VIABILITY OF WETLAND TREES AFTER TWENTY YEARS ON PHOSPHATIC CLAY SETTLING AREAS AND THEIR ROLE IN ECOSYSTEM DEVELOPMENT

By

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Clay settling areas (CSAs) are constructed on about 2,000 acres of land every year to contain waste clays following phosphate mining. The reclamation of CSAs to foster wetland ecosystems has been proposed for these areas but not yet demonstrated as a viable alternative, due to the lack of natural colonization of species typical of mature wetlands. Clay settling areas planted with wetland trees in an early test of forested wetland viability were revisited after twenty years. Survival and growth of species typical of riverine swamps demonstrated the suitability of planted trees in seasonally wet areas, but the general lack of recruitment does not assure long-term sustainability of the populations. After twenty years planted trees provide additional canopy structure but they are less influential in the development of soil and understory ecosystem components than site-specific exogenous factors. Engineering of CSAs to promote hydrology typical of natural wetlands and supplementing tree planting with understory species are likely to lead to more persistent and diverse wetland communities.

INTRODUCTION

Statement of the Problem

Phosphate mining has been a major industry in central Florida for the past 60 years. Currently about 5,000 acres of land are mined every year (Richardson 2005). Clay settling areas (CSAs) are dominant features of the post-mining landscape that comprise about 40% of the post-mining area. The land use options for CSAs after they have been filled are partially limited due to the unstable nature of the consolidating ground surface.

The design and planting of these areas to create wetland ecosystems is one option the industry and state are still exploring for the use of abandoned CSAs. Species characteristic of wetlands naturally colonize depressional areas on CSAs in the years following abandonment. Recognition of the potential for wetland establishment led to attempts to augment the composition of wetland species on these areas. In an attempt to determine if forested wetland ecosystems will persist on CSAs, a limited number of CSAs have been planted with wetland trees. But the success of these plantings has not been evaluated after the initial few years of estalishment. The long-term development and viability of forested wetland ecosystems on CSAs are critical to the determination of the suitability of wetlands on CSAs. In this study CSAs planted with wetland trees were evaluated after 20 years in one attempt to evaluate forested wetland development and viability on CSAs. The questions explored in this study have been grouped under three foci:

1. How have the planted trees fared over time; what are the primary factors influencing tree growth, survival, and recruitment?
2. How might the tree populations change in the future?
3. Are differences discernable in the ecosystem development of areas planted with trees and those not planted?

Background

Clay Settling Areas

CSAs are depositories for residual clay separated from phosphate rock and sand in the first stage of processing following mining. The residual phosphatic clay is then slurried for pipe transport. The handling of the residual clays has changed during the history of phosphate mining in Florida. In the early years of large scale mining clays were pumped into mining cuts. More recently large impoundment areas with high walls, often 1 mile square, have been created for disposal of the clay. Alternatively, clays are sometimes mixed with residual sand before being pumped into settling areas. Though the name is typically reserved for impoundment areas for unmixed clay disposal, in this study CSAs refers to all three types of depositories for residual clays.

As clay slurry is pumped into CSAs, clay particles settle to the bottom and water is drawn off through outfall structures. A solid crust forms on the pond surface after 3-5 years (Richardson 2005), but consolidation of clays under the surface continues for decades. The consolidated ground surface is often at an elevation above the original ground elevation and higher than the surrounding landscape. Rate of consolidation of clays is not even across the CSAs, which are often built on mined land characterized by patterns of mine cuts and spoil piles, resulting in an uneven land surface. One result of the differential consolidation is the formation of deeper depressions that hold surface water. These depressions often sink below the elevation of the outfall structure causing them to become hydrologically isolated such that they seasonally retain water.

Wetlands on Clay Settling Areas

Isolated depressions on CSAs as well as water features drained by an outfall structure support the establishment of hydrophytic vegetation characteristic of wetlands. Vegetation begins to colonize these areas before the slurry-water has completely drained off in a phase called dewatering. Algae often colonizes the water surface in the initial phases, followed by winddispersed herbaceous macrophytes like *Typha* spp. and *Scirpus* spp. or shrubs and small trees like *Ludwigia peruviana* and *Salix caroliniana*. But the continuation of seral succession with the establishment of species characteristic of mature systems is not common even on the oldest CSAs (Rushton 1983). Rushton (1988) suggested the dominance of these early successional wetlands are characteristic of arrested succession, whereby climax species fail to establish. However the successional pathway of a CSA and the composition of a 'climax' system are unclear. CSAs are examples of what some members of the scientific community have referred to as "emerging ecosystems" (Odum 1971, Hobbs et al. 2006), defined as "new" environments which result from heavy modification of the environment by human agency. Such ecosystems lack a precedent from which to anticipate long-term composition and dynamics.

A few obstacles hinder natural succession on these areas: (1) the landscape surrounding CSAs has generally been cleared and modified, so the recruitment of native species is difficult due to hydrologic isolation, above-grade elevation, and distance to seed sources (Odum et al. 1983); (2) soils on CSAs contain a high percentage of clay (60-80%) and initially lack structure, differing significantly from soils characteristic of wetlands in central Florida, which are sandier with developed horizons (Rushton 1988, Myers and Ewel 1990, Graetz and Reddy 1997); and (3) the hydrologic regime of these clay depressions may be different than natural wetlands due to the high water-holding capacity of clay, the continuing consolidation of the clays, and large watershed:wetland ratios (Rushton 1988).

Hydrologic regime and the physical and chemical nature of the soil are important factors in the determination of the type of wetland that may be established (Mitsch and Gosselink 1993). Water level is perhaps the most important factor for determining if a marsh (herbaceous wetland) or swamp (forested wetland) will establish in these areas. Though the period and depth of inundation in CSA depressions is typically unknown, existing vegetation may provide a clue as to what the hydroperiod is like. Areas where *Salix caroliniana* has established may indicate locations appropriate for forested species. Phosphorous (P) is often the limiting nutrient in

Florida freshwater wetlands systems (Reddy et al. 1999) but residual inorganic phosphorus is high in phosphatic clays (Rushton 1988). Phosphorous has been directly correlated with producitivity in cyress ecosystems (Brown 1981). Highly productive systems situated on a substrate with high clay content is characteristic of some alluvial forested wetlands in the southeastern United States (Faulkner et al. 1991). Depressional areas on CSAs may be suitable for the establishment of forested wetlands.

Planting of Wetland Species on Clay

Planting species characteristic of mid- to late-succession is one method to direct the successional process (Brown and Tighe 1991). Monitored field trials on CSAs using wetland tree species began in the 1980s (Rushton 1988, Paulic and Rushton 1991a, Everett 1991), and tree survival and growth has been documented during the initial years after planting. Water availability, species properties, tree size, and edaphic factors including soil age and nutrient levels have all been shown to effect tree survival on clay settling areas. The following list summarizes findings of earlier studies of wetland trees on CSAs.

- Hydrology was more important in determining tree survival than canopy or understory cover (Rushton 1998, Paulic and Rushton 1991b).

- Wetland trees typical of floodplain and backwater swamps of central and northern Florida have had greater than 50% survival after 1 year on clays, including *Acer rubrum*, *Betula nigra*, *Carya aquatica*, *Liquidambar styraciflua*, *Quercus laurifolia*, *Quercus lyrata*, *Quercus michauxii*, *Sabal palmetto*, and *Ulmus americana*. (Paulic and Rushton 1991b)

- *Fraxinus* spp. and *Taxodium* spp. had high (>80%) survival after 3 years (Paulic and Rushton 1991a, Everett 1991);

- Clay is a suitable medium for wetland species (Cates 2001);

- After three years, trees growing on a sand-clay mix and on sand had higher survival than those on clay. Trees in clay grew faster than trees in sand (Paulic and Rushton 1991a);

- Most major nutrients are available in sufficient quantities for tree growth. Nitrogen may be the limiting nutrient. N-fertilizer increased growth but had no effect on survival of *Acer rubrum* in a greenhouse experiment (Paulic 1991). Fertilizer enhanced growth of *Taxodium spp.* in clay both in the field and in the greenhouse (Everett 1991, Paulic 1991).

- Soil age was positively correlated with *Acer rubrum* growth in a greenhouse experiment (Paulic 1991);
- Animal grazing can reduce tree survival (Rushton 1988).

These earlier studies have censused planted and non-planted trees in a variety of hydrologic conditions, among different vegetation communities, and on a number of CSAs. However, these earlier studies did not census planted trees after more than a few years, and thus could not consider longer-term survival and growth, nor the potential ecosystem function of more mature trees on CSAs. Time until maturity for forested swamps can be as long as 250 years in a natural environment. Long-term monitoring is necessary to understand the long-term dynamics of a restored forested system (Clewell 1999).

Recruitment

An important ingredient for the sustainability of a constructed forested system and an indicator of the appropriateness of an environment for introduced species is the ability to propagate. Wetland trees have specific moisture requirements for successful reproduction (Mitsch and Gosselink 1993). These requirement can be important for seed set, germination, and establishment. Poor seed set may occur from pollen limitations (McLanahan 1986). Dispersal is important in order for fertilized seeds to find a viable location in which to germinate. Together water levels and microtopography are important in determining seed dispersal. Because some seeds float in water they tend to accumulate in greatest densities near the edge of water or near obstructions. Seeds of wetland trees do not germinate in standing water. Thus areas of permanent standing water may preclude the emergence of new seedlings. In areas with infrequent drawdown, seed germination may still occur but viability of seeds may be decreased by long periods of inundation (Schneider and Sharitz 1986). If seeds are able to germinate, water conditions during the first few months can be critical to survival. Most wetland tree seedlings cannot survive extended periods of inundation.

The recruitment success of wetland trees characteristic of mid to late succession is unknown on CSAs. One direct seeding experiment on phosphate mined land was largely unsuccessful: 10 of 14 plots that were covered with litter collected from floodplains in the vicinity failed to produce seedlings (Rushton 1988). The quantity of viable seeds in the collected litter was unknown.

Ecosystem Development

A series of gradual changes in the dominant vegetation community toward a predictable climax state summarizes the traditional concept of succession. Numerous theories have emerged both further elucidating the mechanisms of succession (Clements 1916, Egler 1954, Connell and Slayter 1977), and challenging its linearity and predictability (Anand and Desrochers 2004). Yet the changes in the composition of the vegetation community are just one aspect of alterations to both the abiotic and biotic environment that are associated with succession. In the context of the entire system this dynamic process has been called ecosystem development (Odum 1969).

A key aspect in the development of an ecosystem is an increasing effect of the biotic components of the system on the modification of the environment and the selection of the biota. The increasing control exerted by the biotic components is a characteristic of self-organization (Odum 1989). The dynamics of self-organization in the “emerging” ecosystems on CSAs are unclear. Measures of the modifications that the biota are making to the environment and the changes in the community composition that may be resulting from those changes are potential indicators of ecosystem development.

In forested ecosystems, trees are key agents of influence over the local environment and thus the ecosystem. As trees mature and canopies develop, they reduce the quantity of light that is able to penetrate to the lower vertical strata of the forest. The reduction in light penetration alters the microclimate (notably temperature and humidity) underneath the tree canopy. These changes to the abiotic environment imparted by the trees may in turn cause changes in the cover and composition of the understory vegetation (Beatty 1984) and the rate of organic matter decomposition in the soil. Trees also contribute a substantial amount of the detritus that decomposes and becomes incorporated in soil organic matter (Rhoades et al. 1998). In a study of carbon budgets in the Dismal Swamp, tree leaf litter and fine tree roots composed the largest annual input to the detritus pool in both cypress-dominated swamps and mixed forested wetlands (Megongial and Day 1988). All these effects are expected to be enhanced with increasing tree size and dominance in the landscape.

Planted wetland trees on CSAs may serve the role of directing ecosystem development. Restoration ecologists have traditionally looked at a spectrum of similar sites of different ages to study the dynamics of ecosystem development. A number of studies of the progress of restoration efforts in the phosphate mining districts have adopted this approach (Rushton 1983, Carstenn 2000), and identified trends in ecosystem development across sites. A potential drawback of this approach is that is overlooks the site-specific influences. The topography and its influence over the hydrology and the proximity to seed source are unique to a site and important external drivers of ecosystem development. These external factors may create challenges for cross-site comparison of CSAs.

Plan of Study

Rushton planted tree species on a number of abandoned CSAs in 1985-1986 as part of her doctoral study (Rushton 1988). Because she published precise information on location, number, and type of species planted as well as growth and survival rates after one year and descriptions of sites conditions, monitoring these planted areas and adjacent non-planted areas provided an opportunity to evaluate tree growth and ecosystem development of areas with and without planted trees after a 20-year time period.

To evaluate how the planted trees have fared over time and to determine what factors are influencing growth and survival, survival, size, and reproductive success of planted trees was measured. The tree parameters were statistically evaluated in the context of site hydrology and soils. Elevation data and water levels were collected to estimate water depths and period of inundation in planted plots during the 2005 growing season, and data on site soils were gathered from the Rushton study (1988). The effect of disturbance was qualitatively assessed through site histories and field evidence.

In effort to project how the tree populations might change in the future, the tree data were used to calibrate population models to determine future population trajectories.

To determine if the planted trees were steering ecosystem development, selected ecosystem development measures were collected in planted and non-planted areas with similar hydrologic conditions and external influences. Woody vegetation was measured to assess the development of the tree and shrub strata; canopy photos were taken to estimate canopy cover; soil samples were collected to estimate percent organic matter; and understory vegetation was sampled. The raw data were summarized by plot and statistical techniques were then used to compare measures of ecosystem development in planted and non-planted areas.

METHODOLOGY

Site and Plot Selection

Five of the CSAs planted by Rushton were selected for study. Sites were chosen that were currently accessible and that Rushton (1988) had determined had an average of at least 50% tree survival after one year. Table 1 presents a summary of the selected sites. Figure 1 provides an overview map of site locations.

CFI SP-1 (CFI) is a sand-clay mix settling area abandoned in the early 1980s with two distinct connected lobes. Plots were planted on the fringe of the east lobe. Since the Rushton planting, the site has been planted with additional tree and understory species and the water level has been lowered by adjusting the weir. The upland area surrounding the wetland and adjacent to the plots is regularly mowed and shrubs have been removed. The understory of a few of the plots were planted with ferns on their upland half.

Homeland (HOM) is a pond formed over an old mine cut backfilled with clay and capped with sand around 1979. The pond is surrounding by pasture that is part of the DEP Homeland office property. Bill Hawkins planted *Taxodium distichum* trees in 2/3 of the pond approximately in 1982. The Rushton plots traverse the east side of the pond.

OH Wright (OHW) is an older CSA (abandoned approximately in 1960) adjacent to the Whidden Creek floodplain. One plot (R1A) traverses a swale just above the outfall structure, which is still active. Four plots (R2A, R2B, H1, and H4) are on the fringe of a pond. Two other plots (H2, H3) lie in a depression between two spoil rows.

Peace River Park (PRP) was abandoned in 1968 and leased for pasture until 1986. Two plots are located in small depressions (H1, H6) and two are located on the edge of a pond (H4, H5). All plots are connected by surface water when water levels are high.

Tenoroc 4 (TEN) was abandoned around 1972 and is now part of the Tenoroc Fish Management Area. Four plots (R2A, R2B, H2, H3) were located in a depression on the NW corner of the site. The other plots are on the north and south side of an interior spoil pile in the north central area of the site. Prior to a ditching effort in this area to connect isolated depressions and convey water off the site in 2001, the seasonal water levels in the plots were likely higher.

Rushton plots. A total of 37 planted plots on 5 CSAs were selected for study. Selected plots were located in the field from site diagrams (Rushton 1988) and matched to an original plot number. All selected plots had at least one surviving tree at the present time. Plots were representative of the two planting schemes used and referred to by Rushton as cypress-gum (CG) plots and hydric-swamp (HS) plots. Figures 2 and 3 depict planting schemes for these two types of plots. Twenty-five cypress-gum plots and 12 hydric swamp plots were included in the current study. Species planted in the two plots types are listed in Tables 2 and 3. Cypress-gum plots were planted with all three species except for 4 plots at Tenoroc 4 planted only with two species. Among the 12 hydric swamp plots, 8 were planted with species with a group of ‘transitional’ trees and 4 were planted with a group of ‘wet’ trees.

Reference plots. In order to compare the ecosystem development on non-planted areas that were similar to the Rushton plots, adjacent ‘reference’ plots of equal dimensions to the Rushton plots were selected. Reference plots were at least 25 meters away from Rushton plots to minimize potential influence from Rushton plots. A single reference plot was designated for all plots that shared connection to a water feature. Reference plot selection was random provided that a plot met the following conditions: (1) it was adjacent to the same water feature as a Rushton plot; (2) the topography was such that a hydrologic regime similar to the Rushton plot could be inferred. An exception to the first condition occurred at Homeland, where the reference plot was located in a pond fed by a ditch from the pond containing the Rushton plots, because not enough non-planted area within the pond with the Rushton plots was available.

Field Data Collection

Topography

A laser level was used to determine elevations within the plot relative to the water level at the time of first visit. Figure 4 shows where data were collected in cypress-gum plots. For these plots, elevation was recorded every meter along a 42 m longitudinal axis which traversed the planted area as well as 6m in front and back of it. The plots were originally laid out such that this axis ran parallel to the elevation gradient. Additionally, elevation data were recorded from spots 6m to each side and at the beginning, middle, and end of the longitudinal axis. Figure 5 shows where data were collected in hydric swamp plots. For hydric swamp plots, elevation data were recorded every two meters along two perpendicular axes crossing from 6m away from the edge through the center of the plot to 6m beyond the far edge. In these plots elevation data were also collected at the soil and plant sample points within the planted plot, and at the four planted plot corners.

For reference plots, elevation data were collected in the same manner, except in these plots only data within the plot boundary were collected.

Hydrology

Water levels at a point of recorded elevation were manually measured to the nearest centimeter each month through October 2005after the initial visit to a plot in the spring or early summer of 2005.

On CFI SP-1 and Tenoroc 4, continuous digital data loggers were installed close to or within Rushton plots to record hourly water levels. On these sites, one surface water well within the water feature and one ground water well 25m into the upland were equipped with loggers. The loggers were operational from the date of installation in the early part of the growing season of 2005 through the end of October 2005.

Planted Trees

Planted trees were identified by location and species. Using a two-dimensional grid, X,Y plot location was recorded for planted trees to the nearest meter. Diameter at 1.5 meters (DBH) was recorded to the nearest centimeter for all stems originating below that height. If no stems reached 1.5m, height of the tallest stem was recorded to the nearest centimeter.

Other Tree Species

Each tree within the planted plot of a species not planted was identified to species and its DBH was recorded if it had reached 1.5m in height. Woody plants were classified as trees or shrubs according to Tobe et al. (1998). For *Salix caroliniana*, which is classified as a tree or shrub, individuals with at least one stem with a DBH ≥ 5cm were classified as trees. In cypress-gum plots, the 10m segment (0-10,10-20,20-30) that a tree was found in was noted.

Recruited Trees

Recruited trees are defined in this study as individuals of the same species as planted trees not occurring in originally planted locations, irrespective of the size of the individuals. X,Y plot location, species, and DBH or height were recorded for recruited trees inside or within 6m of the plot boundary.

In the plot on TEN where the greatest number of seedlings emerged, the seedlings were resampled at the end of the growing season to determine the survival rate.

Additional Measures of Ecosystem Development: Shrub and Understory Layers; Soils; Canopy Photos

Figure 6 and 7 show the standardized sampling locations for shrubs, understory vegetation, soil, and canopy photos for cypress-gum and hydric swamp plots. Three 3x3m subplots within each plot were sampled for shrubs. DBH and species were recorded for all stems ≥ 1.5m in height. Nine 1x1m subplots within each plot were used to sample all understory macrophytes with stem heights ≤ 1.5m. Each species occurring was identified and the coverage of each species was estimated into one of five possible coverage classes: 1: 1-10%, 2: 10-25%, 3: 25-

50%, 4: 50-75%, 5:75-100%. Coverage was defined as the percentage of the 1x1m horizontal plot area covered by the plant. In the case where different species occupied the same horizontal location but different vertical strata, both species were counted. Cores of the top 10cm of the soil were collected with a 7.6 cm-diameter auger within all 1x1m understory sampling plots. To estimate canopy cover, hemispherical photographs were taken using a Nikon digital camera, with 180 degree "fish-eye" lens. Inside all plots, photos were taken in 3 equidistant understory subplots. For the Rushton plots, photos were also taken from the understory subplots outside of the canopy. The camera was placed on a tripod approximately 50 cm above the ground or slightly above the surface of the water, whichever was higher. The camera was then leveled with the lens pointing up, oriented so the back of the camera faced north, and zoomed out to 100%. When possible photos were taken close to dawn or dusk or on overcast days to avoid distortion from direct sunlight.

Site Histories

Information about possible disturbance or site modification during the 20 year period since the trees were planted was collected from site managers, from the Rushton dissertation, through consultation with Betty Rushton, or through inference from evidence found in the plot in 2005 such as burnt stems or plot markers.

Data Analysis

Topography and Water Levels

Topographic data collected were input in X-Y-Z form into Surfer surface mapping software, from which a kriging function was used to create a surface map. From this interpolated map, relative elevations were output for every square meter. Using these elevation data and the monthly water level data, water levels were calculated for the entire sampling area for every date water level was recorded. 'Average water depth' as referred to in the remainder of the study refers to the average of these monthly water levels.

When the water level was below the ground, the level measured in one location was assumed to be the same across the plot because of the small area of the plots and the small differences in ground elevation across the plots.

On the two sites with continuous data-logging water level recorders (CFI and TEN), the average of the sampled monthly water levels was compared with the average of all the hourly water levels recorded by the data-loggers to determine if monthly water levels accurately approximated hourly water levels on those sites.

Average change in elevation was computed for each plot as the average change in elevation along the longest axis of the plot. Percent inundation was calculated as the area of the plot covered by water at the time of sampling divided by the total plot area.

Elevation data for every planted tree along with monthly water level measurements allowed for determination of the average sampled depth of water for every tree and at every location where soils, shrubs, understory vegetation, and canopy photo sampling occurred. Box plots were created to show the distribution of all trees along the average water depth at the tree base.

Tree and Plot Basal Area

Basal area, BA(cm^2), was calculated for trees and shrubs as the sum of the all stem area at 1.5m for an individual according to the following equation:

$$BA = \sum \pi * DBH^2 \quad [1]$$

Plot basal area (m^2/hec) was the sum of the tree and shrub basal area (m^2) divided by the plot area (hectares). Plot basal area was calculated for every 10m section of cypress-gum plots as well as for the entire plot, but only for the entire plot in hydric swamp plots because trees were not sub-sampled in these plots.

Tree Growth Comparisons

Basal area of all surviving Rushton trees was compared by species and soil type for trees with an average water level in the range of -0.75 to 0.25m. Trees with a basal area < 7.8 cm^2 were assumed to be resprouts, and they were eliminated from the growth comparison because the stem age was unknown. Tree basal area of the remaining trees was then log-transformed for normality. T-Tests were conducted to compare the effect of two soil types in areas with similar average water depths, assuming that similar hydrologic regimes can be inferred from similar average water depth at the tree base during the 2005 season. Two way ANOVA was used to simulataneously compare the effect of water level, soil type, and soil type-water interactions on tree growth. In the two way ANOVA test trees were split into shallow and deep water levels by species based on the median water level of surviving trees.

Soil Percent Organic Matter

Soil cores were manually homogenized and three 40g samples of each core were dried a minimum of 48 hours at 30° C. The ignition method without rehydration was then used to estimate % organic matter (% OM) . Dried samples were ground with a mortar and pestle and three 1 g sub-samples were ashed in a muffle furnace for 6 hours at 450° C. This temperature was deemed appropriate for burning off the organic matter without removing inorganic carbon ($CaCO_3$). The following equation is used to calculate percent organic matter:

*((dry weight – ashed weight) / dry weight)*100% = % organic matter* [2]

Population Size Class Distributions

All surviving planted trees and offspring were placed into size classes that represented 5 or 10 cm DBH intervals (Table 4). Classification was done by basal area to accommodate multiple stem trees where summation of DBH would have resulted in inflated values and inconsistent classification.[1] Classified trees were then grouped by species and by basins to define a

[1] For example, a tree with two 5 cm DBH stems has less basal area (39.4 cm^2) than a tree with one 10 cm DBH stem (78.5 cm^2).

population. Basins are defined as areas where multiple plots are adjacent to the same body of water and no plot is more than 50 meters away from its nearest neighbor. The sampled area of each basin represented the sum of the seedling sampling areas of every plot within the basin; not the area of the entire basin.

Canopy Photos

Canopy photos were analyzed in Adobe® Photoshop software. Photos were transformed into 2-color black and white images using the Threshold function. The threshold level was subjectively chosen to yield the most accurate conversion of vegetation pixels to black and sky pixels to white. Before transformation images were cleaned up with editing tools to remove shadows, clouds, sun spots, glare, or other aspects of the image that would been incorrectly assigned to black or white. After transformation, the black and white pixels were counted in Keigan Systems® MFworks software. The percent canopy cover was then calculated as the sum of black pixels divided by the sum of black and white pixels.

Understory Vegetation

Cover for all understory vegetation in a plot was estimated using the mean of the coverage class. The classes thus corresponded to the following percentages: Class 1: 5.0%; Class 2: 17.5%; Class 3: 37.5%; Class 4: 62.5%; Class 5: 87.5%.

Species richness was calculated for all plots as the sum of the unique species occurring. Species evenness, a measure of the evenness of the distribution of species, was calculated with the Shannon evenness formula (Gurevitch et al. 2002):

$$E = H / \ln(S) \; [3]$$

$$H = \sum_{i=1}^{s} (p_i * \ln(p_i)) \; [4]$$

where evenness, *E*, is equal to the Shannon-Wiener index, *H*, divided by the natural log of the total number of species, *S*. The Shannon-Wiener index was calculated as in Equation 4.

Importance Value is a metric that combines the relative frequency and relative cover in order to consider together both characteristics of a species presence in an understory (Cole 1978). Importance Value for species occurring in the understory were calculated using the following equation:

$$IV_s = rf_s + rc_s \quad [5]$$

where Importance Value of a species, IV_s, is equal to the sum of the relative frequency, rf_s ,and relative cover, rc_s , of that species. Relative frequency was calculated using the following equations:

$$rf_s = f_s / \sum_{s=1}^{n} f_s \quad [6]$$

$$f_s = o_s / q \quad [7]$$

where relative frequency is equal to the frequency of a species, s, divided by the sum of the frequency of species encountered on a plot. The frequency of a species was calculated by the number of a $1m^2$ quadrats in which species s occurred, o_s, divided by the number of $1m^2$ quadrats, q, in a plot.

Relative cover was calculated using following equations:

$$rc_s = c_s / \sum_{s=1}^{n} c_s \quad [8]$$

$$c_s = \sum_{i=1}^{q} c_{si} \quad [9]$$

where the relative cover of a species, rc_s, is the cover of a species divided by the sum of the cover all species, n, in a plot. The cover of a species, c_s, is equal to the sum of the mean cover of a species, s, in all $1m^2$ quadrats, q. Because a cover class was assigned to a species rather than a mean cover, each cover class was translated to a mean cover (reference on method) as follows: 1: 5%, 2: 17.5%, 3: 37.5%, 4: 62.5%, 5: 87.5%.

Ordination of Plots by Prevalent Understory Species

In order to visualize the differences in the cover of prevalent understory species between plots, the Nonmetric Multidimensional Scaling (NMDS) ordination technique was applied. The prevalent understory species were those with a Importance Value of > 0.10 (out of a possible 2.0) for a plot. The NMDS method does not require assumptions that the data fit a normal distribution nor that the data fit a linear pattern (Faith et al. 1987, McCune and Grace 2002). The NDMS was run on a (n x p) contingency table of average species cover in a matrix where the rows, n, were plots, and the columns, p, were species. The data were first standardized using a Wisconsin double standardization and then square-root transformed. A Bray-Curtis dissimilarity method was used as to create the dissimilarity matrix necessary to rank plots by dissimilarity and to position the points along the two principal component axes, so that the ordination could be shown in two-dimensional space.

Correlation Matrices of Ecosystem Development Variables

To find patterns in the relationship between Rushton trees and total basal area, canopy cover, understory cover, understory species richness, understory species evenness, and soil organic matter, correlation matrices were created using R statistical software. Pearson's formula was the correlation method used to produce the matrices.

Tree Population Model

In order to predict the population trajectory of a planted tree population, a size class matrix population model was constructed for populations of planted *Taxodium distichum* at CFI and in one basin at OHW.

Size class matrix population models use principles of matrix algebra to estimate changes in population distribution over a time series as well as the steady-state population distribution and growth rate (Caswell 2001). Size class bins are determined and individuals are classified into size classes. A transition matrix, A, is constructed by determining probabilities after a year that a tree will remain in a size class, P_i, transition, G_i, and/or reproduce, F_i (Figure 8). The transition matrix is multiplied by a vector of the number of individuals in each size class, N_t, to determine the number of individuals in each size class after one time increment, N_{t+1}. According to matrix theory the transition matrix alone determines the long-term population state. Mathematically decomposing the transition matrix, A, yields a vector of eigenvalues and their associated eigenvectors. The dominant eigenvalue of A, λ, gives the population growth rate when there is a stable population distribution. The stable population distribution is given by the right eigenvector of the transition matrix.

Customarily tracking the growth, survival, and seed production of a cohort of trees over a period of years provides the data from which transition probabilities are calculated. In this case, empirical time series data was not available for the entire period. Using data from the most current year and incorporating data on survival and growth after 1 and 3 years, growth of individual trees were interpolated by fitting a curve based on the growth rate of other *Taxodium distichum* in the phosphate mining area (Miller 1983). Mortality after years 1,3, and 20 years were used to estimate mortalities of the given size classes, with the assumption that slower-growing trees were more likely to die. Reproductive probabilities were calculated based on the ratio of first year seedlings to mature adults, distributing this probability among the mature size classes such that each successively larger size class had a greater reproductive probability. The matrix populations models were created in the Python 2.3 programming language. The model was programmed to estimate population change over a 50 year period. An elasticity analysis (Caswell 2001) of the model was conducted to estimate the relative sensitivity of the model to the changes in the probability values of the transition matrix, A. The code for the population model is included at the end of the Appendix.

Table 1. Site summary table

Site Name	Symbol	Years Abandoned (Estimated)	Type	# Cypress-gum Plots	# Hydric Swamp Plots
CFI-SP1	CFI	23	Sand-Clay	6	0
Homeland	HOM	46	Sand Cap	8	0
O.H. Wright	OHW	46	Clay	3	4
Peace River Park	PRP	38	Clay	0	4
Teneroc 4	TEN	34	Clay	8	4

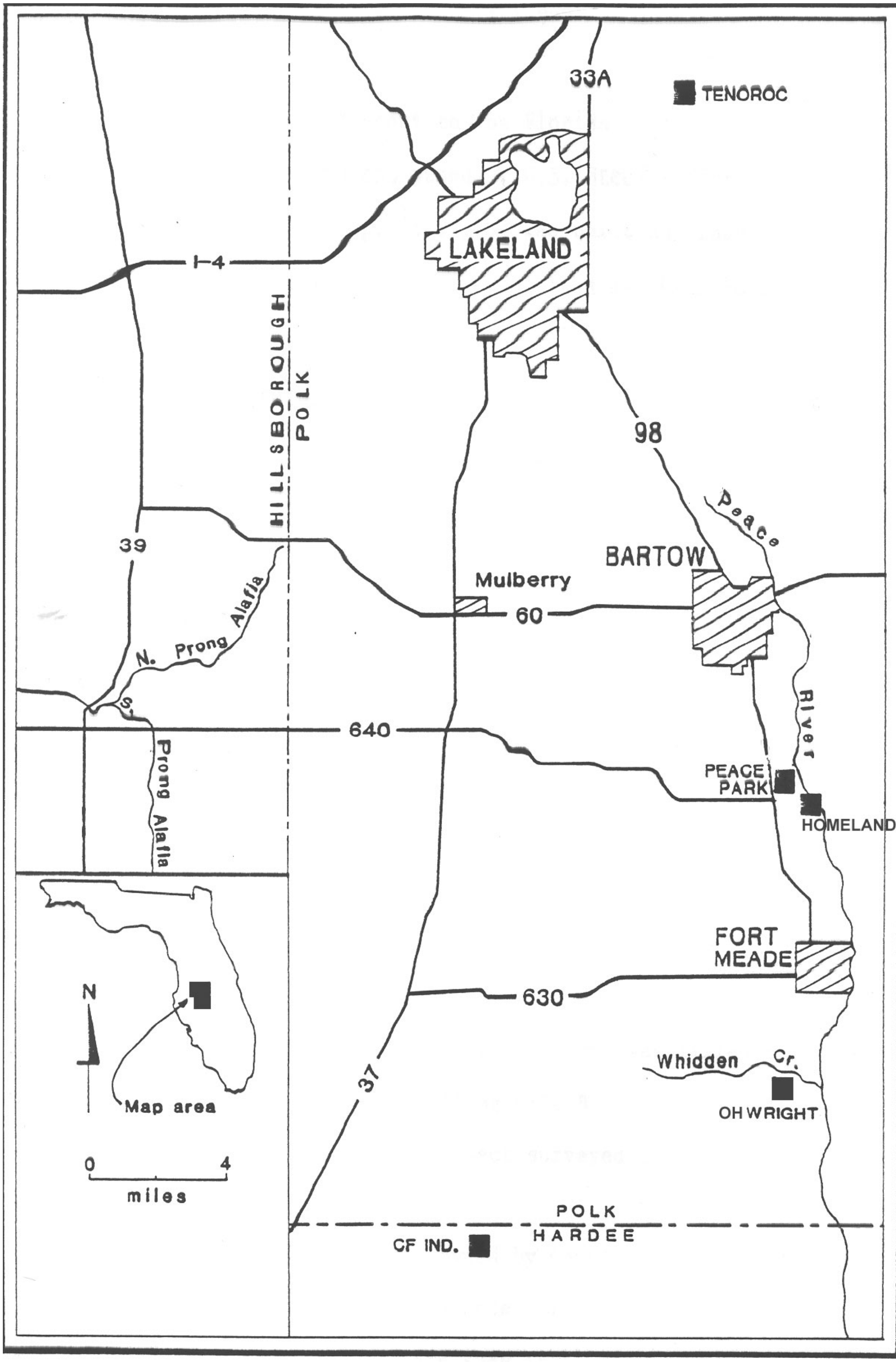

Figure 1. Study site locations. Map adapted from Rushton (1988).

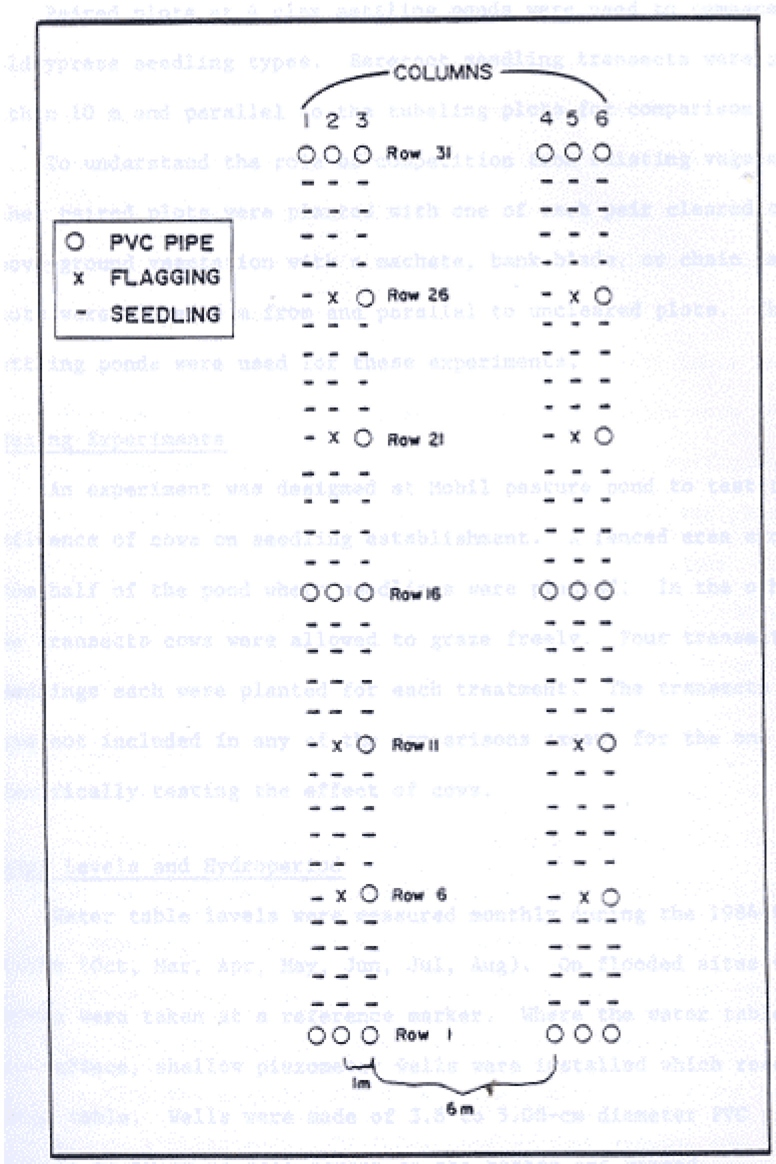

Figure 2. Cypress-gum plot layout from Rushton (1988). Two plots are pictured. Each plots was planted with 93 seedlings.

Table 2. Species list for cypress-gum plots

Species	Symbol
Fraxinus pennsylvanica	FRPA
Nyssa aquatica	NYAQ
Taxodium distichum	TADI

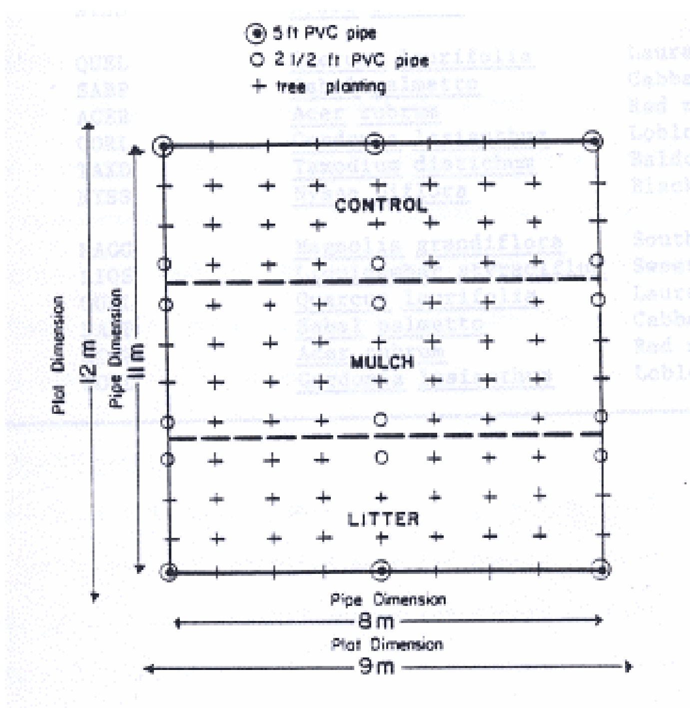

Figure 3. Hydric swamp plot layout from Rushton (1988). Two plots are pictured. Each plots was planted with 108 seedlings.

Table 3. Species list for ‘wet’ and ‘transitional’ hydric swamp plots

"Wet" Plots		Transitional' Plots	
Species	Symbol	Species	Symbol
Fraxinus caroliniana	FRCA	*Acer rubrum*	ACRU
Nyssa sylvatica	NYSY	*Gordonia lasianthus*	GOLA
Persea palustris	PEPA	*Nyssa sylvatica*	NYSY
Quercus laurifolia	QULA	*Quercus laurifolia*	QULA
Taxodium distichum	TADI	*Sabal palmetto*	SAPA
Ulmus americana	ULAM	*Taxodium distichum*	TADI

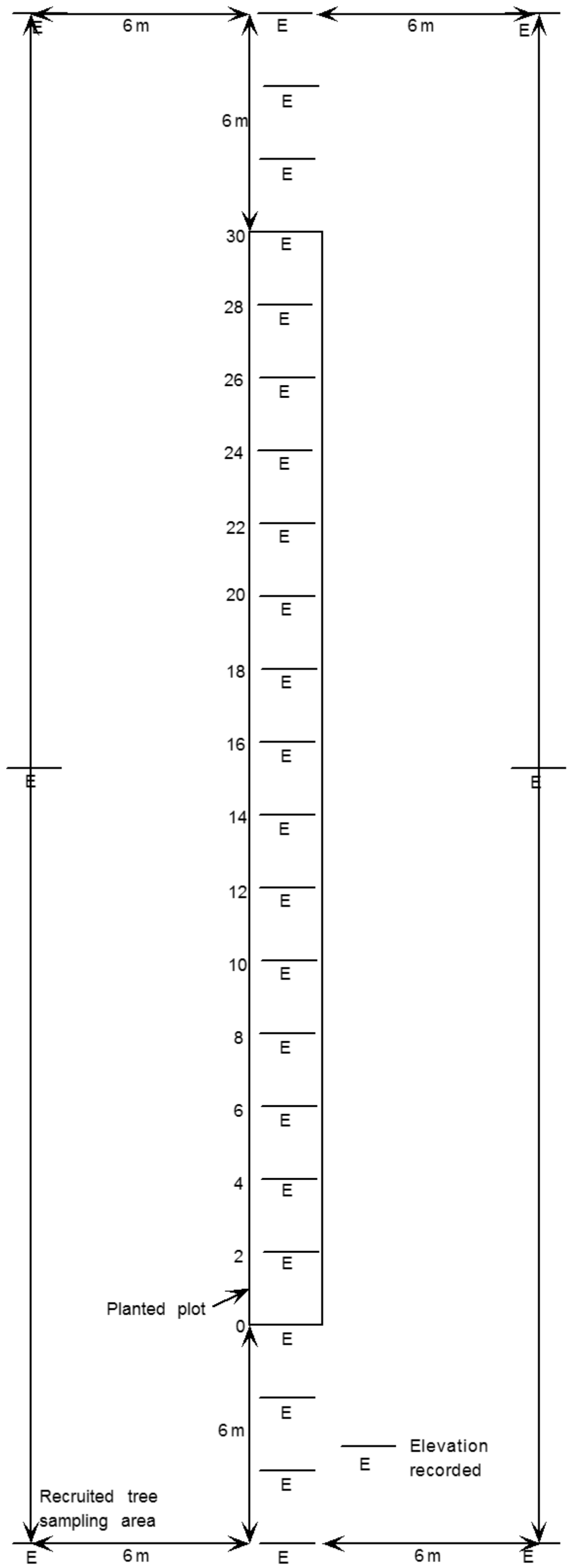

Figure 4. Elevation diagram for a cypress-gum plot. Numbers are in meters.

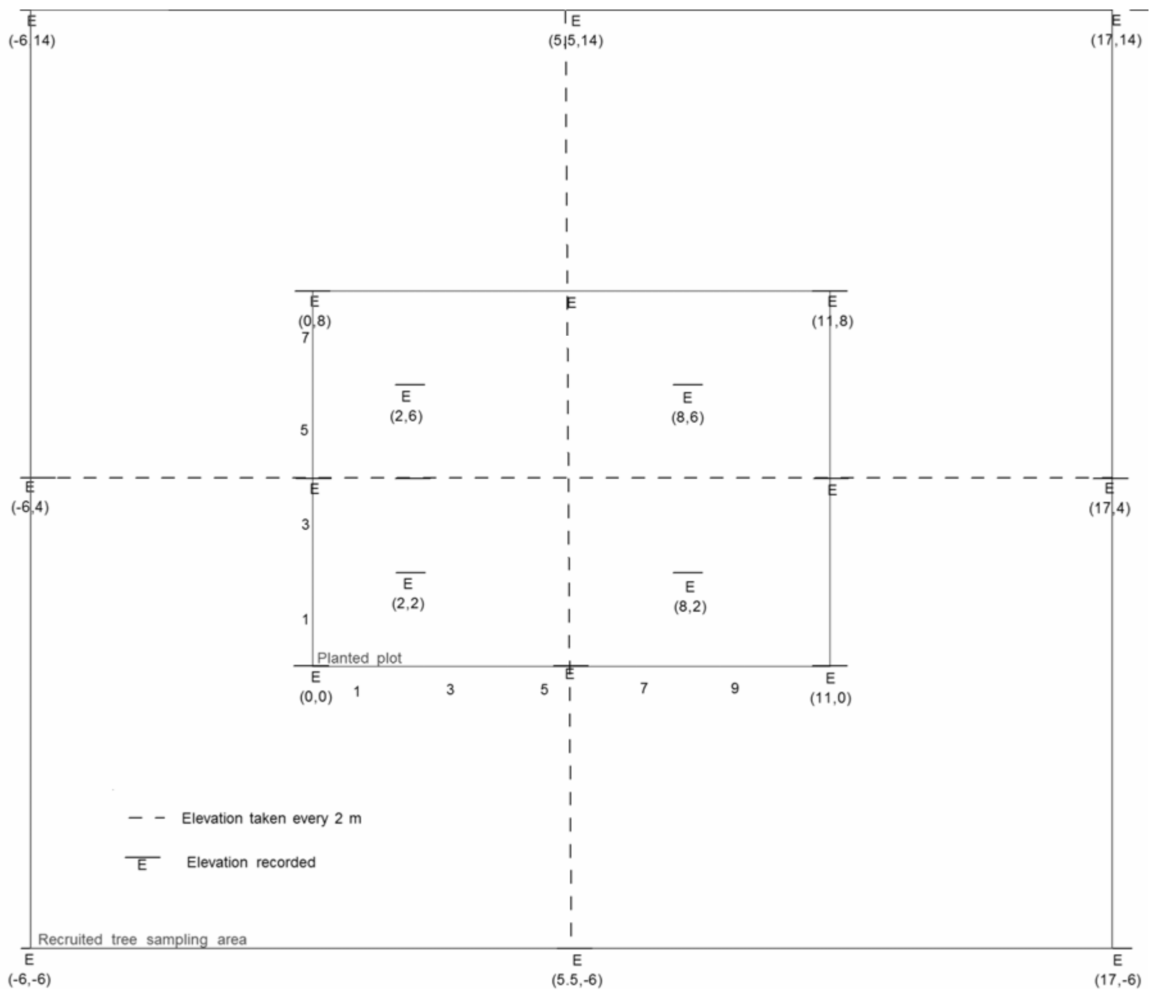

Figure 5. Elevation diagram for a hydric swamp plot. Numbers are in meters.

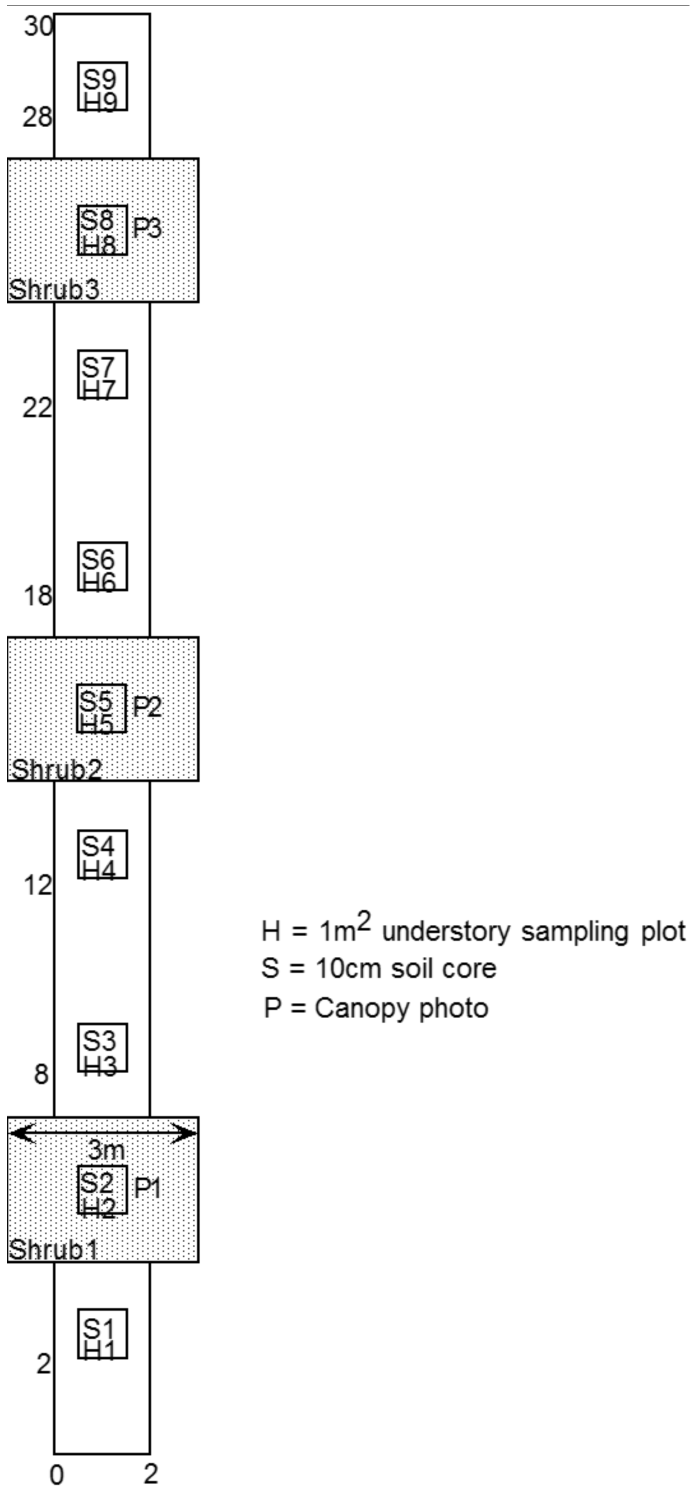

Figure 6. Soil, understory, shrub, and canopy photo sampling scheme for cypress-gum plots. Numbers are in meters.

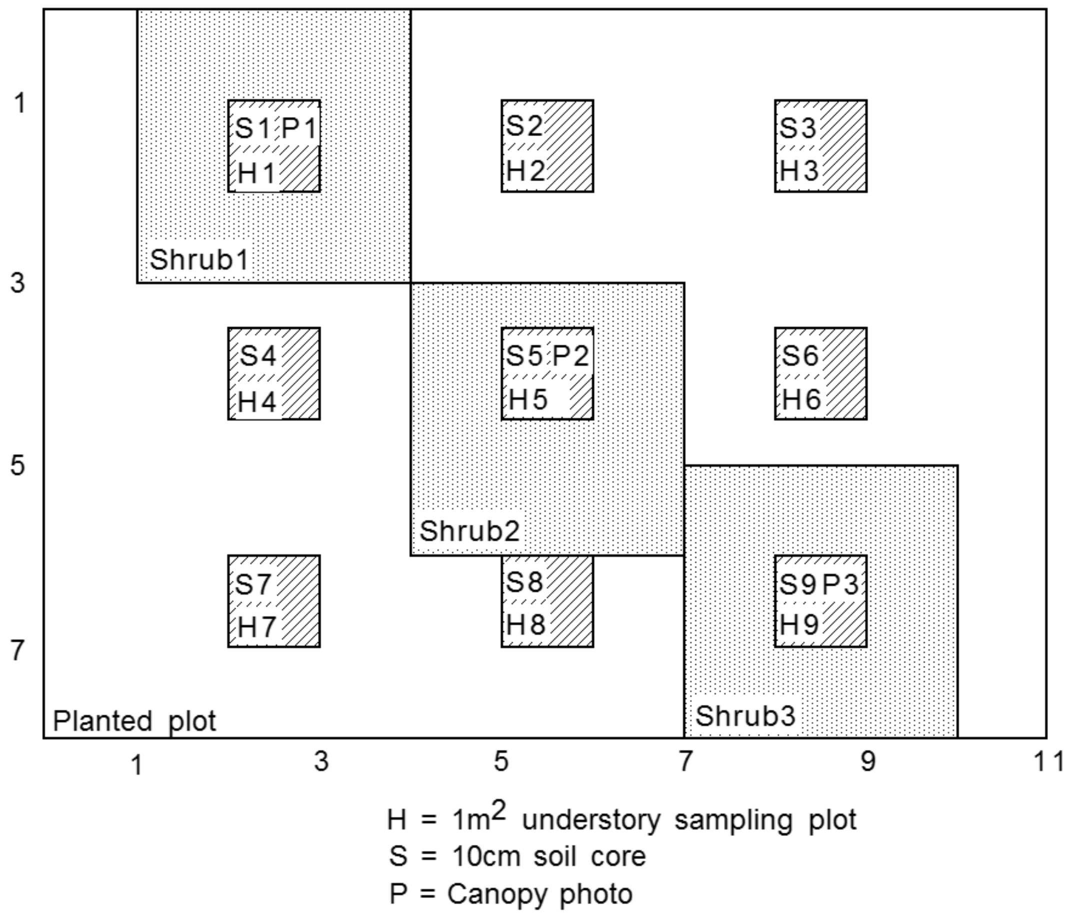

Figure 7. Soil, understory, shrub, and canopy photo sampling scheme for hydric swamp plots. Numbers are in meters.

Table 4. Size class key used in tree size class distributions.

size class	DBH(cm)	BA(cm^2)
0	NA	0
1	0.1-5	0.01-19.6
2	5-10	19.7-78.5
3	10-15	78.6-176.7
4	15-20	176.8-314.2
5	20-30	314.3-706.9
6	30-40	707-1256.6
7	>40	>1256.6

$$A = \begin{pmatrix} P_0 & F_1 & F_2 & F_3 & F_4 & F_5 & F_6 & F_7 \\ G_0 & P_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_1 & P_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_2 & P_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & G_3 & P_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & G_4 & P_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & G_5 & P_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & G_6 & P_7 \end{pmatrix}$$

Figure 8. The format for the transition matrix, *A*, for the matrix population model. The figure above is a matrix for a population with eight size classes (0-7). The *P* values along the diagonal represent probabilities of remaining in the same size class; the *G* values represent the probability of advancing into the next class, and the F, values represent the probability of successful reproduction.

RESULTS

Tree Populations in Relation to Environmental Factors

Survival of trees planted by Rushton is first summarized. Hydroperiod of the planted plots is compared and tree survival is examined across different water depths and on three soil types. The consequences of initial tree growth and site disturbances are considered. Population scale questions are approached by looking at populations of recruited trees within and on the periphery of plots, tree size class distributions, and population models of *Taxodium distichum* on two sites.

Tree Survival by Site and Species

Cypress-gum plots. Table 5 summarizes the planted tree survival percentages after 1, 3, and 20 years. Aggregating all sites, *Taxodium distichum* survived best after 20 years (34%), though *Fraxinus pennslyvanica* had the best survival at the end of the three years (70%).

Figure 9 presents survival trends by site and species in cypress-gum plots. Aggregating all three species, trees at the CFI site had the highest survival after 20 years (50%), and trees at TEN had the lowest survival (9%). More *Fraxinus pennslyvanica* were found after three years than after one year at CFI and OHW, most likely due to resprouting. Survival of *Fraxinus pennslyvanica* after 20 years was the poorest at HOM (8%), but highest of the three species at CFI (70%) and TEN (27%), two of the four sites with cypress-gum plots. Survival of *Taxodium distichum* was greater than 98% year^{-1} (indicated by the slope of the trend line) between years 3 and 20 at all but the TEN site. *Nyssa aquatica* had poorest survival in the initial year, but the survival rate between years 3 and 20 was the best of the three species at OHW and TEN, and better than *Fraxinus pennslyvanica* at CFI and HOM. Compared with the survival rate during the first year, all species had improved annual survival rates between years 3 and 20.

Hydric swamp plots. Table 6 summarizes tree survival in hydric swamp plots after 1 and 19 years. *Acer rubrum*, *Fraxinus caroliniana,* and *Taxodium distichum,* and *Ulmus americana* were the only species present in sampled plots after 19 years. No individuals of *Gordonia lasianthus*, *Nyssa sylvatica*, *Persea palustris*, *Quercus laurifolia*, or *Sabal palmetto* were found surviving in any of the plots after 19 years.

Figure 10 shows tree survival in hydric swamp plots by site and species. Only one individual of *Ulmus americana* survived 19 years and is not depicted. Of the three other surviving species, total survival after the first year for each was greater than 80% (see Table 2 for survival data by species). Survival of *Acer rubrum* after 19 years was 20% or less at all sites, with no surviving individuals found at TEN. *Fraxinus caroliniana* had the best survival in HS plots. At both OHW and TEN, all individuals survived after 19 years, a few having resprouted after the original stem died during the initial year. About half of *Taxodium distichum* trees that were surviving after 1 year survived 19 years, except at OHW where 20 year survival was only 12%, due to high mortality in two plots.

Hydrology

Average hourly water levels on the two sites where continuous data loggers were installed were within 3 cm of the average monthly water level measurements. Appendix Figures 33 and 34 show the continuous recorded levels and the monthly sampled levels at CFI and TEN.

Cypress-gum plots. Figure 11 shows the percentage of a plot that was inundated at the time of monthly water level sampling. Variation of inundated area occurs within and between sites, with some obvious trends apparent. Plots at CFI demonstrate a range of inundation, varying from R1, which was almost totally inundated on all dates, to plot R6, which was at most 15% inundated. Thus all trees at R1 stood in standing water much of the season, whereas water level was below ground for most trees in R6. Nearly all eight plots at HOM were inundated upon every visit. At OHW, plots R2A and B, adjacent plots on a pond fringe, were more than 50% inundated in 4 of 5 months sampled, whereas about one third R1A, which crosses a drainage channel, was consistently covered in water. At TEN all plots were dry in May but for most of the season more than 50% of R2A and R2B were inundated. R5A, R5B, R6A, R6B, R7A, and R7B are on a pond fringe, and all plots were mostly inundated when sampled in July and August, but on visits earlier and later in the season were wet only in the deepest ends, if at all.

Hydric swamp plots. Occupying less of an elevation gradient than cypress-gum plots, hydric swamp plots exhibit a more uniform response to water level than cypress-gum plots (see Figure 12). Many plots were inundated through the season, including all plots at PRP and H1 and H4 at OHW, whereas others, such as OHW H2, were dry at every sampling. Sites at TEN all were completely dry when sampled during May, and only H2 and H3 had a small area inundated at the September sampling, but during other months H2 and H3 were completely inundated. TEN and OHW both had two rather wet and two dry sites, whereas at PRP, all sites were wet.

Tree Survival and Hydrology

Cypress-gum plots. A box plot (Figure 13) showing the average water depth for the planted trees by species are shown in comparison with a box (first from left) showing the average water depth for the plots. As all species were initially planted along the entire water level gradient in a plot, this box represents the distribution of water depths at all original planting locations. A comparison of this first box of all planting locations with plots of surviving individuals of each species shows where tree survived along the water level gradient. The range of surviving *Fraxinus pennslyvanica* extends from a water depth of 0.5 to –1.0 m, excluding the deeper portion of the original range. The population of surviving *Nyssa aquatica* and *Taxodium distichum* withstood more inundation than the population of surviving *Fraxinus pennslyvanica*. Only a few outliers of the two populations occur where the average water level was below –0.6 meters. *Taxodium distichum*, which had the highest survival, occurs along a broader continuum of water depths than *Nyssa aquatica*. No individuals of any of the three species survived in the deepest part of the originally planted range.

In Figures 14-16, tree survival after 1 and 20 years is compared by species for all cypress-gum plots within the same site. For instance, in the bottom chart in Figure 14, *Taxodium distichum* are split into those surviving after 20 years and those that died between years 1 and 20. These two groups are then classified by average water depth either at the tree base, or the former location of the tree for those that died between years 1 and 20. At CFI, the range of water depth in which all three species survived did not change between years 1 and 20. More *Fraxinus pennsylvanica* and *Nyssa aquatica* trees died than lived in the shallowest water depths at this site. Once established, *Taxodium distichum* at CFI appears to be capable of tolerating the entire water level range over which the trees were planted. At OHW (Figure 15), *Fraxinus pennsylvanica* appears to have a much more limited water tolerance range, as only trees with an average water depth of 0.2-0.3 meters survived. Only a few *Nyssa aquatica* survived and they appear to have tolerated depths between 0.2 and 0.4 meters, as *Taxodium distichum* appears to have tolerated those depths as well as 0.0-0.2 meters. At TEN (Figure 16) *Fraxinus pennslyvanica* tolerated the drier locations where it established, but not in locations with average water levels above the ground surface (0.0 meters). *Taxodium distichum* survived where water levels were higher than -0.3 meters. *Nyssa aquatica* survival was poor across the range.

Hydric swamp plots. Figure 17 shows distributions of *Taxodium distichum* in hydric swamp plots where average depths at the surviving trees ranged from –0.5 to 0.9 meters. This species was not found in drier locations from –0.75 to –0.5 meters and not in the wettest locations where average depth was >0.9 meters. The range of original planting locations of *Fraxinus caroliniana* were similar to that for *Taxodium distichum* but not drier than –0.3 meters because it was not planted in the drier plots. Surviving individuals were not found where average depths were < –0.2 or >0.9 meters.

Tree Survival and Soil Type

Cypress-gum plots. Figure 18 summarizes trees survival on the sand-clay, sand-capped, and 3 clay sites. Trees growing on sites with clay soils had the lowest survival after 20 years.

CFI, the sand-clay site, had the best overall survival. Though *Nyssa aquatica* survived poorly on the clay sites after the first year, the survival rate between years 3 and 20 on clay was better than on the sand-cap site (HOM) and similar to sand-clay site (CFI). The slope of the trend line can be used to estimate annual survival rates of species. *Taxodium distichum* average survival rate between years 3 and 20 was poorest on the clay sites at about 97% yr^{-1}, and high on both the sand-cap and sand-clay site, at >99% $year^{-1}$. The population of *Fraxinus pennslyvanica* declined about 50% on the clay and sand-cap site between years 3 and 20. Due in part to resprouting, almost as many *Fraxinus pennslyvanica* trees were alive at CFI after 20 years as there were after 1 year, where a very high percentage (70%) survived.

Tree Growth Comparison Between Sand-Clay and Clay Sites

Tree populations in clay and sand-clay were compared to examine the effects of soil medium on tree growth. In 2005, all surviving trees on clay occurred within the range of water depths to which trees growing in sand-clay were exposed (see Figure 19). Results of t-tests to determine if a significant difference existed between growth of trees on clay and sand-clay are presented in Table 7. *Taxodium distichum* trees from both cypress-gum plots and hydric swamp plots were considered in the analysis. Growth of *Fraxinus pennslyvanica* and *Taxodium distichum* on clay and sand-clay was not statistically different. Growth of *Nyssa aquatica* was better (at a 95% confidence level) on clay, however there were only 13 *Nyssa aquatica* trees surviving on clay, a very small percentage of those originally planted.

Results of the two-way ANOVAs performed to simultaneously compare the effect of water level and soil type on tree growth for trees growing in clay and sand-clay are presented in Tables 8 and 9. Trees on the sand-cap site (HOM) were eliminated from consideration because of higher water levels. For *Fraxinus pennslyvanica*, trees with an average water depth of less than -0.25m were grouped as ‘shallow’ and those with a water depth greater than -0.25 were grouped as ‘deep’. *Fraxinus pennslyvanica* did not show a significant difference for either the soil type, water level, or interaction of the two. *Taxodium distichum* trees were split into ‘shallow’ and 'deep' classes using the median average water level of 0.0m. This test showed a significant effect for water level and for the interaction of water level and soil type. Trees in deep water had an average basal area of 5.4 cm^2, .4cm cm^2 greater than trees in shallow water, but the variance in basal area was also much higher for deep trees (1.53 to 1.19). Though planted on both soils, survival of *Nyssa aquatica* in clay was too low to allow for a comparison of the effects of soil type and water level on growth for this species.

Initial Tree Growth and 20-year Tree Survival

Records of tree height on cypress gum plots after 1 year were paired with tree survival records within the same plot to determine if trees that grew faster during the 1st year were more likely to survive 20 years. Tree height records after one year were available for 6 plots on CFI, 2 plots on OHW, and 6 plots on TEN. Of the trees with a height record, 296 were surviving in 2005 and 408 were dead. A T-Test was performed to determine if the heights of the trees after one year were different for these two groups, after the height was square root-transformed to satisfy the condition of similar between-group variance. The outcome, a p-value of 2.2E-16, indicated with a very high level of confidence that the surviving trees had a greater height after 1 year than the trees that died between 1 and 20 years.

Among the six plots on TEN, the average height of planted trees after one year was 35 cm, in comparison with 95 cm at CFI. Twenty-year survival of the TEN trees was 17%, versus 54% at CFI. Among these plots there is a strong correspondence between tree height after 1 year and 20-year survival.

Site Disturbance and Tree Survival

On a number of sites, disturbance factors directly caused mortality or damage to the planted trees within the initial year of establishment or in years since. Where records of these disturbances exist, they are presented in Table 10. Fire, heavy grazing, and mechanical disturbance (tractors, etc.) are known to have influenced a number of plots. A fire occurred in two hydric swamp plots (as well as in a number of cypress-gum plots not monitored in this study) that lie within a gully between two spoil piles on OHW. Multiple fires burned into all four of the hydric swamp plots in PRP, where dead tree trunks blackened from burning still stand as evidence. On HOM, four transects were subjected to grazing by cattle during their early years. In one basin of TEN, heavy herbivory negatively effected tree growth and survival during the first year (Rushton 1988). Segments of a few transects were damaged by earth-moving equipment, including the first 8 meters of CFI R2 and the first few meters of both TEN 5A and 5B. Numerous other disturbances may have occurred without leaving any direct or anecdotal evidence, including prolonged flood events, drought or heavy winds.

Recruited Trees

In a few cases, seedlings and mature trees of the same species as planted trees (‘recruited trees’) were found in abundance inside seedling sample plots, whereas in some plots no recruited trees were found. Tree populations in plots are presented in Table 11, where they are ranked by the ratio of the number of surviving planted trees to the number of recruited trees (reproductive ratio). Populations are defined in this table as all trees of a given species within the seedling sampling area of a plot. Only populations with at least one surviving tree and one planted tree are listed; 30 populations met this criterion. Where another plausible source for the recruited trees exists, this source is mentioned in the table. In nine populations, the number of recruited trees was greater than or equal to the number of planted trees. In two of these populations, the number of recruited trees was approximately 100 times greater than the number of planted trees. But in both of these two populations, there are clear seed sources other than the planted trees. Additional plantings of *Taxodium distichum* adjacent to or within sampling areas since 1985 occurred at CFI and HOM, but locations of those plantings were not available and thus trees not planted by Rushton could have either been planted later or are offspring of trees from another planting.

New Seedling Survival

The *Taxodium distichum* seedling (0-100 cm in height) population at TEN H3 was the largest of any plot sampled in June with 128 individuals. In November, the population had been reduced to 52 individuals. As location of the seedlings was noted only to the nearest meter and seedlings were not tagged, it was not possible to track individual seedling growth with certainty. But size class distributions of the seedling populations during both periods reveal in which segments of the population mortality occurred (Figure 20). A comparative look at the two distributions reveals a close match between trees in classes > 20 cm, but there are many more trees in the first two classes in June than in November. In June there were a total of 87 trees in the first two classes, whereas there were only 10 in November. The size of class '3' in November indicated that only a few of these trees likely grew into a larger size class during this period. The water level record reveals that the water was between -0.5 and the ground surface in May at the locations were the 87 individuals less than 20 cm stood in June. Of those seedlings, 72 were completely inundated in water during the June and July sampling.

Tree Population Size Class Distributions

Figure 21-24 show size class distributions of *Taxodium distichum*, *Nyssa aquatica*, *Fraxinus pennsylvanica*, and *Fraxinus caroliniana*. The composition of each size class is split into planted and recruited trees. Populations of *Taxodium distichum* are shown in six basins in Figure 21. Trees at CFI are the most evenly distributed across size classes. Recruited trees at CFI appear in the first four size classes. At HOM there is a more normal-shaped distribution, with obvious omissions in the seedling class (class 0). At OHW, PRP, and TEN there are fewer trees, in part because some of the plots were hydric swamp plots, where fewer trees of a species were planted, and in part because of lower survival. The first basin at TEN had an exceptionally high number of seedlings (see Table 11, row 1). Four trees in classes 4, 5, and 6 in this basin appear as 'recruits' but are actually trees planted by Rushton in a plot not included in this study that overlapped with the recruited tree sampling area.

Nyssa aquatica populations were too small in basins at OHW and TEN such that trees were only distributed between 2-3 middle range size classes (Figure 22). CFI has a small number of seedlings but the approximately the same number relative to other size classes in comparison with its *Taxodium distichum* population.

The CFI basin had six times as many surviving *Fraxinus pennslyvanica* as the other basins and a normal shaped population distribution (Figure 23), but the distributions of the populations are similar in the other basins, albeit they were lacking in smaller trees.

Only a small number of *Fraxinus caroliniana* were planted in two basins and in both cases there are more individuals than originally planted (Figure 24).

Tree Population Model

The model for *Taxodium distichum* at CFI used the records of 266 trees to construct the transition matrix (Figure 25). The λ of this transition matrix was 1.005; the model predicts that if the population were to obtain a stable population distribution, it will increase but at a slow pace. The population projection for the next 50 years shows at first a slowing decline from 150 to a low of about 120 trees after 20 years, but then growing again to 130 at the end of 50 years (Figure 26). The model for the *Taxodium distichum* population on the OHW basin used records of 106 trees for construction of the transition matrix (Figure 27), with no trees presently in the largest size class (7). The λ of this transition matrix was .991, indicating a slow long-term population decline. After 50 years the model predicted that the tree population would fall from 36 to 16 trees in the basin (Figure 28). Though the λ values represent potential opposite long-term projections for the two populations, the model does not predict drastic population change for either basin within the next 50 years.

Relative to the mature tree population size, the larger number of new seedlings at CFI compared to OHW resulted in slightly higher fecundity values, or the probability of creating a successful offspring. These values are depicted in the first row of the transition matrices.

The stasis values, or the probability of remaining in the same size class over the year, are presented along the diagonal. These values are similar for the two sites. Predicted growth values (the value below the diagonal) were also similar at both sites. Because no trees were present in the largest size class at OHW, there was no probability of advancement into the largest size class at OHW, which does not represent a realistic scenario.

Figure 29 shows the results of the elasticity analysis of the CFI model. The elasticity analysis was nearly identical for the OHW model. This analysis shows the chief importance of the stasis values for the largest three size classes. Though there are different growth rates for the two populations, the stasis values for the last size class were 0.99 for both models, suggesting that 99 of 100 trees in the largest size class are likely to survive a given year. This value was, according to the sensitivity analysis, nearly five times as important as any other value in the transition matrix.

Ecosystem Development in Rushton and Reference Plots

Comparisons between pairs of one or more Rushton and a reference plot were made based on the canopy cover, plot vegetation including trees, shrubs, and understory vegetation, and soil percent organic matter. Samples from Rushton plots were only considered when basal area density of Rushton trees was > 10 m^2/hec in the sample area.

Selection of Plots for Comparison

Table 12 presents all the Rushton plots and subplots ordered by basal area (m^2/hec) of Rushton trees. The plots/subplots considered in the comparative analysis with reference plots are those listed above the dotted line. A distinction was drawn at a basal area of 10 m^2/hec below which survival in plots was so poor as to potentially nullify the effect of planted species on the surrounding environment. This distinction was drawn based on an arbitrary but clear break in the basal area in plots/subplots between the plot with a basal area of approximately 13 m^2/hec and the next lowest with a basal area of approximately 8 m^2/hec. Five hydric swamp plots and 1 complete cypress-gum plot along with portions of five others were thus removed from consideration in the following comparative analysis.

In addition to the Rushton plots removed from consideration, one subplot of the reference plot at CFI was removed from consideration upon realizing that this segment had been subjected to repeated disturbance from mowing and would not be representative of reference conditions.

Topographic Comparison of Rushton and Reference Plots

Table 13 shows a comparison of topography and water levels in Rushton plots and their corresponding reference plots, which are the highlighted items appearing at the bottom of the groups of Rushton plots. In most cases all reference plot variables - including average change in elevation, average water depth, minimum and maximum water depth - fell within 3 standard errors of the mean of the variable for the corresponding Rushton plots.

Plot Basal Area in Rushton and Reference Plots

Table 14 provides data on plot basal area from Rushton and reference plots. Plot basal area includes the total basal area of all trees and shrubs. For all but TEN R2A and R2B, the plot basal area (m^2/hec) in reference plots was less than in Rushton plots. The mean plot basal area in Rushton plots was up to 12 times greater than in corresponding reference plots. Typically the difference in plot basal area between Rushton and reference plots grew as planted species made up a larger portion of the plot basal area in a Rushton plot.

Percent Canopy Cover

Table 15 compares percent canopy cover determined from canopy photos in Rushton and reference plots. In 7 of 10 pairs Rushton plots had greater canopy cover than corresponding reference plots. In the remaining 3 pairs, reference plots' canopy cover were within 1% of Rushton plots. Except at HOM, there was not a difference between the canopy cover in Rushton and reference plots of more than 10%. Figure 30 demonstrates the trend in canopy cover as subplot basal area increases at HOM, which is typical of other sites. As subplot basal area increases, the canopy cover increases steeply and then levels out between 80 and 90%.

Soil Organic Matter

Table 16 provides a comparison of the percent soil organic matter found in samples of the top 10cm of the soil in Rushton and reference plots. At CFI, HOM, and PRP, soil organic matter was greater in Rushton plots, but in most pairings at the older sites of OHW and TEN, percent soil organic matter was higher in reference plots. In all cases the differences between the Rushton and reference plots as indicated by T-tests were significant at the 90% confidence level. At HOM there was a very wide range of organic matter within the Rushton plots, not present at the other sites.

Table 17 compares Rushton and reference plot percent organic matter by site. The variation between reference plots on different sites is greater than the variation between Rushton plots on different sites. Excluding HOM, the average %OM in Rushton sites varies between 9 and 10.5%.

Understory Vegetation

Table 18 presents a comparison of the understory coverage in Rushton and reference plots. Inconsistent differences occur between the Rushton and reference plots. Among the Rushton plots, the highest cover occurs at CFI, where ferns were planted underneath the drier portions of the plots. Understory coverage at OHW is consistent around 30% for Rushton plots, lower than at other sites.

Table 19 summarizes species richness and evenness among pairs of Rushton and references plots. No consistent signal of a difference in richness and evenness is apparent between Rushton and reference plots. The average number of species occurring in Rushton plots is never more than 13, whereas reference plots at CFI and TEN have as many as 21 and 20 species. Species evenness follows a similar trend to species richness when comparing within Rushton and reference pairs.

The range of both richness and evenness is greater in the reference than in the Rushton plots.

In order to determine the dominant species in the understory assemblage within each plot, Importance Values were calculated for each species. Lists of the most prevalent species for each plot determined by Importance Values can be found in Appendix Tables 21-30. Each table includes a list of prevalent species for every plot in a comparison pair.

The ordination of species assemblages based on the average cover of species can be a useful means of visualizing the similarity of assemblages in different plots. Figure 31 presents the result of an Nonmetric Multidimensional Scaling (NMDS) of the most prevalent species in the plots. The diagram shows a clear separation of sites and pairs. CFI reference plots are clustered on the left side, with the drier plots R-6 and R-4 close together and R1, the wettest site, on the other end. The CFI reference plots are closer to the HOM Rushton plot. All the HOM Rushton plots (names starting with ‘2’) are clustered among themselves and with the 3 PRP sites (names starting with ‘6’). The HOM reference plot is isolated from the other groups. All the OHW (names starting with ‘3’,’4’, and ‘5’) and TEN plots are clustered within their respective sites. Overall there is a much greater difference in species assemblies between sites than within sites or within pairs.

Relationship among measures of ecosystem development. Table 20 contains correlations among selected ecosystem development variables by site. Rushton and reference plots are combined in this analysis by site. Differences in the relationship strength and the direction of the relationships between these variables occur between different sites.

Two hydrologic variables - average depth and range of average depth - are included in the correlations, along with the total Rushton tree basal area (Rush_BA). The response variables included are total basal area, canopy cover, understory cover, understory richness, understory evenness, and soil percent organic matter. The relationship of the response variables to Rush_BA is of primary interest, though the correlations between response variables are also worth noting.

At all sites Rush_BA is strongly positively correlated with total basal area, as was apparent in Table 14, which showed that Rushton trees made up the majority of total basal area in most Rushton plots. However the correlation with canopy cover is less clear. At CFI correlation is nearly absent, because all plots including Rushton and reference have very similar canopy coverage (see Table 15). The trend is more positive at the sites where reference plots have less canopy cover. The correlations between Rush_BA and understory cover are mostly negative, except at CFI where understory planting occurred, though the relationship is weak at the older sites of OHW and TEN. Rush_BA ranges from being strongly negatively correlated with understory richness at PRP to strongly positively correlated at OHW. The correlations between understory evenness and also range from strong negative to strong positive.

OWH and TEN show the same direction of correlation for all response variables. HOM and PRP, the wettest sites, also show the same direction of correlation in all variables but species evenness.

Table 5. Tree survival from initial planting in 25 sampled cypress-gum plots.

	No. Planted	% Survival 1yr	3yrs	20yrs
Fraxinus pennsylvanica	651	72%	70%	29%
Nyssa aquatica	837	44%	34%	18%
Taxodium distichum	837	66%	55%	34%

Table 6. Tree survival from initial planting in 12 sampled hydric swamp plots.

	No. Planted	% Survival 1yr	19yrs
Acer rubrum	126	94%	6%
Fraxinus caroliniana	72	99%	82%
Taxodium distichum	216	89%	31%

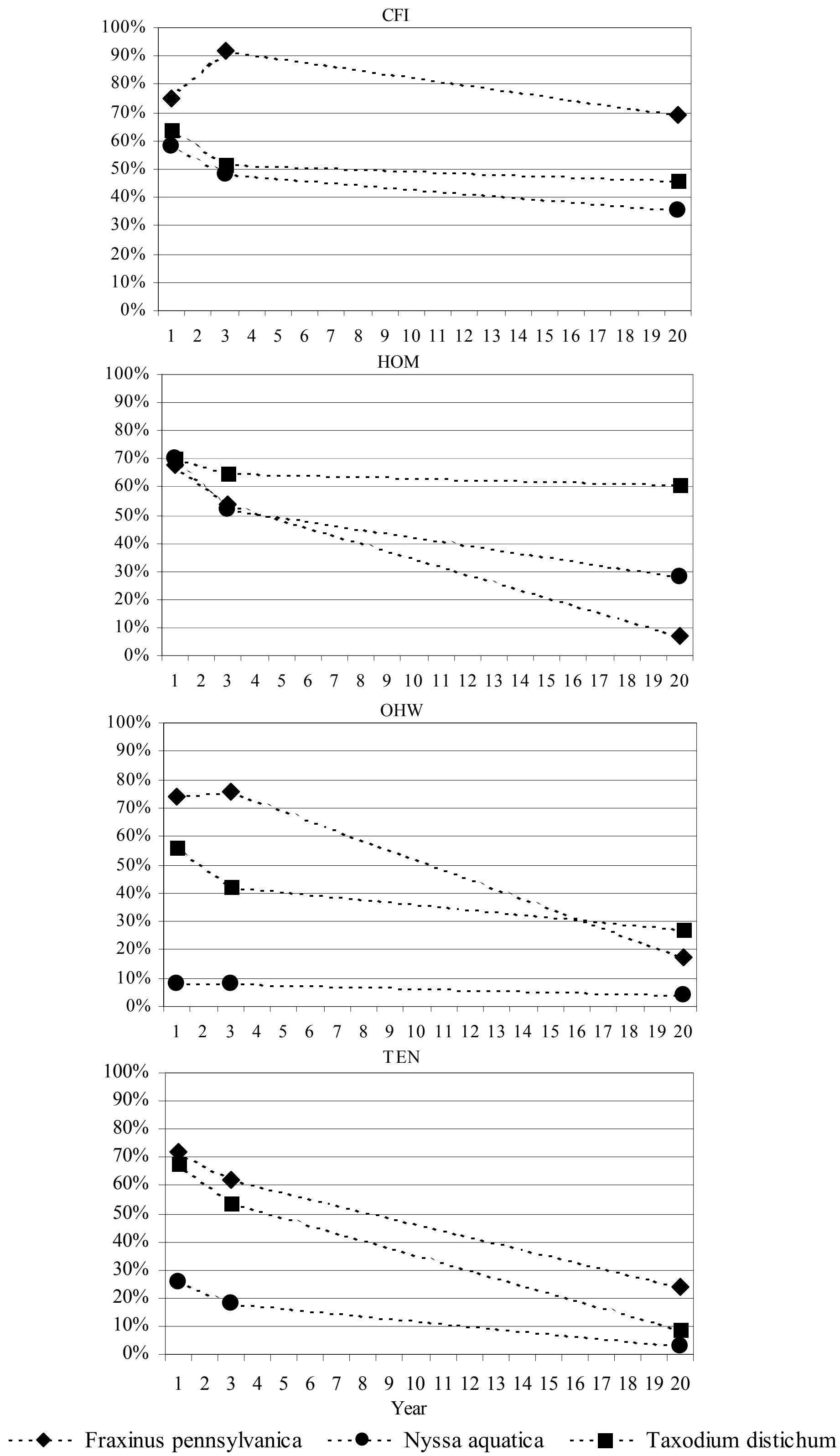

Figure 9. Percentage of planted trees surviving by site and species in cypress-gum plots after 1 year (Rushton 1988), 3 years (Paulic and Rushton 1991a), and 20 years. The dashed line represents a hypothetical trend in between the sampled years.

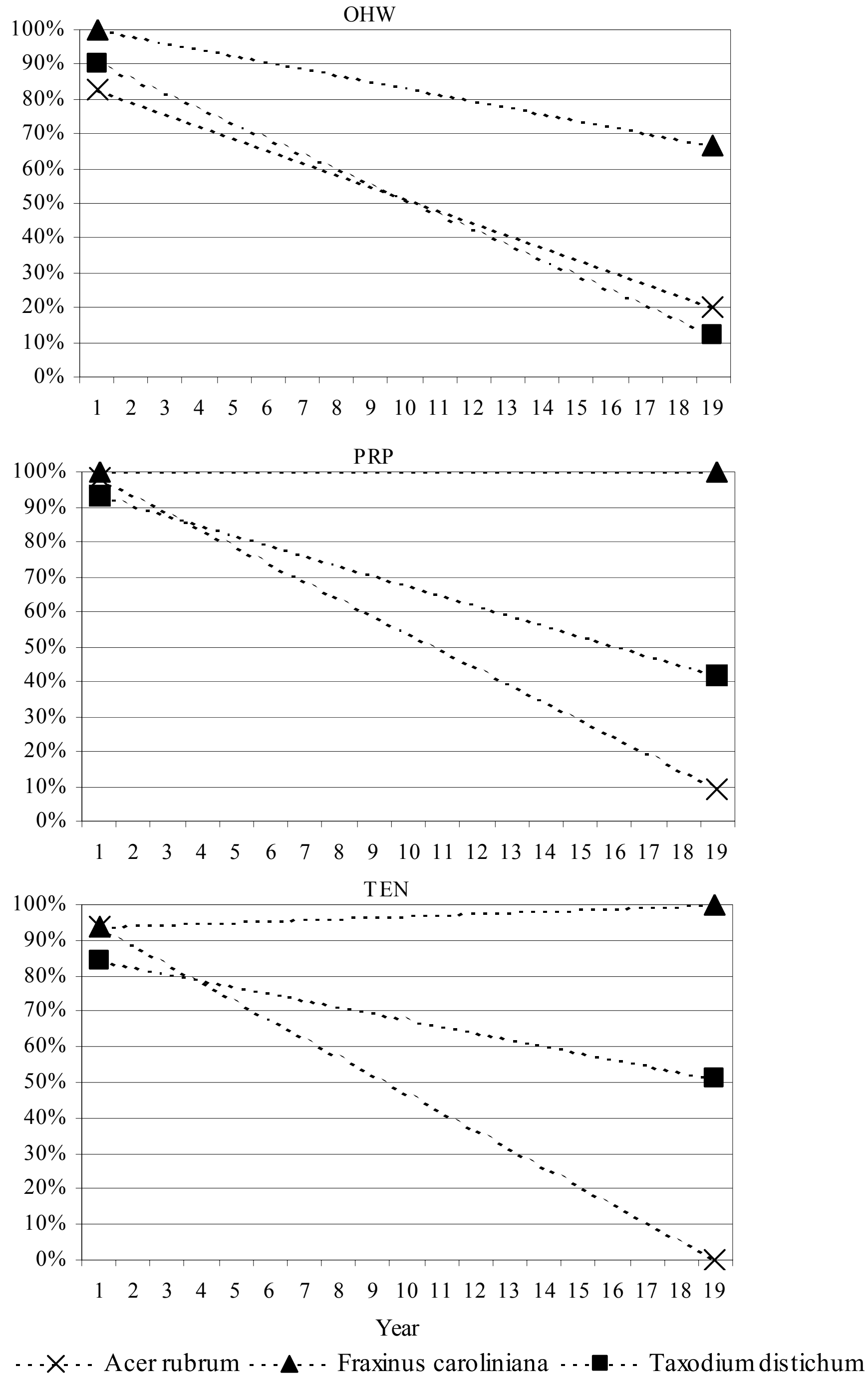

Figure 10. Percentage of planted trees surviving by site and species in hydric-swamp plots after 1 year (Rushton 1988) and 19 years. The dashed line represents a hypothetical trend in between the sampled years.

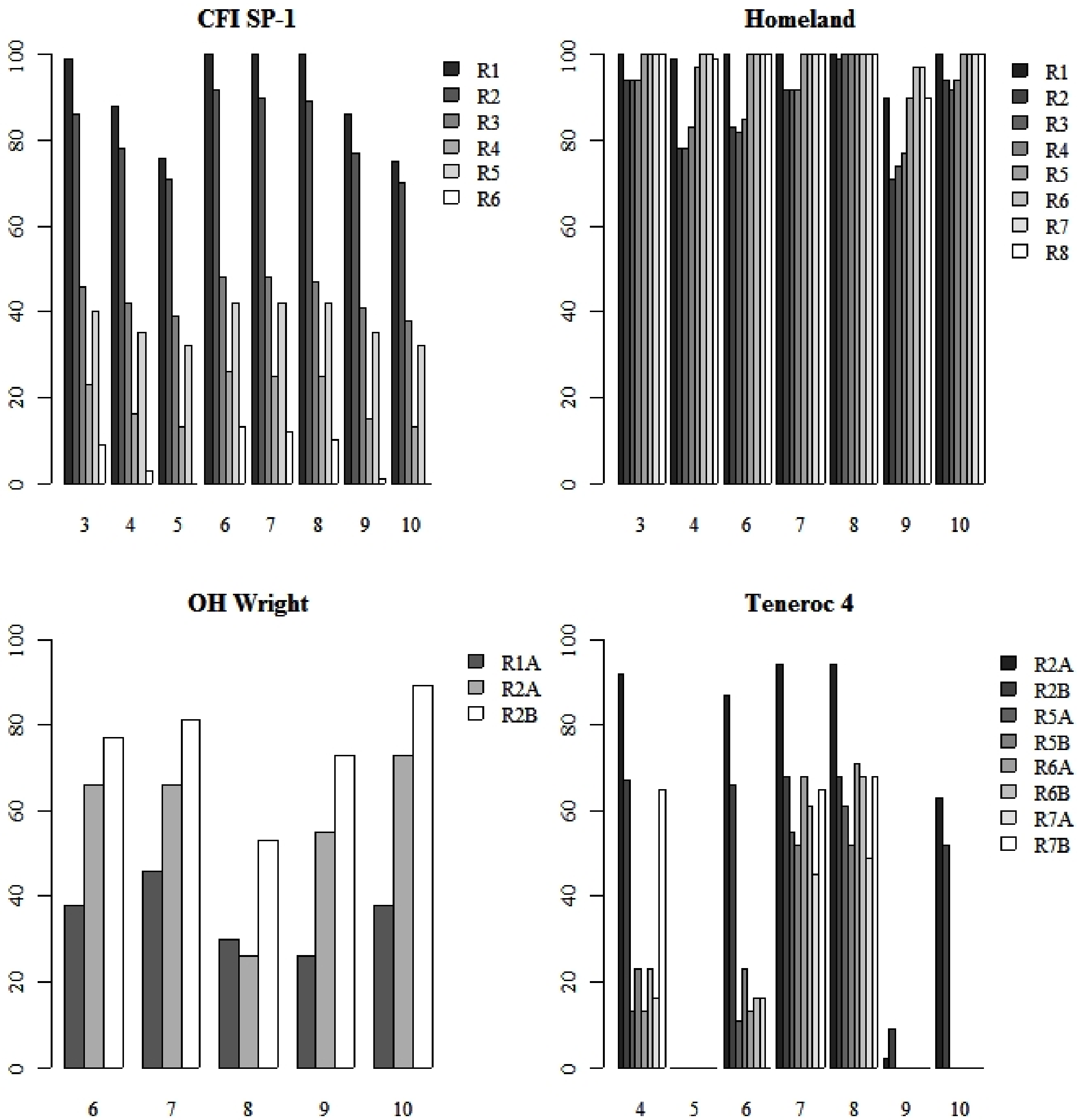

Figure 11. Percentage of plot inundated at time of monthly sampling during the period of record on cypress-gum plots. The numbers on the x-axis represent month of the year (e.g. 3 = March)

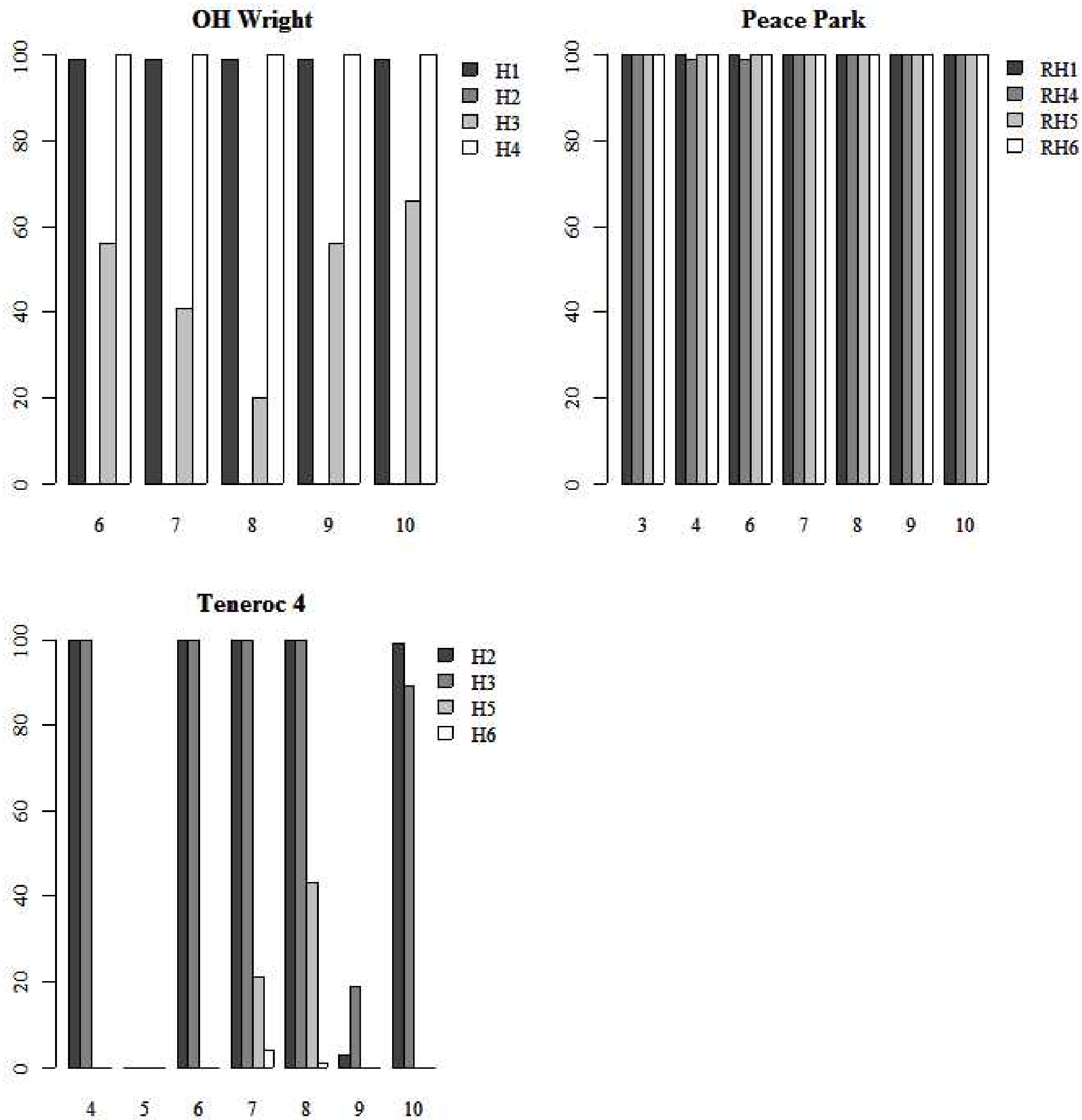

Figure 12. Percentage of plot inundated at time of monthly sampling during the period of record on hydric swamp plots. The numbers on the x-axis represent month of the year (e.g. 3 = March).

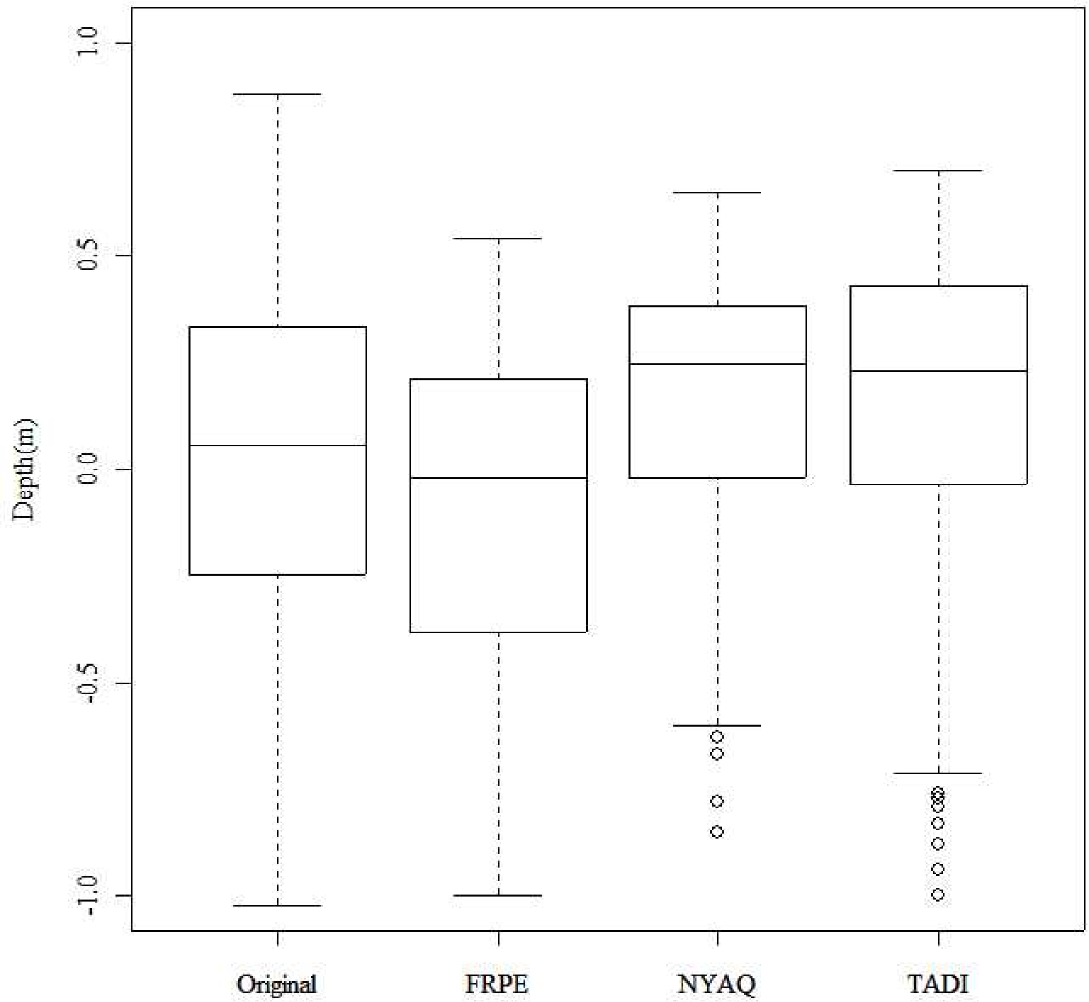

Figure 13. Distribution of average water depth inside original plot boundaries (Original) of cypress-gum plots, and at the locations of surviving trees for each of the species planted (*Fraxinus pennsylvanica, Nyssa aquatica,* and *Taxodium distichum*). The distributions are presented as box plots that break the data into four quartiles. The middle box represents the 25-75th percentiles, with includes the median value represented by the middle line. The upper and lower hashes represent the 0 and 100 percentiles. The circles beyond the lower hash are outliers.

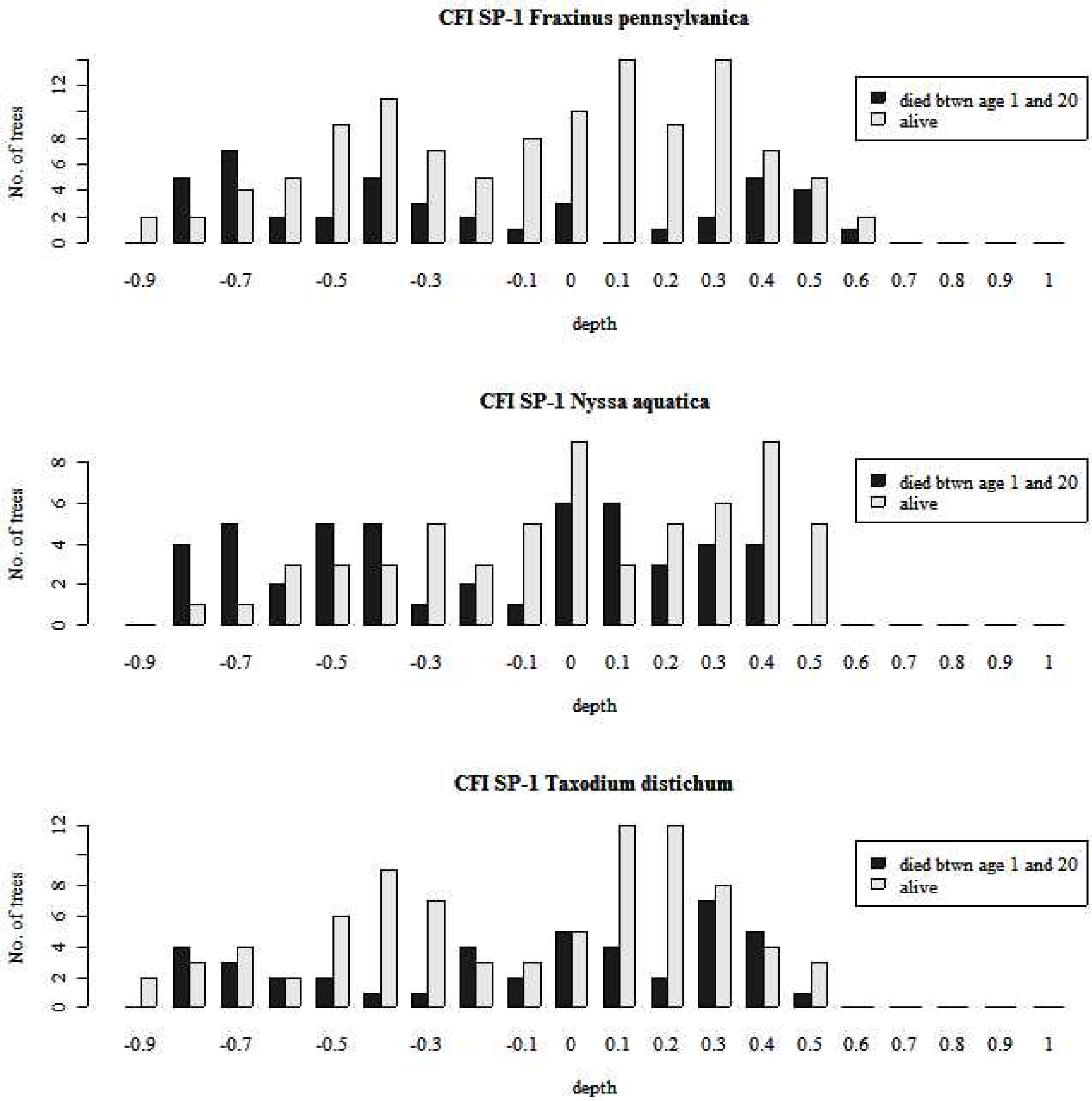

Figure 14. Number of planted trees that died between years 1 and 20 and trees alive in 2005, in 0.1m depth classes on CFI (sand-clay) on plots R1-R6.

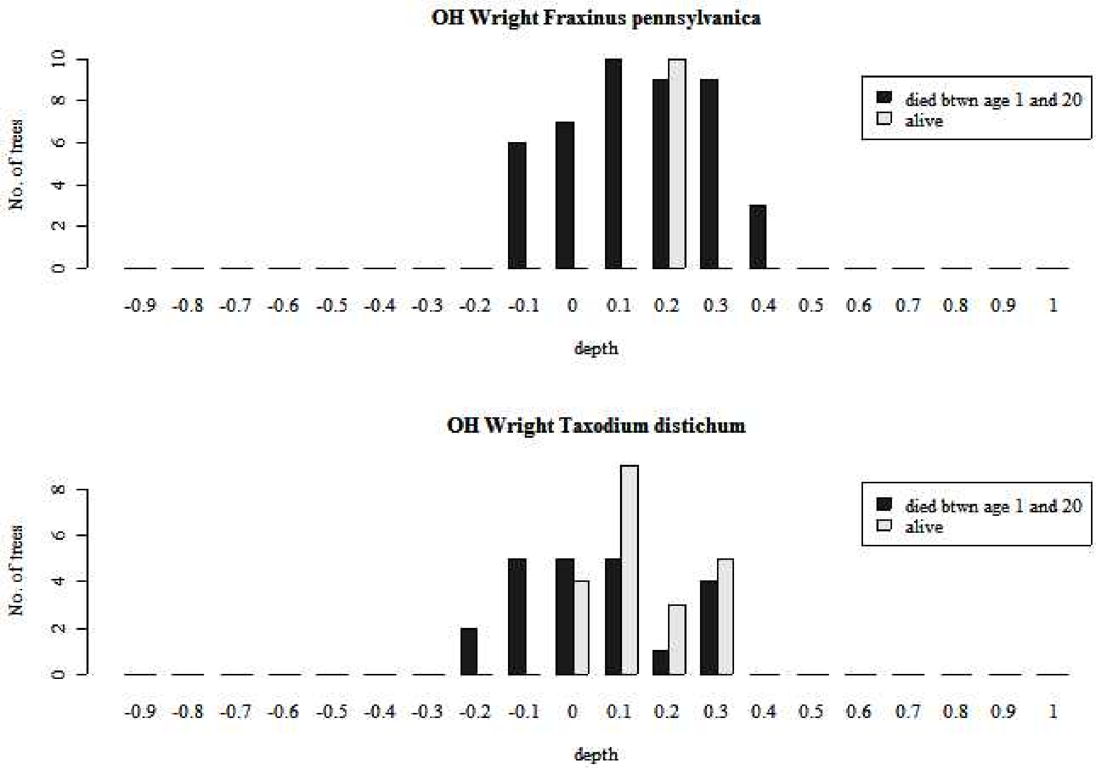

Figure 15. Number of planted trees that died between years 1 and 20 and trees still alive, in 0.1m depth classes on OHW (clay) plots R2A and R2B.

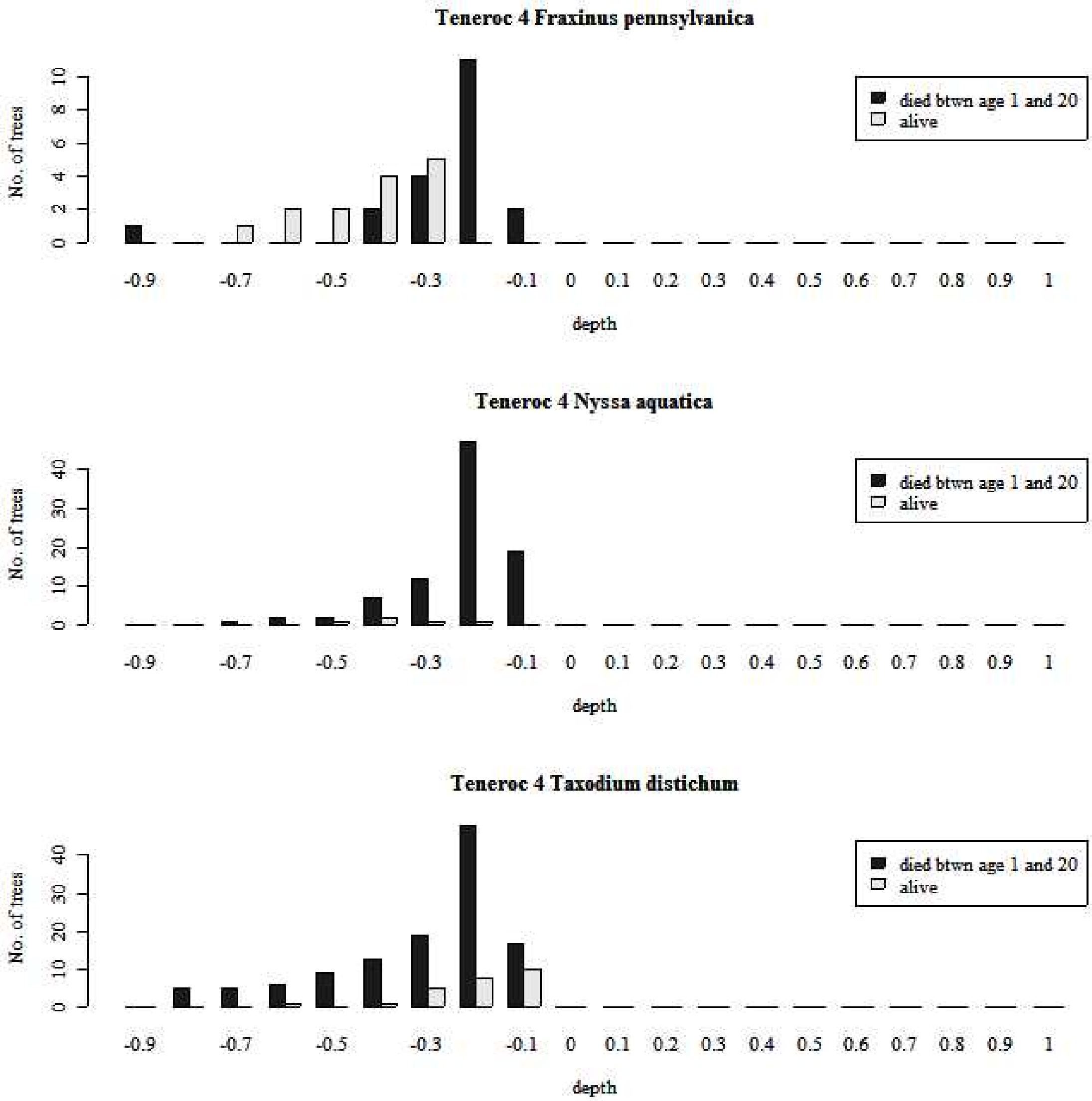

Figure 16. Number of planted trees that died between years 1 and 20 and trees still alive, in 0.1m depth classes on TEN (clay) plots R5A, R5B, R6A, R6B, R7A, and R7B.

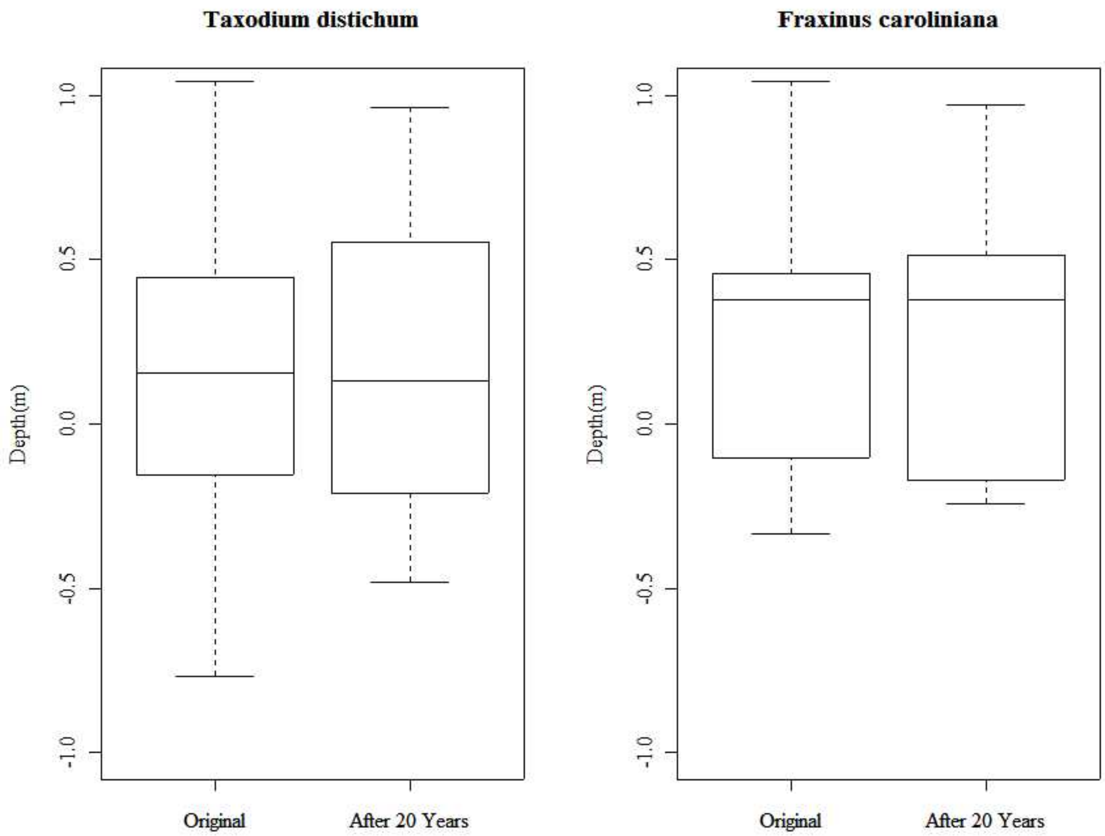

Figure 17. Distribution of average water depth inside plots boundaries (Original) of hydric swamp plots and at locations of surviving trees. See Figure 3 for explanation of box plot construction.

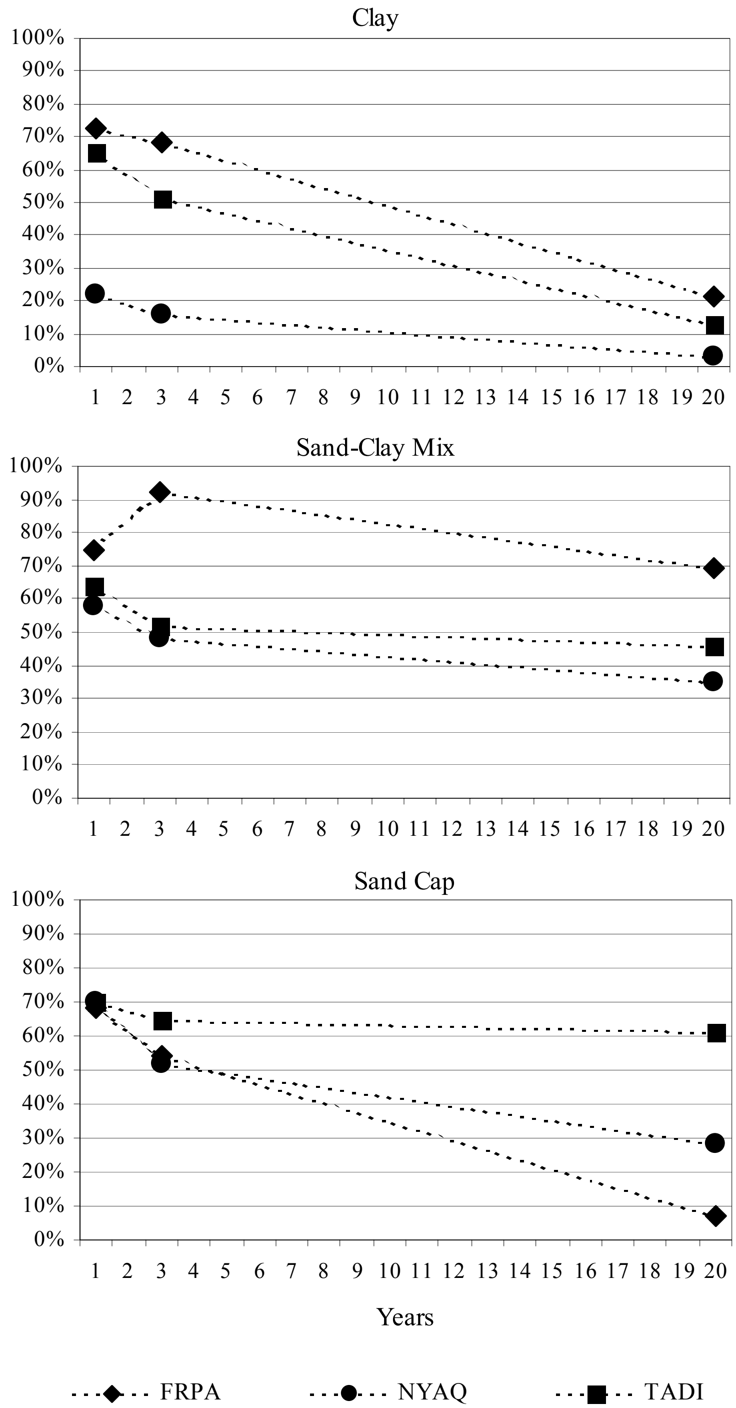

Figure 18 Percentage of planted trees surviving in cypress-gum plots by soil type after approximately 1 (Rushton 1988), 3 (Paulic and Rushton 1991a), and 20 years.

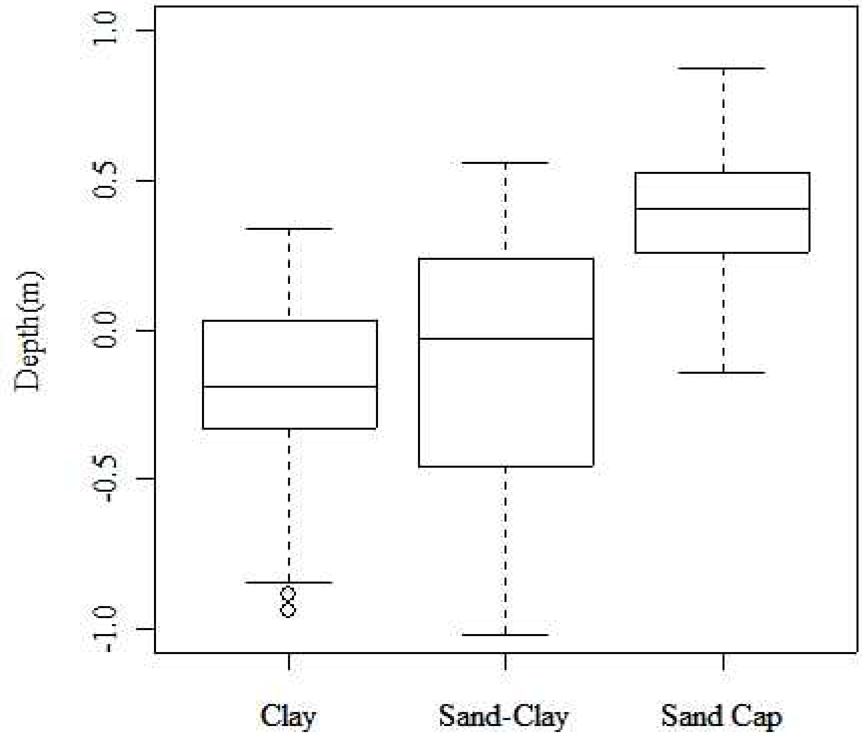

Figure 19. Distribution of average water depth in cypress-gum plots grouped by soil type.

Table 7. Comparison of trees growing in different soil media by species, among those with similar average water depth.

	No. of Trees		Mean of log(Basal Area)		p-value
Species	Clay	Sand-Clay	Clay	Sand-Clay	
Fraxinus pennslyvanica	45	89	4.24	4.44	0.20
Nyssa aquatica	13	37	4.61	3.96	0.02*
Taxodium distichum	82	67	5.23	5.44	0.63

*Significantly different at the 95% confidence level

Table 8. Results of a two-way ANOVA comparing the effect of two soil types (clay and sand-clay) and two water levels (shallow and deep) on *Fraxinus pennsylvanica* growth.

Variable	p-value
Soil Type	0.39
Water Level	0.52
Interaction	0.16

Table 9. Results of a two-way ANOVA comparing the effect of two soil types (clay and sand-clay) and two water levels (shallow and deep) on *Taxodium distichum* growth.

Variable	p-value
Soil Type	0.40
Water Level	0.02*
Interaction	0.01*

*Significantly different at the 95% confidence level

Table 10. Site Disturbance Record

Site	Plot(s)	Fire	Disturbance Heavy Grazing	Mechanical
CFI	1,3,4,5,6	-	-	-
	2	-	-	+
HOM	1,2,3,4	-	-	-
	5,6,7,8	-	+	-
OHW	1A,2A,2B	-	-	-
	H1,H4	-	-	-
	H2,H3	+	-	-
PRP	H1,H2, H3,H4	+	-	-
TEN	5A,5B	-	+	+
	6A,6B, 7A,7B	-	+	-
	H5	-	+	-
	H2,H3,H6	-	-	-

+ Record of incidence

- No record of incidence

Table 11. Plots with potential offspring of planted trees ordered by reproductive ratio

Site	Plot	Species	# Planted trees	# Recruited trees	Reproductive ratio (planted/recruited)	Possible alternate source for non-planted?	Alternate source	Rank
Teneroc 4	H3	TADI	1	133	0.01	Y	other plots	1
OH Wright	H2	ACRU	3	223	0.01	Y	floodplain	2
CFI SP-1	R4	TADI	4	9	0.44	Y	other planting	3
OH Wright	H1	FRCA	4	8	0.50	N		4
Peace Park	RH6	TADI	2	4	0.50	N		5
CFI SP-1	R5	TADI	10	16	0.63	Y	other planting	6
OH Wright	H1	TADI	2	3	0.67	N		7
CFI SP-1	R2	TADI	12	13	0.92	Y	other planting	8
OH Wright	R2B	FRPE	1	1	1.00	N		9
OH Wright	H4	FRCA	16	15	1.07	N		10
OH Wright	R1A	TADI	4	3	1.33	N		11
CFI SP-1	R3	NYAQ	8	6	1.33	N		12
CFI SP-1	R1	TADI	15	11	1.36	Y	other planting	13
Teneroc 4	R6A	TADI	2	1	2.00	N		14
CFI SP-1	R3	TADI	24	9	2.67	Y	other planting	15
Homeland	R1	TADI	25	8	3.13	Y	other planting	16
Teneroc 4	H6	TADI	17	4	4.25	N		17
CFI SP-1	R4	FRPE	14	3	4.67	N		18
OH Wright	H4	TADI	5	1	5.00	N		19
CFI SP-1	R5	FRPE	15	3	5.00	N		20
Peace Park	RH1	TADI	10	2	5.00	N		21
OH Wright	R2B	TADI	8	1	8.00	N		22
Teneroc 4	H5	TADI	9	1	9.00	N		23
Teneroc 4	H6	FRCA	19	2	9.50	N		24
CFI SP-1	R6	TADI	20	2	10.00	Y	other planting	25
Peace Park	RH5	TADI	12	1	12.00	N		26
CFI SP-1	R3	FRPE	25	2	12.50	N		27
CFI SP-1	R1	NYAQ	15	1	15.00	N		28
Homeland	R3	TADI	15	1	15.00	Y	other planting	29
Peace Park	RH5	FRCA	20	1	20.00	N		30

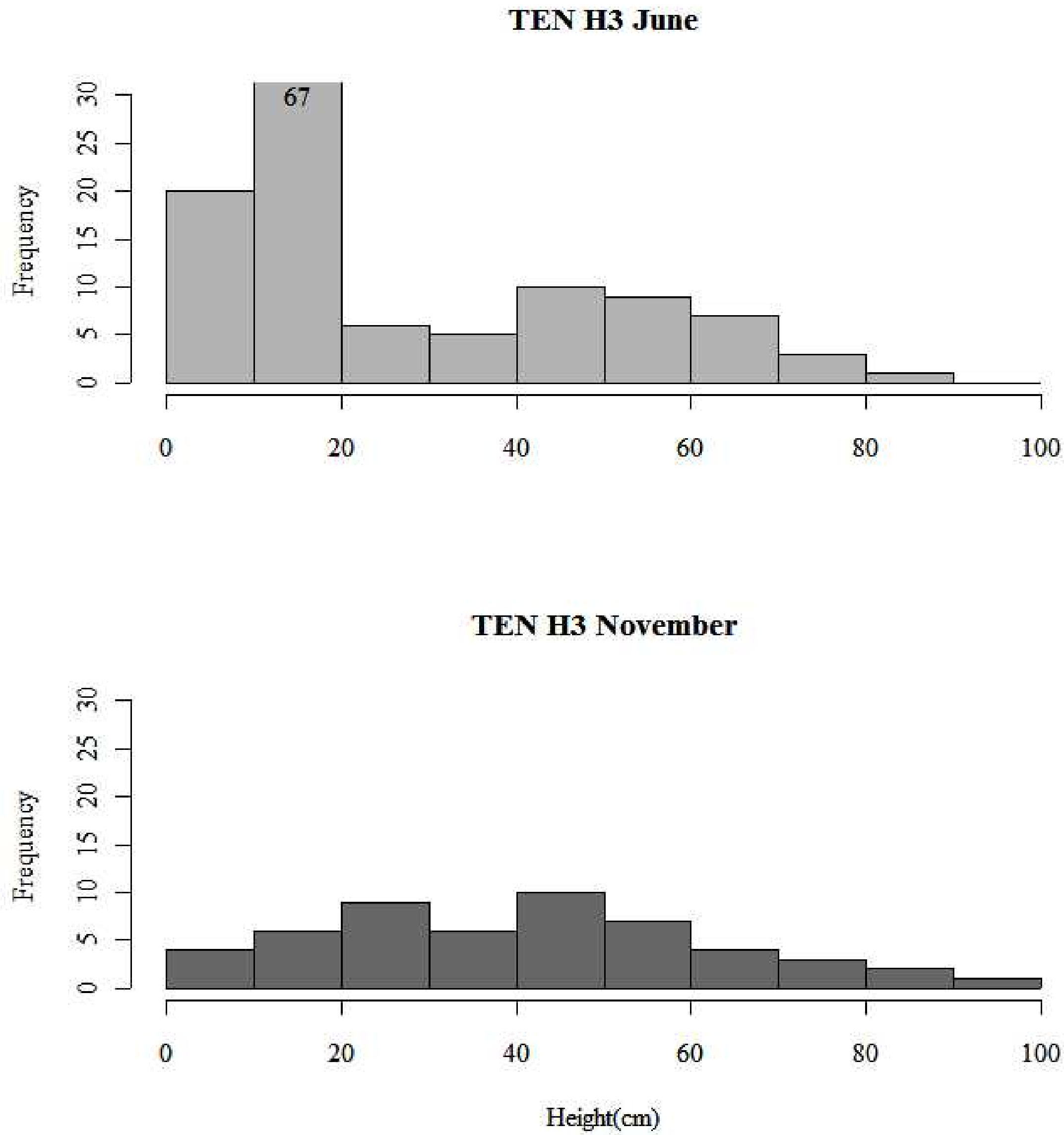

Figure 20. Size class distributions of *Taxodium distichum* seedlings at Ten H3 counted in June and November, 2005.

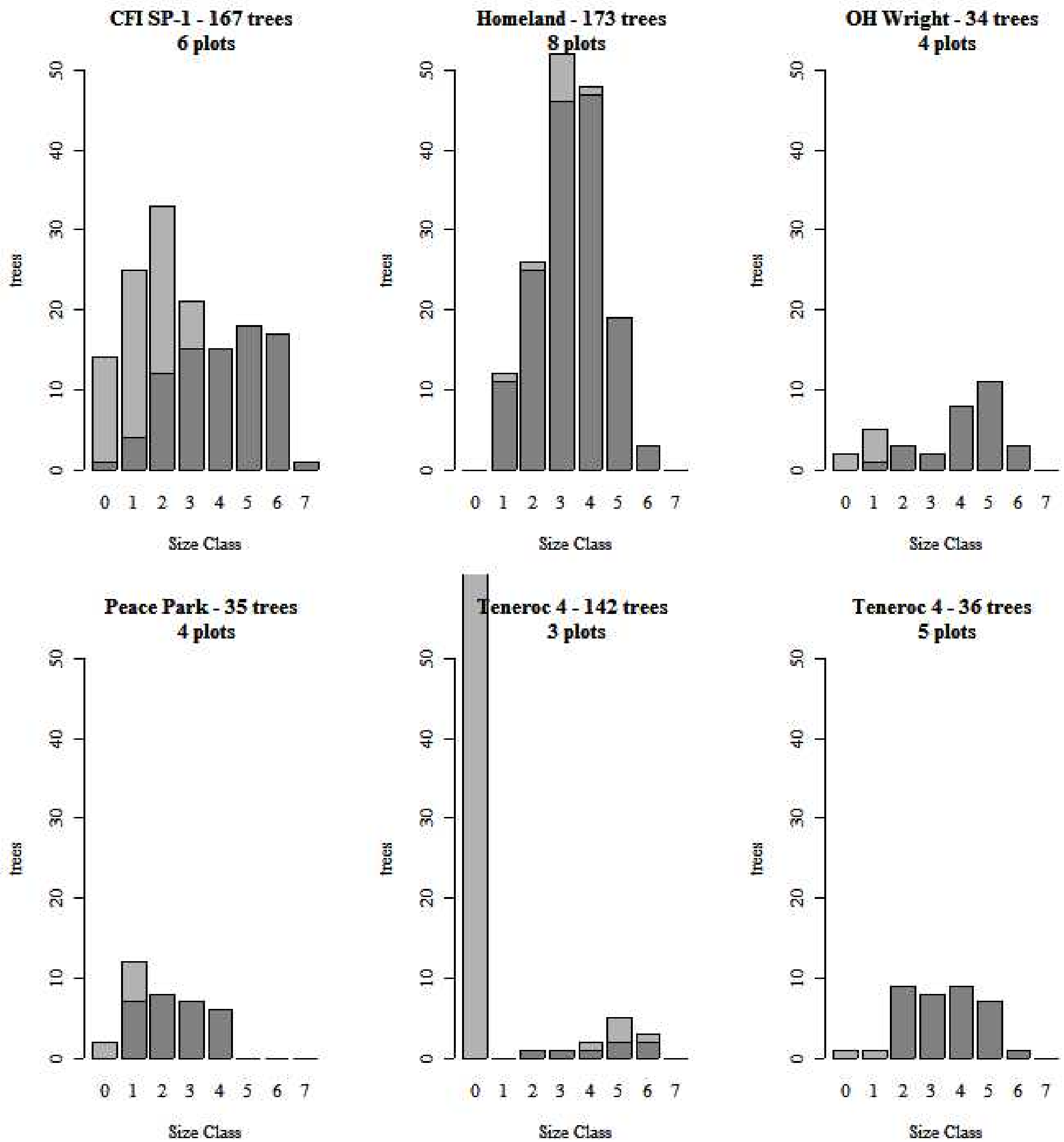

Figure 21. Size class distribution of *Taxodium distichum* in 6 basins on five CSAs. Light sections represent recruited trees; dark sections planted trees. The size classes represent the following DBH ranges: 0:no DBH; 1: 0-5cm; 2: 5-10cm; 3: 10-15cm; 4: 15-20cm; 5: 20-30cm; 6: 30-40cm; 7: >40cm.

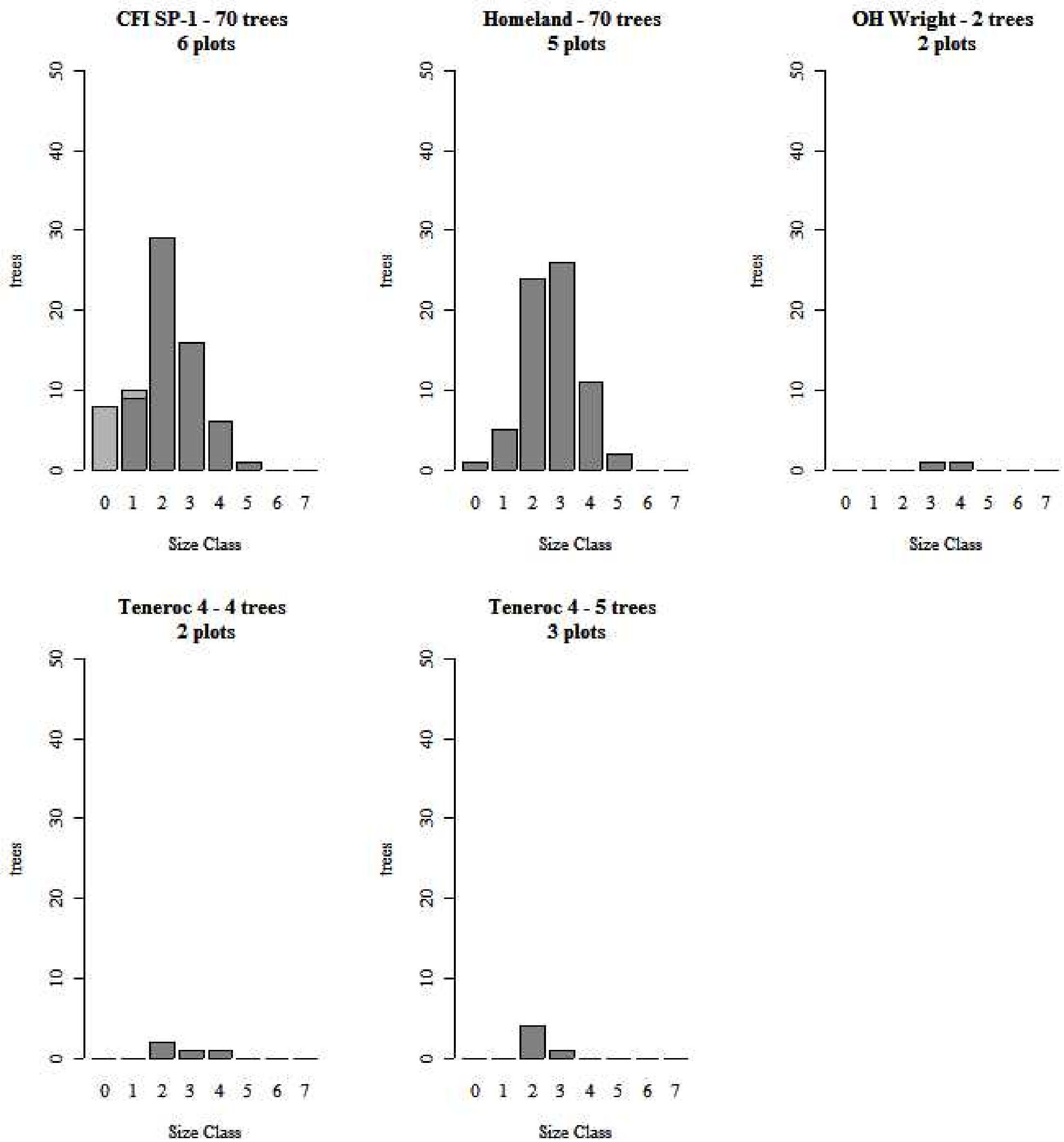

Figure 22. Size class distributions of *Nyssa aquatica* in five basins on four CSAs. Light sections represent recruited trees; dark sections planted trees. The size classes represent the following DBH ranges: 0:no DBH; 1: 0-5cm; 2: 5-10cm; 3: 10-15cm; 4: 15-20cm; 5: 20-30cm; 6: 30-40cm; 7: >40cm.

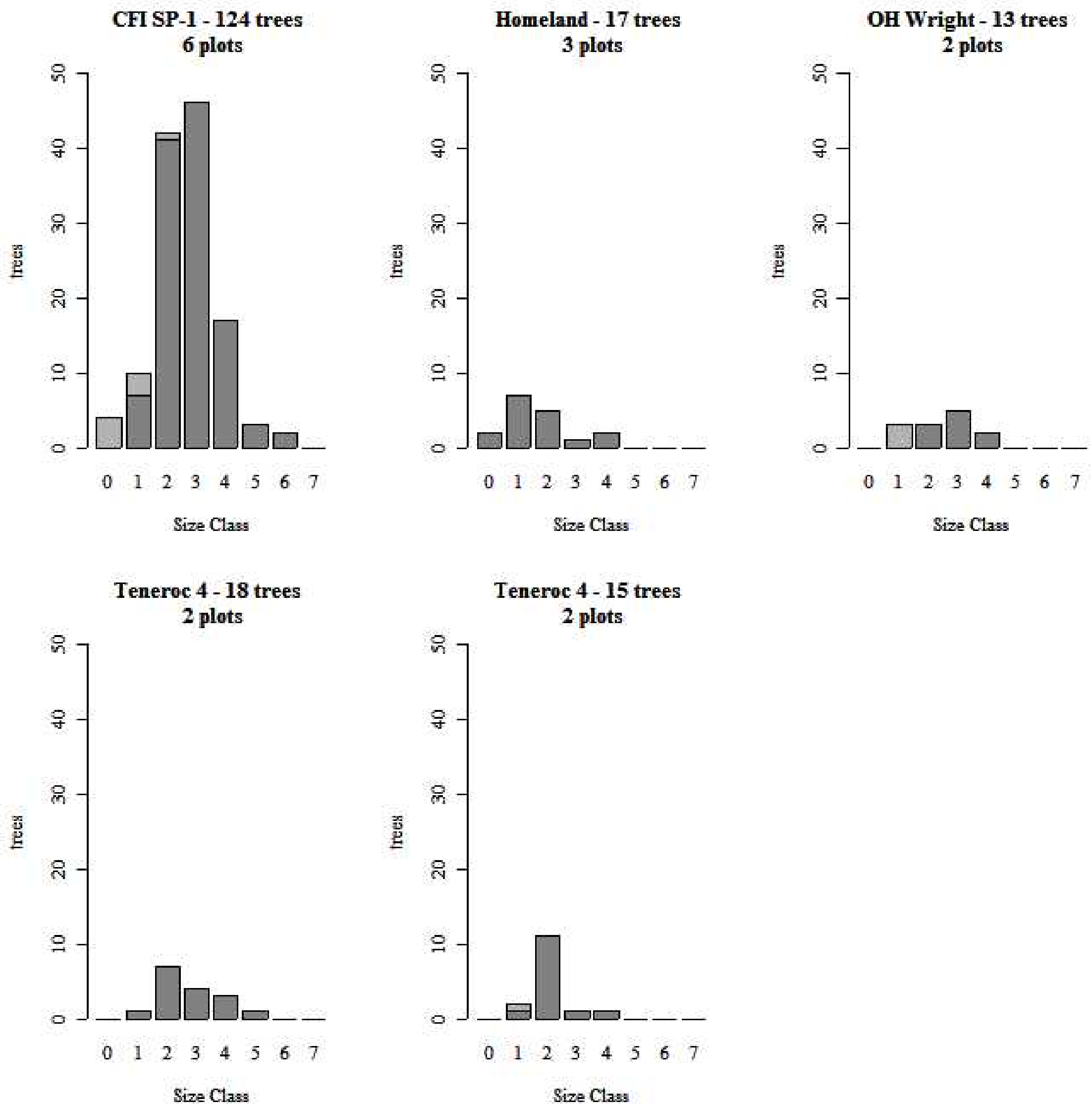

Figure 23. Size class distribution of *Fraxinus pennsylvanica* in five basins on four CSAs. Light sections represent non-planted trees; dark sections planted trees. The size classes represent the following DBH ranges: 0:no DBH; 1: 0-5cm; 2: 5-10cm; 3: 10-15cm; 4: 15-20cm; 5: 20-30cm; 6: 30-40cm; 7: >40cm.

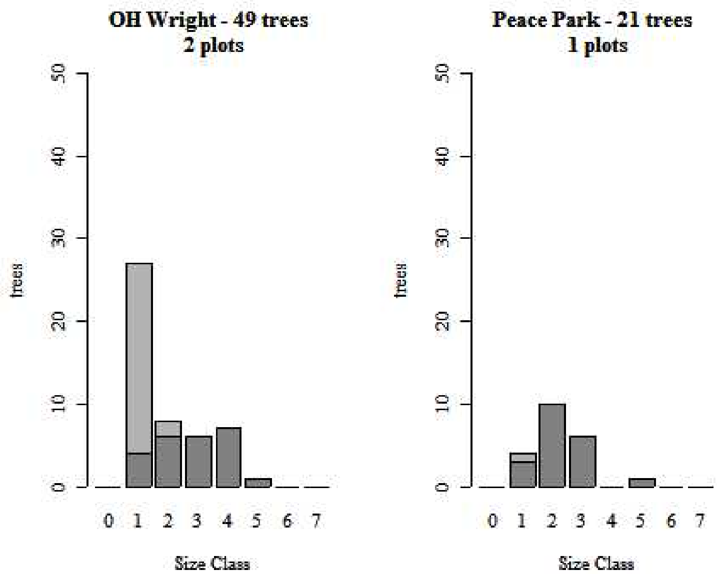

Figure 24. Size class distribution of *Fraxinus caroliniana* in two basins on two CSAs. The size classes represent the following DBH ranges: 0:no DBH; 1: 0-5cm; 2: 5-10cm; 3: 10-15cm; 4: 15-20cm; 5: 20-30cm; 6: 30-40cm; 7: >40cm.

CLASS	0	1	2	3	4	5	6	7
0	0.699	0.012	0.013	0.015	0.023	0.034	0.051	0.076
1	0.173	0.751	0.	0.	0.	0.	0.	0.
2	0.	0.212	0.804	0.	0.	0.	0.	0.
3	0.	0.	0.139	0.731	0.	0.	0.	0.
4	0.	0.	0.	0.223	0.725	0.	0.	0.
5	0.	0.	0.	0.	0.244	0.902	0.	0.
6	0.	0.	0.	0.	0.	0.078	0.946	0.
7	0.	0.	0.	0.	0.	0.	0.04	0.991

Figure 25. Transition matrix for CFI SP-1 *Taxodium distichum* population model

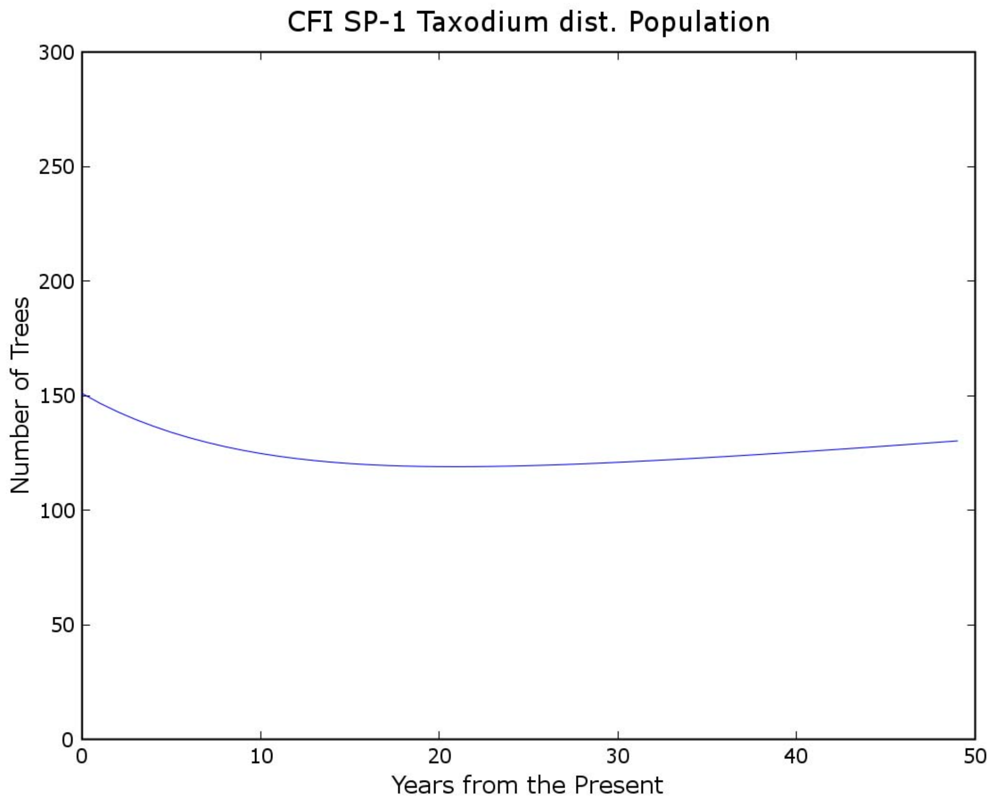

Figure 26. Model predicted population change of CFI SP-1 *Taxodium distichum*

CLASS	0	1	2	3	4	5	6	7
0	0.67	0.005	0.006	0.004	0.006	0.01	0.015	0.022
1	0.247	0.775	0.	0.	0.	0.	0.	0.
2	0.	0.194	0.799	0.	0.	0.	0.	0.
3	0.	0.	0.109	0.732	0.	0.	0.	0.
4	0.	0.	0.	0.188	0.78	0.	0.	0.
5	0.	0.	0.	0.	0.189	0.938	0.	0.
6	0.	0.	0.	0.	0.	0.042	0.986	0.
7	0.	0.	0.	0.	0.	0.	0.	0.991

Figure 27. Transition matrix for OH Wright *Taxodium distichum* population model

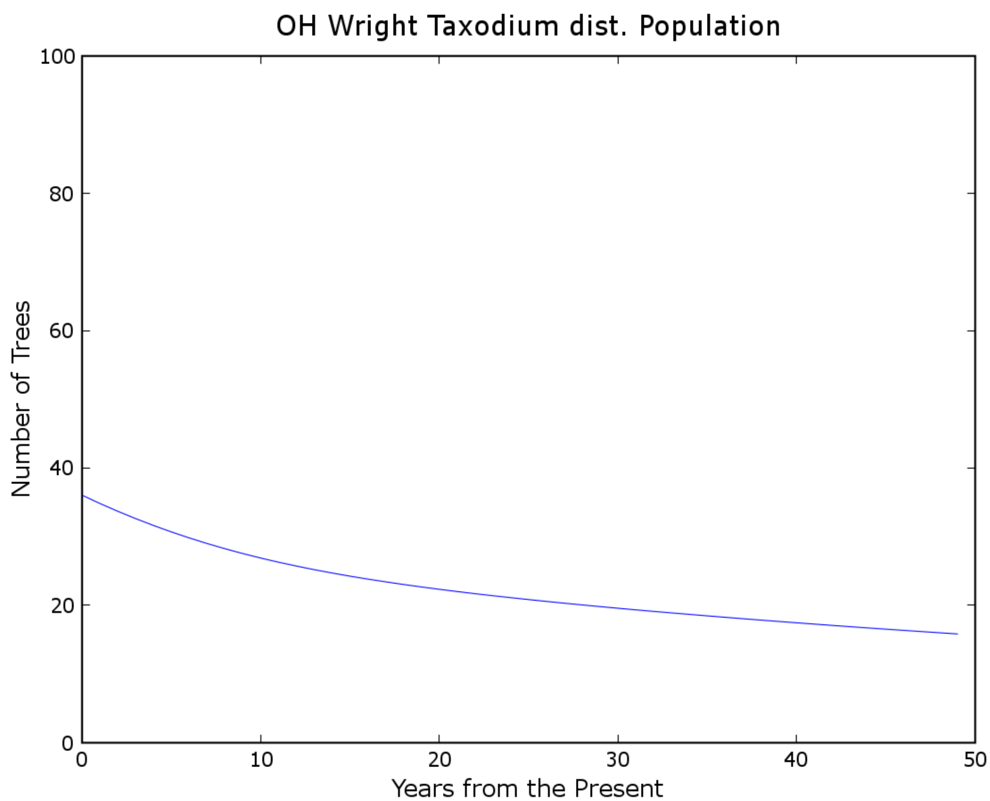

Figure 28. Model predicted population change of OH Wright *Taxodium distichum*

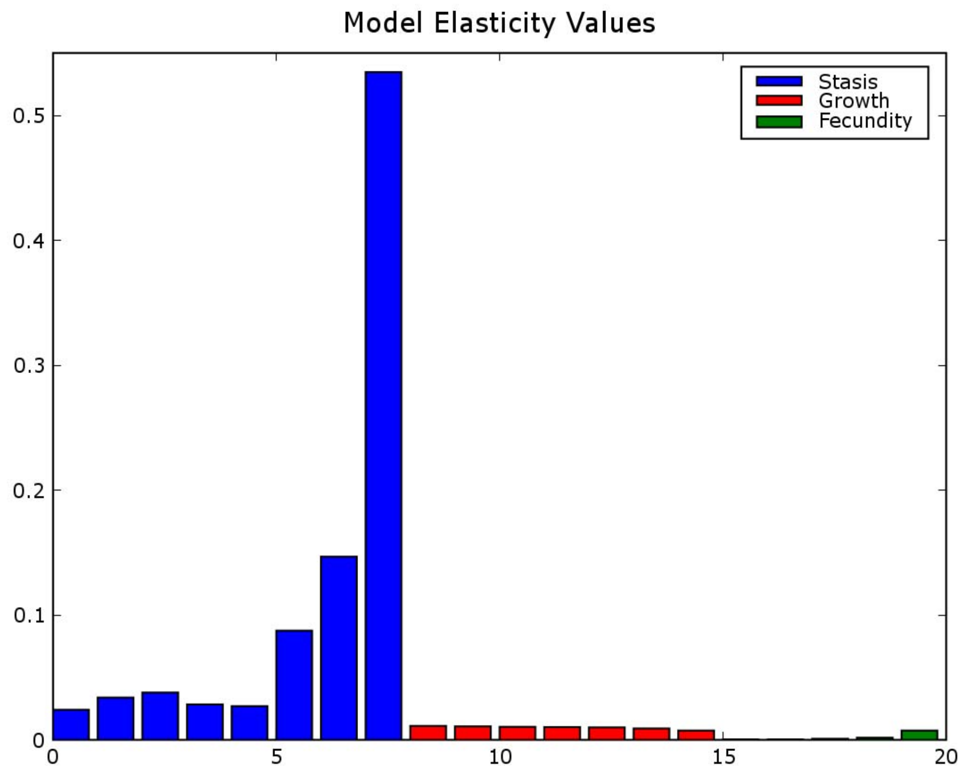

Figure 29. Model elasticity values showing sensitivity of different parameters. For each parameter type (stasis, growth, fecundity) the first bar from the left represents size class 0 with the bars to the right corresponding to size class 1,2,3... to 7.

Table 12. Rushton plots/subplots ranked by planted tree basal area (m^2/hec)

Site	Plot	Subplot	Type	Rushton Tree Basal Area (m^2/hec)
CFI	R1	1	CG	226
HOM	R2	2	CG	158
CFI	R3	3	CG	154
HOM	R1	2	CG	142
CFI	R3	2	CG	140
TEN	H6	NA	HS	128
CFI	R1	3	CG	108
CFI	R2	3	CG	107
CFI	R2	1	CG	105
CFI	R6	2	CG	96
CFI	R6	1	CG	96
HOM	R1	3	CG	92
OHW	R2A	1	CG	90
HOM	R4	2	CG	88
CFI	R2	2	CG	87
CFI	R6	3	CG	87
CFI	R3	1	CG	86
CFI	R5	1	CG	86
HOM	R4	1	CG	82
CFI	R1	2	CG	82
CFI	R5	2	CG	80
CFI	R4	3	CG	79
HOM	R6	1	CG	77
HOM	R3	2	CG	76
OHW	R2B	1	CG	75
CFI	R5	3	CG	65
HOM	R1	1	CG	63
HOM	R5	1	CG	63
HOM	R7	3	CG	61
HOM	R7	1	CG	58
OHW	R2A	2	CG	57
HOM	R6	2	CG	55
HOM	R2	3	CG	50
HOM	R7	2	CG	48
TEN	H5	NA	HS	42
CFI	R4	2	CG	41
HOM	R6	3	CG	36
OHW	R2B	2	CG	35
HOM	R3	3	CG	35
TEN	R2B	1	CG	32
HOM	R5	3	CG	31
HOM	R5	2	CG	26
OHW	H4	NA	HS	24
OHW	H1	NA	HS	24
HOM	R4	3	CG	22
TEN	H2	NA	HS	21
PRP	H5	NA	HS	19
HOM	R2	1	CG	18
TEN	R2B	2	CG	17
TEN	R2B	3	CG	16
HOM	R3	1	CG	15
OHW	R1A	1	CG	14
PRP	H1	NA	HS	14
TEN	R2A	1	CG	13
HOM	R8	1	CG	8
TEN	H3	NA	HS	8
OHW	H2	NA	HS	7
CFI	R4	1	CG	7
HOM	R8	2	CG	6
OHW	H3	NA	HS	4
TEN	R2A	3	CG	4
PRP	H6	NA	HS	4
PRP	H4	NA	HS	3
OHW	R1A	3	CG	2
OHW	R1A	2	CG	1
HOM	R8	3	CG	1
OHW	R2A	3	CG	0
OHW	R2B	3	CG	0
TEN	R2A	2	CG	0

Table 13. Topography and water level[a] comparison of Rushton and reference plots

Pair	Site	Plot	Plot Type	Avg Δ Elev.(m)	Avg Depth(m)	Min Depth(m)	Max Depth(m)	% Inundation
1	CFI	R1	CG	0.04	0.36	0.07	0.63	100%
1	CFI	R2	CG	0.03	0.32	-0.07	0.58	90%
1	CFI	R3	CG	0.03	-0.05	-0.43	0.34	48%
1	CFI	R4	CG	0.05	-0.30	-0.51	0.30	40%
1	CFI	R5	CG	0.04	-0.19	-0.77	0.39	42%
1	CFI	R6	CG	0.03	-0.36	-0.93	0.11	13%
1	CFI	5	CG-Ref	0.05	0.00	-0.49	0.68[b]	55%
2	HOM	R1	CG	0.04	0.39	0.13	0.71	100%
2	HOM	R2	CG	0.04	0.30	-0.11	0.61	94%
2	HOM	R3	CG	0.03	0.32	-0.09	0.51	94%
2	HOM	R4	CG	0.03	0.33	-0.07	0.51	94%
2	HOM	R5	CG	0.06	0.52	0.09	0.91	100%
2	HOM	R6	CG	0.05	0.55	0.15	0.76	100%
2	HOM	R7	CG	0.05	0.51	0.16	0.74	100%
2	HOM	T1	CG-Ref	0.04	0.42	-0.10	0.63	94%
3	OHW	H1	HS	0.01	0.45	-0.01	0.55	99%
3	OHW	H4	HS	0.04	0.37	0.19	0.51	100%
3	OHW	H1R	HS-Ref	0.02	0.39	0.02	0.50	100%
4	OHW	R1A	CG	0.05	0.07	-0.06	0.21	81%
4	OHW	T1	CG-Ref	0.03	0.11	0.02	0.25	100%
5	OHW	R2A	CG	0.03	0.11	0.02	0.21	100%
5	OHW	R2B	CG	0.04	0.20	-0.14	0.35	90%
5	OHW	T2	CG-Ref	0.03	0.37[b]	0.10	0.50[b]	100%
6	PRP	H1	HS	0.02	0.61	0.55	0.71	100%
6	PRP	H5	HS	0.02	0.73	0.37	1.12	100%
6	PRP	H1R	HS-Ref	0.04[b]	0.53	0.18	0.85	100%
7	TEN	H2	HS	0.01	0.23	0.17	0.27	100%
7	TEN	H2R	HS-Ref	0.02	0.25	0.2	0.3	100%
8	TEN	H5	HS	0.02	-0.06	-0.21	0.09	14%
8	TEN	H5R	HS-Ref	0.01	-0.12	-0.20	-0.07	0%
9	TEN	H6	HS	0.01	-0.04	-0.17	0.02	4%
9	TEN	H6R	HS-Ref	0.02	-0.03	-0.09	0.15	13%
10	TEN	R2A	CG	0.05	0.08	-0.10	0.18	81%
10	TEN	R2B	CG	0.03	0.07	-0.41	0.29	68%
10	TEN	T1	CG-Ref	0.048	-0.01[c]	-0.59	0.25	62%

[a]Water depth data from July for all plots

[b]More than 3 standard errors from the mean of Rushton plots

[c]Less than 3 standard errors from the mean of Rushton Plots

Table 14. Plot-scale basal area comparison in Rushton and corresponding reference plots.

		Plots		Percent of BA from Rushton trees		Mean BA(m2/hec)[a]		Standard Deviation BA(m2/hec)
Pair	Site	Rushton	Ref	Rushton	Ref	Rushton	Ref	Rushton
1	CFI	R1 R2 R3 R4 R5 R6	T5	93	NA	**107**	25	26
2	HOM	R1 R2 R3 R4 R5 R6 R7	T1	97	NA	**64**	6	23
3	OHW	H1 H4	H1R	82	NA	**29**	7	5
4	OHW	R1A	T1	30	NA	**48**	16	NA
5	OHW	R2A R2B	T2	71	NA	**90**	7	13
6	PRP	H1 H5	H1R	62	NA	**27**	11	4
7	TEN	H2	H2R	47	NA	**45**	17	NA
8	TEN	H5	HR	79	NA	**53**	20	NA
9	TEN	H6	H6R	98	NA	**131**	11	NA
10	TEN	R2A R2B	T1	51	NA	33	**47**	13

[a] Bolded numbers indicate a difference of more than 1 standard deviation

Table 15. Percent canopy cover comparison in Rushton and corresponding reference plots

		Plots		Mean		SD
Pair	Site	Rushton	Ref	Rush	Ref	Rush
1	CFI	R1 R2 R3 R4 R5 R6	T5	0.88	0.85	0.03
2	HOM	R1 R2 R3 R4 R5 R6 R7	T1	**0.82**	0.30	0.03
3	OHW	H1 H4	H1R	**0.86**	0.76	0.02
4	OHW	R1A	T1	**0.91**	0.89	NA
5	OHW	R2A R2B	T2	0.90	0.90	0.01
6	PRP	H1 H5	H1R	**0.79**	0.68	0.08
7	TEN	H2	H2R	0.89	0.89	NA
8	TEN	H5	HR	0.89	0.89	NA
9	TEN	H6	H6R	**0.90**	0.88	NA
10	TEN	R2A R2B	T1	0.87	0.88	0.02

[a] Bolded numbers indicate a difference of more than 1 standard deviation

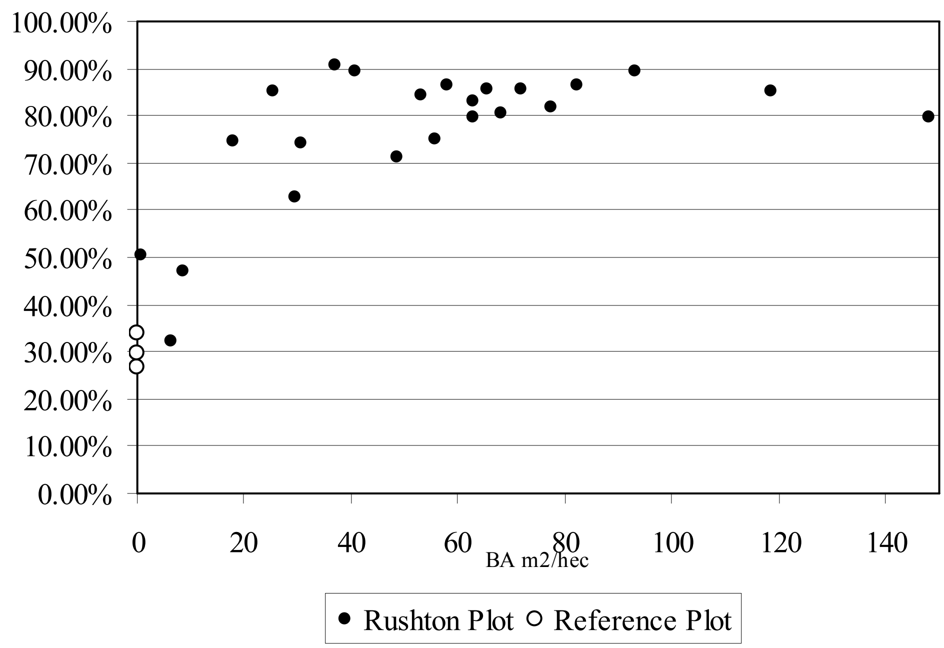

Figure 30. Subplot basal area and percent canopy cover at HOM. The first 3 (from the left) Rushton subplots had < 10 m2/hec Rushton tree basal area, but are included to help illustrate a continuous trend.

Table 16. Soil percent organic matter comparison in Rushton and corresponding reference plots.

Pair	Site	Plots Rushton	Plots Ref	Samples Rushton	Samples Ref	Mean %OM[a] Rushton	Mean %OM[a] Ref	Standard Deviation %OM Rushton	Standard Deviation %OM Ref	P-value from T-test
1	CFI	R1 R2 R3 R4 R5 R6	T5	153	18	9.06	7.47	3.39	1.96	0.01
2	HOM	R1 R2 R3 R4 R5 R6 R7	T1	57	27	8.78	4.7	11.24	3.06	0.01
3	OHW	H1 H4	H1R	54	27	10.19	9.2	1.65	1.2	3.00E-03
4	OHW	R1A	T1	9	18	10.31	13.4	3.59	5.11	0.08
5	OHW	R2A R2B	T2	36	18	10.8	13.14	3.82	3.92	0.04
6	PRP	H1 H5	H1R	36	27	10.21	7.7	3	1.54	6.00E-05
7	TEN	H2	H2R	27	27	9.26	11.58	1.25	2.49	1.00E-04
8	TEN	H5	H5R	27	27	8.06	**14.06**	1.69	2.94	1.60E-11
9	TEN	H6	H6R	27	27	11.48	**14.84**	3.2	2.68	1.00E-04
10	TEN	R2A R2B	T1	36	18	8.1	10.28	3.1	4.29	0.07

[a] Bolded numbers indicate a difference of more than 1 standard deviation

Table 17. Soil percent organic matter summarized by site and plot type.

Site	Mean %OM Rushton	Mean %OM Ref
CFI	9.06	7.47
HOM	8.78	4.70
OHW	10.42	11.52
PRP	10.21	7.70
TEN	9.16	12.91

Table 18. Average percent understory cover comparison between Rushton and reference plots

						Average Cover %[a]		
		Plots		Samples		Mean		SD
Pair	Site	Rushton	Ref	Rushton	Ref	Rushton	Ref	Rush
1	CFI	R1 R2 R3 R4 R5 R6	5	34	6	0.96	0.84	0.18
2	HOM	R1 R2 R3 R4 R5 R6 R7	T1	63	9	0.94	0.86	0.17
3	OHW	H1 H4	H1R	18	9	0.32	0.22	0.20
4	OHW	R1A	T1	3	6	0.35	0.25	NA
5	OHW	R2A R2B	T2	12	5	0.32	**0.86**	0.12
6	PRP	H1 H5	H1R	12	9	0.83	**1.20**	0.20
7	TEN	H2	H2R	9	9	0.59	0.62	NA
8	TEN	H5	H5R	9	9	**0.68**	0.58	NA
9	TEN	H6	H6R	9	8	**0.38**	0.15	NA
10	TEN	R2A R2B	T1	12	6	0.47	0.37	0.21

[a] Bolded numbers indicate a difference of more than 1 standard deviation

Table 19. Species richness and evenness comparison in Rushton and reference plots

				Species Richness[a]			Species Evenness[a]		
		Plots		Mean		SD	Mean		SD
Pair	Site	Rushton	Ref	Rushton	Ref	Rush	Rushton	Ref	Rush
1	CFI	R1 R2 R3 R4 R5 R6	5	12	**21**	3.9	0.59	0.70	0.15
2	HOM	R1 R2 R3 R4 R5 R6 R7	T1	12	12	3.4	0.51	**0.86**	0.12
3	OHW	H1 H4	H1R	7	**9**	0.7	0.71	**0.86**	0.06
4	OHW	R1A	T1	9	8	NA	0.81	0.85	NA
5	OHW	R2A R2B	T2	**12**	7	2.1	0.84	0.45	0.00
6	PRP	H1 H5	H1R	5	**7**	0.7	**0.70**	0.53	0.02
7	TEN	H2	H2R	4	3	NA	**0.51**	0.27	NA
8	TEN	H5	H5R	13	**20**	NA	0.80	0.77	NA
9	TEN	H6	H6R	**10**	5	NA	0.78	0.77	NA
10	TEN	R2A R2B	T1	9	**12**	2.1	0.72	0.77	0.05

[a] Bolded numbers indicate a difference of more than 1 standard deviation

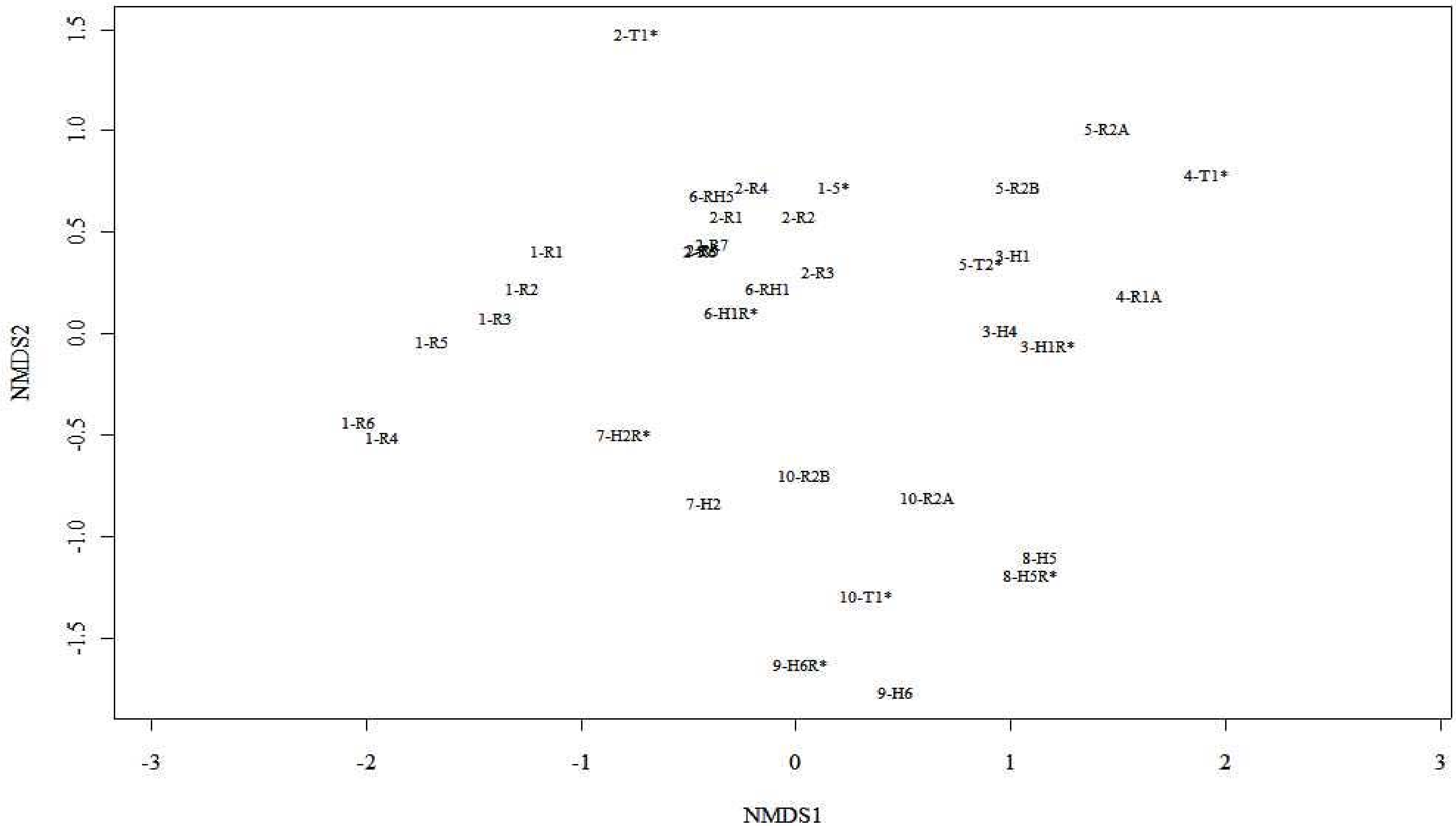

Figure 31. NMDS plot of understory species assemblages. Plot names are condensed to ‘pair-plot name’ with a ‘*’ added to the reference plots. The greater the distance between the plots, the less similar their species assemblages.

Table 20. Correlation matrices for ecosystem development variables by site. Correlations between Rushton BA and response variables (last five) are highlighted in gray.

CFI

	Rush_BA	Depth	Range	Tot_BA	Canop_Cov	U_Cover	U_Richness	U_Evenness	Soil_OM
Rush_BA	1.00	0.35	-0.72	1.00	-0.03	0.55	-0.91	-0.68	-0.08
Depth	0.35	1.00	-0.65	0.37	-0.83	0.82	-0.23	-0.87	-0.70
Range	-0.72	-0.65	1.00	-0.75	0.42	-0.45	0.65	0.72	0.16
Tot_BA	1.00	0.37	-0.75	1.00	-0.06	0.54	-0.92	-0.68	-0.07
Canop_Cov	-0.03	-0.83	0.42	-0.06	1.00	-0.47	0.00	0.54	0.46
U_Cover	0.55	0.82	-0.45	0.54	-0.47	1.00	-0.36	-0.93	-0.80
U_Richness	-0.91	-0.23	0.65	-0.92	0.00	-0.36	1.00	0.47	-0.16
U_Evenness	-0.68	-0.87	0.72	-0.68	0.54	-0.93	0.47	1.00	0.73
Soil_OM	-0.08	-0.70	0.16	-0.07	0.46	-0.80	-0.16	0.73	1.00

HOM

	Rush_BA	Depth	Range	Tot_BA	Canop_Cov	U_Cover	U_Richness	U_Evenness	Soil_OM
Rush_BA	1.00	-0.23	-0.47	0.99	0.71	-0.33	-0.28	-0.95	0.27
Depth	-0.23	1.00	0.17	-0.30	-0.09	0.79	-0.60	-0.01	-0.86
Range	-0.47	0.17	1.00	-0.40	-0.34	0.09	-0.03	0.41	-0.24
Tot_BA	0.99	-0.30	-0.40	1.00	0.66	-0.43	-0.23	-0.91	0.30
Canop_Cov	0.71	-0.09	-0.34	0.66	1.00	0.09	0.12	-0.68	0.33
U_Cover	-0.33	0.79	0.09	-0.43	0.09	1.00	-0.19	0.15	-0.62
U_Richness	-0.28	-0.60	-0.03	-0.23	0.12	-0.19	1.00	0.48	0.58
U_Evenness	-0.95	-0.01	0.41	-0.91	-0.68	0.15	0.48	1.00	-0.14
Soil_OM	0.27	-0.86	-0.24	0.30	0.33	-0.62	0.58	-0.14	1.00

OWH

	Rush_BA	Depth	Range	Tot_BA	Canop_Cov	U_Cover	U_Richness	U_Evenness	Soil_OM
Rush_BA	1.00	-0.33	-0.16	0.95	0.34	-0.12	0.71	0.32	-0.19
Depth	-0.33	1.00	0.75	-0.57	-0.46	0.21	-0.65	-0.47	-0.31
Range	-0.16	0.75	1.00	-0.32	-0.48	0.11	-0.48	-0.13	-0.53
Tot_BA	0.95	-0.57	-0.32	1.00	0.42	-0.17	0.80	0.40	-0.16
Canop_Cov	0.34	-0.46	-0.48	0.42	1.00	0.29	0.03	-0.33	0.49
U_Cover	-0.12	0.21	0.11	-0.17	0.29	1.00	-0.19	-0.72	0.49
U_Richness	0.71	-0.65	-0.48	0.80	0.03	-0.19	1.00	0.52	-0.04
U_Evenness	0.32	-0.47	-0.13	0.40	-0.33	-0.72	0.52	1.00	-0.41
Soil_OM	-0.19	-0.31	-0.53	-0.16	0.49	0.49	-0.04	-0.41	1.00

PRP

	Rush_BA	Depth	Range	Tot_BA	Canop_Cov	U_Cover	U_Richness	U_Evenness	Soil_OM
Rush_BA	1.00	0.93	-0.14	0.86	0.89	-0.94	-1.00	0.93	0.78
Depth	0.93	1.00	0.24	0.61	1.00	-1.00	-0.95	0.73	0.49
Range	-0.14	0.24	1.00	-0.62	0.33	-0.22	0.06	-0.49	-0.73
Tot_BA	0.86	0.61	-0.62	1.00	0.53	-0.63	-0.82	0.99	0.99
Canop_Cov	0.89	1.00	0.33	0.53	1.00	-0.99	-0.92	0.66	0.40
U_Cover	-0.94	-1.00	-0.22	-0.63	-0.99	1.00	0.96	-0.75	-0.51
U_Richness	-1.00	-0.95	0.06	-0.82	-0.92	0.96	1.00	-0.90	-0.73
U_Evenness	0.93	0.73	-0.49	0.99	0.66	-0.75	-0.90	1.00	0.95
Soil_OM	0.78	0.49	-0.73	0.99	0.40	-0.51	-0.73	0.95	1.00

TEN

	Rush_BA	Depth	Range	Tot_BA	Canop_Cov	U_Cover	U_Richness	U_Evenness	Soil_OM
Rush_BA	1.00	-0.22	-0.16	0.96	0.43	-0.06	0.05	0.27	-0.19
Depth	-0.22	1.00	-0.20	-0.22	-0.08	0.30	-0.79	-0.88	-0.27
Range	-0.16	-0.20	1.00	0.04	-0.13	-0.34	0.10	0.35	-0.47
Tot_BA	0.96	-0.22	0.04	1.00	0.47	-0.11	0.09	0.28	-0.29
Canop_Cov	0.43	-0.08	-0.13	0.47	1.00	-0.23	-0.01	-0.20	-0.29
U_Cover	-0.06	0.30	-0.34	-0.11	-0.23	1.00	0.22	-0.26	-0.26
U_Richness	0.05	-0.79	0.10	0.09	-0.01	0.22	1.00	0.64	0.18
U_Evenness	0.27	-0.88	0.35	0.28	-0.20	-0.26	0.64	1.00	0.10
Soil_OM	-0.19	-0.27	-0.47	-0.29	-0.29	-0.26	0.18	0.10	1.00

DISCUSSION

Summary

Evaluating the progress of a created wetland after a long period of time (20 years in this study) is valuable for determining which species are appropriately adapted for site conditions and what the role of these species may be in the development of an ecosystem.

Though tree survival was higher on the sand-clay mix soil than on pure clay or sand, hydrology and site disturbances were more important factors than soil type in determination of tree survival. Each wetland tree species survived in positions along a hydrologic gradient that fit a species-specific tolerance range for inundation. This positional range was more apparent for a species after twenty years than it was after 1 or 3 years. This information provides a good indicator of long-term hydrology within these plots and would be valuable for future planting efforts on these sites.

Tree growth among surviving individuals was just as high on pure clay soils as on the sand-clay surface. By this measure, established trees were successful on clay. Nevertheless, the sustainability of planted tree populations on CSAs is uncertain. In most cases offspring of the planted trees were scarce after twenty years. Models showed that the size of tree populations on two sites, each with few offspring, will not grow significantly or possibly decline after 50 years, assuming high survival of current mature trees. The cause(s) of the low numbers of new seedlings still needs to be clarified. The presence of a high number of seedlings on one clay site proved, however, that the clay soils alone do not prohibit seedling establishment.

Plants plots are more structurally mature than non-planted area and this is promoting the accumulation of soil organic matter, but the rate of accumulation does not always exceed accumulation under other CSA communities. No strong relationship between planted plots and understory vegetation has yet emerged on the selected CSAs. The assemblage of understory vegetation appears to be more strongly determined by the site surroundings and the plot hydrology. The influence of the trees may become stronger as the trees continue to mature. For sites planted with trees, the intentional introduction of additional species in the understory could provide the source for a more diverse community.

Tree Populations in Relation to Environmental Factors

Tree Survival By Site and Species

The presence of wetland trees planted 20 years ago on multiple CSAs is an indication that conditions alone in the planted plots are within the range of conditions in which these wetland trees have evolved to persist. *Taxodium distichum*, both *Fraxinus caroliniana* and *pennsylvanica*, and *Nyssa aquatica* survived on all sites chosen for the study, though not in equal percentages. Though the typical lifespan of trees of these species is much greater than 20 years, their growth and healthy condition on some sites herald continued persistence. For the species that did not survive at any of the sites, questions remain as to the site factors that they were unable to tolerate. Mature trees of some of the other species planted by Rushton were present on one or more of the study sites. *Acer rubrum*, which survived in small numbers at some sites, was dominant in the understory under canopies with many mature individuals at OHW, and to a lesser extent at TEN. This species also occurs in high densities in some areas of CFI. *Ulmus americana* has also been recruited on some of these same sites, though to a lesser extent than *Acer rubrum*. *Quercus laurifolia* is not uncommon at CFI and OHW. Isolated individuals of *Persea palustris* were found outside the sampled area at OHW. The failure of these species to persist in these planted plots does not preclude their capacity to survive on CSAs, but does indicate a relatively poorer survival capacity in the conditions to which the plots were subjected.

Overall *Fraxinus caroliniana* had a very high survival rate, though it was planted in a limited range of water depth and a smaller number of individuals were planted. *Taxodium distichum* was planted more than any of the aforementioned four species and over a range of water depths, most of which it tolerated. In terms of survival it was the most successful species of the three in the cypress-gum plots.

One and three-year survival was a good predictor of 20-year survival for these four species. Though annual survival rate generally improved as mortality was more common in the first three years, the change in the percentage of each species surviving relative to the other species was relatively consistent across sites. In other words, a similar survival trend was present for these species, and the species with the highest survival after three years was most likely the species with the highest survival after 20 years. This perhaps indicates a similar response to environmental stresses among the species.

Though individuals become more resistant to environmental stress with age, assuming that the same regime of environmental conditions persisted from years 3 to 20 as did from years 0 to 3, notwithstanding sporadic disturbances, trees likely succumbed to the same pressures during both periods.

Tree Survival and Hydrology

Time allows for a clear determination of a suitable landscape position of a wetland species relative to its period of exposure to saturated conditions and the depth of inundation. At CFI, water depth did not preclude 20-year survival among the trees living after year 1, however, hydrological factors may have had an effect on likelihood of survival of *Nyssa aquatica* and *Fraxinus pennsylvanica*.

OHW was likely affected by a disturbance event that affected the drier end of plots R2A and R2B (see Table 10), thus water was not likely the key factor in mortality of the trees in the drier area. *Fraxinus pennslyvanica* did not tolerate the wetter locations of this transect, though it appears to have tolerated the same average depth at CFI.

That *Fraxinus pennsylvanica* did not tolerate locations where the average depth was 0.2 and 0.3m at OHW , though it did tolerate those depths at CFI, could be interpreted as a greater tolerance for standing water in sand-clay than in clay. But there are likely differences in the hydrologic regime between the two sites that could have effected tree survival. In both plots, trees are growing on the fringe of a pond where surface water outfall occurs at a given depth. Though data are not available to determine at what water level relative to the trees that surface outflow occurs in the two basins, it is possible that water could be retained longer at the same average water level depths at OHW, increasing the period of inundation. This case exemplifies the difficulty of inferring hydrologic similarity from monthly measurements over a single growing season. Inside the plots perhaps the location of surviving trees relative to one another is a better indication of hydrology than monthly water level measurements, but was an assumption that could not be made within this study.

The shallower water depth distribution of surviving trees in the TEN basin (Figure 16) likely does not represent the average depth of water trees were exposed to before the basin was ditched in 2001, when average seasonal depths for all trees were likely greater. Hydrologic factors may have impacted mortality, as the less tolerant *Fraxinus pennsylvanica* did not survive in the deeper part of the range where *Taxodium distichum* did, but the animal grazing (see Table 10) noted during the initial years of establishment was likely also major factor in the high tree mortality in this basin.

The long-term change in the hydrology on CSAs due to the continuing settling of the clays is a challenge to long-term wetland creation unique to CSAs. But this study only revealed anecdotal indications of an effect of clay consolidation and resultant hydrologic alteration on planted trees. At TEN, laterally branching roots of *Taxodium distichum* and *Fraxinus caroliniana* with rigid epidermal cells not typically found above the ground surface were found in two basins. Faint clay stains were present on these roots which were as much as 3.5 feet above the ground surface. These root features are potentially signs of clay consolidation, but since the basin hydrology was altered by ditching in 2001, they could also be remnants of a dramatic decrease in water levels.

Tree Growth Comparison Between Sand-Clay and Clay Sites

Comparison of the effects of soil medium on tree growth could not include sand-capped sites because there was no control for the effect of water level on tree growth.

The data clearly indicate that trees survived in greater numbers after 20 yrs on the sand-clay site than in the clay, despite similar survival after 1 year for *Taxodium distichum* and *Fraxinus pennsylvanica*. For all three species planted in cypress-gum plots survival was better on the sand-clay site. Nevertheless, the soil medium is not the most probable explanation for this difference. Initial growth after one year was similar for cypress-gum plots on CFI and OHW, on which no notable growth occurred. Twenty year survival on OHW R2A and R2B was effected by the death of all trees in 1/3 of the plot. Because death occurred for all species and because the area experienced similar water level conditions to part of CFI on which some all species survived, it is probable that one or multiple disturbance events, likely fire, caused the mortality rather than the water level or the clay soil . The domination of that area now by a fire-adapted species, *Imperata cylindrica*, and reported fires that consumed trees in nearby plots provide further evidence of this mortality hypothesis on OHW.

On TEN, the poor initial survival of some of the trees in the basin used in the survival figure (Figure 16) was reported to be partially due to heavy grazing. Grazing significantly reduced initial tree growth, an important indicator of future survival, and thus likely was the principle cause the high mortality in the proceeding years. However, water levels possibly resulted in *Fraxinus pennsylvanica* death in the deeper areas and all species in the extreme dry areas. Though *Fraxinus pennsylvanica* survived into a much deeper average water depth on other sites, it is likely that this basin stored more water before the hydrology was altered in 2001 and that these trees then earlier were subjected to more frequent inundation.

High survival percentages in other plots in clay where the same trees were planted, like TEN H6, is further evidence that, given appropriate hydroperiods and freedom from devastating disturbance, viability of *Taxodium distichum* and *Fraxinus spp.* species on clay is good.

Across the board, *Nyssa aquatica* had poor initial survival in the clay sites, as the clay possibly impeded the establishment process. Yet once the species established, it grew as well or better and survived at a similar rate on the clay.

Recruited Trees

The scarcity of recruited trees in the periphery of most plots made it impossible to make broad inferences about the conditions appropriate for seedling establishment on CSAs. Lack of data on seed production, germination success, and seedling survival did not enable a determination of the causes of absence of recruits.

First-year *Taxodium spp.* seedlings cannot tolerate long periods under water (Wilhite and Toliver 1990). On Ten H3, a particular abundance of new seedlings emerged in the spring and early summer 2005, where in May water levels dropped below ground but remained close enough to the surface to maintain saturated conditions appropriate for germination. However water levels rose and likely remained high enough to completely inundate 72 of 85 of these seedlings. This rise in water level is the most likely explanation for the high mortality among these first-year seedlings. If those seedlings that were inundated are assumed to have died during the period, the survival rate for the remaining seedlings up to 100 cm would be close to 90%. Though unique in the density of seedlings in this study, this plot provides evidence that given the presence of viable seed and appropriate water levels, *Taxodium distichum* can germinate and establish on a CSA, and that water levels are of critical importance in the establishment process.

The source of seedlings present on some of the sites was impossible to establish when other mature trees had been planted by other parties. At CFI, >500 *Taxodium distichum* seedlings had been planted on the site since the Rushton planting. Mature trees not planted by Rushton are present just off the deeper margin of the plots and in between plots in cases. It could not be determined with certainty that the recruited trees found inside the plots were offspring of the planted trees. At HOM *Taxodium distichum* trees had been planted in the same basin a few years before the Rushton plantings. The recruited trees found at HOM were perhaps planted or offspring of trees from the previous planting.

Seedling establishment of wetland tree species depends heavily on a gentle rise in the relative topography of the landscape. In natural floodplain systems, the extent of the spread of the population is determined by the extent of the flood zone. In some CSAs the flood zone is restricted due to a steep elevation gradient, often a residual of the mine cut – spoil pile pre-fill topography. This topography may restrict the area favorable to wetland tree seed establishment, which require fluctuating water level conditions for adequate but tolerable moisture.

The size class distributions show normal to left-skewed shape distributions for most sites. A right skewed or inverse-J shape distribution is a sign of a growing population dominated by smaller individuals (Manabe et al. 2000). Overall scarcity of new seedlings at the sites poses challenges to future population success. In all species of planted trees monitored in the study, at least some individuals had reached a maturity to produce seed based on what is reported for individuals of those species (USDA 2004). Though there was no formal collection of seed production data, there were records of seeds present on trees or floating in water for each of the species present. If the trees continue to survive it would be natural that they would become more fecund as they grow.

Though this study shows that failure of seedling establishment is not endemic of CSAs, studies need to be conducted to show if establishment presents any particular challenges. Further study into seedling establishment and growth could reveal any obstacles exist on CSAs related to soil clay content or vegetation cover. But to be conclusive, any such study needs to take into account all stages of seedling establishment: including seed production, dispersion, viability, germination and initial survival and along a variety of environmental gradients typical of CSAs.

Tree Population Model

Because this was a young population there was not good data on survival of older trees. Reclamation of phosphatic clay settling areas did not begin until the early 1980s and therefore there is no reference for longevity of *Taxodium distichum* in these areas. To fill in the data gap, survival probability of larger trees was assumed to continue to increase in larger size classes. The estimated survival probability of the largest size class of *Taxodium distichum* in the models was consistent with the survival probability of the largest size class in models of other woody species (Zuidema and Zagt 2000). Since the mortality of the largest size classes was the most sensitive parameter in the model, the confidence of the model could be improved by real data of large tree mortality.

The probabilities of growth, survival, and reproduction are affected by the hydrologic conditions. Incorporating the effect of different hydrologic regimes in the transition probabilites of multiple transition matrices is one technique for implicitly accounting for the effect of hydrology on a wetland tree population (Lytle and Merritt 2004). For these models, a time series of data and a hydrologic record would be necessary to build this model.

The small changes in population size predicted by the models for trees on CFI and OHW are a consequence of both high survival probabilities of larger trees and low reproductive probabilities of mature trees. These same trends would have likely been present in models of a number of the other tree populations in this study, but such trends cannot yet be generalized for *Taxodium distichum* or other tree populations on CSAs.

Characteristics of Successful Species on CSAs

A common trait among the tree species that survived on multiple sites after 20 years (*Fraxinus caroliniana, Fraxinus pennsylvanica, Nyssa aquatica, Taxodium distichum*) is the ability to tolerate anaerobic conditions for an extended period of time during the growing season. The least tolerant, *Fraxinus pennsylvanica* , can tolerate inundation for up to 40% of the growing season (Fowells 1965). Each of these species has special adaptations that permit extended survival in when the root zone is saturated, including adventitious rooting and buttressing.

Also common to these species is the ability to resprout from the root stock and to coppice (resprout from a stump) following disturbance. For environments that may be frequently exposed to disturbances, especially fire, resprout ability could be important for long term survival (Pausas et al. 2004). Evidence of resprouting was present in each of the four species.

These four species naturally occur in riverine swamps (Myers and Ewel 1990). *Fraxinus caroliniana* and *Taxodium distichum* are also naturally present in a number of other forested wetland types, such as cypress stands and lake fringe swamps. Two of the species, *Fraxinus pennsylvanica* and *Nyssa aquatica* do not natively occur in Polk County. The southern extent of the range of these species is in the big bend region. Among natural forested wetlands in Florida, these two species are typically restricted to riverine swamps

The similarity of the natural habitat of these species and the CSA environment may help to further explain their success on CSAs. Characteristics of riverine swamps, a common habitat of these species, include a short hydroperiod and mineral soils typically containing clays. Plots in the study had a mix of hydroperiods during the 2005 growing season, but *Fraxinus pennsylvanica* and *Nyssa aquatica* were more successful in plots that had a short to moderate hydroperiod. *Fraxinus caroliniana* and *Taxodium distichum* naturally occur in areas with a range of hydroperiod and on CSAs were successful in areas with longer hydroperiods. Clay, sand-clay, and sand capped sites in this study all had a low organic matter content at the time of planting that would fit a mineral soil characterization. Other species found surviving or volunteering in transitional areas including *Acer rubrum*, *Quercus laurifolia*, and *Ulmus americana* are also naturally found in riverine swamps. Two species that did not survive, *Gordonia lasianthus* and *Sabal palmetto,* are more often found in ecosystems with sandier soils and less dramatic fluctuation in inundation.

Species characteristics are important in determining capacity to survive in the new anthropogenic environment of CSAs, and copying species assemblages that exist in natural wetlands with similar characteristics is a potential method for finding appropriate species. Yet because the CSA conditions are unique, there is no perfect correlate ecosystem from which to select appropriate species. The species that were most successful after 20 years in these plots were those that not only occurred naturally in riverine wetlands, but also those with the most tolerance for anaerobic conditions and the ability to resprout. Species biological characteristics and the similarity of its native habitat are more important to tree success in CSAs than native range, confirming an earlier finding by Paulic and Rushton (1991b).

In a 2005 survey not included in this study of Homeland FM-07, another CSA where trees were planted in 1988 (see Paulic and Rushton 1991b for details), a similar assemblage of surviving species was found. A species not planted by Rushton *Quercus lyrata* and two of the species found surviving in this study, *Fraxinus pennsylvanica* and *Taxodium distichum,* were the only species found *Quercus lyrata* is another native of north Florida riverine swamps adapted to anaerobic environments.

The hydric swamp plots in less wet to more transitional conditions at PRP, OHW, and TEN were mostly devoid of trees or any plot boundary markings. Fire was a likely cause of death at PRP and OHW, whereas circumstances are unclear at TEN. On PRP the transitional areas are dominated by *Imperata cylindrica*. On another site mentioned in the previous paragraph (FM-07) no trace of plots set-up in transitional areas was available and these areas were also dominated by *Imperata cylindrica*. At OHW, a mixed forested canopy is now present over transitional plots H2 and H3. *Schinus terebinthifolius* was dominant in a the remnants of two TEN transitional plots.

Drier areas are more susceptible to fire and post-fire colonization, and overall had poorer survival after 20 years, leaving the long-term viability of transitional tree species on CSAs uncertain.

Ecosystem Development in Rushton and Reference Plots

Plot Selection and Comparison

Though the study intended to examine whether the surviving Rushton trees have played a role in ecosystem development, there was no clear presumption of the quantity of trees, tree biomass, or tree cover necessary to reveal an effect. It was not the purpose of this study to find a minimum level of some quantitative measure of the trees at which an effect could be detected, but at whether or not an effect on ecosystem development could be detected under an condition in which trees were present. Because the measurements of ecosystem development had different degrees of spatial precision, it was safer to assume common influence on a plot or subplot when survival of trees was higher and thus spatially more homogenous.

Adequate descriptions of the vegetation composition in reference plots and Rushton plots at the time of planting (1985-1986) were not available to determine if the composition was identical. By selecting areas adjacent to the same water feature with similar hydrology it was assumed that: (1) the vegetation in the areas at the time of planting was similar ; (2) the depth and duration of flooding for the Rushton and reference plots was similar; and (3) no significant disturbances that would radically alter the vegetation and/or soil affected the plots unevenly since the time of planting. The comparison of Rushton and reference plots rests on these assumptions, and plots or subplots were eliminated from the comparison if they violated one of these assumptions.

Hydrology is perhaps the primary driver of wetland ecosystem development (Mitsch and Gosselink 1993). Thus the most important criterion for selection of a reference plot within the site was its hydrology. Though it was impossible to establish a reference plot in the same water feature at Homeland, the reference plot was within 100m of the closest Rushton plot and had a similar minimum, maximum, and average depth, and average change in elevation.

In some cases, there was considerable variation of water depth and percent inundation within a group of Rushton plots. Mean water depths at CFI ranged from 0.36 m at R1 to –0.36 meters at R6. The mean water depth of the reference plot was appropriately exactly in the middle at 0.0m, but the difference in depth and percent inundation within Rushton plots was large enough to lead to detectable differences in ecosystem development parameters among the Rushton plots. The R1,R2, R3, and R5 understories were dominated by floating aquatic vegetation, whereas R4 and R6 were dominated by ferns. Yet the understories in these plots were still more similar to one another than the reference plot (see Figure 31). There was also a -0.70

correlation (Table 20) between the between water depth and organic matter on CFI, indicating a difference in soil OM within Rushton plots. Hydrologic variation within Rushton plots made delineation of differences from reference plots more difficult.

Structural Differences

The clearest distinction between Rushton and reference plots was present in the tree and shrub strata. In planted areas with moderate to high survival of planted trees there was significantly more structure at these levels in the plots. Rushton plots had in 9 of 10 cases a more developed shrub and canopy layer. In plots on CFI, in TEN R2A and R2B, and in TEN H6, plot basal area was more than twice as high as what has been found in natural forested wetland systems, including mixed hardwood forest and cypress domes, but this difference is confined to the narrow boundaries of the Rushton plots.

However, the estimates of canopy cover interpreted from the canopy photos showed little difference between Rushton and reference plots. A possible explanation is the trend that occurs with the estimation of canopy cover as plot basal area increases (Figure 30). Estimated canopy cover increases very rapidly and then levels off as basal area continues to increase. Generally the Rushton plots had enough structure so that all were near that asymptotic 'level' of canopy cover.

The canopy photo technique was used to estimate the proportion of light blocked by the tree and shrub layers from reaching the understory. Because of the proximity of the shrub level to the camera lens, also true of the understory, the shrub layer potentially had a more significant effect on this estimation. The technique does not estimate layering in the canopy, nor the opacity differences in different vegetative structures. Because there is more opaque, woody structure in Rushton plots and likely more frequent overlap of structure in different strata, the differences in the light reaching the understory could be greater than estimated in Rushton and reference plots.

Soil Organic Matter

Woody vegetation is an important contributor of litter that becomes incorporated into soil organic matter. At TEN higher percent soil OM was found in reference plots dominated by *Salix* *caroliniana* than in corresponding Rushton plots (pairs 7,8,9), though this was not the case at PRP or CFI, where *Salix caroliniana* dominated reference plots. At OHW two reference plots dominated *Ludwigia peruviana* had higher organic matter than corresponding Rushton plots. Both of these species are characteristic of wetlands on CSAs, and may result in faster organic matter buildup than planted species, but this trend is not consistent across all sites. Other factors, such as fire frequency, also were important. At Peace Park, frequent fire and high tree mortality likely caused high deposition of woody particulate matter in Rushton plots that led to high soil organic matter. The presence of floating woody debris and burn scars on dead stumps was qualitative evidence of this effect. Surprisingly, correlation of water depth with soil OM was negative at most sites (see Table 20), which contradicts what is commonly found in wetland systems, where sediment deposition is higher in lower areas (Hupp and Bazemore 1993). This could be due to lack of vegetative colonization of deeper areas.

In wetland systems wood biomass and soil organic matter often represent the largest storages of organic matter (Megongial and Day 1988). In Rushton plots a larger amount of total basal area and smaller amount of a soil organic matter relative to Rushton sites indicates that relatively more organic matter is bound up in living biomass in Rushton sites. A high percentage of the organic matter pool tied up by living organisms has been proposed as an indicator of a more mature ecosystem (Odum 1969). In a transition period the net production of organic matter theoretically peaks and declines as biomass continues to increase (Figure 32). Though gross production is likely still increasing in these systems as indicated by continual tree growth and a greater total basal area in older sites, a greater proportion of the organic matter is being tied up in woody biomass and less deposition to the soil is occurring.

Understory Vegetation

For most plots, the coverage of plants in the understory, the species richness, and the species evenness was similar among Rushton and reference plots. The similarity among Rushton and corresponding reference plots was made apparent by the NMDS (Figure 31). A distinct site-based grouping of understory assemblages emerged in this plot. CFI (without the reference plot), OWH, and TEN are clustered by themselves, and PRP and HOM overlap. This finding demonstrates the importance of site surroundings on understory composition. The dispersal of propagules from outside is the only plant source in CSAs, as there is no seed bank in the clay from which plants can emerge. Seeds must be carried in by wind or animals, and this process is limited by the distance to the nearest seed source. Interestingly, the HOM and PRP sites, which overlap on the NMDS, are within a mile from one another and likely share the same source (the Peace River floodplain) of propagules.

Alternatively, propagules of wetland species other than trees could be brought in during the reclamation process. This was done at CFI, where *Nephrolepis spp.* were planted under the canopy of Rushton trees.

There was some similarity in the understory across sites based on plot hydrology. Floating aquatics, primarily duckweed (*Lemna minor* and *Spirodella polyrhiza*) and *Salvinia minima*, were often the most prevalent vegetation on wetter transects. Where they occurred they often accounted for the majority of cover. Though these species have limited to medium shade tolerance, they were present in Rushton and reference plots, without a clear trend in a relationship between basal area or canopy cover in their occurrence, except in pair 5 at OHW and pair 6 at PRP.

By and large the species found in the understory of plots have autecological characteristics associated with plants present in early to middle succession. These characteristics include a rapid growth rate, short lifespan, poor shade tolerance, high seed abundance, ability to spread vegetatively, and seed dispersal via wind and or water (Odum 1969, Ricklefs 1990, Mitsch and Gosselink 1993). Table 31 in the Appendix presents the prevalent understory species with scores for each of species for all six autecological traits. Plant autecological characteristics can be related to the stage of succession (Van der Valk 1981). If Rushton trees were helping to accelerate succession on these areas, understory vegetation in Rushton plot would possess characteristics typical of later succession. This could be occurring, but the differences between the species assemblages in Rushton and reference plots were too small to test for differences in the autecological characteristics of species.

An exception to the trend of similarity among species assemblages may exist at HOM, where the species present in the reference plot were more typical of a freshwater marsh than a shrub or tree-dominated system. The Rushton trees planted at HOM may be directing succession toward a forested wetland whereas it otherwise might be developing into a marsh.

Relationships Among Measures of Ecosystem Development

The correlation matrices presented by site show some across-site similarity in relationship between causal and response variables for OHW and TEN, and also for PRP and HOM. Generally weak correlations are present between Rushton BA and the response variables . This could be because of they are older sites abutted on one side by a source of propagules, and because the ecosystems reference plots are more developed on these sites, dampening the effect of planted trees. Still there are large differences in total basal area and thus more organic material stored in the living biomass in the Rushton plots on these sites, so differences do exist.

On both PRP and HOM, the Rushton plots stand out more in their structural differences with reference plots than at other sites. These structural differences appear to have a strong effect upon the understory vegetation, and clearly contribute to increased organic matter buildup. Planted trees may have more detectable influence on ecosystems development on less vegetated sites.

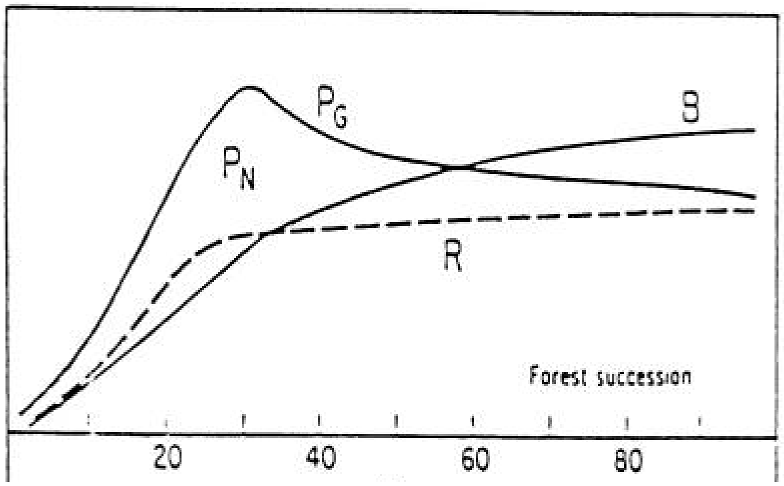

Figure 32. Succession in a forested system. From Odum (1969). PG=gross production; PN=net production; R=respiration; B=total biomass.

APPENDIX
SUPPLEMENTAL FIGURES, TABLES, AND CODE

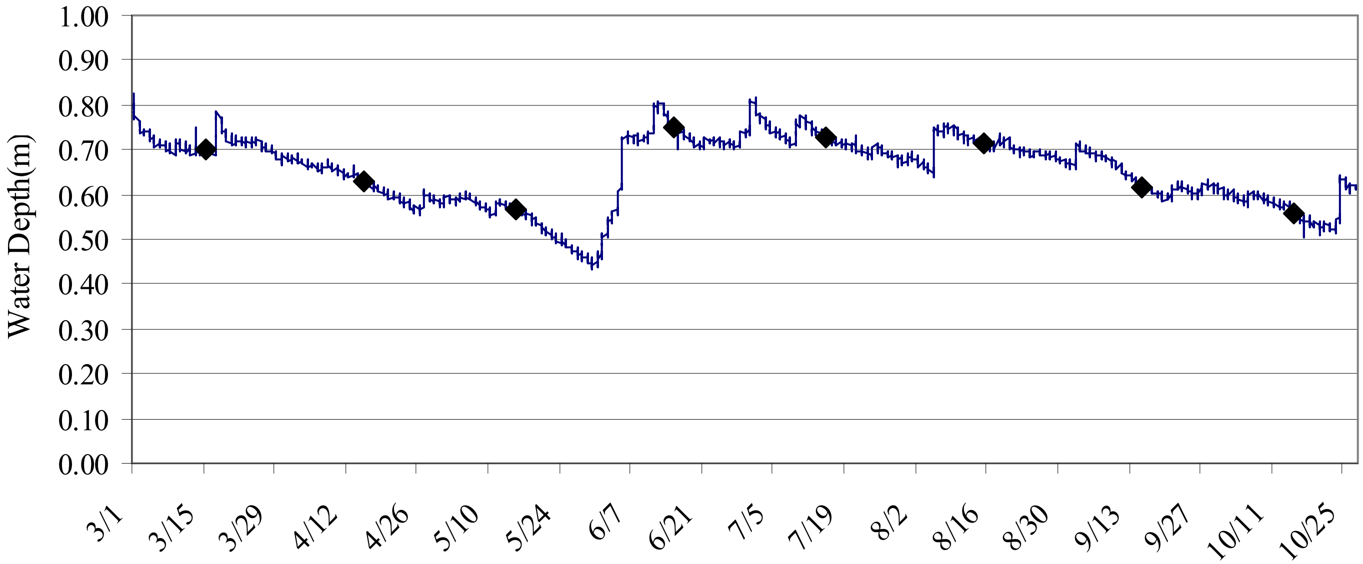

Figure 33. 2005 water depth in a well at CFI measured by continuous data logger. Sampling times are marked with diamonds. The average of the monthly sampled water levels was 0.66 meters, and the average of the hourly sampled water levels was 0.65 meters. The close proximity of the monthly and hourly sampled water levels (within 1cm) indicates that the monthly sampled water level provided an accurate average water level for the time period.

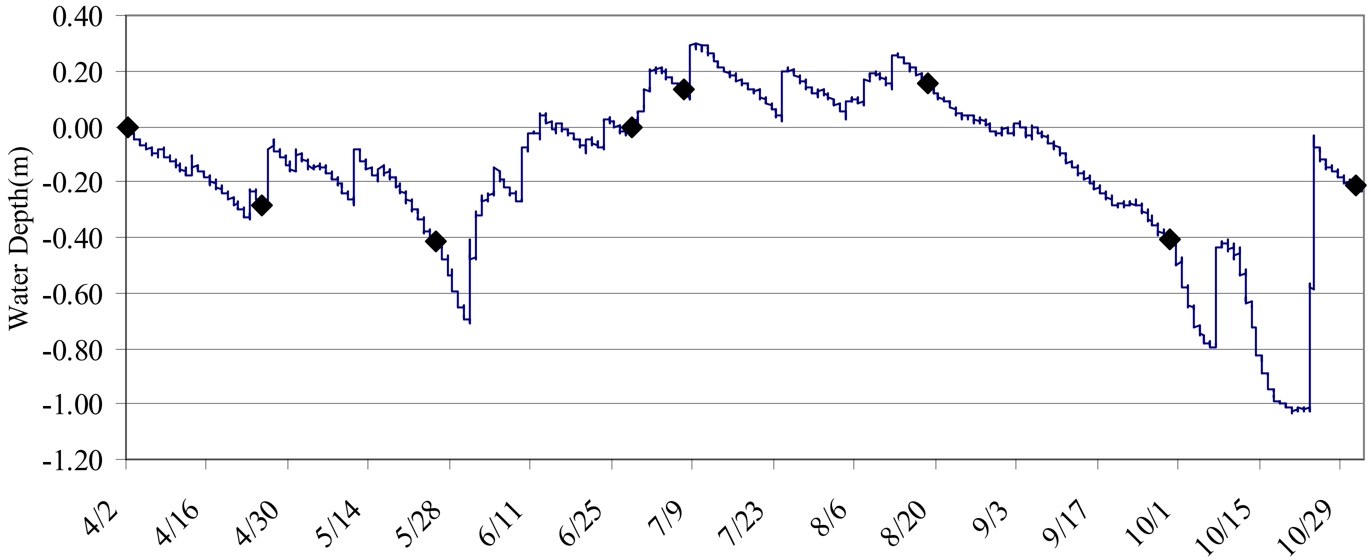

Figure 34. 2005 water depth in a well at TEN measured by continuous data logger. Sampling times are marked with diamonds. The average of the monthly sampled water levels was -0.18 meters, and the average of the hourly sampled water levels was -0.15 meters. The close proximity of the monthly and hourly sampled water level (within 3 cm) indicates that the monthly sampled water level provided an accurate average water level for the time period.

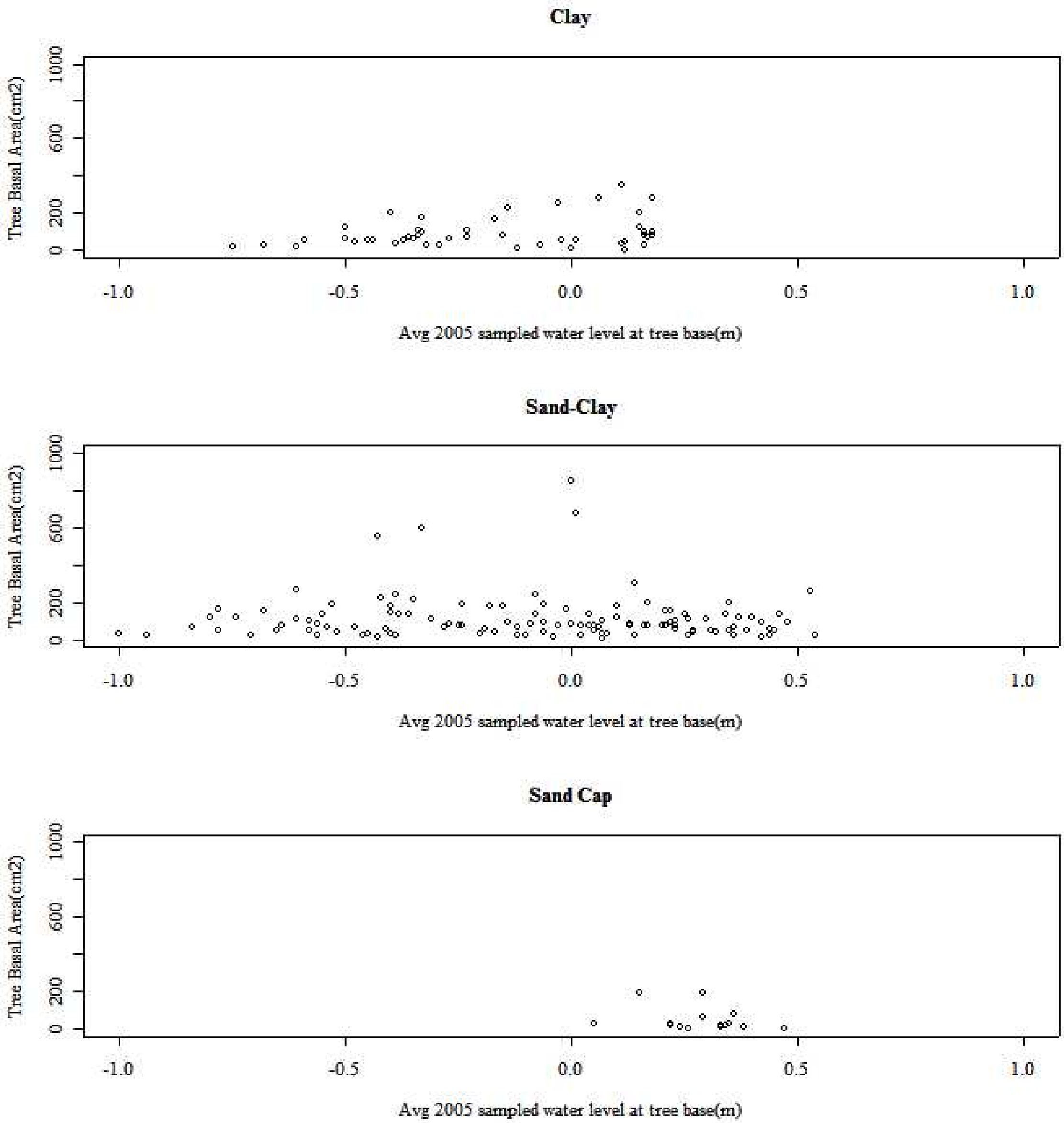

Figure 35. Distribution of *Fraxinus pennsylvanica* basal area by average water depth for clay, sand-clay, and sand cap sites.

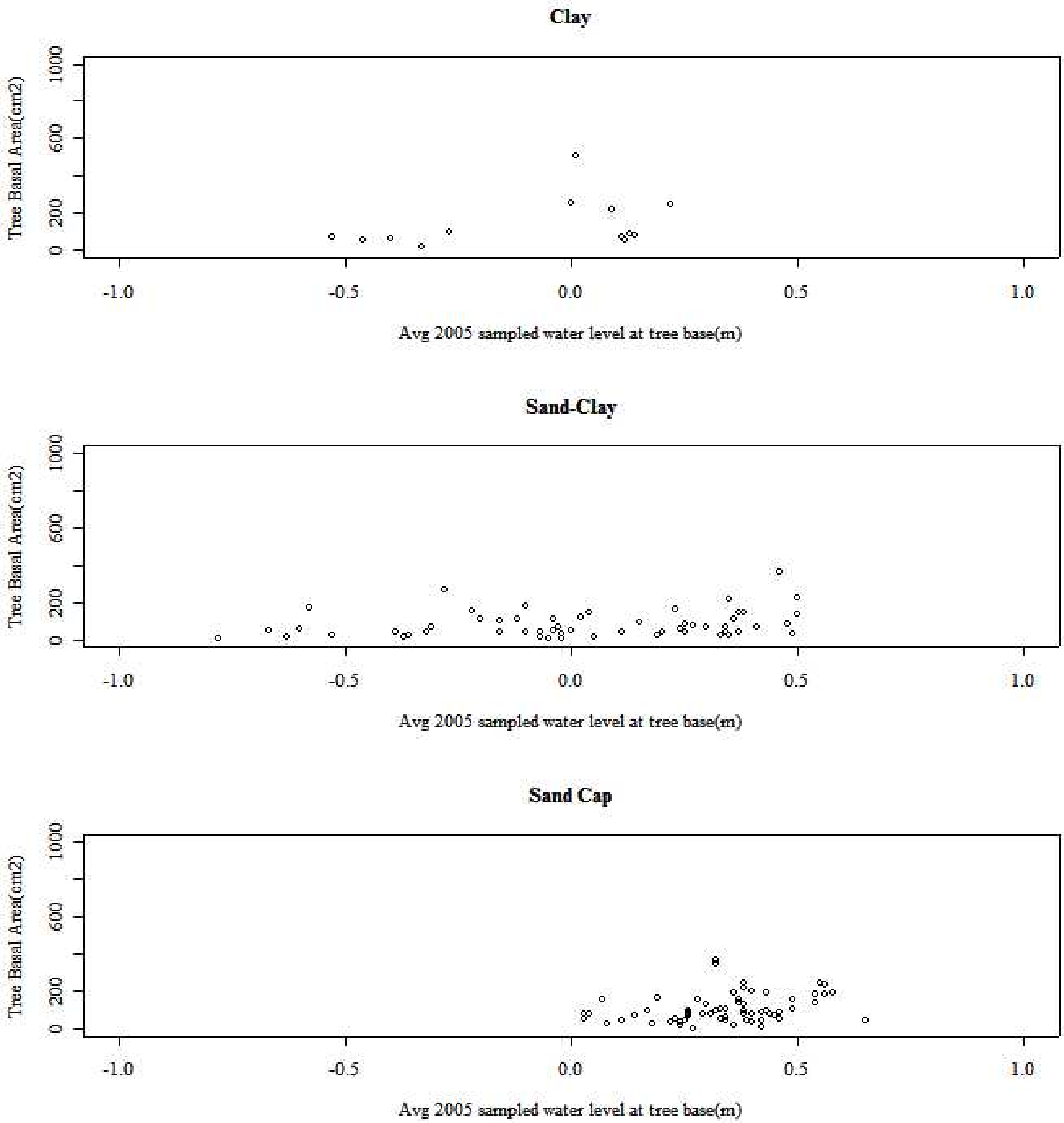

Figure 36. Distribution of *Nyssa aquatica* basal area by average water depth for clay, sand-clay, and sand cap sites.

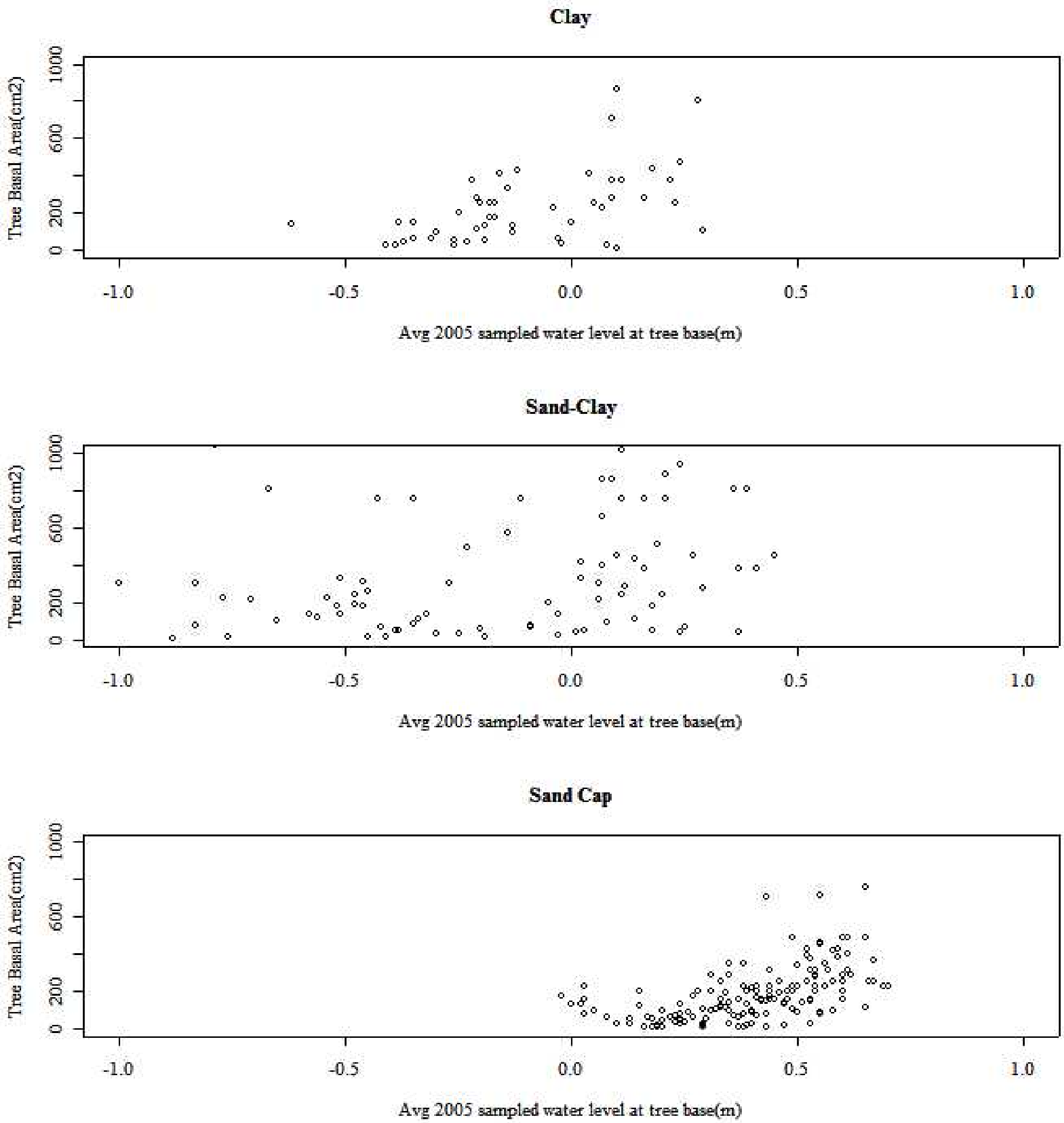

Figure 37. Distribution of *Taxodium distichum* basal area by average water depth for clay, sand-clay, and sand cap sites.

Table 21. Understory species in pair 1 (CFI) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
R1	*Lemna minor*	0.98	5	*Lemna minor*	0.45
R1	*Limnobium spongia*	0.28	5	*Salvinia minima*	0.31
R1	*Pistia stratiotes*	0.24	5	*Eryngium baldwinii*	0.16
R1	*Salvinia minima*	0.16	5	*Ludwigia peruviana*	0.15
R1	*Cladium jamaicense*	0.12	5	*Hydrocotyle umbellata*	0.10
R2	*Lemna minor*	0.95			
R2	*Limnobium spongia*	0.27			
R2	*Pistia stratiotes*	0.17			
R3	*Lemna minor*	0.71			
R3	*Nephrolepis cordifolia*	0.71			
R3	*Limnobium spongia*	0.30			
R3	*Pistia stratiotes*	0.18			
R4	*Lemna minor*	0.39			
R4	*Nephrolepis cordifolia*	0.29			
R4	*Clematis virginiana*	0.25			
R4	*Parthenocissus quinquefolia*	0.13			
R4	*Sambucus canadensis*	0.13			
R4	*Thelypteris hispidula*	0.13			
R4	*Urena lobata*	0.12			
R5	*Lemna minor*	0.54			
R5	*Nephrolepis cordifolia*	0.25			
R5	*Thelypteris hispidula*	0.22			
R5	*Limnobium spongia*	0.21			
R5	*Sambucus canadensis*	0.16			
R6	*Nephrolepis cordifolia*	0.48			
R6	*Thelypteris hispidula*	0.43			
R6	*Lemna minor*	0.21			
R6	*Clematis virginiana*	0.18			
R6	*Sambucus canadensis*	0.16			
R6	*Parthenocissus quinquefolia*	0.11			

Table 22. Understory species in pair 2 (HOM) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
R1	*Salvinia minima*	1.25	T1	*Lemna minor*	0.46
R1	*Lemna minor*	0.42	T1	*Alternanthera philoxeroides*	0.32
R1	*Typha spp.*	0.14	T1	*Pistia stratiotes*	0.24
R2	*Salvinia minima*	0.86	T1	*Scirpus cubensis*	0.18
R2	*Lemna minor*	0.25	T1	*Salvinia minima*	0.17
R2	*Ludwigia peruviana*	0.25	T1	*Scirpus validus*	0.17
R3	*Salvinia minima*	0.67	T1	*Panicum repens*	0.14
R3	*Lemna minor*	0.29	T1	*Hydrocotyle ranunculoides*	0.10
R3	*Typha spp.*	0.16	T1	*Pontederia cordata*	0.10
R3	*Alternanthera philoxeroides*	0.15			
R3	*Mikania scandens*	0.13			
R3	*Ludwigia peruviana*	0.11			
R4	*Salvinia minima*	0.71			
R4	*Lemna minor*	0.45			
R4	*Typha spp.*	0.20			
R4	*Imperata cylindrica*	0.18			
R4	*Ludwigia peruviana*	0.10			
R5	*Lemna minor*	0.69			
R5	*Salvinia minima*	0.57			
R5	*Typha spp.*	0.32			
R5	*Hydrocotyle ranunculoides*	0.10			
R6	*Lemna minor*	0.78			
R6	*Salvinia minima*	0.58			
R6	*Typha spp.*	0.28			
R6	*Alternanthera philoxeroides*	0.10			
R7	*Lemna minor*	0.70			
R7	*Salvinia minima*	0.57			
R7	*Typha spp.*	0.26			
R7	*Scirpus validus*	0.12			

Table 23. Understory species in pair 3 (OHW) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
H1	*Salvinia minima*	0.77	H1R	*Salvinia minima*	0.51
H1	*Scirpus validus*	0.45	H1R	*Mikania scandens*	0.37
H1	*Ludwigia peruviana*	0.35	H1R	*Ludwigia peruviana*	0.31
H1	*Mikania scandens*	0.21	H1R	*Acer rubrum*	0.25
H1	*Acer rubrum*	0.18	H1R	*Aster carolinianus*	0.19
H4	*Salvinia minima*	1.06	H1R	*Scirpus cyperinus*	0.12
H4	*Acer rubrum*	0.24	H1R	*Salix caroliniana*	0.12
H4	*Aster carolinianus*	0.16			
H4	*Ludwigia peruviana*	0.16			
H4	*Mikania scandens*	0.16			
H4	*Salix caroliniana*	0.16			

Table 24. Understory species in pair 4 (OHW) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
R1A	*Aster carolinianus*	0.51	T1	*Imperata cylindrica*	0.53
R1A	*Ludwigia peruviana*	0.49	T1	*Ludwigia peruviana*	0.43
R1A	*Hydrocotyle umbellata*	0.25	T1	*Acer rubrum*	0.35
R1A	*Salvinia minima*	0.12	T1	*Ampelopsis arborea*	0.17
R1A	*Polygonum hydropiperoides*	0.12	T1	*Hydrocotyle umbellata*	0.17
R1A	*Mikania scandens*	0.12	T1	*Rubus argutus*	0.17
R1A	*Commelina diffusa*	0.12			
R1A	*Ampelopsis arborea*	0.12			
R1A	*Acer rubrum*	0.12			

Table 25. Understory species in pair 5 (OHW) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
R2A	*Ulmus americana*	0.38	T2	*Salvinia minima*	1.09
R2A	*Hydrocotyle umbellata*	0.36	T2	*Ludwigia peruviana*	0.26
R2A	*Ludwigia peruviana*	0.31	T2	*Mikania scandens*	0.25
R2A	*Acer rubrum*	0.21	T2	*Acer rubrum*	0.16
R2A	*Salvinia minima*	0.16			
R2A	*Cephalanthus occidentalis*	0.16			
R2A	*Aster carolinianus*	0.11			
R2B	*Salvinia minima*	0.54			
R2B	*Ludwigia peruviana*	0.36			
R2B	*Imperata cylindrica*	0.28			
R2B	*Acer rubrum*	0.18			
R2B	*Aster carolinianus*	0.18			

Table 26. Understory species in pair 6 (PRP) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
H1	*Salvinia minima*	0.75	H1R	*Salvinia minima*	0.80
H1	*Lemna minor*	0.73	H1R	*Lemna minor*	0.73
H1	*Typha spp.*	0.35	H1R	*Salix caroliniana*	0.16
H1	*Mikania scandens*	0.11	H1R	*Typha spp.*	0.15
H5	*Salvinia minima*	0.94			
H5	*Lemna minor*	0.49			
H5	*Typha spp.*	0.42			
H5	*Spirodela polyrhiza*	0.16			

Table 27. Understory species in pair 7 (TEN) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
H2	*Lemna minor*	1.21	H2R	*Lemna minor*	1.46
H2	*Polygonum hydropiperoides*	0.39	H2R	*Pistia stratiotes*	0.41
H2	*Salix caroliniana*	0.29	H2R	*Salix caroliniana*	0.14
H2	*Cyperus virens*	0.11			

Table 28. Understory species in pair 8 (TEN) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
H5	*Polygonum hydropiperoides*	0.37	H5R	*Mikania scandens*	0.38
H5	*Schinus terebinthifolius*	0.31	H5R	*Eupatorium serotinum*	0.31
H5	*Eupatorium capillifolium*	0.30	H5R	*Polygonum hydropiperoides*	0.26
H5	*Mikania scandens*	0.30	H5R	*Eupatorium capillifolium*	0.23
H5	*Eupatorium serotinum*	0.17	H5R	*Schinus terebinthifolius*	0.22
H5	*Ludwigia peruviana*	0.17			
H5	*Salix caroliniana*	0.10			

Table 29. Understory species in pair 9 (TEN) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
H6	*Schinus terebinthifolius*	0.57	H6R	*Salix caroliniana*	0.88
H6	*Cyperus virens*	0.37	H6R	*Polygonum hydropiperoides*	0.56
H6	*Polygonum hydropiperoides*	0.30	H6R	*Cyperus virens*	0.34
H6	*Boehmeria cylindrica*	0.26	H6R	*Cirsium nuttallii*	0.11
H6	*Pluchea odorata*	0.15	H6R	*Eupatorium capillifolium*	0.11
H6	*Salix caroliniana*	0.15			

Table 30. Understory species in pair 10 (TEN) ranked by Importance Value (IV)

Rushton			Reference		
Plot	Species	IV	Plot	Species	IV
R2A	*Ludwigia peruviana*	0.60	T1	*Eupatorium serotinum*	0.43
R2A	*Sapium sebiferum*	0.23	T1	*Cyperus virens*	0.35
R2A	*Eupatorium serotinum*	0.19	T1	*Lemna minor*	0.31
R2A	*Mikania scandens*	0.19	T1	*Mikania scandens*	0.17
R2A	*Schinus terebinthifolius*	0.19	T1	*Polygonum hydropiperoides*	0.14
R2A	*Lemna minor*	0.16			
R2A	*Salix caroliniana*	0.16			
R2A	*Clematis virginiana*	0.10			
R2A	*Cyperus virens*	0.10			
R2A	*Eupatorium capillifolium*	0.10			
R2B	*Lemna minor*	0.82			
R2B	*Schinus terebinthifolius*	0.43			
R2B	*Salix caroliniana*	0.27			
R2B	*Eupatorium serotinum*	0.20			
R2B	*Ludwigia peruviana*	0.14			

Table 31. Autecological characteristics of species prevalent in understory. Values (0 to 2) are relative to other species with the same growth habit (e.g. grass, shrub, tree)

General Key 0 = early succession 2 = late succession	0 = Rapid 1 = Moderate 2 = Slow	0 = Short 1 = Moderate 2 = Long	0 = Short 1 = Moderate 2 = Long	0 = Intolerant 1 = Intermediate 2 = Tolerant	0 = High 1 = Medium 2 = Low	0 = Rapid 0.67 = Moderate 1.33 = Slow 2 = None	0 = Wind&Water 1 = Wind/Water 2 = Mechanical Only
Species	Growth Rate	Time to Max Intrinsic Growth Rate	Lifespan	Shade Tolerance	Seed Abundance	Vegetative Spread Rate	Dispersal Strategies
Acer rubrum	0	2	2	2	0	2	0
Alternanthera philoxeroides	0	0	0	1	2	0	1
Ampelopsis arborea	0	0	1	2	2	0	2
Aster carolinianus[a]	1	1	1	1	1	2	1
Boehmeria cylindrica	1	0	1	2	2	2	1
Cephalanthus occidentalis	1	1	0	2	1	2	2
Cirsium nuttallii	0	0	1	1	1	2	1
Cladium jamaicense	1	1	1	0	1	1.33	1
Clematis virginiana	2	1	2	1	2	1.33	1
Commelina diffusa	0	0	0	2	1	0.67	1
Cyperus virens	1	0	0	0	1	2	1
Eryngium baldwinii	1	0	1	1	2	2	1
Eupatorium capillifolium	0	0	1	1	1	1.33	1
Eupatorium serotinum	0	0	1	1	1	1.33	1
Hydrocotyle ranunculoides	0	0	1	1	1	0	1
Hydrocotyle umbellata	0	0	1	1	1	0	1
Imperata cylindrica	0	0	1	1	0	0	1
Lemna minor	0	0	0	0	1	0	1
Limnobium spongia	1	0	0	0	0	0	1
Ludwigia peruviana[b]	0	1	1	1	0	0.67	1
Mikania scandens	0	0	1	2	0	2	2
Nephrolepis cordifolia[c]	0	0	1	2	0	0.67	2
Panicum repens	0	0	1	1	1	0	2
Parthenocissus quinquefolia	0	0	1	1	2	0	2
Pistia stratiotes	0	0	0	0	1	0	1
Pluchea odorata	1	0	0	0	1	2	1
Polygonum hydropiperoides	0	0	0	0	0	2	2
Pontederia cordata	1	1	1	0	1	2	1
Rubus argutus	0	0	1	0	0	0.67	2
Salix caroliniana	0	1	2	1	1	1.33	0
Salvinia minima	0	0	0	1	1	0	1
Sambucus canadensis	0	1	1	1	0	2	2
Sapium sebiferum[d]	0	1	2	2	0	1.33	2
Schinus terebinthifolius	1	1	1	0	0	2	2
Scirpus cubensis	1	0	1	1	1	2	1
Scirpus cyperinus	1	0	1	1	1	2	1
Scirpus validus	1	0	1	1	1	2	1
Spirodela polyrhiza	0	0	0	0	1	0	1
Thelypteris hispidula[a]	1	0	1	2	0	1.33	2
Typha spp.	0	0	1	1	0	0	0
Ulmus americana	0	2	2	1	0	1.33	1
Urena lobata[e]	0	0	0	1	0	2	2

a SFWMD. 2003. "Ground Covers and Grasses." WaterWise: South Florida Landscapes. Retrieved February 28, 2006 from http://www.sfwmd.gov/newsr/plant_guide/plant_guide.html

b Jacobs, SWL, F Perrett, GR Sainty, KH Bowmer, and BJ Jacobs. 1994. Ludwigia peruviana (Onagraceae) in the Botany Wetlands near Sydney, Australia. Australian Journal of Marine and Freshwater Research 45, no. 8: 1481 - 1490.

c Gillman, Edward. 1999. Nephrolepis exultata. Gainesville, FL: University of Florida Institute of Food and Agricultural Sciences, FPS-427.

d McCormick, Cheryl M. 2005. Chinese Tallow Management Plan for Florida. Tallahassee, FL: Florida Exotic Plant Pest Council.

e Francis, John K. 2003. Urena lobata. San Juan, Puerto Rico: USDA International Institute of Tropical Forestry.

The code for the matrix population model was written for Python 2.3. Executing the code requires the Matplotlib and Numeric libraries. The model consists of two files, CSATreeModel.py, which includes all the model code, and Elasticity.py., which is imported by CSATreeModel.py to calculate model elasticity values. Both are pasted below.

```
# CSATreeModel.py
# Size Class Marix Population Model for Taxodium distichum on Two Clay Settling Areas
# Written in Python 2.3
# Method and Model Output described in:
# Ingwersen, Wesley. 2006. Viability of Wetland Trees After 20 Years on Phosphatic Clay
Settling Areas and Their Role in Ecosystem Development.  M.S. Thesis. Gainesville:
University of Florida
#
# This is a modified version orginally created for the course FOR 6156 'Simulation
Analysis of Forest Ecosystems',
# Univ. of Florida, Spring 2005, taught by Dr. Wendell Cropper
#
# Modifications in this version include
# uses .txt files of tree BA rather than DBH, so skips the BA conversion
# changes the size classes puts a time delay of two years in before trees have BA, based
on realistic average of the data
# changes to the estimate of fecundity
# fixed fecundity so first size class fecundity was not changing

import math
import random
from matplotlib.matlab import *
from Elasticity import *
import Numeric
import LinearAlgebra as LA

#Imports tree data from three groups of trees - planted trees, planted trees that died
and resprouted, and offspring
def data_in():
    #This file is one column of Basal Areas(BAs) and one of the year during which BA
became greater than 0
        indata = open(file_names[0], 'r')
        data = indata.readlines()
        for t in data:
            lin = t.split()
            planted_BA.append(float(lin[0]))
            time_till_BA.append(float(lin[1]))
        indata.close()

        #Resprouted trees - one column of (BAs)
        indata = open(file_names[1], 'r')
        data = indata.readlines()
        for t in data:
            lin = t.split()
            for i in range(len(lin)):
               try:
                   resprouted_BA.append(float(lin[i]))
               except:
                   x = missing
        indata.close()

        #Offspring - one column of (BAs)
        indata = open(file_names[2], 'r')
        data = indata.readlines()
        for t in data:
            lin = t.split()
            for i in range(len(lin)):
               try:
                   offspring_BA.append(float(lin[i]))
               except:
```

```
                x = missing
        indata.close()
        del(data)

#Solves for growth rate,'a' variable, in the tree growth equation
#Created so that the time,t is the years since it began having a basal area
def solve_for_a():
    for i in range(len(planted_BA)):
        t = 20-time_till_BA[i] #to get t= the time at which tree got a DBH
        BAt = planted_BA[i]
        den = b*math.log10(b+t)
        planted_a.append(BAt/(t-den))

#For resprouts.  Create a random growth rate (a) using the mean and std of the planted
tree growth rates
def monte_carlo_for_a(trees,trees_a):
    mu = mean(planted_a)
    sigma = std(planted_a)
    for i in range(len(trees)):
        BAt = trees[i]
        thisa = abs(random.normalvariate(mu,sigma))
        trees_a.append(thisa)

#Solves for BA with a given growth rate, a
def solve_for_BA(a,t):
    BA = a*t-b*math.log10(b+t)
    print a,b,BA
    return BA

def deriv(x,t):
    dBAdt = (a*t)/(b+t)
    return(dBAdt)

#This function generates tree size in BA for 0 to 20 years for planted,resprouted,
#and offspring and puts each tree in a row of the growth_mat matrix.
def simulate_growth():
    global a
    for t in rplanted:
        a = planted_a[t]
        start_time = time_till_BA[t]
        growing_yrs = 21 - time_till_BA[t]
        tim = arange(0, growing_yrs, 1)
        growth = rk4(deriv,0,tim)
        #Before tree has BA, give it zero
        for i in range(int(start_time)):
            growth_mat[t][i] = 0.0
        #After tree has basal area, assign it calculated BA
        for j in range(len(growth)):
            col = int(start_time+j)
            growth_mat[t][col] = growth[j]
        #print growth_mat[t], planted_BA[t]
    del(t)
    a = min(planted_a)
    #Assume time starts at 2 years, when trees have BA
    start_time = 2
    growing_yrs = 19
    tim = arange(0,growing_yrs,1)
    calc_ba = list(rk4(deriv,0,tim))
    #Add two yrs where it doesn't grow)
    calc_ba.insert(0,0)
    calc_ba.insert(0,0)
    #print 'calc_ba=',calc_ba
    #Loop for trees dead by year 3
    for t in rdeady3:
        for i in range(0,3):
            growth_mat[t][i] = 0 #Don't allow any of the trees to emerge from class 0
        #Half die after year 2, half after year 3
        if(random.random()<0.5):
            growth_mat[t][2] = -1
            #print t,'Dies at 2'
    del(t)
```

```
    for t in rdeady1:
        growth_mat[t][0] = 0
    del(t)

    #Selects a random year for these trees to die
    for t in rdeadlater:
        ##Pick a random year between 3 and 20
        death_year = int(ceil(random.random()*(20-3)+3))
        #print death_year
        for i in range(death_year):
            growth_mat[t][i] = calc_ba[i]
    del(t)

    #Resprouted trees : generate growth with a normally distributed random growth rate
    for t in range(len(resprouted_BA)):
        #Grow tree until it reaches current size
        a = resprouted_a[t]
        tim = arange(0,growing_yrs,1) #max 21 years
        ba = list(rk4(deriv,0,tim))
        #At time zero it doens't have a BA. But add another so after 1 yr it still doesnt
have a basal area
        ba.insert(0,0.0)
        for i in range(len(ba)):
            if round(ba[i]) > round(resprouted_BA[t]):
              #print 'ba before',ba
              ba = ba[0:i]
              #print 'ba after', ba
              break
            #If basal area is still over 19, delete it and choose another
        #Now find a dead tree to resprout from
        sprout_space='false'
        tries=0
        random.seed()
        while(sprout_space=='false' and tries<25):
            #Randomly choose the row# of a dead tree
            j = random.choice(rsprout)
            dead_tree = list(growth_mat[j]) #Make into list so index works
            try:
                death_yr = dead_tree.index(-1)
                dead_yrs = 21 - death_yr
                #print 'len(ba)',len(ba),'\n len(dead_yrs)',dead_yrs,'\n'
                #If there is room, insert this resprouted tree into this row of the
growth matrix
                if dead_yrs >= len(ba):
                    sprout_year = (20-len(ba))+1
                    #print 'growth_mat before', growth_mat[j]
                    growth_mat[j][sprout_year:21] = ba #Replace dead years until 20 with
resprout
                    for i in range(21):
                          if growth_mat[j][i]==-1:
                              growth_mat[j][i]=0
                    sprout_space = 'true'
                    #print 'growth_mat_replaced,',growth_mat[j]
                else:
                    del(resprout[j]) #del row so it's not selected again
                    tries+=1
                    print 'into else loop, try',tries
            except:
                #print 'Already resprouted=',j,growth_mat[j]
                tries+=1
                if tries==24:
                    raise 'Exception', 'Space for resprouts not found'
                del(j)

    #Offspring : generate growth like with resprouted
    for t in range(len(offspring_BA)):
      #Grow tree until it reaches current size
        a = offspring_a[t]
        tim = arange(0,growing_yrs,1) #max 18 years
        ba = rk4(deriv,0,tim)
```

```
        ba = list(rk4(deriv,0,tim))
        #First 2 yrs it doesnt have a BA, but at the end of the 3rd it might
        ba.insert(0,0.0)
        ba.insert(0,0.0)
        for i in range(len(ba)):
          if round(ba[i]) > round(offspring_BA[t]):
              ba = ba[0:i-1]
              #print 'offspring ba',ba
              break
    #Now put offspring into the growth matrix
        birth_yr = 21-len(ba)
        row_num = roffspring[t]
        #growth_mat[row_num][0:birth_yr:-1] = 0
        growth_mat[row_num][birth_yr:21] = ba
        #print 'offspring row :',growth_mat[row_num]

#This function classifies a Basal Area(ba) in its appropriate size class
def classify(ba):
    if ba==sc.get('0'):
        return 0
    if ba>=sc.get('0') and ba<sc.get('1'):
        return 1
    if ba>=sc.get('1') and ba<sc.get('2'):
        return 2
    if ba>=sc.get('2') and ba<sc.get('3'):
        return 3
    if ba>=sc.get('3') and ba<sc.get('4'):
        return 4
    if ba>=sc.get('4') and ba<sc.get('5'):
        return 5
    if ba>=sc.get('5') and ba<sc.get('6'):
        return 6
    if ba>=sc.get('6'):
        return 7
    if ba==sc.get('D'):
        return 8

#This creates creates size classification matrix from the growth_mat
def categorize():
    for t in range(trees_planted):
            t_classes = map(classify,growth_mat[t])
            for i in range(len(t_classes)):
                class_mat[t][i] = t_classes[i]

#This function fills the 'State-fate' matrix, state_fate_mat, by determining how many
trees stay
#in the same size class, move to a another, or die in a given year
def tally():
    for t in range(trees_planted):
        for y in range(1,20):
            current = class_mat[t][y]
            previous = class_mat[t][y-1]
            #print 'c=',current,'p=',previous
            if current==previous:
                #Don't count dead to dead
                if current==8:
                    break
                else:
                    row,col = current,current
                    state_fate_mat[row][col]+=1
            else:
                row,col = current,previous
                state_fate_mat[row][col]+=1

#Counts all the trees capable of reproducing, which includes all size classes but the
first
def sum_mature_trees(y):
    mature_trees=0
    for t in range(trees_planted):
        if 0<class_mat[t][y]<no_classes:
            mature_trees+=1
```

```
    return mature_trees

#This creates the transition mat, trans_mat, from state_fate_mat, by finding the
probabilities
#of remaining in a class or moving to another class.
#It also adds in probability of successful reproduction for mature classes
def fill_trans_mat():
    colsums = sum(state_fate_mat)
    b=1
    for j in range(no_classes):
        for i in range(no_classes):
            if colsums[i]==0:
                #Set survival to 1 for now if there are no trees there
                if i==j: trans_mat[j][i] = 1
            else:
                trans_mat[j][i] = float(state_fate_mat[j][i])/float(colsums[i])
    print 'Transition matrix before adding fecundity',trans_mat
    #Add in fecundity by assuming that each successive size class has 1.5 times the
probability of reproductive success
    print 'trans_mat before fecundity]',trans_mat[0]
    for j in range(no_classes-1):
        trans_mat[0][j+1]+= b*x
        b*=1.5
    print trans_mat[0]

#This function subtracts the probability of death from the probability of stasis in the
transition matrix
def subtract_estimated_mortality(trans_mat, start_ind, mort_list):
    A2 = trans_mat[:]
    for i in range(len(mort_list)):
        #print 'before', A2[start_ind+i][start_ind+i]
        A2[start_ind+i][start_ind+i] = trans_mat[start_ind+i][start_ind+i]-mort_list[i]
        #print 'after',A2[start_ind+i][start_ind+i]
    return A2

def fill_size_dist(size_dist_mat,largest_class):
    for t in range(len(living_BA)):
        cl = classify(living_BA[t])
        if (0<=cl<=largest_class):
            size_dist_mat[cl]+=1

def run(years,A,size_d,pop_size):
    popvec = size_d[:]
    for t in range(years):
        Tot = sum(popvec)
        time.append(float(t))
        pop_size.append(Tot)
        popvec = matrixmultiply(A,popvec)
        print "Year",t,popvec

def calc_lamba(mat):
    e = eig(mat)
    #print e
    return max(abs(e [0]))  # largest eigenvalue

#End of function definitions
##########################################################################################
#####
#Program starts

if __name__ == '__main__':


    #Enter site configuration data
    site_name= 'CFI SP-1'
    file_names = ['CFplanted.txt','CFresprouted.txt','CFoffspring.txt']
    trees_planted = 183
    surviving_y1 = 123
    surviving_y3 = 93

#OH Wright Basin with H1,H4, R2A,R2B
```

```
##    site_name='OH Wright'
##    file_names = ['ohplanted.txt','ohresprouted.txt','ohoffspring.txt']
##    trees_planted = 18+18+31+31
##    surviving_y1 = 17+18+18+24 #Assume site average of 90% for H1 and H4 =
##    surviving_y3 = 15+16+15+24 #Just have to estimate for H1 and H4

    time_till_BA = []
    planted_BA = []
    resprouted_BA = []
    offspring_BA = []
    data_in()
    b = 6.000 #Half of the time it takes until a max growth rate is reached
    #This b gives good approximations of BA when A is calculated
    #Calculated by setting BA
    planted_a = []
    resprouted_a = []
    offspring_a = []
    solve_for_a() #Solve integral for a
    monte_carlo_for_a(resprouted_BA,resprouted_a)
    monte_carlo_for_a(offspring_BA,offspring_a)

    #create blank matrix for growth


    num_trees = trees_planted + len(offspring_BA)
    print 'tot_num_trees used in model=',num_trees
    #The growth mat needs to be big enough for all the trees for 0 to 20 years
    growth_mat = array([[-1.0]*21]*num_trees)


    #Define growth rate
    #a = 0.0
    #Assume trees that die after 1 year don't advance out of class 0

    #Assume that trees that die later have min growth rate
    min_growth_rate = min(planted_a)

    #Determine the indicies of the tree groups for iterating through growth_mat
    rplanted = range(0,len(planted_BA)-1)
    rdeady1 = range(max(rplanted)+1,max(rplanted)+1+trees_planted-surviving_y1)
    rdeady3 = range(max(rdeady1)+1,max(rdeady1)+1+surviving_y1-surviving_y3)
    rdeadlater = range(max(rdeady3)+1,trees_planted)
    roffspring = range(trees_planted,num_trees)

    #Resprouts may occur in any dead spot
    rsprout = range(rdeady1[0],trees_planted)

    #print rplanted,rdeady1,rdeady3,rdeadlater,rsprout

    simulate_growth()

    #Create a dictionary of max BA values for each size class bin
    sc = dict({'0':0,'1':19.7,'2':78.6,'3':176.8,'4':314.3,'5':707.0,'6':1256.6,'D':-1})
    no_classes = 8 #7 classes put a dead one
    class_mat = array([[no_classes]*21]*num_trees)
    categorize()
    #print 'Class-mat',class_mat[0:20]

    state_fate_mat = array([[0]*(len(sc)+1)]*(len(sc)+1))
    tally()
    #print 'State-fate table',state_fate_mat

    #Fecundity
    num_seedlings = offspring_BA.count(0)
    # of Mature trees that could have produced seed one year ago that led to current # of
seedlings
    mature_trees = float(sum_mature_trees(19))
    #Use year 19 because they are possible parents
    total_fecundity = num_seedlings/mature_trees
    #Assume each size class produces 1.5 as many seedlings as the class below it
    #x = fecundity of smallest mature class(1)
```

```
    #class 1 = x
    #class 2 = 1.5x
    #class 3 = class2+1.5*x
    div=1
    for i in range(no_classes-1):
        div+=1.5*i
    #print 'div',div
    x = total_fecundity/div
    #print 'x=',x


    #Make transition matrix
    trans_mat = array([[0.0]*len(sc)]*len(sc))
    trans_mat_w_mortal = array([[0.0]*(len(sc)+1)]*(len(sc)))
    fill_trans_mat()
    #fill_trans_mat_w_mortal()
    #print 'Transition matrix',trans_mat


    #Estimate mortalities for the largest size classes because we don't have good data on
death of those size trees
    #Mortalities for classes 0,1,2 =0.15839695,  0.04427083,  0.0694864
    #Estimate mortalites for classes 3-7 based on fractions of class 2, so each class is
2/3 as likely to die
    start_ind = 3
    mort_list =
list([(2.0/3)*.069,(4.0/9)*.069,(8.0/27)*.069,(16.0/81)*.069,(2.0/3)*(16.0/81)*.069])
    A2 = subtract_estimated_mortality(trans_mat,start_ind,mort_list)
    #print 'A2',A2
    Transition_matrix = A2[:]
    for j in range(no_classes):
       for i in range(no_classes):
               Transition_matrix[i][j]=round(A2[i][j],3)
    #print Transition_matrix
    #Find lamba value
    Lamba = calc_lamba(A2)
    print 'Lamba A2=',Lamba

    living_BA = planted_BA + resprouted_BA + offspring_BA
    size_dist2 = [0]*no_classes
    fill_size_dist(size_dist2,no_classes)

    #Run approach 2
    time = []
    popsize2 = []
    #Years to run model
    yrs = 50
    run(yrs,A2,size_dist2,popsize2)

#Plot results
    figure(1)
    plot(time,popsize2)
    xlabel('Years from the Present')
    ylabel('Number of Trees')
    font = {'family' : 'Times New Roman'}
    dim = (0,50,0,300)
    axis(dim)
    titl = site_name+' Taxodium dist. Population'
    title(titl)

#Must show() from command line

    #Elasticity
    #Change A and dimensions of matrix to run for approach 2
    A = A2

    #ms = 5  #dimension (size) of matrix
    ms = no_classes #Approach 2
    B = Numeric.transpose(A)
    Aev = LA.eigenvectors(A)
    Bev = LA.eigenvectors(B)
```

```
    A_righteigen = ev_of_dom_ei(Aev)
    print "Right_eigen", A_righteigen
    A_lefteigen = ev_of_dom_ei(Bev)
    ESmat= Numeric.zeros((ms,ms), Numeric.Float32)

    x = elastic(A_lefteigen, A_righteigen, A, ESmat)

    #Graph it
    sum2 = 0.0

    yS = []
    yG = []
    yF = []
    yR = []

    for i in range(len(x)):  # separate values by growth, stasis, etc.

        for j in range(len(x)):

            sum2 = sum2 + x[i][j]

            if A[i][j] > 0.0:

                if i == j:

                    yS.append(x[i][j])  #stasis

                elif i > j and i > 0.0:

                    yG.append(x[i][j])  #growth

                elif i < j and i > 0.0:

                    yF.append(x[i][j])  #fragmentation

                elif i==0 and j > 2:

                    yR.append(x[i][j])

                else:

                    pass



    Slen = len(yS)
    Glen = len(yG)
    Flen = len(yF)
    Rlen = len(yR)

    figure(2)

    S = bar(arange(Slen),yS)
    G = bar(arange(Slen,Slen+Glen),yG, color='r')
    F = bar(arange(Slen+Glen, Slen+Glen+Flen), yF, color='y')
    R = bar(arange(Slen+Glen+Flen, Slen+Glen+Flen+Rlen), yR, color='g')
    ylim(0,0.55)
    title('Model Elasticity Values')
    legend((S[0],G[0],R[0]),('Stasis','Growth','Fecundity'))

###########END OF CSATreeModel.py########################################################
```

```
#Elasticity.py
#Elasticity analysis for a matrix population model
#Authors: Wendell P. Cropper, Wes Ingwersen

#Returns the left and right eigenvectors of the dominant eigenvalue of a Leslie matrix

import Numeric
import LinearAlgebra as LA

print 'Imported elasticity.py'


#The next goal is to find the dominant eigenvalue, find it's associated eigenvector,
# and transform that vector by dividing through by the greatest value


def E_scaler(Lv, Rv):  #left and right eigenvectors

    n = len(Lv)

    sumES = 0.0

    for i in range(n):

        sumES = sumES + Lv[i] * Rv[i]

    return sumES  #scalar product of eigenvectors


def elastic(Lv, Rv, A, ESmat):  #left, right eigenvectors and A matrix


    N = len(A)

    WV = E_scaler(Lv, Rv)

    maxE = 0.0

    evals = LA.eigenvalues(A)

    for ev in evals:

        if abs(ev) > maxE: maxE = abs(ev)

    for row in range(N):

        for col in range(N):

            a1 = A[row][col]/maxE

            a2 = Lv[row]*Rv[col]/WV

            ESmat[row][col] = a1 * a2

    return ESmat



def vector_max(vector): #Finds the maximum value and it's index in a vector
    ind = 0
    max = abs(vector[0])
    for x in range(len(vector)):
        #print vector[x]
        if abs(vector[x]) > max:
               ind = x
               max = abs(vector[x])

    return ind, max
```

```
def dividethrough_vector(vector,dom_ind): #Divides through a vector by the greatest value
    list_from_vector = []
    for x in range(len(vector)):
        vector[x] = vector[x]/vector[dom_ind]
        list_from_vector.append(abs(vector[x]))
    return list_from_vector

def ev_of_dom_ei(array):  #Returns transformed eigenvector of dominant eigenvalues

    EI = array[0]
    domEI_ind,domEI = vector_max(EI)
    #print 'domEI_ind ',domEI_ind,'domEI ',domEI
    EV = array[1][domEI_ind]
    domEV_ind,domEV_val = vector_max(EV)
    return dividethrough_vector(EV,domEV_ind)


if __name__ == '__main__':

    #Get right eigenvector
    A_righteigen = ev_of_dom_ei(Aev)

    print '  '
    print 'Right Eigenvector of matrix A ',A_righteigen
    print '  '

    #Repeat for  transpose of A to get left eigenvector:
    A_lefteigen = ev_of_dom_ei(Bev)
    print 'Left Eigenvector of matrix B ',A_lefteigen
    print '  '
    print '  '

    ES = E_scaler(A_lefteigen, A_righteigen)

    Eval = LA.eigenvalues(A)

    print ' Eigenvalues = ', Eval

    print '  '
    print '  '

    x = elastic(A_lefteigen, A_righteigen, A)

    print x

    print '  '
    print '  '

    sum2 = 0.0

    yS = []
    yG = []
    yF = []
    yR = []

    for i in range(len(x)):  # separate values by growth, stasis, etc.

        for j in range(len(x)):

            sum2 = sum2 + x[i][j]

            if A[i][j] > 0.0:

                if i == j:

                    yS.append(x[i][j])  #stasis

                elif i > j and i > 0.0:

                    yG.append(x[i][j])  #growth
```

```
            elif i < j and i > 0.0:

                yF.append(x[i][j])  #fragmentation

            elif i==0 and j > 2:

                yR.append(x[i][j])

            else:

                pass


print ' sum of elasticity values = ', sum2
print '  '
print '  '

from matplotlib.matlab import *

Slen = len(yS)
Glen = len(yG)
Flen = len(yF)
Rlen = len(yR)

figure(1)

S = bar(arange(Slen),yS)
G = bar(arange(Slen,Slen+Glen),yG, color='r')
F = bar(arange(Slen+Glen, Slen+Glen+Flen), yF, color='y')
R = bar(arange(Slen+Glen+Flen, Slen+Glen+Flen+Rlen), yR, color='g')
title('Elasticity Values')
legend((S[0],G[0],F[0], R[0]),('Stasis','Growth','Fragmentation', 'Fecundity'))

figure(2)

x = fliplr(x)
x = rot90(x)
x = rot90(x)

pcolor(x, cmap=cm.jet)

show()
```

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BIOGRAPHICAL SKETCH

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