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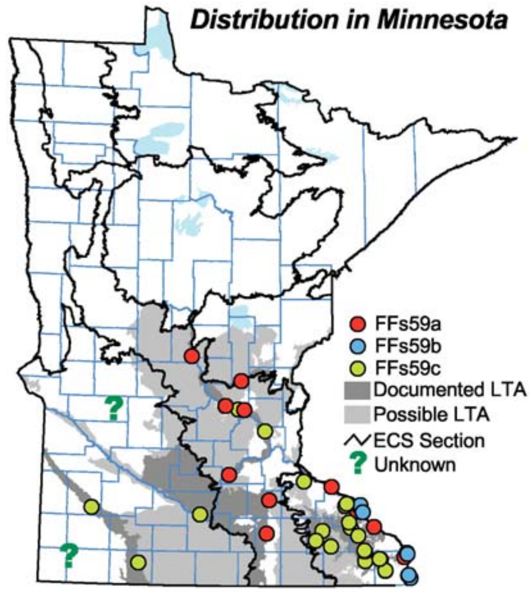
# FFs59 – Southern Terrace Forest

Natural Disturbance Regime, Stand Dynamics, and Tree Behavior

## Introduction and Management Highlights

Southern Terrace Forests (FFs59) are a common riparian community found mostly within the Paleozoic Plateau ecological Section of Minnesota. Outliers of this community though are associated with any major river in southern Minnesota, including the Mississippi, Minnesota, and Des Moines rivers. Detailed descriptions of this community are presented in the DNR Field Guides to Native Plant Communities of Minnesota.




The range of FFs59 forests in Minnesota (shaded) and distribution of releve samples (red, blue, and green dots).

### Commercial Trees

As a commercial forest, FFs59 sites offer an incredible selection of crop trees because they are transitions between upland forests and forests of active floodplains. Within FFs59 stands, microsites favor either terrestrial or floodplain species. Silver maple, American elm, cottonwood, green ash, hackberry, swamp white oak, and box elder are all ranked as excellent crop trees (see Suitability Tables), and these species would be favored on FFs59 microsites that resemble active floodplains. Basswood, red elm, and black ash are also ranked as excellent crop trees, and they would be favored on FFs59 microsites that appear more terrestrial. Black walnut stands alone as the excellent-ranked crop tree that is unique to the transitional habitat of FFs59 forests. Bitternut hickory is ranked as a good crop tree, and stands could be managed to perpetuate bitternut hickory as a co-dominant on the more terrestrial microsites, especially when bitternuts are already present.

Among these species, basswood, willow (*Salix amygdaloides* or *S. nigra*?), American elm, green ash, black ash, and swamp white oak were the dominant native trees that have occupied FFs59 sites for a long time and have had the opportunity through successive generations to adapt to physical conditions typical of these sites **(PLS/FIA-1)**. Red elm, hackberry, and black walnut, are likewise native to FFs59 sites but occurred naturally at lower abundance. The consequence of logging, settlement, tiling, and flood control in the past century has been to promote much more silver maple, black ash, and green ash than was usual. Past history and land use as also encouraged the ingress of species that were not significant in native FFs59 stands such as box elder. The increased abundance of the silver maple, the ashes, and box elder complicates our interpretations and the use of natural regeneration models as silvicultural strategies.

### Natural Silvicultural Approaches

In the historic landscape, most FFs59 stands (85%) were in the mature growth-stage. Roughly, these were stands 35-155 years old. At this time, stands had naturally thinned to densities far short of full stocking in southern mesic hardwood forests. These stands were in a perpetual state of offering large-gap regeneration opportunities. Large-gaps were formed by the demise of very large-diameter, full-crowned elms or by the natural interruptions of FFs59 sites such as overflow channels. No tree showed small-gap behavior, even though they might do so in the adjacent mesic hardwood forests (e.g. basswood). Only cottonwood was restricted to the behavior of an open strategist. All other species exhibited large-gap behavior whether primary or secondary. Normally, we would recommend silvicultural systems that create large gaps like some seed-tree practices, shelterwooding, and group selection. In this case, we believe that prescribing *a priori*, a pattern of tree removal at the stand scale would be a mistake. FFs59 stands have inherent large-gap pattern that can only be evaluated in the field. To perpetuate mature FFs59 stands, we recommend selective systems that allow for the forester to react to microsite, tree quality, and advance regeneration. The forester should keep in mind the idea that removal patches should involve a few large trees and that the likely pool of recruits are already saplings or poles. Flooding could easily wipe out the seedlings that one might expect to fill a gap.

Historically, there were not extensive areas of young, small-diameter FFs59 forests. Just 7% of the historic landscape was modeled to be under 35 years old. Our vision of post-flooding FDs59 sites is that the flood's effect was to eliminate canopy trees and all advance regeneration. The new forest composition was set mostly but the vigorous saplings and poles of the parent stand. For stands with full mid-canopies, removal of the large canopy trees and selection of future crop tree among the poles and saplings would approximate the effect of intermittent flooding. Clear-cutting with reserves might approximate severe floods, but attention should be paid to creating the mineral-soil seedbeds that were naturally accomplished by the erosive or depositional effect of natural floods. If seed-origin trees are to populate the future forest, open strategists like cottonwood, silver maple, and green ash should be among the target species.

Old FFs59 forests occupied about 8% of the historic landscape. Compositionally they were not much different from mature FFs59 stands. Structurally, they were park-like and had very large-diameter, large-crowned trees. The natural pattern of mortality and replacement involved the death of individual trees and replacement from below. Selective harvesting from above best approximates the natural dynamics. Though single-tree, the gaps were naturally large an should favor the FFs59 species restricted to the large-gap strategy such as swamp white oak, bur oak, hackberry, bitternut hickory, and American elm.

It is important to note that FFs59 bottomlands are prime agricultural land, and much of this habitat has been converted to fields. Considerable acreage of these fields has come into public ownership, and private land owners are being pressured to create buffers of natural vegetation to alleviate flooding and improve water quality. Thus, there is a need to restore young FFs59 forests. Direct seeding has proven effective and should be directed to FFs59 species with open regeneration strategies. Willow, cottonwood, basswood, silver maple, green ash, and black walnut are the obvious choices for meeting the goal of forest cover. Trees of high value like black walnut and perhaps swamp white oak and black ash could be added to the seeding mix in anticipation of tending individuals of superior form for sawlogs or veneer.

**Management Concerns**

By definition, FFs59 forests occur only on river and stream terraces. Because they are no longer active terraces, the terrace surface is capped with finer soil particles than are active floodplains. Because flood energy varies from year-to-year and because energy wanes in the course of a single flood, a variety of soil particle sizes are removed or deposited. The consequence is the formation of fine-loamy surfaces that are very susceptible to compaction by heavy equipment. Because water tables are high and drainage generally poor, the surface is often saturated and subject to rutting. Rarely there are active groundwater seeps that must be avoided by heavy equipment. Frozen soil represents the only safe condition to avoid compaction or rutting. Late-summer, dry conditions may provide operational opportunities, but monitoring current site conditions is essential.

The landscape balance of growth-stages and stand ages for the FFs59 community is not much different than it was historically (PLS/FIA-1). Today, there is slightly more young forest (<35 years) and slightly less old forest (>155 years) than in pre-settlement times. We believe that wildlife populations are probably reacting to FFs59 habitat as they always have at the stand scale. The greatest loss has been to agricultural conversion and restoration of FFs59 forest in general is a reasonable management goal. Compositional changes are more of a concern. Most obvious is the loss of willow, basswood, and black walnut. Willow and basswood are gone from young forests and old forests have almost no black walnut. The loss of black walnut almost certainly signals a corresponding loss of butternut as well. In either case, conservation of walnut and butternut on these sites is important. Dutch elm disease has caused the decline of old American elms, but elm is still present and abundant in smaller diameter classes. Both black and green ash have been the benefactors of the modern situation, but neither tree achieves enough cover to warrant control.

## Natural Disturbance Regime

Natural rotation of catastrophic and maintenance disturbances were calculated from Public Land Survey (PLS) records at 817 corners within the primary range of the FFs59 community. At these corners, there were 1,627 bearing trees comprising the species that one commonly finds in FFs59 forests.

The PLS field notes described none of the FFs59 landscape as recovering from stand-regenerating fire.

The surveyors described some lands as sparse forest or scattered timber without suitable-sized trees for scribing. Such corners were encountered at about 5% of the time, and windthrow was cited as the proximal cause of tree mortality, however stress caused by flooding may initiate decline in tree vigor to precede windthrow. We have estimated a rotation of 308 years for windthrow.

Far more common at FFs59 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, open bottoms, or scattered timber with distances to bearing trees that were intermediate between the distances for windthrown lands and what is typical for fully stocked terrace forests. About 12% of the survey corners were described as such, resulting in a calculated rotation of 40 years for disturbances that maintained early and mid-successional trees on FFs59 sites. That no corners were described as burned or windthrown is unusual in Minnesota, and it suggests that disturbance agents like flooding and disease were the more prevalent, but undocumented cause of partial canopy loss.

| **Natural Rotations of Disturbance in FFs59 Forests Graphic** | |
|---|---|
| | **Banner text over photo** |
| **Catastrophic fire photograph** | **NONE elim photo or x-out** |
| **Catastrophic windthrow photograph** | **308 years** |
| **Partial Canopy Loss, photograph** | **40 years** |

The rotation of 308 years exceeds the longevity of most species in FFs59 forests. Natural stand dynamics, therefore, involves at least a few generations of trees. Apart from the loss of some initial cohort willow and basswood, there was little compositional succession as the dominant elms and ashes were capable initial-cohort species, and were able to replace themselves indefinitely. The rotation of 40 years for maintenance disturbances matches rather closely those of southern mesic hardwood forests (MHs), but it seems unlikely that the disturbance agents are the same, especially because there were no explicit references to fire or windthrow in the survey notes. We believe that chronic flooding was the major stressor on floodplain and terrace forests. We believe also that the effects of flooding are less predictable than fire and windthrow because timing and duration selected differently among the many species in these forests and differently among the diameter cohorts. Flooding differs from fire and windthrow in that dormant, young trees are most likely to survive. Thus, our methodological assumption that small diameter stands were the most recently disturbed may be wrong and our calculated rotations in error. Nonetheless, it seems clear that catastrophic disturbance was rare and that large- to small-gap silvicultural strategies would most applicable in managing these forests.

## Natural Stand Dynamics & Growth-stages

FFs59 forests are among several wetland communities where a particular hydrologic regime translates into dominance of a single species. Here, intermittent flooding and possibly the flux of groundwater in shallow aquifers strongly favored American elm in historic times. Because of the devastating effect of Dutch elm disease on the larger-diameter elms, dominance is now shared among American elm, black ash, and green ash. There is little "succession" because American elm and the ashes dominate all growth-stages. Proximal disturbances like fire and windthrow, while noteworthy in the PLS records, were not the main means of re-setting stands to a youthful structure and composition to be followed by predictable compositional changes that we attribute to stand maturation processes. Storm events that erode overflow channels within FFs59 sites, the deposition of sediment during floods, down-cutting of the main stream and river channels below the FFs59 terraces, and outbreaks of diseases and pests targeting flood-stressed trees probably had as much to do with the mortality of large American elms (and now ash) on FFs59 sites as did events as obvious as fire or windthrow.

| Views and Summaries for FFs59 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. |

The general pattern of compositional change during stand maturation is for lots of initial change followed by significant deceleration in the mature growth-stage and even more in the old growth-stage **(PLS-4)**. We believe that prolonged flooding was the primary regenerative event for FFs59 forests by directly killing mature trees or weakening them to the point were secondary agents would kill trees. Windthrow of these weakened trees was probably a secondary consequence (**PLS-3**, and Natural Disturbance Regime). Most of the compositional movement initially is caused by the positive reaction of basswood and willow to flooding and the rapid demise if these initial-cohort trees. From that point on, compositional change about the core elm population was steady and directional **(PLS-4)**. This movement seems to be related to the tendency of FFs59 stands to undergo steady decline in tree density. This concept comes from our observation that that average distance to bearing trees increases steadily across the growth-stages from 31 feet in young forests, to 42 feet in mature forests, to 51 feet in old FFs59 forests. In more descriptive terms, FFs59 stands in the course of maturation achieve a park-like structure of widely spaced, very large (>30" dbh) trees. This is quite different from the typical model of succession in upland hardwoods where tree density is fairly stable among the growth-stages (~30 feet mean distance to bearing trees), where the formation of multiple understory layers chokes out all sunlight, and where shade-tolerance tables are predictive of the seral pattern.

**Young Growth-stage: approximately 0-35 years**
Just 7% of the FFs59 landscape in pre-settlement times was covered by forests estimated to be under 35 years old **(PLS-1)**. About half of these young forests were monotypic. American elm and willow were the most common pure cover-types, but there were examples where all bearing trees were black ash, box elder, and silver maple. Survey corners of mixed composition were some combination of elm or ash mixed with minor species like cottonwood, black walnut (butternut), or swamp white oak (bur oak). American elm, black ash, green ash, basswood, and willow were the

true initial-cohort species.

Catastrophic re-initiation of FFs59 forests was a rare event. No young stands were described by the surveyors as having been burned (PLS-3). Windthrow was more commonly observed but still, its rotation of 308 years exceeds the normal longevity of the community dominants. Using a 308 year rotation for stand-replacement does not yield an equilibrium solution of even 8% forests under 35 years. Clearly events other than fire or windthrow moved FFs59 stands into the young growth-stage. Our best guess is that prolonged flooding was the proximal agent to kill mature trees and create smaller-diameter stands that we would have modeled as belonging to the young growth-stage. Flooding is quite different from fire and windthrow as it favors vigorous trees in the small-to-mid-diameter ranges and tends to kill most advance regeneration and weakens canopy trees. In terrestrial hardwood forests, windthrow seems to favor release of shade-tolerant seedling banks, whereas flooding seems to favor release of saplings and small trees. It is significant that American elm, green ash, and black ash – the post-disturbance dominants – are among the few trees with excellent recruitment indices for saplings (R-2). It is significant also that no tree showed excellent regenerant and seedling indices. Many of these species bank incredible numbers of seedlings in terrestrial habitats, but not on FDs59 sites. Apparently flooding, even floods that don't re-initiate FFs59 stands, causes significant mortality of seedlings.

We suspect that a significant component of young FFs59 forests were seed-origin trees that were established on mineral soils of either the erosional or depositional surfaces following floods. FFs59 terraces offer fine-scale variation in mineral soil particle sizes. The overflow channels tend to be sandier and provide more eroded surfaces, which we believe favored species shared in common with active floodplains like silver maple, American elm, green ash, willow, and cottonwood. Interfluves and the more stagnant backwaters tend to be depositional surfaces with silty soils, which we believe favored species shared in common with upland, mesic hardwood forests such as basswood, black ash, hackberry, box elder, and the oaks.

**Mature Growth-stage: approximately 35-155 years**

Most of the historic FFs59 landscape was mature forest (85%, PLS-1) where the rate of successional change slowed greatly (PLS-4). Stands in this stage were more likely to be mixed (74%) than monotypic (26%). An amazing number of species could occur in monotype. Most frequent was black ash, silver maple, and American elm, but there were examples of box elder, red oak, green ash, cottonwood, hackberry, and basswood. Our interpretation is that this is testimony to the patchy habitat offered on FFs59 terraces. Mixed compositions involved mostly American elm and the ashes as they co-occurred with a wide variety of trees. There were 147 different combinations of overstory and understory trees at mature FFs59 survey corners. The incredible mixture of trees is the most striking feature of mature FFs59 forests.

The beginning of the mature growth-stage represents a period where FFs59 forests naturally thinned to densities below what we usually consider full stocking. Some of what seems to be free growing space for trees could have been caused by the demise of initial-cohort willow and possibly basswood (PLS-1). Some of this space could be related to self-thinning of elm and creation of a tall canopy. Regardless, many trees reacted to this event and found it favorable for establishment and recruitment. Among common FFs59 trees, hackberry, black ash, green ash, silver maple, swamp white oak, and bur oak increased in abundance at this time. Several infrequent species show cameo ingress at this time including: quaking aspen, box elder, bitternut hickory, ironwood, red oak, sugar maple, and paper birch. Our interpretation is that there was "something" about 35-55 year-old FFs59 stands that favored trees that we would normally consider terrestrial. Given the variety of shade-tolerances ascribed to this set of trees, "something" could not have been a particular stocking density. For now, we don't understand the forces driving the dynamics of 35-55 year-old FFs59 stands.

The shift to terrestrial species in FFs59 forests early in the mature growth-stage didn't last forever. Eventually maintenance disturbances eliminated the terrestrial species, leaving mature sites dominated by elm and ash (PLS-1). We favor the idea that flooding was a factor of varying intensity and that modest flooding was far more effective at killing advance regeneration than mature trees. Shade-tolerant species counting on low-light establishment and seedling banks were eliminated. Species maintaining a higher proportion of their regeneration as vigorous saplings and poles were favored, such as: American elm, hackberry, box elder, green ash, and black ash **(R-2)**.

**Old Growth-stage: approximately >155 years**

About 8% of the historic FFs59 landscape was estimated to have been FFs59 stands older than 155 years **(PLS-1)**. Nearly all (95%) of the corners with these large old trees were mixed in composition. Many trees that one would find in the initial cohort – American elm, black ash, green ash, black walnut, swamp white oak, and bur oak – are still present in old FFs59 forests. We attribute the dominance of American elm and the ashes in all growth-stages, as well as the persistence of minor initial-cohort trees throughout stand maturation to the fact that flooding is both the primary stand-regenerating event and maintenance disturbance. The frequency of flooding must have been sufficiently short, perhaps matching the 40-year rotation that we calculated, to have assured the continued dominance of American elm and the ashes.

Old FFs59 forests must have been a magnificent sight. The dominant elms and ashes achieved massive diameters (30-50" dbh) and incredible heights; the spacing of trees was park-like; and there was little in the way of tree regeneration and shrubs. Between Dutch elm disease wiping out the very large elms and "improved" control of runoff that historically diminished the shrub layer, such stands are exceedingly rare today and relegated to sites protected from commercial exploitation and agricultural development.

## 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?

## Silver Maple

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

**Identification Problems**
The PLS surveyors did not consistently distinguish between silver and sugar maple. They often referred to silver and red maples as soft maple and to sugar maples as hard maple or just "sugar." For our analysis, references to just "maple" were assigned to silver maple because it is more common in modern FFs59 forests. Releve samples show that red maple doesn't occur in FFs59 forests; silver and sugar maples didn't co-occur; 19% of the samples had sugar maple without silver maple; 81% of the samples were silver maple without sugar maple. Thus, interpretations of the PLS data for the more common silver maple should always be done knowing that some of these trees were likely sugar maple.

**Suitability**
FFs59 sites provide ***excellent habitat*** for silver maple trees. The ***suitability rating*** of 4.9 for silver maple is influenced mostly by its high presence (51%) as trees on these sites in modern forests **(R-1)**. When present, silver maple is an important co-dominant tree, contributing 22% mean cover in mature stands. The ranking is first among a long list of species common on FFs59 sites as sampled by releves. Southern floodplain forest communities in general offer excellent habitat for silver maple, especially FFs68 where silver maple is the dominant tree (see Suitability Tables).

**Young Growth-stage: 0-35 years**
Historically, silver maple was present in just trace amounts in young FFs59 stands recovering mostly from prolonged flooding **(PLS-1, PLS-2)**. No young FFs59 forests were described as burned. Young silver maples were represented 5% of the trees at survey corners described as windthrown, well behind elm, ash, and oak **(PLS-3)**. We believe that windthrow wasn't a major means of re-initiating FFs59 stands, but probably worked in concert with the physical stresses that can weaken trees on river and stream terraces. Small-diameter, silver maple regeneration had its peak abundance and good success in the 30-year age class at the close of the young growth-stage **(PLS-5)**. There were, however, too few bearing tree records in this growth-stage to determine if silver maples had a preference for coming in under certain species.

**Mature Growth-stage: 35-155 years**
In the mature growth-stage silver maple steadily increases in abundance, beginning a trend that will continue into the old growth-stage. Its average abundance in the mature growth-stage was just 5% and well-behind the community dominants **(PLS-1)**. Silver maple's increase in relative abundance is mostly the result of good-to-fair establishment early in the growth-stage and lasting until about age 50 **(PLS-5)**. Recruitment and survivorship must have been good for silver maple to remain an important tree for the next 100 years. During the mature growth-stage, silver maples were present about as often as the largest tree at a corner as they were as the smallest tree. This suggests that recruitment success was about the same throughout the first 50 or so years of stand recovery, creating a variety of diameter classes. Most small-diameter silver maple regeneration was coming in among green ash and American elm.

**Old Growth-stage: >155 years**
In the old growth-stage silver maple was an important co-dominant, occurring always at survey corners of mixed composition. At 9% relative abundance, it was still well behind the dominant American elm and ashes **(PLS-1)**. Because silver maple has its peak abundance in the old growth-stage, we consider it to be ***late-successional***. However, we believe that its importance in old FFs59 forests was not the result of much regeneration and recruitment, but rather silver maple's incredible ability to persist by sprouting. Individual rootstocks commonly maintain a set of several tree-sized boles of varying diameter with individual stems dating to past injuries. Small-diameter

silver maple regeneration coming in among larger trees was not detected during the old growth-stage **(PLS-5)**. At this time, silver maple showed a balance of diameters both smaller and larger than other trees. When silver maple was the smaller tree, it still was most often beneath larger American elm and green ash.

**Regeneration Strategies**

Silver maple's primary, sexual regenerative strategy on FFs59 sites is to establish seedlings in ***open*** conditions. In the historic PLS data this interpretation is supported by: (1) it being most abundant at survey corners recovering from windthrow **(PLS-3)**, and (2) it showing peak establishment in the post-disturbance window rather than gap or ingress windows **(PLS-5)**. More compelling is its poor performance in the understory of older, modern FFs59 stands. Its ability to establish regenerants is just fair and survival to seedling size is poor **(R-2)**. Its indices of success in these categories are typical of trees that require high-light conditions for seedling success. Normally open regeneration strategists are early-successional, but silver maple's incredible sprouting ability carries it through all growth-stages. It's relative abundance actually increases in growth-stages well removed from its early success as seedlings because is a superior competitor when disturbances favor vegetative reproduction. We have the impression that sprout recruitment is best in ***large-gaps***. The peak presence of silver maple as poles in tree stands (situation 23) is typical of large-gap species **(FIA-1)**.

**Historic Change in Abundance**

Today, silver maple is more abundant than it was historically on FFs59 sites **(PLS/FIA-1)**. This is most evident in the earlier growth-stages. In young FFs59 stands, silver maple is now 3% of the FIA trees where it had just trace presence as a bearing tree. In the mature growth-stage, it is now 18% of the trees compared to just 5% historically. Our best guess is that modern stands are more often regenerated by logging than floods, which could favor silver maple's sprouting abilities. Surprisingly, no silver maples were recorded in the FIA sampling of old FFs59 forests. This could be due to chance as there are very few old FFs59 forests today.

## American, Red, and Rock Elm

- ***excellent habitat suitability rating for American and red elms***
- ***poor habitat suitability rating for rock elm***
- ***early successional***
- ***large-gap regeneration strategists***
- ***regeneration window at 0-50 years***

**Identification Problems**
The PLS surveyors did not distinguish among American, red, and rock elms. Thus, interpretations of PLS data for the more common American elm should always be done knowing that some of these trees were likely red or rock elms. FFs59 releve samples show that for plots with elm present: 3% have all three species present; 11% were American elm with red elm; 3% were American elm with rock elm; 3% were red elm with rock elm; 3% were rock elm only; 14% were red elm only; and 63% were American elm only. We consider these elms to be ecologically equivalent for most silvicultural considerations.

**Suitability**
FFs59 sites provide ***excellent habitat*** for **American elm** trees. The ***suitability rating*** of 4.8 for American elm is influenced mostly by its very high presence (65%) as trees on these sites in modern forests **(R-1)**. When present, American elm is an important co-dominant tree, contributing 16% mean cover in mature stands. The ranking is second, tied with cottonwood and behind silver maple on FFs59 sites as sampled by releves. Southern terrace and floodplain communities in general offer excellent habitat for American elm, especially the FFs59 terrace community where it was the historic dominant (see Suitability Tables).

FFs59 sites provide ***excellent habitat*** for **red elm** trees. The ***suitability rating*** of 4.2 for red elm is influenced mostly by its presence (26%) as trees on these sites in modern forests **(R-1)**. When present, red elm is a minor co-dominant tree, contributing 15% mean cover in mature stands. The ranking is eleventh, following silver maple, American elm, cottonwood, box elder, swamp white oak, basswood, hackberry, black ash, green ash, and black walnut on FFs59 sites as sampled by releves. FFs59 forest is the only southern floodplain community that is habitat for red elm (see Suitability Tables).

FFs59 sites provide ***poor habitat*** for **rock elm** trees. The ***suitability rating*** of 1.7 for rock elm is influenced mostly by its low mean cover when present of just 5%. The ranking is 15th among trees common on FFs59 sites (see Suitability Tables). Rock elm is an infrequent tree anywhere in Minnesota and it had just 9% presence in FFs59 forests. Our ranking system is quite misleading for rock elm as FFs59 forests are the best habitat available for rock elm in the state. FFs59 habitat is "poor" for rock elm only in that it doesn't occur in abundance when compared to other species.

**Young Growth-stage: 0-35 years**
Historically, elm was the dominant tree in young FFs59 stands recovering mostly from episodes of prolonged flooding **(PLS-1, PLS-2)**. No young FFs59 forests were described as burned. Young elms represented 37% of the trees at survey corners described as windthrown, which is the most of any FFs59 trees **(PLS-3)**. About 27% of all young FFs59 corners were pure elm. Elm's dominance in the young growth-stage and its leading abundance following windthrow is why we consider elm to be an ***early successional*** species on FFs59 sites. Small-diameter elm regeneration coming in among larger trees was extremely abundant immediately after disturbance, creating a solid cohort of seedlings from which to draw recruits well into the mature growth-stage **(PLS-5)**. This is typical of early successional species, and we interpret this as elm showing excellent ability to recruit into under-stocked areas after major floods and windthrow.

**Mature and Old Growth-stages: 35-155 years and older**
In mature and old FFs59 stands the relative abundance of elm stabilized at about 40% relative abundance **(PLS-1, PLS-2)**. Although diminished from the young growth-stage, it was certain that

elm would remain as the dominant species in the absence of any disturbance. Elm's persistence and abundance in the older growth-stages required continued regeneration, recruitment, and reliance of its secondary strategies that allowed it to respond to fine-scale or maintenance disturbances. Small-diameter elm regeneration was abundant until about the 50-year age-class and remained detectable until about the 70 year age-class **(PLS-5)**. Throughout the mature and old growth-stages elm was about as common as the largest tree at survey corners as it was as the smallest tree, which was the consequence of steady recruitment. Elm regeneration favored coming in under itself. This was true in 45% of all cases in the mature growth stage and this increased to 60% of all cases in old FFs59 forests. This behavior is typical of species able to indefinitely dominate sites. In other cases, elm seemed most likely to replace silver maple and green ash. Of all species common on FFs59 sites, American elm has the greatest ability to develop a seedling bank and recruit seedlings **(R-2)**. This ability allowed elm to remain the dominant tree on FFs59 sites.

**Regeneration Strategy**

FFs59 sites are such good habitat for elm that it is hard to say which regenerative strategy was most important. It did well establishing seedlings and recruiting saplings under any canopy condition. Several characters point to a preference for ***large canopy gaps*** as the most favored strategy. In the historic PLS data this interpretation is supported by: (1) its peak presence at survey corners showing partial canopy loss due to maintenance events **(PLS-3)**, and (2) its excellent performance in the gap regeneration window although it was slightly better post-disturbance **(PLS-5)**. Stronger evidence of its gap tendencies come from the releve sampling of modern forests. Although it has the highest regeneration indices, the good rankings for regenerants and seedlings (3.8) are more in line with species that do well in large-gaps. The FIA data for both American and red elm show that they are successfully regenerating in almost any situation as the balance of their occurrence is in the understory (not situation 33, **FIA-1**).

**Historic Change in Abundance**

Today, elm is less abundant than it was historically and it now shares dominance of FFs59 sites with the ashes **(PLS/FIA-1)**. The relative abundance of elm has slipped 11-16% in all growth-stages. Throughout Minnesota, mature elms have suffered from Dutch elm disease. In many towns, boulevard elms are entirely gone and we usually assume similar loss in native habitats. For FFs59, this is not entirely true. Although diminished from historic abundance, elms are still a common tree. In the FIA sampling there was a surprising amount of large, old elms. The mean diameter of all FFs59 elms is 15", and 10% of the population have diameters over 24". In the PLS data the mean diameter of elm bearing trees was 13" and 7% of the population had diameters over 24". Thus, the diameter distributions of elm bearing trees and FIA trees are not so different and if anything, there are more large elms today. Our interpretation is that FFs59 elms have lost some ground due to Dutch elm disease, but less than we often suspect. Other factors, like altered drainage due to tiling and flood control could be equally responsible for the historic loss of elm.

## Cottonwood

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

### Suitability

FFs59 sites provide ***excellent habitat*** for cottonwood trees. The ***suitability rating*** of 4.8 for cottonwood is the result of balanced presence (30%) and mean cover when present (31%, **R-1**). The ranking is second, tied with American elm and following silver maple on FFs59 sites as sampled by releves. Southern floodplain and terrace communities in general offer excellent habitat for cottonwood (see Suitability Tables). FFs59 and FFs68 communities are the prime habitat of cottonwood in Minnesota.

### Young Growth-stage: 0-35 years

Historically, cottonwood was a minor co-dominant in young FFs59 stands recovering mostly from episodes of prolonged flooding **(PLS-1, PLS-2)**. No young FFs59 forests were described as having been burned. Just a single young cottonwood (1%) was recorded at a windthrown corner **(PLS-3)**. Cottonwood has peak relative abundance (8%) in the 30-year age class and its abundance declines slowly in following age-classes. For this reason, we consider cottonwood to be an ***early successional*** species on FFs59 sites. This behavior is not evident though when its relative abundance is calculated across entire growth-stages **(PLS-1)**. Small-diameter, cottonwood regeneration was detected only in the 30-year age class **(PLS-5)**. The sample size of very young (<20 years) FFs59 forests is very small and the lack of cottonwood is probably due to chance. In modern situations, cottonwood shows almost no ability to establish seedlings under a canopy **(R-2)**. We interpret this as cottonwood showing good ability to recruit into open, under-stocked areas of FFs59 stands recovering from flooding.

### Mature and Old Growth-stages: 35-155 years and older

In mature FFs59 stands the relative abundance of cottonwood stabilizes at about 2% and it persists into the old growth-stage at about 3-4% relative abundance **(PLS-1, PLS-2)**. On FFs59 sites cottonwood can achieve extremely large diameters and old age. We doubt that its presence in mature and old FFs59 forests is related to any establishment and recruitment beyond the first 30 years of the stand's history. No small-diameter cottonwood regeneration was detected in the mature and old growth-stages **(PLS-5)**. Cottonwood was never recorded as the smaller tree at a survey corner past the 30-year age class. Also, it shows no ability to establish and recruit seedlings under the canopy of modern forests **(R-2)**. Our interpretation is that cottonwood's presence in older growth-stages is due entirely to its longevity on FFs59 sites.

### Regeneration Strategy

Cottonwood's primary regenerative strategy on FFs59 sites is to invade ***open habitat*** after stand-floods or windthrow. In the historic PLS data this interpretation is supported by: (1) the fact that cottonwood had its peak abundance in the 30-year age-class, and (2) cottonwood's peak regeneration was in the post-disturbance window **(PLS-5)**. The PLS sampling of young FFs59 forests though is sparse and unreliable. More compelling it cottonwood's behavior in modern forests, where it has very poor ability to establish seedlings or recruit them to heights over 2m **(R-2)**. Its regeneration indices (0.7-1.2) are typical of trees that require open habitat to reproduce by seed. The FIA sampling shows some occurrence of cottonwood as poles in tree stands (situation 23), which is more typical of large-gap strategists **(FIA-1)**. This sampling though involved just 12 trees and is not reliable.

### Historic Change in Abundance

Today, cottonwood is about as abundant as it ever was in FFs59 forests. The sample size of both PLS survey corners and FIA plots is sparse for both the young and old growth-stages, where no cottonwoods were recorded at FIA subplots **(PLS/FIA-1)**. The bulk of both the historic and modern

FFs59 stands though are in the mature growth-stage, where cottonwood had 2% relative abundance in both samplings. FFs59 habitat is prime “bottomland” for agricultural purposes and it might explain the lack of young FFs59 forests in general. Tiling and “improved” drainage might account for far fewer stand-regenerating floods that created the conditions for cottonwood success.

## Box Elder

- ***excellent habitat suitability rating***
- ***mid-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 40-50 years***

**Suitability**
FFs59 sites provide ***excellent habitat*** for box elder trees. The ***suitability rating*** of 4.7 for box elder is influenced mostly by its high presence (56%) as trees on these sites in modern forests **(R-1)**. When present, box elder is an important co-dominant dominant tree, contributing 14% mean cover in mature stands. The ranking is fourth, tied with swamp white oak and following silver maple, American elm, and cottonwood on FFs59 sites as sampled by releves. Southern floodplain and terrace communities in general offer good-to-excellent habitat for box elder, with its performance increasing on the better-drained and silty habitats offered by FFs59 sites in comparison to the active floodplain FFs68 community (see Suitability Tables).

**Young Growth-stage: 0-35 years**
Historically, box elder was presence in just trace amounts in young FFs59 stands recovering mostly prolonged flooding **(PLS/FIA-1)**. No young FFs59 forests were described as having been burned. A single box elder tree was present (1% abundance) at a survey corner affected by stand-regenerating wind **(PLS-3)**. Small-diameter, box elder regeneration was not observed coming in among larger trees immediately after disturbance, but the shape of the curve suggests its presence and we have guessed that it may have had fair regeneration in the post-disturbance window **(PLS-5)**. Because the abundance of box elder increases during the young growth-stage, we believe that it had some ability to recruit into recently flooded habitat.

**Mature Growth-stage: 35-155 years**
In the mature growth-stage box elder is consistently present across the age-classes, averaging about 1% relative abundance for the whole growth-stage **(PLS-1)**. Because of its consistency in this period, we consider box elder to be a ***mid-successional*** species, although it was present in the old growth-stage. Box elder's increase in relative abundance is mostly the result of fair establishment and recruitment during the beginning of the mature growth-stage up until about the 60-year age class **(PLS-5)**. There were insufficient records of box elder regeneration to draw any conclusions about preference for coming in under any particular species. Our interpretation is that box elder had some success coming in among initial-cohort elms and was able to recruit to tree size when openings presented themselves.

**Old Growth-stage: >155 years**
In the old growth-stage box elder was a minor co-dominant tree on FFs59 sites **(PLS-1)**. Small-diameter, box elder regeneration coming in among larger trees was not detected during this growth-stage **(PLS-5)**. In modern forests, box elder shows good ability to recruit under a canopy **(R-2)**. For this reason, we believe that box elder could maintain about 1% relative abundance indefinitely in old FFs59 forests.

**Regeneration Strategy**
Box elder's primary regeneration strategy on FFs59 sites is to establish and recruit seedlings in ***large gaps***. In the PLS data this interpretation is supported by: (1) its peak abundance at survey corners showing partial canopy loss due to maintenance events **(PLS-3)**, (2) its increase in abundance when initial-cohort elms were thinning and likely creating some large-gap habitat, and (3) its fair regeneration in the G-1gap window with peak regeneration in the 30-year age-class **(PLS-5)**. Its high presence as poles in tree stands (situation 23) is also typical of large-gap trees; however, its high presence as canopy saplings and poles (situations 11 and 22) would suggest ability as an open regeneration strategist **(FIA-1)**. Because both the PLS and FIA samplings were sparse, we placed greater emphasis on box elder's performance on releve plots. Box elder has good ability to germinate and establish seedlings under the FFs59 canopy **(R-2)**. Its regenerant and seedling indices (3.2) are typical of species that use large gaps for establishment.

Recruitment to sapling and tree heights is excellent, meaning that establishment is the regenerative bottleneck.

**Historic Change in Abundance**

Box elder is incredibly more abundant today on FFs59 sites than it was historically. It has increased from basically trace amounts to 11-12% relative abundance in both the young and mature growth-stages **(PLS/FIA-1)**. The increase is even more impressive in the old growth-stage where it once accounted for just 1% of the trees and now it has 28% relative abundance. The presence of box elder as a tree (16%) and in the understory (29%) at FIA subplots is far less than its presence as a tree (56%, **R-1**) and in the understory (60%, **R-2**) in FFs59 releves. This suggests that box elder is making greater gains in undisturbed FFs59 forests. This result is quite surprising given box elder's reputation as a ruderal tree.

## Swamp White and Bur Oaks

- ***excellent habitat suitability rating for swamp white oak***
- ***fair habitat suitability rating for bur oak***
- ***late-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at ~50 years***

### Identification Problems

The PLS surveyors did not distinguish between swamp white and bur oaks. Thus, interpretations of PLS data for the more common swamp white oak should always be done knowing that some of these trees were likely bur oak. FFs59 releve samples show that for plots with oak present: there were no plots with both species present; 33% are bur oak without swamp white oak; 67% are swamp white oak without bur oak. We consider swamp white oak and bur oak to be ecologically equivalent for silvicultural considerations concerning release; however, swamp white oak has much better establishment ability under a canopy. White oak (*Quercus alba*) was not recorded in the releve samples of FFs59 sites.

### Suitability

FFs59 sites provide ***excellent habitat*** for **swamp white oak** trees. The ***suitability rating*** of 4.7 for swamp white oak is influenced mostly by its very high mean cover when present (40%) as trees on these sites in modern forests **(R-1)**. For a tree with such local success on FFs59 sites, its presence is surprisingly low, just 19% of the releve samples. This ranking is fourth highest, tied with box elder and following silver maple, American elm, and cottonwood on FFs59 sites. Southern terrace and floodplain communities in general offer good-to-excellent habitat for swamp white oak, with the better-drained FFs59 community being the best (see Suitability Tables). The range of swamp white oak in Minnesota is essentially limited to these FFs habitats.

The ***suitability rating*** of 2.1 for **bur oak** is based upon its 9% presence and 7% mean cover when present **(R-1)**. Its rating is ***fair*** and its ranking is 14th highest among trees common on FFs59 sites (see Suitability Tables). FFs59 terrace sites provide the FFs habitat for bur oak, as it is absent from active floodplains. Its occurrence in this community is due mostly to its widespread distribution within the southern floristic region, where it plays an important and often dominant role in adjacent terrestrial forests.

### Young Growth-stage: 0-35 years

Historically, swamp white oak was an occasional tree in young FFs59 stands recovering mostly from fire **(PLS-1, PLS-2)**. No PLS survey corners assigned to the FFs59 community were described as burned. Surveyor references to windthrow were occasional and swamp white oaks were represented 16% of the trees at corners affected by stand-regenerating wind **(PLS-3)**. This is a high percentage, behind only American elm and ash. This suggests that windthrow was favorable for releasing swamp white oaks that we believe were present as advance regeneration in the parent stand. Small-diameter, swamp white oak regeneration was not detected in the post-disturbance window using our restrictive half-diameter rule **(PLS-5)**.

### Mature Growth-stage: 35-155 years

In the mature growth-stage swamp white oak becomes about as abundant as it will ever be in the course of stand maturation. Its relative abundance increases steadily throughout the growth-stage **(PLS-1, PLS-2)**. Swamp white oak's increase in relative abundance is mostly the result of establishment and recruitment in the G-1 gap window, approximately 30-50 years after stand initiation **(PLS-5)**. Consistent with this idea is its rather high sapling recruitment index (3.8, **R-2**), meaning that likelihood of recruitment to pole and tree size is good for seedlings that have achieved the height of 2m. Small-diameter swamp white oak regeneration was recorded only in the 50-year age-class. For the few records that we had, it seemed that swamp white oak was able to come in under what we usually consider to be tolerant hardwoods such as basswood, black ash, and American elm. It seems likely to us that the window of establishment at about 50 years could reflect swamp white oak having success filling gaps in the American elm canopy as the some of the weaker, initial-cohort elms declined. A property of FFs59 forests is for tree density to decline throughout the course of stand maturation, starting from a mean distance of 31 feet to bearing trees in the young growth-stage and ending at 51 feet in the old growth-stage. The mean distance of 31 feet is typical of closed-canopy forest, but the mean distances for the swamp white oak establishment window were about 42 feet and suggestive of a forest with some large canopy gaps. Perhaps tree density at about 50 years was just right for a burst of swamp white oak regeneration.

**Old Growth-stage: >155 years**

In the old growth-stage swamp white oak was an important co-dominant, occurring always at survey corners of mixed composition. At 10% relative abundance, it was behind only the dominant elms and ash on old FFs59 sites **(PLS-1)**. Because swamp white oak has its peak relative abundance in the old growth-stage, we consider it to be ***late-successional*** on FFs59 sites. Small-diameter swamp white oak regeneration coming in among larger trees was not detected in the old growth-stage **(PLS-5)**. At this time swamp white oaks were almost always the largest tree at a survey corner, suggesting that they could not sustain their abundance through establishment and recruitment. While it is possible that swamp white oaks in old FFs59 forests date back to their window of establishment early in the mature growth-stage, our samples of modern forests suggest that it was nearly as capable as American elm, black ash, and green ash in establishing and recruiting seedlings **(R-2)**. Our interpretation is that when established, swamp white oak seedlings are as capable as any other species in recruiting to taller strata. Its presence as regeneration though is very much lower than most important FFs59 trees, suggesting that establishment is spotty. Swamp white oaks would probably benefit from silvicultural attention to establishment in old FFs59 forests.

**Regeneration Strategy**

Swamp white oak's primary regenerative strategy on FFs59 sites is to fill ***large-gaps***. It was most successful at this when the canopy of initial-cohort of American elms had considerably thinned. In the historic PLS data this interpretation is supported by: (1) the fact that swamp white oak abundance increased in response to the first decline of the initial-cohort species such as American elm and possibly willow **(PLS-1, PLS-2)**, (2) it has high abundance at survey corners showing partial canopy loss **(PLS-3)**, and (3) it shows peak establishment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**. The releve sampling of mature FFs59 forests supports the idea that swamp white oak is a large-gap strategist. Its regeneration indices are good (3.1-3.8) and quite in line with species that tend to recruit in large gaps **(R-2)**. Establishment seems to be a greater regenerative obstacle than recruitment.

**Historic Change in Abundance**

The comparison of historic and modern abundance of swamp white oak is confounded by the fact that the PLS surveyors did not accurately identify swamp white oaks, and apparently the FIA inventory crews did not either as they recorded just one tree in the 1990 dataset as swamp white oak on FFs59 sites. Both cases are out of line with the releve sampling where swamp white oaks were more often recorded than the most probable look-a-like, bur oak. If swamp white and bur oak records are combined it is clear that together, they are now much less abundant in the young and mature growth-stages of FFs59 forest **(PLS/FIA-1)**. It is especially apparent in the mature growth-stage where the abundance of these oaks was 7% historically and now they are just 1% of the FIA trees. In the old growth-stage, the modern abundance of these oaks (12%) is comparable with their historic abundance (10%).

## Basswood

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

**Suitability**
FFs59 sites provide ***excellent habitat*** for basswood trees. The ***suitability rating*** of 4.6 for basswood is influenced mostly by its high presence (37%) as trees on these sites in modern forests **(R-1)**. When present, basswood is an important co-dominant tree, contributing 19% mean cover in mature stands. The ranking is sixth, tied with hackberry and following silver maple, American elm, cottonwood, box elder, and swamp white oak on FFs59 sites as sampled by releves. Only the southern terrace community (FFs59) offers excellent habitat for basswood (see Suitability Tables) because basswood cannot tolerate the flooding regime of an active floodplain.

**Young Growth-stage: 0-35 years**
Historically, basswood was an important tree in young FFs59 stands recovering mostly from prolonged flooding **(PLS-1, PLS-2)**. No young FFs59 survey corners were described as having been burned. Young basswood represented 4% of the trees at survey corners described as windthrown, but the sample is small and unreliable **(PLS-3)**. Its peak abundance in the young growth-stage is why we consider basswood to be an ***early successional*** species on FFs59 sites. Small-diameter basswood regeneration was most often observed coming in among larger trees in the post-disturbance window **(PLS-5)**. This is typical of early successional species, which is an unusual characterization of basswood. Normally, basswood does well in older forests because it has the ability to establish a seedling bank and recruit into canopy gaps. Basswood's performance in the regenerating strata of mature FFs59 forests is just fair **(R-2)** and well below its normal understory abundance. In fact, all trees have diminished performance in the understory of FFs59 forests compared to their performance in terrestrial communities. Prolonged flooding must have effectively eliminated seedlings, and diminished greatly the strategy of banking seedlings. Our interpretation is that basswood's excellent sprouting ability allowed it to be important in young FFs59 forests.

**Mature Growth-stage: 35-155 years**
In mature FFs59 stands the relative abundance of basswood stabilized or decreased very slowly, averaging 9% **(PLS-1, PLS-2)**. Although diminished from the young growth-stage, 9% abundance is still important and basswood followed only elms and ashes as the most common trees on southern terraces. For basswood to persist in this long growth-stage, it must have had some success establishing seedlings and recruiting them to tree size. Small-diameter, basswood regeneration was detected in the early years of stand maturity until the 60-year age-class **(PLS-5)**. At this time, basswood was about equally present as the largest tree at survey corners (11%) as it was as the smallest tree (8%). This is typical of trees that have had recruitment success throughout a fairly long window (60 years here). When basswood was the smallest tree at survey corners, it showed a preference for coming in under itself or under elms. Our interpretation is that during flood-free episodes, basswood could revert to its seedling bank strategy and once established, recruitment of basswood saplings was good. This is supported by basswood's good SA-index, (3.3) in modern FFs59 forests **(R-2)**.

**Old Growth-stage: >155 years**
Basswood was present at low abundance in old FFs59 forests **(PLS-1)**. The sample size of old FFs59 forest though is small and we doubt that basswood had just 1% relative abundance, because it seemed to be so able to re-colonize flood-damaged forest by sprouting. Small-diameter basswood regeneration was not detected using our restrictive half-diameter rule **(PLS-5)**. However, all basswood trees present at old FFs59 survey corners were the smallest trees. It would seem that the basswoods established in the first 60 years of stand maturation were probably dead as they would have all been over 100 years old. Perhaps basswood persisted in

the subcanopy of old forests among massive old elms (many diameters >30 inches) and they just weren't commonly used as bearing trees.

**Regeneration Strategies**

Basswood's primary regenerative strategy on FFs59 sites is to dominate ***open habitat*** after stand-regenerating disturbance. We believe that basswood had some success following windthrow **(PLS-3)**, but it was most successful by sprouting after prolonged floods killed canopy trees. In the historic PLS data this interpretation is supported by: (1) the fact that basswood had its peak presence in young FFs59 forests **(PLS-1)**, and (2) basswood'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 basswood as saplings in sapling stands (situation 11) in the FIA data **(FIA-1)** is also characteristic of species that regenerate effectively in the open. However the FIA sample size of basswood is too small for reliable interpretation. The releve sampling of mature FFs59 forests is our most reliable dataset for interpreting basswood's regenerative strategies **(R-2)**. Basswood has just fair ability to establish seedlings under a canopy on FFs59 sites. Its regenerant and seedling indices (2.3-2.2) are most in line with trees that regenerate in the open or very large canopy gaps. This is considerably diminished from its usual good or excellent ability to establish seedlings in the shade of terrestrial forests. Its good SA-index (3.3) is more in line with trees able to recruit in ***large-gaps***. Basswood's persistence in mature and old forests is evidence that it can function secondarily as a large-gap strategist if it can get seedlings into the subcanopy. Intermittent flooding is the maintenance disturbance on FFs59 sites and we believe that its effect was to kill small seedlings, including those of basswood. Getting basswoods to diameter classes where they have a good chance of surviving flooding was probably a matter of chance. Once past that bottleneck, it seems that basswood were able to recruit into canopy gaps.

**Historic Change in Abundance**

Today, basswood has been nearly eliminated from FFs59 forests. No longer is it important in young forests with just 1% relative abundance compared to 15% historically **(PLS/FIA-1)**. In the mature growth stage it is now just 2% of the FIA trees compared to 9% of the PLS bearing trees. No basswoods were recorded as present in old FFs59 forests. There is great disparity between the FIA sampling of FFs59 sites and our releve sampling of the community. The basswood's presence as a tree in the releve sampling is 37% **(R-1)** compared to 3% presence at FIA subplots. Basswood regeneration was present in 33% of our releves **(R-2)**, far more than the 2% present at FIA subplots. It seems obvious that basswood is doing well in the less-disturbed forests that were the focus of releve sampling in comparison to its fate in average stands with FIA plots. In this case, "undisturbed" may not be the more natural condition. "Improved" management of surface water throughout the range of FFs59 forests may have diminished the frequency of flooding that maintained FFs59 communities, allowing these sites to become more terrestrial and favoring basswood.

## Hackberry

- ***excellent habitat suitability rating***
- ***mid-successional***
- ***large-gap regeneration strategist***
- ***regeneration window at 40-50 years***

**Suitability**

FFs59 sites provide ***excellent habitat*** for hackberry trees. The ***suitability rating*** of 4.6 for hackberry is influenced mostly by its high presence (40%) as trees on these sites in modern forests **(R-1)**. When present, hackberry is an important co-dominant tree, contributing 17% mean cover in mature stands. The ranking is sixth, tied with basswood and following silver maple, American elm, cottonwood, box elder, and swamp white oak on FFs59 sites as sampled by releves. Southern terrace and floodplain communities in general offer good-to-excellent habitat for hackberry, especially the better drained FFs59 community (see Suitability Tables).

**Young Growth-stage: 0-35 years**

Historically, hackberry was present in just trace amounts in young FFs59 stands recovering mostly from prolonged flooding **(PLS-1, PLS-2)**. No young FFs59 sites were described as burned by the PLS surveyors. Hackberries were not recorded at any corners affected by stand-regenerating wind **(PLS-3)**. Small-diameter, hackberry regeneration coming in among larger trees was not detected in the post-disturbance window **(PLS-5)**. Our interpretation is that prolonged flooding effectively killed most adult hackberry trees and also most of the advance regeneration, which is usually present in older FFs59 forests **(R-2)**.

**Mature Growth-stage: 35-155 years**

Hackberry had peak presence as a co-dominant in mixed mature stands, which is why we consider hackberry a ***mid-successional*** species **(PLS-1, PLS-2)**. The first hackberry bearing trees were detected in the 40-year age-class, and its relative abundance rises to about 10% in the 50-70 year age-classes after which it declines. The peak in relative abundance is mostly the result of establishment and recruitment early in the mature growth-stage **(PLS-5)**. Small-diameter, hackberry regeneration was observed coming in among larger trees at the beginning of the growth-stage but not much beyond 50 years **(PLS-5)**. In most cases, hackberry regeneration was coming in under itself, perhaps creating some rather pure pockets of hackberry. Most likely hackberry groves formed on included areas of better-drained soils like old levees, where we commonly see the tree on modern terraces. We interpret this as success of recruiting seed-origin trees as FFs59 stands self-thinned early in the mature growth-stage.

**Old Growth-stage: >155 years**

In the old growth-stage hackberry was barely present **(PLS-1)**. After the 70-year age class, hackberry's abundance declined steadily and stabilized at just about 1% in old FFs59 forests. Small-diameter hackberry regeneration coming in among larger trees was not detected in the old growth-stage **(PLS-5)**. In modern forests, hackberries are quite able to develop a modest bank of seedlings under a canopy **(R-2)** and we presume that there was limited recruitment during the old growth-stage. The hackberry trees present in old FFs59 forests were always the smallest trees at survey corners and were always below elms. Perhaps hackberry persisted in the understory and subcanopy of old forests among massive old elms (many diameters >30 inches) and they just weren't commonly used as bearing trees.

**Regeneration Strategy**

Hackberry's primary regenerative strategy on FFs59 sites is to fill ***large-gaps***. It was most successful at this as FFs59 stand thinned during the young growth-stage and into the early mature growth-stage. In the historic PLS data this interpretation is supported by: (1) the fact that hackberry abundance peaks in response to the decline in tree density at about age 40-50 years **(PLS-2)**, (2) it was present at survey corners showing partial canopy loss but not stand-regenerating windthrow **(PLS-3)**, and (3) it shows peak establishment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**. The releve sampling of mature FFs59 forests represents a far more reliable sampling of hackberries as they were infrequent as PLS bearing trees in many age-classes and were hardly recorded at all in the FIA plots **(FIA-1)**. The indices of regeneration for hackberry are good beneath the canopy of FFs59 forests **(R-2)**. Its regenerant and seedling indices are in a range (3.0-3.5) that is in line with other large-gap species. Once, established though, hackberry seedlings have an excellent chance of becoming saplings 2-10m tall. Because of its low regenerant index (3.0) and because its window of establishment is limited to the 40- and 50-year age-classes **(PLS-5)** it would seem that the greatest obstacle for hackberry in FFs59 forests is the paucity of appropriate habitat for germination and establishment of seedlings.

**Historic Change in Abundance**

Today, hackberry has been nearly eliminated from FFs59 forests. It was not recorded in the FIA inventory in any young or mature forests **(PLS/FIA-1)**. Just a few trees in old FFs59 forests represented all of the hackberry included in the FIA inventory of these sites. There is great disparity between the FIA sampling of FFs59 sites and our releve sampling of the community. Hackberry's presence as a tree in the releve sampling is 40% **(R-1)** compared to 2% presence at FIA subplots. Hackberry regeneration was present in 65% of our releves **(R-2)**, far more than the 1% present at FIA subplots. It seems obvious that hackberry is doing well in the less-disturbed forests that were the focus of releve sampling in comparison to its fate in average stands with FIA plots. In this case, "undisturbed" may not be the more natural condition. "Improved" management of surface water throughout the range of FFs59 forests may have diminished the frequency of flooding that maintained FFs59 communities, allowing these sites to become more terrestrial and favoring hackberry.

## Green and Black Ash

- ***excellent habitat suitability ratings***
- ***mid- (late) successional***
- ***large-gap (open, small-gap) regeneration strategist***
- ***regeneration window at 0-20 years***

### Identification Problems

The PLS surveyors did not distinguish between green and black ash. In modern forests green ash is more common. However, we suspect that black ash was more common historically because green ash has generally shown greater population increases in response to settlement. FFs59 releve samples show that for plots with ash present: 7% have both species present; 34% are black ash without green ash; 59% are green ash without black ash. These species are not much alike with regard to soil and drainage preference, with black ash being more of a wetland species and green ash being more terrestrial. FFs59 sites represent a segment of habitat overlap where they can co-occur. Given though that we are considering just FFs59 habitat, green and black ash do not show much difference with regard to successional position and reaction to light and canopy conditions. Thus, the historic account below is for the species combined, but modern data where they were reliably distinguished is given greater weight in assessing their individual behavior.

### Suitability

FFs59 sites provide ***excellent habitat*** for **black ash** trees. The ***suitability rating*** of 4.4 for black ash is influenced mostly by its presence (28%) as trees on these sites in modern forests **(R-1)**. When present, black ash is an important co-dominant tree, contributing 17% mean cover in mature stands. The ranking of black ash is eighth, tied with green ash and following silver maple, American elm, cottonwood, box elder, swamp white oak, basswood, and hackberry. Black ash is limited to just the FFs59 terrace community (see Suitability Tables).

FFs59 sites provide ***excellent habitat*** for **green ash** trees. The ***suitability rating*** of 4.4 for green ash is influenced mostly by its high presence (44%) as trees on these sites in modern forests. When present, green ash is a minor co-dominant, contributing 10% mean cover in mature stands. The ranking of green ash is eighth, tied with black ash and following silver maple, American elm, cottonwood, box elder, swamp white oak, basswood, and hackberry. Southern terrace and floodplain forests in general are excellent habitat for green ash (see Suitability Tables).

### Young Growth-stage: 0-35 years

Historically, ash was an important tree in young FFs59 stands recovering mostly from prolonged flooding **(PLS-1, PLS-2)**. No FFs59 sites were described as having been burned. Young ashes represented 33% of the trees at survey corners described as windthrown, second only to the elms **(PLS-3)**. Small-diameter ash regeneration coming in among larger trees was abundant in the post-disturbance window **(PLS-5)**. These ash showed some tendency to come in under themselves, but it was also common to have ash regeneration beneath elm and silver maple. Our interpretation is that the immediate presence of ash was from stump sprouts as both species are good sprouters. Because ash populations increase throughout the young growth-stage, we believe that its abundance at the close of the young growth-stage must have been subsidized by seed-origin trees. Both species do well seeding-in on fresh mineral soil left in the wake of floods. FFs59 terraces offer fine-scale variation in mineral soil particle sizes. The overflow channels tend to be sandier and provide more eroded surfaces, which we believe favored green ash like it does on the adjacent, active floodplains. Interfluves and the more stagnant backwaters tend to be depositional surfaces with silty soils, which we believe would be habitat for both species but black ash would be favored if organics were deposited along with the silt.

### Mature Growth-stage: 35-155 years

In the mature growth-stage ash becomes about as abundant as it will ever be in the course of stand maturation. Its relative abundance of 21% is second only to the elms **(PLS-1)**. Ash's ability to decisively replace the initial-cohort trees is why we consider ash to be a ***mid-successional*** species, although it remains important in the older growth-stages. Ash's increase in relative abundance is mostly the result of good establishment and recruitment during the young growth-stage and high survivorship. Regeneration during the mature growth-stage was good. Small-diameter ash regeneration coming in among larger trees was steadily present until the 90-year age class **(PLS-5)**. At this time ash bearing trees were about equally represented as the largest tree at a survey corner as they were as the smallest tree. This pattern is typical of species that have had continued success establishing and recruiting seedlings for a long time. In most cases, these ash showed some tendency to come in under themselves, but it was also common to have ash regeneration beneath elm and silver maple. We interpret this as ash establishing itself as an important co-dominant tree, able to sustain itself indefinitely by establishment and recruitment in the absence of stand-regenerating disturbance. Both black and green ash show good ability to establish seedlings in mature FFs59 forests under a canopy and recruitment to heights above 2m is excellent **(R-2)**.

**Old Growth-stage: >155 years**

In the old growth-stage ash persists at 17% relative abundance, not much different from the mature growth-stage **(PLS-1, PLS-2)**. The persistence of ash in the old growth-stage at levels just slightly lower than in the mature growth stage is why we consider ash to be secondarily a ***late-successional*** species on FFs59 sites. Small-diameter ash regeneration coming in among larger trees was not detected in this growth-stage using our restrictive half-diameter rule **(PLS-5)**. Ash trees though rather commonly occurred as the smaller tree at a survey corner in this growth-stage. At this time it was more common to see it beneath elms. Our interpretation is that in old FFs59 forests, massive elms (many >30" dbh) formed a supercanopy, beneath which ash could persist indefinitely but at slightly lower abundance than during the mature growth-stage.

**Regeneration Strategies**

Ash's primary regenerative strategy on FFs59 sites is to fill ***large-gaps***, although it was clearly successful in almost any canopy situation. Ash's success was most evident when gaps formed as elms self-thinned during the early part of the mature-growth stage. In the historic PLS data this interpretation is supported by: (1) the fact that ash abundance peaks in response to the decline of the initial-cohort willow, basswood, and elm **(PLS-1, PLS-2)**, and (2) it is abundant at survey corners showing partial canopy loss due to maintenance disturbances **(PLS-3)**. Because of the taxonomic confusion in the PLS data we placed greater emphasis on modern samplings of FFs59 forests. In the FIA data, both black and green ash are successful in any canopy situation. The clear dominants of modern FFs59 forests, elms and ashes, are far more prevalent as regeneration rather than trees (not situation 33, **FIA-1**), yet they are among the tree dominants **(R-1)**. The ability to fill all strata is the hallmark of dominant behavior. Ash were dominant in all growth-stages because they have secondary strategies that allow them to behave like ***open*** and ***small-gap*** strategists in addition to their obvious abilities in large-gaps. The releve sampling provides our most reliable information on the behavior of black and green ash. Both species are similar in having good ability to germinate and establish seedlings **(R-2)**. Both species have excellent chances of recruiting seedlings to sapling and eventually tree heights. Their indices of success are most in line with species that do well in large canopy gaps. It is important to remember that FFs59 sites in the mature and old growth-stages have tree densities suggestive of perennial large-gap situations. Part of this is due to the fact that the terrace landform is beset with treeless channels and sometimes open, graminoid-dominated inclusions. Part of this is due to the fact that massive, supercanopy elms with their spreading growth form also led to greater distances from survey corners to bearing trees. In this situation, all trees to some extent show regeneration indices typical of large-gap and open strategists.

**Historic Change in Abundance**

Today, ash is considerably more abundant in FFs59 forests that it was historically. Most obvious is its 41% relative abundance in young forests compared to just 9% historically **(PLS/FIA-1)**. In the mature growth-stage it is now 32% of the trees compared to their abundance of 21% as bearing trees. Ashes are now 30% of all trees in old FFs59 forests compared to 17% in the past. The presence of black ash between releves and FIA subplots is comparable, suggesting little difference between less-disturbed FFs59 forests and the average forest. The presence of green ash is substantially higher in releves compared to FIA subplots, suggesting that it may prefer the less-disturbed releve sites. This is quite backwards of our usual impression that green ash is the more ruderal of the two species.

## Black Walnut (Butternut)

- ***excellent habitat suitability rating for black walnut***
- ***late-successional***
- ***large-gap (open) regeneration strategist***
- ***regeneration window at ~50 years***

**Identification Problems**

The PLS surveyors normally distinguished black walnuts from butternuts. In fact, the PLS surveyors recorded slightly more butternut or “white walnut” than black walnut for FFs59 sites. Our releve sampling of these forests though is almost entirely black walnut, with just a single record of butternut as an understory tree. Almost certainly this is the consequence of butternut canker, which has endangered the tree in Minnesota and elsewhere. Thus, interpretations of PLS data where we have assigned generic “walnut” records to black walnut should be done knowing that historically a good portion of those trees were probably butternut. We consider black walnut and butternut to be ecologically equivalent for most silvicultural considerations.

**Suitability**

FFs59 sites provide ***excellent habitat*** for black walnut trees. The ***suitability rating*** of 4.3 for black walnut is influenced mostly by its high mean cover when present (30%) as trees on these sites in modern forests **(R-1)**. Black walnut was present in just 14% of the releves. When trees have greater mean cover when present than presence, we often suspect an absence of seed trees and believe that such species would perform better if seed trees were more prevalent or if they were more often planted. The ranking is tenth, behind silver maple, American elm, cottonwood, box elder, swamp white oak, basswood, hackberry, black ash, and green ash on FFs59 sites. Only the FFs59 terrace community offers excellent habitat for black walnut as it is not sufficiently tolerant of annual flooding to be of much importance in the FFs68 community (see Suitability Tables). Curiously, it can do well also in southern mesic-hardwood and fire-dependent forests, meaning that the flooding regime of FFs59 forests is not a habitat requirement.

**Young Growth-stage: 0-35 years**

Historically, black walnut was an occasional tree in young FFs59 stands recovering mostly from prolonged flooding **(PLS-1,PLS-2)**. No young FFs59 were described by the early surveyors as having been burned. A single, young black walnut tree was recorded as present at a windthrown survey corner, and it would seem that this was not an important means of providing regeneration opportunities for black walnuts **(PLS-3)**. Small-diameter black walnut regeneration coming in among larger trees was not detected in the post-disturbance window **(PLS-5)**. Our interpretation is that black walnut had very limited success establishing seed-origin trees when the large nuts were buried in alluvium by occasional floods.

**Mature Growth-stage: 35-155 years**

In the mature growth-stage black walnut maintains its modest (3%) abundance on FFs59 sites **(PLS-1)**. Some persistence of black walnut into the mature growth-stage was most likely a result of good survivorship from the young growth-stage and its longevity. During the early years of the mature growth-stage, black walnut regeneration coming in among larger trees was detectable in the G-1 gap window, but at quite low levels **(PLS-5)**. The PLS data are too sparse to suggest any preference that black walnut might have had for coming in under certain species. We believe that black walnuts had limited success establishing seedlings and recruiting them to saplings and trees during this growth-stage because tree density was naturally dropping (see Stand Dynamics).

**Old Growth-stage: >155 years**

In the old growth-stage black walnut was an important co-dominant, occurring always at survey corners of mixed composition. During this growth-stage it has its peak relative abundance at 7% **(PLS-1)**, and for this reason we consider black walnut to be a ***late-successional*** tree on FFs59 sites. Small-diameter black walnut regeneration coming in among larger trees was not detected during this growth-stage **(PLS-5)**. However, we believe that this level of abundance could have been sustained by establishment and recruitment because black walnut has fair ability to do so in old FFs59 forests today **(R-2)**.

### Regeneration Strategies

Black walnut's primary regenerative strategy on FFs59 sites is to fill ***large-gaps***. It was most successful at this when gaps formed due to self-thinning of the dominant elms and tree densities dropped. In the historic PLS data this interpretation is supported by: (1) the fact that it is far more abundant  at survey corners showing partial canopy loss **(PLS-3)**, and (2) it shows peak establishment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**. No black walnuts were recorded in the FIA samples. The releve sampling of mature FFs59 forests is quite consistent with a large-gap strategy. Black walnut has just fair ability to establish seedlings and recruit them to heights over 2m **(R-2)**. Its indices of regeneration (2.3-2.8) are most in line with species needing very large gaps or perhaps ***open*** conditions for recruitment. The chances that black walnut regeneration will survive and recruit to higher strata increase steadily as the seedlings/saplings get larger.

### Historic Change in Abundance

Today, black walnut has been virtually eliminated from FFs59 sites. Just two black walnuts were recorded among 2,447 trees at FIA subplots assigned to the FFs59 community **(PLS/FIA-1)**. No butternut trees were recorded, though there were a handful of records of small-diameter butternuts in the regenerating layer. Thus, the disparity between the releve and FIA samplings of these forests is great. While the 14% presence of black walnut trees **(R-1)** and 7% presence in the regenerating layer **(R-2)** of releves seems modest, it is far more than the trace presence encountered in the average FIA stand. Nearly all of the releve records of black walnut were from lands protected from timber harvest. It seems obvious that the lack of black walnuts in the average FFs59 stand is related to exploitation for their highly valued wood. Butternut is a different story. Butternuts have been nearly eliminated by the exotic butternut canker. Just five butternuts were present at the FIA subplots and just one was present in a releve. All examples were small understory trees or saplings. Black walnuts and butternuts have reached the point where they are far too valuable as seed trees and for their contributions to the gene pool to be exploited for commercial purposes on FFs59 sites.

## Bitternut Hickory

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

### Suitability

FFs59 sites provide ***good habitat*** for bitternut hickory trees. The ***suitability rating*** of 3.1 for bitternut hickory is the consequence of balanced presence (14%) and mean cover when present (11%, **R-1**). The ranking is twelfth among trees common on FFs59 sites as sampled by releves. Only the FFs59 terrace community offers good habitat for bitternut hickory as it is not sufficiently tolerant of annual flooding to be of much importance in the FFs68 community (see Suitability Tables). Bitternut hickory is primarily a tree of southern mesic-hardwood forests that are often adjacent to FFs59 stands.

### Young Growth-stage: 0-35 years

Historically, bitternut hickory was infrequent as a bearing tree in FFs59 stands in all growth-stages **(PLS/FIA-1)**. There were no records of hickory at burned or windthrown FFs59 survey corners. We did not detect any hickory as regeneration in the post-disturbance window **(PLS-5)**. From this we conclude that hickory was absent or at such low abundance that we did not detect it in young FFs59 stands.

### Mature Growth-stage: 35-155 years

During the mature growth-stage there was a short-lived peak of bitternut hickory establishment and recruitment that is lost in the averaging and smoothing of the abundance data **(PLS/FIA-1)**. We believe that this peak, to about 3% relative abundance at age 60 is real because it occurs in the most populated age-classes, and is seen in other southern communities. Because hickory peaks during this growth-stage, we consider it to be a ***mid-successional*** species on FFs59 sites. Small-diameter, hickory regeneration was most evident in the 50 and 60 year age-classes **(PLS-5)**. In most cases, young hickories were the smallest tree at a survey corner, suggesting that the rise in abundance was from recruitment. In modern stands hickory has just fair ability to establish seedlings **(R-2)**. Its regenerant index is slightly higher than its seedling index, suggesting that there is some mortality of seedlings when they exhaust the nutrient supplies of their large seeds. Established seedlings have a good chance of recruiting to heights over 2m. There were not enough hickory bearing trees to suggest that they preferred to come in under certain, overtopping species. Our interpretation is that some hickory regeneration and recruitment happened when FFs59 stands started to self-thin and develop a more remote canopy.

### Old Growth-stage: >155 years

In the old growth-stage there was but a single record of a bitternut hickory bearing tree accounting for its trace abundance **(PLS/FIA-1)**. Small-diameter hickory regeneration was not detected in the old growth-stage **(PLS-5)**. No conclusions can be drawn from the PLS data for bitternut hickory in this growth-stage.

### Regeneration Strategies

The primary regenerative strategy of bitternut hickory on FFs59 sites is to fill ***large-gaps***. They were most successful at this as stands thinned and the canopy elms approached their peak heights. Some gaps may have formed when initial-cohort willows and basswoods declined. In the historic PLS data this interpretation is supported by: (1) the fact that bitternut hickory abundance peaks in response to the decrease in tree density and possibly the decline of the initial cohort species **(PLS-1)**, and (2) they showed peak establishment in a gap window rather than post-disturbance or ingress windows **(PLS-5)**. In modern forests, bitternut hickory shows just fair ability to establish seedlings **(R-2)**. Its regenerant and seedling indices (2.7-2.3) are in line with species that need very-large gaps or perhaps even open conditions for establishment. Established seedlings though have a good chance of recruiting to sapling and pole sizes (SA-index, 3.2). Thus, the regeneration bottleneck for bitternut hickory would seed to be seedling establishment.

This is a curious reversal of bitternut hickory's behavior in southern mesic hardwood forests where seedlings are incredibly abundant, and the bottleneck is recruitment. Perhaps, the episodic flooding of FFs59 sites is especially detrimental to seedlings and reduces the importance of seedling-banking as a regenerative strategy.

**Historic Change in Abundance**

Today bitternut hickory is as infrequent in the average FFs59 stand as it was historically, showing abundance under 1% in every growth-stage whether as estimated by PLS bearing trees or as FIA trees **(PLS/FIA-1)**. Its species account is included here because it is successful in the little-disturbed stands preferentially sampled by releves. Its presence as trees (14%, **R-1**) and as regeneration (16%, **R-2**) in releves is obviously far more than its trace presence in either the PLS or FIA datasets. In this case, the preference for "undisturbed" stands may not be the more natural condition. "Improved" management of surface water throughout the range of FFs59 forests may have diminished the frequency of flooding that maintained FFs59 communities, allowing these sites to become more terrestrial and favoring bitternut hickory.

**(PLS-1)** Historic Abundance of FFs59 Trees in Natural Growth-stages

Table values are relative abundance (%) of Public Land Survey (PLS) bearing trees at corners modeled to represent the FFs59 community by growth-stage. Growth-stages are periods of compositional stability during stand maturation. Arrows indicate periods of compositional change during which tree abundances increase or decrease substantially. Yellow, green, and purple shading groups trees with abundance peaks in the same growth-stage. Percents on the bottom row represent a snapshot of the balance of growth-stages across the landscape *ca.* 1846 and 1908 AD.

| Dominant Trees | Forest Growth Stages in Years | | | | |
|---|---|---|---|---|---|
| | 0 - 35 | ~ 35 | 35 - 155 | ~ 155 | > 155 |
| | Young | | Mature | | Old |
| Basswood | 15% | | 9% | | 1% |
| Willow | 12% | | 1% | | – |
| American (Red, Rock) Elm | 47% | | 36% | | 43% |
| Hackberry | – | | 4% | | 1% |
| Green (Black) Ash | 9% | | 21% | | 17% |
| Cottonwood | 3% | | 2% | | 4% |
| Black Walnut (Butternut) | 3% | | 3% | | 7% |
| Silver Maple | – | | 5% | | 9% |
| Swamp White (Bur) Oak | 3% | | 7% | | 10% |
| Miscellaneous | 8% | | 12% | | 8% |
| Percent of Community in Growth Stage in Presettlement Landscape | 7% | | 85% | | 8% |

**PLS-1**

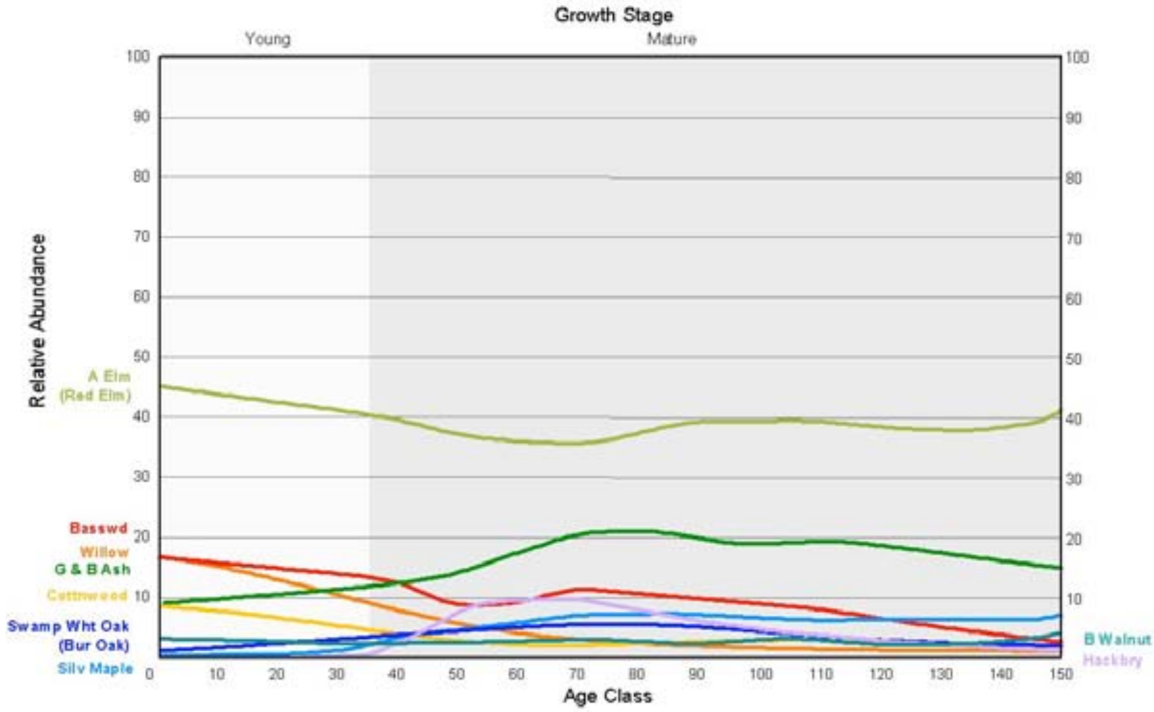
Trees included in Table PLS-1 are species with greater than 3% relative abundance in at least one growth-stage. Species that are now abundant in FFs59 forests, but were rare historically appear in Table **PLS/FIA-1**.

On FFs59 sites the PLS surveyors did not consistently distinguish the more prevalent American from red and rock elms; the more prevalent green from black ash; the more prevalent black walnut from butternut; the more prevalent swamp white oak from bur oak.

Public Land Survey linked text

## (PLS-2) Abundance of trees throughout succession in FFs59

**Caption:** Graphed for the different species of FFs59 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 FFs59 Trees Following Disturbance

Table values are raw counts and (percentage) of Public Land Survey (PLS) bearing trees at survey corners likely to represent FFs59 forests. The columns represent our interpretation of disturbance at the survey corners. Trees in parentheses are minor species that occur in modern forests but couldn't be separated from more common trees because the surveyors did not distinguish them in their field notes. Shading associates trees that peak in the same disturbance category.

| Tree | Burned | | Windthrown | | Maintenance | | Mature | |
|---|---|---|---|---|---|---|---|---|
| Green (Black) ash | 0 | 0% | 19 | 33% | 28 | 17% | 270 | 21% |
| Swamp white (Bur) oak | 0 | 0% | 9 | 16% | 20 | 12% | 91 | 7% |
| American (Red, Rock) elm | 0 | 0% | 21 | 37% | 84 | 51% | 536 | 42% |
| Black walnut (Butternut) | 0 | 0% | 1 | 1% | 4 | 17% | 19 | 1% |
| Cottonwood | 0 | 0% | 1 | 1% | 11 | 7% | 27 | 2% |
| Box elder | 0 | 0% | 1 | 1% | 6 | 4% | 13 | 1% |
| Basswood | 0 | 0% | 2 | 4% | 6 | 4% | 124 | 10% |
| Silver maple | 0 | 0% | 3 | 5% | 0 | 0% | 81 | 6% |
| Hackberry | 0 | 0% | 0 | 0% | 5 | 3% | 60 | 5% |
| Sugar maple | 0 | 0% | 0 | 0% | 2 | 1% | 47 | 4% |
| Bitternut hickory | 0 | 0% | 0 | 0% | 0 | 0% | 8 | 1% |
| Total (% of grand total, 1499) | 0 | 0% | 57 | 4% | 166 | 11% | 1276 | 85% |

**PLS-3**

Table PLS-3 includes only trees ranked as having excellent, good, or fair suitability for FFs59 sites. Tree sums will not match the totals in the Natural Disturbance Regime text, because trees of poorer suitability were included in that analysis.

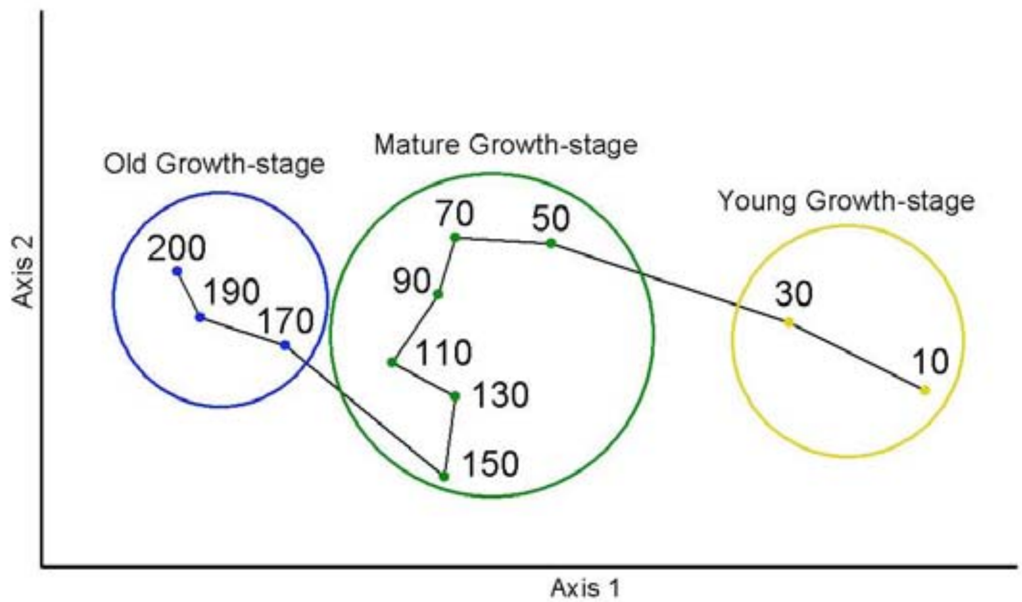
PLS survey corners were assigned to four disturbance categories:

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 FFs59 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 FFs59Trees

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 30-50 years | I-1 50-150 years | G-2 150-170 years | I-2 >170 years |
|---|---|---|---|---|---|---|---|
| Yes | Willow[1] | 0-10 | -- | -- | -- | -- | -- |
| Yes | Cottonwood[2] | 0-30 | Good at 30 | -- | -- | -- | -- |
| Minor | Silver Maple[2] | 0-30 | Good | Fair to 50 | -- | -- | -- |
| Yes | Basswood | 0-30 | Excellent | Fair | Poor to 60 | -- | -- |
| Yes | Green Ash[3] | 0-20 | Excellent | Good | Good to 90 | -- | -- |
| Yes | American Elm[4] | 0-50 | Excellent | Excellent | Poor to 70 | -- | -- |
| No | Hackberry[2] | 40-50 | -- | Fair to 50 | -- | -- | -- |
| Yes | Box Elder[2] | 40-50 | Poor | Fair | Fair to 60 | -- | -- |
| Minor | Swamp White Oak[2] | 50 | -- | Poor | -- | -- | -- |
| No | Black Walnut[2,5] | 50 | -- | Poor at 50 | -- | -- | -- |
| No | Bitternut Hickory[2] | 50-60 | -- | Poor at 50 | Poor at 50 | -- | -- |
| Minor | Bur Oak[2] | 50-60 | -- | -- | Fair to 60 | -- | -- |
| No | Sugar Maple | 50-60 | -- | Poor at 50 | Fair at 50 | -- | -- |

**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 willow, basswood, and elm, 30-50 years
- **I-1:** ingress of seedlings under canopy of elms and ashes with some basswood, bur oak, and silver maple, 50-150 years
- **G-2:** gap filling during decline of basswood and ashes, 150-170 years
- **I-2:** ingress of seedlings under a canopy of elms and ashes with some bur oak, silver maple and black walnut, >170 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; **purple** = trees with peak regeneration by ingress under a mature canopy or by filling small gaps in old forests

1. **Willow** bearing trees were not distinguished to species. Modern samples of this community in later successional stages have no willows. Most likely the tree willows *Salix nigra*, *S. amygdaloides*, and *S. fragilis* were involved. The bearing tree data show no willow trees in subordinate conditions, but we assume regeneration immediately following disturbance.
2. **Box elder, silver maple, bitternut hickory, hackberry, black walnut, cottonwood, swamp white oak, and bur oak** subordinate bearing trees are extremely sparse (<5 trees and the sum of all trees < 200) and the data unreliable.
3. **Green ash** bearing trees couldn't be segregated from black and white ash in the PLS notes for this community. The green ash data probably include some black and white ash, which we consider ecologically similar to green ash.
4. **American elm** bearing trees couldn't be segregated from slippery and Thompson's elm in the PLS notes for this community. The American elm data probably include some slippery and Thompson's elm, which we consider ecologically similar to American elm.
5. **Black walnut** bearing trees were usually separated from **butternut** by the surveyors, but the modern data show almost no butternut in spite of it being a bit more prevalent in the historic data. For this reason, we decided to lump black walnut and butternut records together in the analysis of PLS data so that it could be compared to modern data. We consider them to be ecologically similar.

## 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 FFs59 sites

This table presents an index of suitability for trees in FFs59 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 FFs59 | | | |
|---|---|---|---|
| **Tree** | **Percent Presence as Tree** | **Mean Percent Cover When Present** | **Suitability Index*** |
| **Silver maple (Acer saccharinum)** | 51 | 22 | 4.9 |
| **American elm (Ulmus americana)** | 65 | 16 | 4.8 |
| **Cottonwood (Populus deltoides)** | 30 | 31 | 4.8 |
| **Box elder (Acer negundo)** | 56 | 14 | 4.7 |
| **Swamp white oak (Quercus bicolor)** | 19 | 40 | 4.7 |
| **Basswood (Tilia americana)** | 37 | 19 | 4.6 |
| **Hackberry (Celtis occidentalis)** | 40 | 17 | 4.6 |
| **Black ash (Fraxinus nigra)** | 28 | 17 | 4.4 |
| **Green ash (Fraxinus pennsylvanica)** | 44 | 10 | 4.4 |
| **Black walnut (Juglans nigra)** | 14 | 30 | 4.3 |
| **Red elm (Ulmus rubra)** | 26 | 15 | 4.2 |
| **Bitternut hickory (Carya cordiformis)** | 14 | 11 | 3.1 |
| **Sugar maple (Acer saccharum)** | 12 | 8 | 2.6 |
| **Bur oak (Quercus macrocarpa)** | 9 | 7 | 2.1 |
| *Suitability ratings: **excellent**, **good**, **fair** | | | |

**R-1**

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

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

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

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

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

To communicate our estimates of suitability, we ranked the indices of plants that often occur (>5% presence) in a community and divided that ranking into 5 equal parts to create five suitability classes: excellent, good, fair, poor, and not suitable. Continuing the example above, 113 plants were ranked for MHn35 and basswood had the $8^{th}$ 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 FFs59 Stands

This table presents an index of regeneration for FFs59 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 FFs59 communities. Changes in the index values from one stratum to another can be used to estimate regenerative bottlenecks, whether establishment (R-index) or recruitment (SE-, SA-, or T-indices).

| Natural regeneration indices for germinants, seedlings, saplings, and trees common in the canopy of Southern Terrace Forest – FFs59 | | | | | |
|---|---|---|---|---|---|
| **Trees in understory** | **% presence R, SE, SA** | **R-index** | **SE-index** | **SA-index** | **T-index** |
| **American elm (Ulmus americana)** | **74** | **3.8** | **3.8** | **5.0** | **4.5** |
| **Hackberry (Celtis occidentalis)** | **65** | **3.0** | **3.5** | **4.7** | **4.3** |
| **Box elder (Acer negundo)** | **60** | **3.2** | **3.2** | **4.8** | **4.5** |
| **Green ash (Fraxinus pennsylvanica)** | **49** | **3.3** | **3.2** | **4.0** | **4.0** |
| **Basswood (Tilia americana)** | **33** | **2.3** | **2.2** | **3.3** | **4.5** |
| **Silver maple (Acer saccharinum)** | **28** | **2.0** | **1.8** | **3.2** | **4.5** |
| **Black ash (Fraxinus nigra)** | **26** | **3.3** | **3.7** | **4.2** | **4.3** |
| **Swamp white oak (Quercus bicolor)** | **16** | **3.3** | **3.5** | **3.8** | **4.3** |
| **Bitternut hickory (Carya cordiformis)** | **16** | **2.7** | **2.3** | **3.2** | **3.3** |
| **Sugar maple (Acer saccharum)** | **14** | **2.2** | **1.8** | **3.3** | **3.3** |
| **Red elm (Ulmus rubra)** | **14** | **0.7** | **1.2** | **2.8** | **4.3** |
| **Black walnut (Juglans nigra)** | **7** | **2.3** | **2.5** | **2.8** | **4.0** |
| **Bur oak (Quercus macrocarpa)** | **7** | **1.0** | **1.0** | **1.0** | **2.8** |
| **Cottonwood (Populus deltoides)** | **2** | **0.7** | **0.7** | **1.2** | **4.5** |

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

**% presence:** the percent of 43 FFs59 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 FFs59 Stands

This table presents percentages of structural situations for trees as recorded in Forest Inventory Analysis (FIA) subplots that we modeled to be samples FFs59 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 |
| **Cottonwood** | 12 | | | | 17% | | 83% |
| **Bitternut hickory** | 1 | | 100% | | | | |
| **Sugar maple** | 1 | | | | | | 100% |
| **Silver maple** | 121 | | 2% | 2% | 19% | 1% | 76% |
| **Box elder** | 90 | 10% | 29% | 1% | 14% | 7% | 39% |
| **Bur oak** | 11 | | | | 18% | 18% | 64% |
| **Green ash** | 53 | 26% | 11% | 13% | 19% | 13% | 17% |
| **Red elm** | 13 | 23% | 8% | | 31% | 31% | 8% |
| **American elm** | 68 | 15% | 19% | 16% | 9% | 16% | 25% |
| **Black ash** | 186 | 20% | 24% | 18% | 9% | 17% | 11% |
| **Hackberry** | 4 | 25% | | 25% | | 25% | 25% |
| **Basswood** | 8 | 12% | | | | 50% | 38% |

**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 FFs59 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 FFs59 community and estimated to fall within the young, mature, and old growth-stages. Arrows indicate increase or decrease between historic growth-stages only and for the more common trees. Green shading and text was used for the historic PLS data and blue was used for the FIA data. Percents on the bottom row allow comparison of the balance of growth-stages across the pre-settlement landscape (*ca.* 1846-1908 AD) and the modern landscape (*ca.* 1990 AD).

| Dominant Trees | Forest Growth Stages in Years | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 - 35 | | ~ 35 | 35 - 155 | | ~ 155 | > 155 | |
| | Young | | | Mature | | | Old | |
| Basswood | 15% | 1% | | 9% | 2% | | 1% | 0% |
| Willow | 12% | 0% | | 1% | 0% | | – | 0% |
| American, Red, Rock Elms | 47% | 38% | | 36% | 25% | | 43% | 27% |
| Cottonwood | 3% | 0% | | 2% | 2% | | 4% | 0% |
| Hackberry | – | 0% | | 4% | 0% | | 1% | 3% |
| Black Walnut or Butternut | 3% | 1% | | 3% | 0% | | 7% | 0% |
| Silver Maple | – | 3% | | 5% | 18% | | 9% | 0% |
| Swamp White (Bur) Oak | 3% | 1% | | 7% | 1% | | 10% | 12% |
| Black, Green Ashes | 9% | 41% | | 21% | 32% | | 17% | 30% |
| Box Elder | -- | 12% | | 1% | 11% | | 1% | 28% |
| Red Oak | 0% | 1% | | 2% | 7% | | 1% | 0% |
| Bitternut Hickory | 0% | 1% | | – | 0% | | – | 0% |
| Miscellaneous | 8% | 2% | | 9% | 2% | | 6% | 0% |
| Percent of Community in Growth Stage in Presettlement and Modern Landscapes | 7% | 13% | | 85% | 85% | | 8% | 3% |

Natural growth-stage analysis and landscape summary of historic conditions is based upon the analysis of 817 Public Land Survey records for section and quarter-section corners. Comparable modern conditions were summarized from 644 FIA subplots that were modeled to be FFs59 sites.

Public Land Survey linked text
FIA linked text

## Silviculture Systems for FFs59: 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 | | | | | | | | | | |
| Silver Maple | Open (large-gap) | | | | | | | | | | |
| Am., Red & Rock Elm | Large-gap | | | | | | | | | | |
| Cottonwood | Open | | | | | | | | | | |
| Box Elder | Large-gap | | | | | | | | | | |
| Swamp Wh. & Bur Oak | Large-gap | | | | | | | | | | |
| Basswood | Open (large-gap) | | | | | | | | | | |
| Hackberry | Large-gap | | | | | | | | | | |
| Green & Black Ash | Large-gap (open, small-gap) | | | | | | | | | | |
| Black Walnut | Large-gap (open) | | | | | | | | | | |
| Bitternut Hickory | Large-gap | | | | | | | | | | |

## Forest Health

Forest health considerations and watchouts for important species in this native plant community are under development.

# FFs59 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 |

* Will flood in wet springs or after heavy rain events. Delays of up to a month(?) can be expected after flood waters recede

Plants below indicate wetter inclusions in FFs59 that are more susceptible to compaction and rutting. They are listed in descending order of presence.

- Under development -

**(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

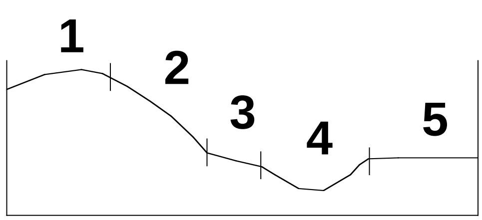
   Poor – water saturation occurs within 10 inches of the surface for most of the growing season

   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