82 sites as sampled by releves. Except for FPn72 and FPn81, the entire FP System offers excellent habitat for black spruce.

Young Growth-stage: 0-55 years

Historically, at 12% relative abundance black spruce was an important initial-cohort tree in young FPn82 stands recovering from stand-regenerating disturbance **(PLS-1, PLS-2)**. Young black spruce represented 14% of the trees at survey corners described as burned **(PLS-3)**. By virtue of their semi-serotinous cones, black spruce are well-adapted to seeding onto burned peatlands after fires. Black spruce was less important following windthrow, representing just 6% of the trees at such survey corners, suggesting that fire favored black spruce regeneration more so than canopy removal. Young FPn82 corners with black spruce trees present were entirely monotypic with all attending bearing trees being black spruce. Using our restrictive half-diameter rule, we did not detect small-diameter black spruce regeneration until the 50-year age-class **(PLS-5)**. This suggests that a substantial amount of the “initial-cohort” black spruce could have been small-diameter survivors rather than newly established trees. Alternatively, FPn82 forests were slow to stock (see Natural Stand Dynamics). Standing dead spruce can hold, and periodically shed viable seed from semi-serotinous cones for up to 20 years or so. It is possible that the growth rate was slow enough that they didn’t reach bearing tree diameters until about age 50. On FPn82 sites tamarack quickly overtops black spruce, and it is possible that the surveyors almost always selected the larger, and apparently more vigorous tamarack as bearing trees when given a choice. This argument is entirely consistent with the observation that all corners with young black spruce were monotypic.

Mature Growth-stage: >55 years

In the mature growth-stage (>55 years), black spruce abundance slowly increases but does not become more frequent than tamarack **(PLS-1, PLS-2)**. The tendency of black spruce to increase relative to tamarack as stands age is the reason we consider it to be ***late-successional*** in FPn82 forests. Unlike forests of the AP System, mature survey corners with spruce were more likely to be mixed (77%). At this point (~50 years), small-diameter black spruce appears, and consistently increases in the following age-classes **(PLS-5)**. It was nearly twice as likely for black spruce to be the smallest tree at a survey corner as it was for it to be the largest one. This pattern, is the signature of an ingressing species, replacing initial-cohort trees by having better establishment and recruitment under a canopy. When black spruce was the smaller tree at a survey corner, it was coming in among larger tamarack 36% of the time, or it was among larger black spruce (45%). On FPn82 sites, black spruce is unequalled in establishing and recruiting seedlings beneath a canopy **(R-2)**. Our interpretation is that FPn82 sites tend to succeed to black spruce because black spruce was able to gain importance in older forests through establishment and recruitment of second-cohort trees.

Regeneration Strategies

On FPn82 sites, the primary regenerative strategy of black spruce is to establish a seedling bank and then recruit individuals in small canopy gaps. It was good at this whether the gap was forming in a declining canopy of tamarack or older black spruce. The PLS data supporting a ***small-gap*** strategy includes: (1) the fact that black spruce steadily increases in abundance as stands age **(PLS-1, PLS-2)**, (2) spruce's peak abundance in undisturbed forest **(PLS-3)**, and (3) the fact that small-diameter regeneration is common beyond about age 50 **(PLS-5)**. More compelling is black spruce's unequalled ability to establish and recruit seedlings in modern forests under a canopy **(R-2)**.

Historic Change in Abundance

Today, black spruce has far greater importance on FPn82 sites than it did historically **(PLS/FIA-1)**. This is most evident in the young growth-stage where black spruce had just 12% relative abundance historically, but now it is at 56%. The abundance of black spruce in mature forests is also higher at 38% abundance today, compared to 20% historically. The trend of black spruce replacing tamarack is widespread in Minnesota peatlands. It is debatable if this trend is natural or a consequence of settlement and land management practices. Pollen diagrams and other means of reconstructing the vegetation history of FPn82 and similar peatlands clearly show a recent shift from tamarack to black spruce. Unfortunately, the time resolution of these investigations are not adequate for separating the possibility that the shift to black spruce was a natural response of vegetation to Little Ice Age cooling or the reaction of peatlands to settlement and logging. Better documented are historic outbreaks of larch sawfly, beginning as early as 1900 in Minnesota. Defoliation by these insects left thousands of acres of stressed tamarack to die from prolonged drought (e.g. 1930's), larch beetle infestations, or disease. Unlike the tamarack in the AP System, site index of tamarack and fairly dense stocking of trees makes FPn82 sites economical and a contributor to the forest industry. The loss of tamarack in the young growth-stage could easily be the result of the standard practice of clear-cutting FPn82 sites and attempted conversion to black spruce by aerial seeding. We doubt that spruce's rise to prominence is threatening to tamarack from a conservation perspective. Long-distance seeding and tamarack volunteers are common even when silvicultural efforts are aimed entirely at black spruce. From a commercial perspective, allowing or encouraging conversion of FPn82 tamarack swamps to black spruce cover-type could be an error in production. All of our data point to tamarack being a far superior competitor on these sites during the young growth-stage, which is about the only time when these swamps show radial growth rates comparable to terrestrial forests.

Northern White Cedar

- ***good habitat suitability rating***
- ***late- (mid-) successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 80-90 years***

Suitability

FPn82 sites provide ***good habitat*** for white cedar trees. The ***suitability rating*** of 3.0 for white cedar is the consequence of rather balanced presence (15%) and mean cover when present (10%, **R-1**). For long-lived conifers with balanced presence and cover, we suspect some loss of seed source, and believe that they might increase significantly if they were planted more often or if seed trees were more numerous. The ranking is third among trees common on FPn82 sites as sampled by releves. White cedar can dominate some FPn peatlands (FPn63), but more often it is a minor component (see Suitability Tables). The FPn82, FPn62, and FPn71 communities all offer good habitat.

Young Growth-stage: 0-55 years

Historically, at 2% relative abundance white cedar was a minor tree in young FPn82 forests **(PLS-1, PLS-2)**. Young cedars represented 9% of the trees at survey corners described as burned **(PLS-3)**, which is surprising given cedar's sensitivity to fire. We attribute its post-fire presence to its tendency to occur in the wetter, "soupier" microhabitats in FDn82 wetlands that were most likely skipped by fire. Following windthrow, white cedar represented 7% of the trees at such survey corners. White cedar does well as a cultivar in open environments, and it seems that following fire or windthrow, residual small-diameter cedars succeeded. Small-diameter white cedar regeneration coming in among larger trees was not detected during the young growth-stage **(PLS-5)**. All cedar records in the young growth-stage were as the largest tree at a corner. Apparently, the effect of wind or fire was to leave the better-established, larger-diameter cedars that we modeled to be under 55 years old.

Mature Growth-stage: >55 years

Although the compositional movement of species in the mature growth-stage of FPn82 forests is small in comparison to terrestrial forests, there is clear movement involving the 70-110 year age-classes in the ordination **(PLS-4)**. This movement is caused by ingress of white cedar and a following pulse of recruitment. In the 80- and 90-year age classes, cedar abundance rises to an unbelievable 80% or more in one of our more restrictive analyses. This pulse coincides with age-classes that have far fewer survey corners contributing (~150) compared to adjacent classes with about 1,000 survey corners. Some data smoothing would suggest that the peak was in reality closer to 10% **(PLS-2)**. In spite of the data problems, we believe that ingress and peak recruitment for white cedar occurred when FPn82 forests were about 80-90 years old. Most compelling is the fact that white cedar shows the same successional pulse of abundance at 80 years in other communities that are well-sampled. Following this peak, cedar abundance drops rapidly to about 5% sustained abundance in older age-classes. Recruitment and survivorship during the pulse must have been excellent as we detected fair amounts of small-diameter regeneration only in the 80-90 year age-classes **(PLS-5)**. Smaller diameter cedars were mostly replacing larger-diameter tamarack (61%); less often cedars were starting to form rather pure inclusions of cedar (30%). Following its pulse of recruitment, persistence from that point forward is attributed mostly to longevity. Because cedar shows pulsing behavior in the mature growth-stage it could be considered a ***mid-successional*** species in FPn82 forests, as it seems to have responded to some condition limited to middle-aged forests. However today, white cedar shows excellent ability to establish and recruit seedlings beneath a canopy **(R-2)**. Its ability to develop significant advance regeneration in combination with its persistence in older forests argues for ***late-successional*** status as its primary attribute.

Regeneration Strategy

White cedar's primary regenerative strategy on FPn82 sites is to fill ***large-gaps***. It is most successful at this when gaps are forming within a declining canopy of tamarack. In the historic PLS data this interpretation is supported by: (1) the fact that white cedar abundance responds to the decline of tamarack in the mature growth-stage **(PLS-2)**, and (2) it has peak regeneration in a gap window rather than an ingress or post-disturbance window **(PLS-5)**. The high percent of white cedar seedlings under poles (situation 12) in the FIA data **(FIA-1)** is also a characteristic of species that tend to regenerate well under a proximal canopy (a large gap strategy) given that in this community trees rarely achieve tree diameter (>10"; note the paucity of situations involving trees, 13, 23, 33). The releve sampling of mature FPn82 forests shows that white cedar has excellent ability to establish and recruit seedlings under a full canopy **(R-2)**. Its indices of regenerative success (4.0-4.3) are most in line with species that do well in small-gaps, but its tree index (3.0) suggests that recruitment to heights >10m is difficult without release at the scale of a large gap. We believe that cedar's success was partially tied to its resistance to pests and disease in comparison to that of tamarack and black spruce, which are subject to outbreaks that minimally created large canopy gaps if not rather open conditions.

Historic Change in Abundance

Today, white cedar is about as abundant as it ever was in young FPn82 forests **(PLS/FIA-1)**. In mature forests, cedar has seemed to lose some ground as historically cedar represented 7% of the trees and now accounts for just 3%. The reversal of landscape abundance of FPn82 forests suggests that significant amounts of older, mixed cedar and tamarack stands on these sites has been lost. The rather high presence of cedar regeneration (42%) in the releves **(R-2)** suggests that silvicultural techniques aimed at releasing advance regeneration of cedar would help to correct the modest losses.

(PLS-1) Historic Abundance of FPn82 Trees in Natural Growth-stages

Table values are relative abundance (%) of Public Land Survey (PLS) bearing trees at corners modeled to represent the FPn82 community by growth-stage*. Growth-stages are periods of compositional stability during stand maturation. Arrows indicate periods of compositional change during which tree abundances increase or decrease substantially. Yellow and purple shading groups trees with abundance peaks in the same growth-stage. Percents on the bottom row represent a snapshot of the balance of growth-stages across the landscape *ca.* 1846 and 1908 AD.

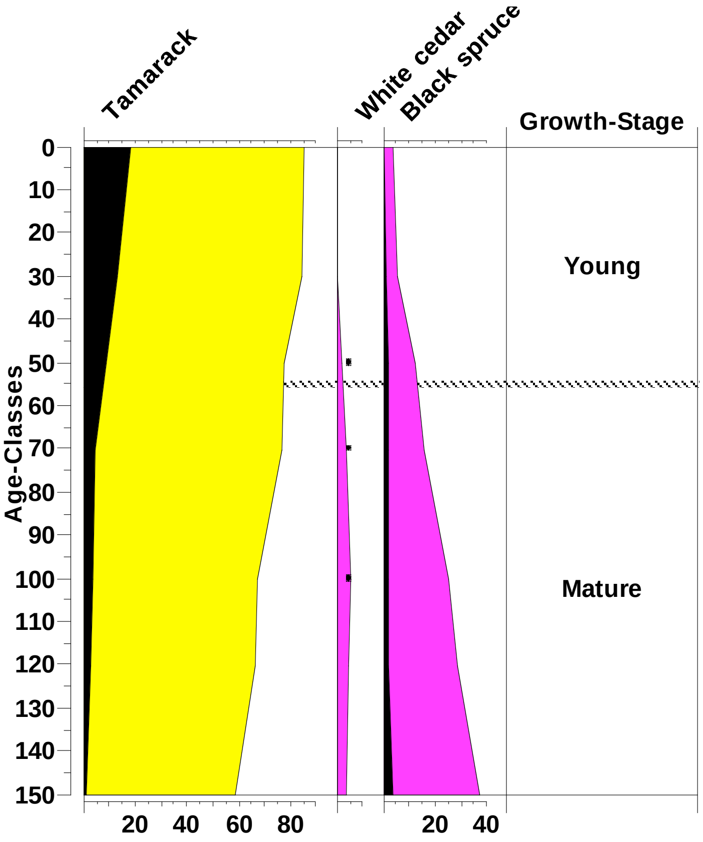
Dominant Trees	Forest Growth Stages* in Years		
	0 - 55	~ 55	> 55
	Young		Mature
Tamarack	80%	↘↘	66%
White Cedar	2%	↗	7%
Black Spruce	12%	↗↗	20%
Miscellaneous	6%		5%
Percent of Community in Growth Stage in Presettlement Landscape	23%		77%

***** FPn82 does not have natural growth-stages as it is dominated by tamarack throughout succession. The break at 55 years was imposed to show slight increase in the relative abundance of black spruce and white cedar in older forests.

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

(PLS-2) Abundance of trees throughout succession in FPn82

Graphed for the individual species of FPn82 trees is their relative abundance (%) as PLS bearing trees by age class. Species with good-to-excellent suitability have graphs colored as follows: early successional (yellow); mid-successional (green); late-successional (magenta). The data were smoothed from adjacent classes (3-sample moving average). Black inset for tamarack and black spruce shows the proportion of bearing trees that were small-diameter trees that were presumably recruiting to bearing tree size (~4" dbh, see **PLS-5**). For white cedar, the presence of small-diameter trees is indicated by black dots rather than insets because the numbers are small.



FPn82, J.C. Almendinger, April 2008

Note: for FPn82 the growth-stage at 55 years was arbitrarily set. Here "succession" amounts only to having black spruce and some white cedar gradually replace tamarack as stands mature.

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

(PLS-3) Historic Abundance of FPn82 Trees Following Disturbance

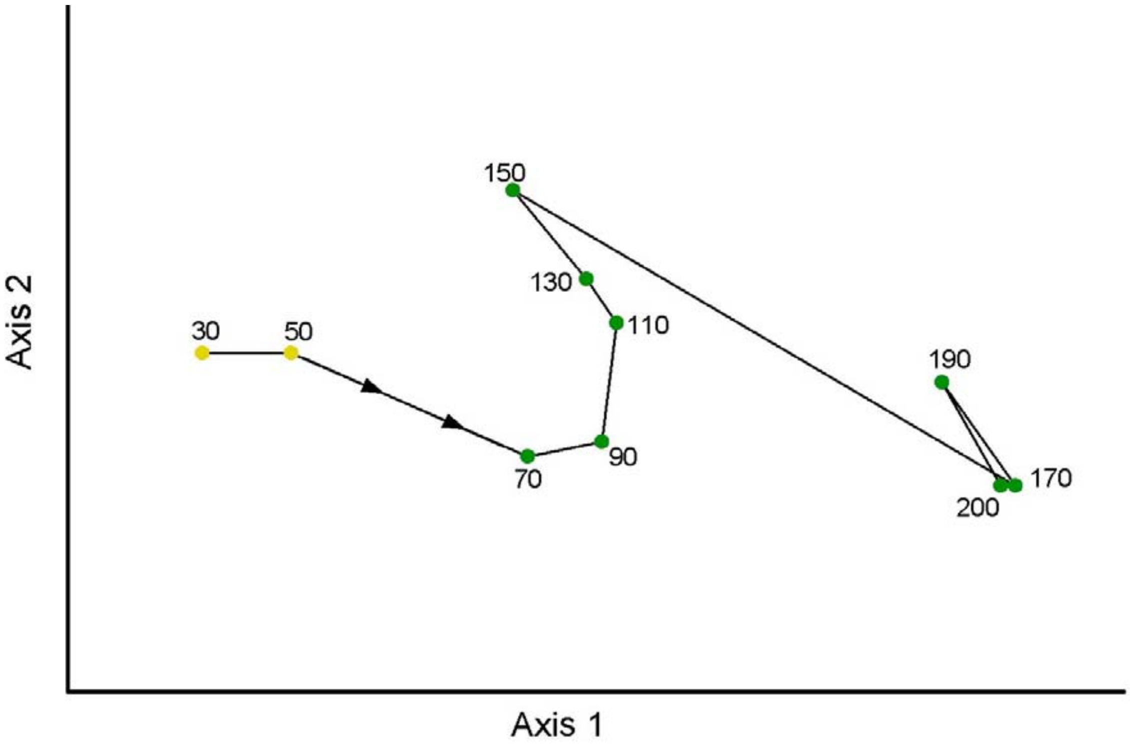
Table values are raw counts and percentage of Public Land Survey (PLS) bearing trees at survey corners likely to represent FPn82 forests. The columns represent our interpretation of disturbance at the survey corners. Shading associates trees that peak in the same disturbance category.

Tree	Burned		Windthrown		Maintenance		Mature	
White cedar	**7**	**9%**	**13**	**7%**	**10**	**3%**	**429**	**7%**
Tamarack	**58**	**76%**	**162**	**87%**	**332**	**87%**	**4268**	**72%**
Black spruce	**11**	**14%**	**12**	**6%**	**41**	**11%**	**1195**	**20%**
Total (% of grand total, 6538)	**76**	**1%**	**187**	**3%**	**383**	**6%**	**5892**	**90%**

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

(PLS-4) Ordination of Historic FPn82 Age-classes

The distance between age-class points reflect change in composition from one age-class to another. Long distances between age-classes indicate some species mortality and replacement by other species. Short distances suggest little change in composition. For the FPn82 community, this entire graphic is highly magnified as movement compared to communities that exhibit true succession is miniscule. If plotted at a comparable scale, the lines and points would be and indecipherable knot near the origin. For this reason there are no recognized growth-stages, rather age 55 was chosen as an arbitrary split to separate young and mature Apn81 forests at a time of silvicultural importance. The general wandering of the points to the right is caused by increased black spruce and white cedar in older age-classes.



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

(PLS-5) Historic Windows of Recruitment for FPn82 Trees

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

Initial Cohort	Species	Peak years	P-D 0-50 years	G-1 50-150 years	I-1 >150 years
Yes	**Tamarack**	**0-30**	**Excellent**	**Fair**	**--**
Yes	**Black spruce**	**>50**	**Poor**	**Fair**	**--**
No	**White cedar**	**80-90**	**--**	**Excellent**	**--**

Recruitment windows from ordination PLS-4:

- **P-D:** post-disturbance filling of understocked areas, 10-50 years
- **G-1:** gap filling during decline of initial-cohort tamarack, 50-150 years
- **I-1:** ingress of seedlings under canopy of tamarack and black spruce, with some whitecedar, >150 years

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

Shading: light yellow = trees with peak regeneration immediately after disturbance; **light green** = trees with peak regeneration in gaps formed during the decline of the initial cohort

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

(R-1) Suitability Ratings of Trees on FPn82 Sites

This table presents an index of suitability for trees in FPn82 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 FPn82

Tree	Percent Presence as Tree	Mean Percent Cover When Present	Suitability Index*
Tamarack (Larix laricina)	81	28	5.0
Black spruce (Picea mariana)	40	14	4.6
White cedar (Thuja occidentalis)	15	10	3.2

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

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

(R-2) Natural Regeneration and Recruitment of Trees in Mature FPn82 Stands

This table presents an index of regeneration for FPn82 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 FPn82 communities. Changes in the index values from one stratum to another can be used to estimate regenerative bottlenecks, whether establishment (R-index) or recruitment (SE-, SA-, or T-indices).

Natural regeneration indices for regenerants, seedlings, saplings, and trees common in the canopy of Northern Rich Tamarack Swamp (Western Basin) – FPn82

Trees in understory	% presence R, SE, SA	R-index	SE-index	SA-index	T-index
Tamarack (Larix laricina)	**90**	**3.7**	**3.7**	**4.7**	**5.0**
Black spruce (Picea mariana)	**73**	**4.8**	**4.7**	**4.7**	**4.0**
White cedar (Thuja	**42**	**4.0**	**4.0**	**4.3**	**3.0**

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

% presence: the percent of 48 FPn82 sample plots with that species present under 10m tall (R, SE, SA layers)
R-index: index of representation as true seedling or under 10cm tall
SE-index: index of representation as seedlings under 2m tall
SA-index: index of representation as saplings 2- 10m tall
T-index: index of representation as a tree >10m tall
All indexes: equally weight (1) presence, (2) mean cover when present, and (3) mean number of reported strata, the frequency distributions of which are segmented equally by area into 5 classes.

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

(FIA-1) Structural Situations of Trees in Mature FPn82 Stands

This table presents percentages of structural situations for trees as recorded in Forest Inventory Analysis (FIA) subplots that we modeled to be samples FPn82 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
Black spruce	**1830**	**48%**	**16%**	**34%**	**1%**	**0%**	**0%**
Tamarack	**1145**	**35%**	**32%**	**28%**	**2%**	**0%**	**2%**
White cedar	**87**	**17%**	**21%**	**61%**	**0%**	**0%**	**1%**

Canopy Situations

† **11** = Sapling in a young forest where saplings (dbh <4”) are the largest trees

† **22 =** Poles in a young forest where poles (4”<dbh<10”) are the largest trees

† **33 =** Trees in a mature stand where trees (>10”dbh) form the canopy

Subcanopy Situations

† **12 =** Saplings under poles

† **23 =** Poles under trees

Understory Situation (remote canopy)

† **13 =** Saplings under trees

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

(PLS/FIA-1) Abundance of FPn82 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 FPn82 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**	**> 55**	
	Young			**Mature**	
Tamarack	**80%**	**39%**	↘↘	**66%**	**57%**
Black Spruce	**12%**	**56%**	↗↗	**20%**	**38%**
White Cedar	**2%**	**2%**	↗	**7%**	**3%**
Miscellaneous	**6%**	**3%**		**7%**	**2%**
Percent of Community in Growth Stage in Presettlement and Modern Landscapes	**23%**	**60%**		**77%**	**40%**

Natural growth-stage analysis and landscape summary of historic conditions is based upon the analysis of 2,840 Public Land Survey records for section and quarter-section corners. Comparable modern conditions were summarized from 1,542 FIA subplots that were modeled to be FPn82 sites.

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

Forest Health

Tamarack

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Water table fluctuations	“	Predispose to mortality
Larch casebearer	Seedlings and saplings	“
Larch sawfly	Saplings and larger	“
E. Larch beetle	Pole-sized and larger	Mortality
Stem decay	“	Volume loss

WATCHOUTS!

- Natural or induced water table fluctuations can predispose tamaracks to mortality, usually caused by larch beetle.

- Prolonged defoliation by larch casebearer or larch sawfly can also predispose tamarack to mortality.

- Presalvage/ salvage stands if larch beetles are causing mortality because, once established, they rapidly spread to both weakened and healthy trees.

- 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.

Black Spruce

Agent	Growth stage	Concern/ Effect
Armillaria root disease	All stages	Mortality
Dwarf mistletoe	“	“
Spruce budworm	“	Topkill, mortality
Butt rot and stem decay	Pole sized and larger	Volume loss

WATCHOUTS!

- Dwarf mistletoe can be controlled by broadcast burning or by using the “5 foot cutting rule” during harvest. All living black spruce needs to killed in order to eradicate dwarf mistletoe on a site. If it is not feasible to use the 5 foot rule, some type of site preparation (hand cutting, winter shearing, herbicides, combination treatments) is needed to eliminate all living black spruces prior to regenerating black spruce on the site.

- If dwarf mistletoe pockets are present on or near a timber sale, adjust sale boundaries to include them and use the pockets as landings.

- If the stand has an unmerchantable edge due to dwarf mistletoe, Site Level Guidelines allow harvest or shearing of that edge. Treat a minimum width of 2 chains into the adjacent stand in order to prevent the spread of dwarf mistletoe onto the harvested site.

- Resurvey harvested sites after 1 to 2 years in order to find any black spruce that survived. All living spruces should be killed or cut down. Repeat 10 years after the initial harvest.

- In northeast and north central counties, presalvage/ salvage stands as budworm defoliation starts to cause mortality of the dominant trees.

- 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.

White Cedar

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

WATCHOUTS!

- Encourage and preserve all white cedar regeneration. Consider retaining white cedar during harvests to ensure a local seed source.

- 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.

Public Land Survey

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

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

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

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

Modern Forest

Releve Samples

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

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

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

For more information on the releve method and NPC Classification:

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

FIA Samples

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

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

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

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

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

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

Link to the USFS website, north central