BIOTIC AND ABIOTIC FACTORS AS INDICATORS OF BOTTOMLAND HARDWOOD HEALTH AND THEIR POTENTIAL USE FOR ECOSYSTEM MANAGEMENT

By

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Abstract: My research focused on investigating anecdotal reports from the U.S. Fish and Wildlife Service of decline in the bottomland hardwoods of the Deep Fork National Wildlife Refuge (DFNWR) outside of Okmulgee, OK. The overall goals of the project were to determine 1) extent and severity of forest decline in the DFNWR and 2) whether decline could be attributed to environmental variables. Data included observations from the vegetation and the soils. Vegetation observations aimed to gather information on species richness, density, health, and size distribution of overstory, midstory, and understory vegetation; **s**oil observations included recording soil texture, color, and the presence or absence of redoximorphic features which aimed to give insight to the water holding and infiltration capacity, as well as relative moisture in the soils of the Deep Fork. The most important finding of this study was there was no evidence of forest decline in the DFNWR bottomland hardwoods. Mortality was limited in the overstory and the principal species included pin oak (*Quercus palustris*), pecan (*Carya illinoensis*), green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), and sugarberry (*Celtis laevigata*). Soil observations demonstrated the prominence of silty clay soils and that overall the bottomland soils drain slowly. Soil redoximorphic features generally indicated that the soils were moderately inundated for prolonged periods of time. In addition Canonical Correspondence Analysis (CCA) indicated that of all environmental variables, soil texture had the most important effect on species composition in the Deep Fork bottomland hardwoods.

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INTRODUCTION

Earth's forests play a pivotal role in the global carbon cycle (Pregitzer et al. 2004) and by extension global climate. Scientists today are now beginning to appreciate the impact of trees on the biosphere; the old-growth forests for example act as major "carbon sinks" sequestering massive amounts of CO_2 from the atmosphere, leading ecologists to see the importance of preserving old-growth for pollution control and climate change strategies (Luyssaert et al. 2008). Yet changes in climate can have a direct impact on the structure, composition, as well as the dynamics of forests (Van Mantgem et al. 2007; Waring 1987). A 2007 review of tree mortality in the Sierra Nevada region found an increase in mortality rate which were attributed to stress and biotic causes, this was also found to correlate with an increase in temperature driven drought (Van Mantgem et al. 2007). The bottomland hardwoods of the U.S. were historically the largest expanse of forested wetlands in the country (Stanturf et al. 2000), the drastic reduction in bottomland hardwoods has not only deprived the country of valuable timber sources and natural flood control, but in particular, an important asset in the global carbon cycle. In order to manage forests for the continued function of trees serving as carbon repositories in the face of global climate change requires a thorough understanding of the variables that impact tree populations' response to macro-environmental factors (temperature, precipitation, CO_2 concentration, etc.) such as lifespans, phenotypic plasticity, competition, and disturbance regimes (Brubaker 1986).

Eastern Oklahoma's bottomland hardwoods at the time of Euro-American settlement encompassed 2.2 million acres (Brabander et al. 1985). This unique ecosystem is home to as many as 50 different species of woody plants including 10 species of oak. But through urban and rural development over the generations the once vast expanse has been drastically reduced; by the 1980's Oklahoma bottomlands were reduced by 85% with roughly 330,000 acres remaining (Brabander et al. 1985). And what remains today are mostly fragmented stands, scattered across the state. One of the largest concentrations of bottomland hardwood forest exists in the Deep Fork National Wildlife Refuge (DFNWR) near Okmulgee, OK. Of the refuge's 9,600 acres, 8,000 consist of bottomland hardwoods (U.S. Fish and Wildlife Service 2014b). But the refuge is just as fragmented as the remaining bottomlands which spans over 34 miles along the Deep Fork River.

The decline of the bottomland hardwoods occurred in stages over the course of European settlement and expansion. Initially people valued the bottomlands for the rich supply of timber, especially oak. The clearing of the bottomlands also provided rich ground for cattle grazing and farming. Only 15% of the remaining bottomland hardwoods in Oklahoma are primary forest and the remaining 85% is regrowth from the abandonment of logging and farming in the watersheds (Brabander et al. 1985; Wilkinson et al. 1987). Further decline of bottomlands are attributed to water control measures, namely the construction of dams. Vast areas of bottomlands were either flooded to serve as reservoirs or drained and cleared for expanded agricultural purposes.

Any further decline to the bottomland hardwoods would not only jeopardize a commercially valuable timber source but also an ecologically important resource as well. Apart from the timber resources, the bottomlands provide ecological services that benefit plants, animals, and humans (Stanturf et al. 2000). One of the key environmental characteristics which define the bottomlands is periodic flooding. As a result, the soils are regularly inundated allowing for greater plant species richness and growth, which in turn can support diverse and rich numbers of wildlife including valuable game. In fact, the U.S. Fish and Wildlife Service (USFWS) has documented as many as 149 species of bird in the refuge, including neo-tropical migrating birds and thousands if not tens of thousands of waterfowl the watersheds support (U.S. Fish and Wildlife Service 2014b). The forest plays an additional role that is crucial to wildlife and human activities, flood control. Bottomland vegetation stabilizes the river banks and the forest itself acts as a buffer zone between the river and agricultural/residential areas. Continued alterations to the Deep Fork River for agriculture and urban expansion will alter the hydrologic cycle (Stanturf et al. 2000) in such a way that could ultimately alter species composition in the bottomlands which would further jeopardize their commercial and ecological value.

Despite the ecological and recreational importance of the bottomland hardwoods, comprehensive empirical datasets on the species composition and condition of the bottomlands of Oklahoma is limited. The agencies that administer the remaining bottomland stands are generally aware of species diversity but abiotic observations from the bottomlands are limited; for effective management there must be data at the site scale concerning the climate, hydrology, and soils (Allen et al. 2004). State and national agencies such as, National Oceanic and Atmospheric Administration (NOAA), Mesonet, U.S. Geologic Survey (USGS), and Natural Resource

Conservation Service (NRCS) have databases available but primarily at a broad scale (region, county, township, etc.) but nothing at the habitat or microhabitat level. Following severe drought in 2006 and flooding in 2007 anecdotal accounts from USFWS staff suggested decline in the bottomland hardwoods of the DFNWR. But there were no actual measurements taken. With the lack of empirical data it is impossible to accurately assess the state of the Deep Fork bottomland hardwoods and the impact, if any, of drought and flooding. To further confound the issue, past research has shown that the scope of flooding can have either positive or negative impacts on community health (Odum et al. 1979; Anderson et al. 2008); one particular study found that when the soils were inundated for more than 40% of the growing season, diversity declined and community structure shifted towards flood tolerant trees (De Jager et al. 2012).

The chances for successful management or restoration are slight unless a monitoring procedure is developed and an empirical dataset created. Using multiple field techniques, I collected both qualitative and quantitative data of selected biotic and abiotic characteristics of the bottomland hardwoods. Through data collection and subsequent analysis of the bottomlands, a reference point for future monitoring may be created which will provide resource scientists the opportunity to develop successional trend models for the bottomland hardwoods.

The overall goals of the project were to determine 1) extent and severity of forest decline in the DFNWR and 2) whether decline could be attributed to environmental variables. To achieve these goals I measured composition and health of forest vegetation and environmental attributes such as soil texture and hydromorphic characteristics. These data were analyzed to determine whether the environmental variables were related to measures of forest health.

CHAPTER II

METHODS

2.1 Research Plot

To adequately cover the expanse of the DFNWR, 500 plots were randomly generated (1 per 20 acres) across the refuge. Plots were distributed with a minimum of 200 feet between each one. During the data collection phase plots were removed from consideration if the following occurred: plot was located within a body of water (river, creek, pond, slough, etc.); plot was within an open area lacking woodland that could not be moved to a wooded area within 200 feet of its original centroid position. In addition, plots that were inaccessible due to distance or local conditions (weather, topography, road conditions) were ignored.

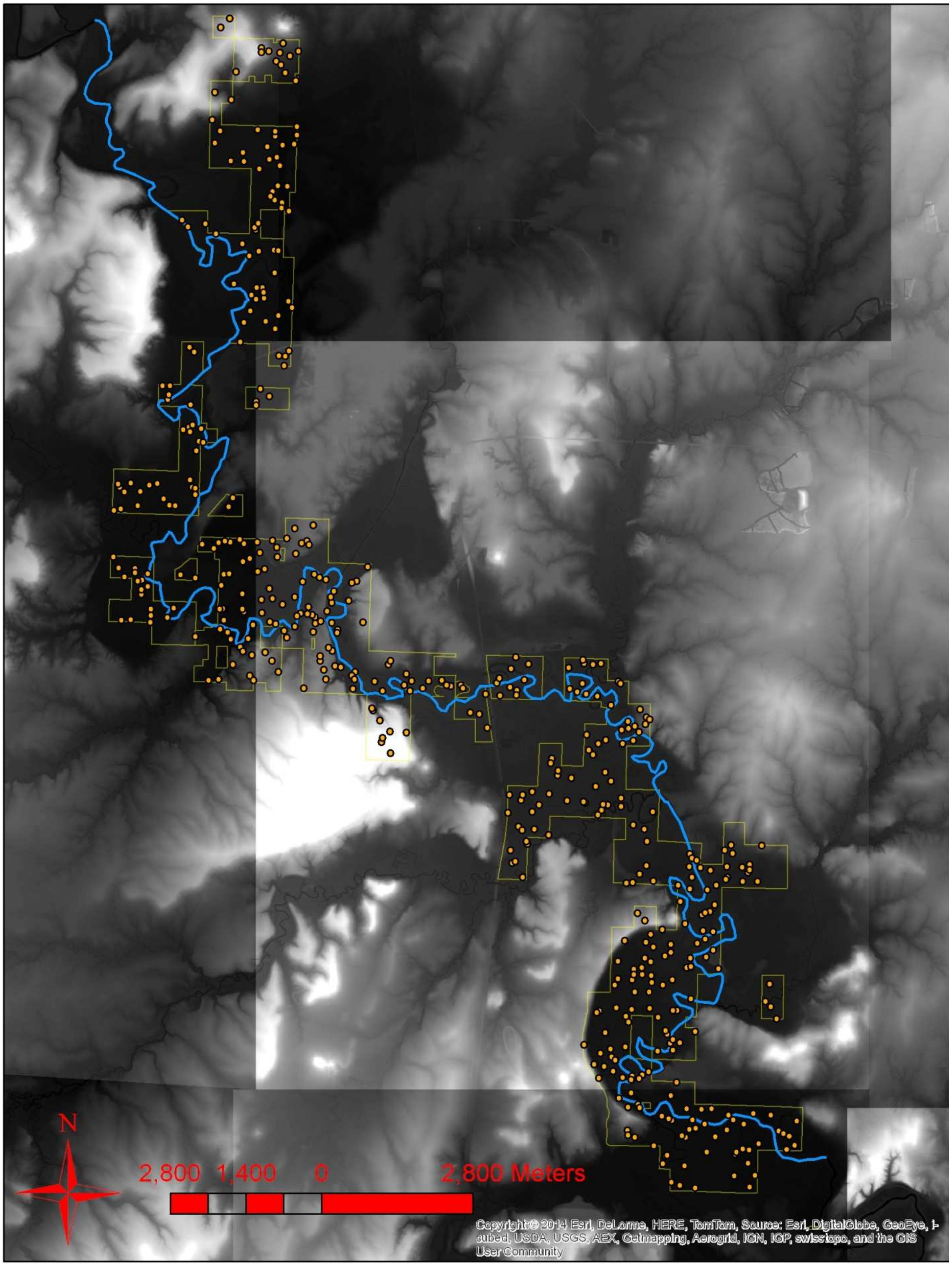

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Figure 1: Lidar imagery map of all generated plots within the DFNWR (refuge boundary outlined in yellow

2.2 Measurements:

2.2a Vegetation

At each sample point, saplings defined as trees > breast height (1.3 m) and < 7.5 cm diameter at breast height (DBH) were measured for DBH by species on a 0.004 ha circular plot (Avery et al. 2002). Overstory trees, DBH was ≥ 7.5 cm, were measured by species for DBH, crown class and crown condition (Petrillo et al. 2011) on a concentric 0.02 ha circular plot.

Polyvinyl chloride (PVC) pipe squares equaling 1 m^2 were used to survey the understory. Measurements were taken at one meter intervals along an orientation of north, south, east, or west which was chosen at random. At each interval all living trees shorter than breast height were tallied (Allen et al. 2001). Ground cover was visually determined using a modified Braun-Blanquet cover scale (Kent et al. 1992) for the following functional groups: graminoids, legumes, forbs, and woody plants (1: <1%, 2: 2-6%, 3: 7-25%, 4: 26-50%, 5: 50-75%, 6: >75%)

Table 1: Criteria for overstory measurements (Petrillo et al. 2011)

Measurement	Criteria
Crown Class	
Dominant	Crown above canopy
Codominant	Crown level with canopy
Intermediate	<50% of crown below canopy
Suppressed	Entire crown below canopy
Crown Condition	
1	Crown with relatively few dead twigs; foliage density and color normal; occasional small dead branches in upper crown; occasional large branch stubs on upper bole
2	Crown with occasional large dead branch in upper portion; foliage density below normal; some small dead twigs at top of crown; occasional large branch stubs on upper bole
3	Crown with moderate dieback; several large dead branches in upper crown; bare twigs beginning to show; several branch stubs on upper and mid bole
4	Approximately half of crown dead
5	Over half of crown dead
6	Tree dead; not cut, standing with fine twigs (less than 2.54 cm (1 in) in diameter) attached to branches
7	Tree dead (natural death); not cut; standing without fine twigs but suntil has some branches attached to bole of tree
8	Tree dead; standing but bole only, no branches attached to bole

2.2b Soils

At plot center, soil cores were excavated with an auger at intervals of 25 cm to a total depth of 100 cm. Texture was determined by standard field procedures (Schoeneberger et al. 2012) to characterize the degree of water holding and infiltration capacity (Schaetzl et al. 2005). The term "rock" in texture observations was generically used to indicate an impermeable horizon; if "rock" was recorded at 50 cm then the horizons at 75 and 100 cm were assumed to be impermeable as well. Presence of redoximorphic concentrations and depletions were determined by standard field procedures with a standardized Munsell color system to classify dominant soil, depletion, and concentration colors (Schoeneberger et al. 2012). In addition to color the relative abundance and visual distinctiveness of features were recorded. Redoximorphic features are the byproduct of respiration in the soil. Aerobic respiration results in redox concentrations which are indicative of the soils being dry for prolonged periods, while anaerobic respiration results in redox depletions which indicate inundation of the soil for prolonged periods.

2.2c Environmental Flow Components

Daily river flow data (ft^3sec^{-1}) for the Deep Fork River was gotten from the USGS' gauging station at Beggs, OK (Latitude 35°40'26" N, Longitude 96°04'06" E). It is located approximately 5 km upriver from the refuge. Data was gotten for the time period of 1974-2014.

2.3 Data Analysis:

2.3a Vegetation

The goal from the analysis was to determine overall forest condition and composition. In addition to important variables such as species richness, density, health, and size distribution of overstory, midstory, and understory vegetation, an important question was whether there were noticeable shifts in species composition between the forest levels. If so, this would indicate a shift in succession within the bottomlands. Species richness in the understory would reflect the present conditions of the environment. And any evidence of high mortality among key species in the overstory would suggest possible shifts in the forest succession away from desirable stand structure and composition. If a prominent overstory species was experiencing high mortality and not regenerating then the dynamics of the forest ecosystem have changed.

Mean and standard deviation were calculated for all trees and major species for basal area and density for the overstory and midstory, and for density of tree regeneration in the understory. Mean and standard deviation for crown class and crown condition were calculated for overstory trees. Frequency distribution of DBH in terms of stems ha^{-1} was plotted for major tree species in the overstory. Relative frequency distribution of crown condition was plotted for overstory trees. The relative frequency of cover class was plotted by plant functional group.

2.3b Soils

Soil texture is a vital characteristic which directly impacts water holding and infiltration capacity. Texture was used to determine saturated hydraulic conductivity (K_{sat}), which is a measure of how easily saturated soils can transmit water through the pore space (Schoeneberger et al. 2012). K_{sat} can further characterize how deep water can move in the soils which could help explain any signs of stress in the trees. K_{sat} classes are simple to define (Table 2, Figure 2); translating texture to K_{sat} class requires the bulk density of the soil. Knowing the range of bulk density determines which textures fall into their respective K_{sat} class (Soil Survey Staff, 1993). Bulk density of soil in the DFNWR was sampled and estimated at 1.33 g cm^{-3} at 0-3 cm and 1.52 g cm^{-3} at 50-53 cm (personal communication, Dr. Brian Carter, Plant and Soil Sciences, Oklahoma State University) which puts the soil in the medium bulk density category (Rawls et al. 1983).

Table 2: Definition of K_{sat} classes (Soil Survey Staff, 1993)

K_{sat} class	K_{sat} scale in analysis	Rate of infiltration (μm sec^{-1})
very low	0	< .01
low	1	.01 to < .1
moderately low	2	.1 to < 1.0
moderately high	3	1.0 to < 10
high	4	10 to < 100

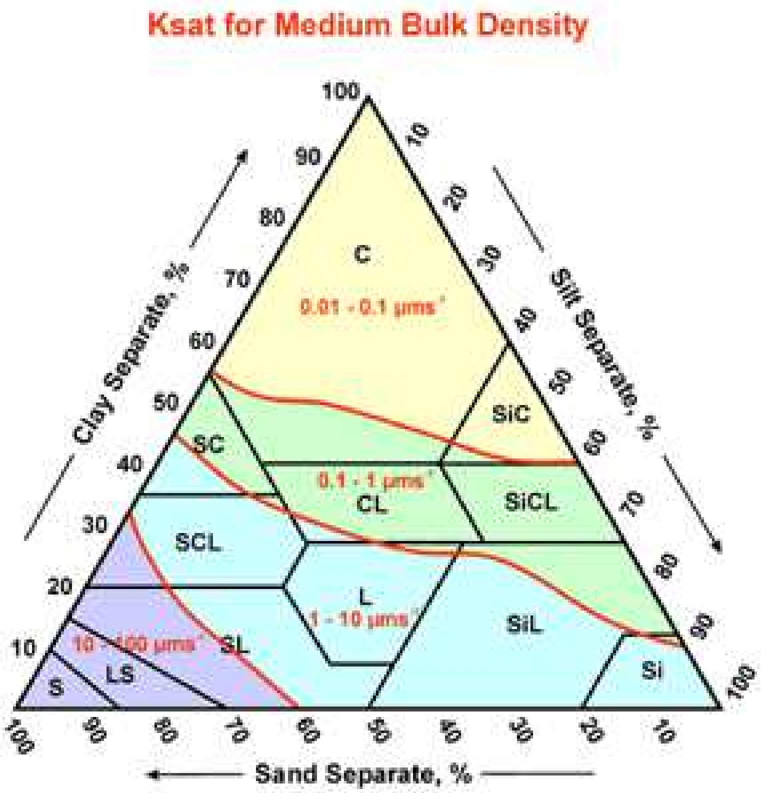


Figure 2: Texture triangle for medium bulk density soils and their corresponding K_{sat} classes (NRCS)

Soil redoximorphic features are standard indicators of the moisture regime, saturation, and reduction of the soils used by soil scientists. For my purposes I specifically examined redox depletions since they are the result of prolonged soil inundation (Schoeneberger et al. 2012; Jacobs et al. 2002). From depletion observations I focused solely on the chroma (strength/purity) of depletion color as well as abundance. In each horizon if depletions were present, scores of 1-3 were designated depending on the chroma. A low chroma would get a numeric score of 3 because the lower the chroma, the stronger the depletion color. Depletion abundance was done in a similar manner. The sum total of scores from each horizon provided the redox moisture regime for the site. For example, if at one site all four horizons had a chroma of either 1 or 2 each horizon would get 3 points, and then if each horizon had many depletions present each horizon would get a further 3 points; added all together the total score for the entire soil profile would be 24, the maximum value, indicating that the soils are inundated for the better part of the year. By our scale: 17-24=heavily saturated, 9-16=moderately saturated, and 0-8=unsaturated.

2.3c Environmental Flow Components

Daily flow data was analyzed with Indicators of Hydrologic Alteration (IHA) software program developed by the Nature Conservancy. The analysis was performed to determine the Environmental Flow Components (EFC) from 1974-2014; EFC directly impacts riparian vegetation. Small floods control distribution and abundance of plants on the floodplain; while periods of extreme low flow purge invasive, introduced species from aquatic and riparian communities (The Nature Conservancy 2015). In addition to identifying trends that can impact species composition along the river, I also wanted to see if overall river flow validated observations in the soil. The Nature Conservancy recommends using at least 10 years of river flow data for any analysis but a longer time period was examined because pin oaks do not reach acorn producing age until age 15-20 (Burns et al. 1990).

2.3d Regression

Multiple regression analysis was conducted to ascertain whether biotic and abiotic variables were impacting forest condition and if so, which variables and to what extent. Pin oak was the primary species of concern to USFWS, so the regression consisted of data relevant to pin oak. Only the plots with pin oak present in the overstory were included in the regression; this brought the sample size to 198 plots. Crown condition acted as the dependent variable in the regression since the overall focus of this study is bottomland health; crown condition of pin oak was averaged out for each plot in the sample. Independent variables included: K_{sat}, soil moisture derived from redox features, total basal area (summed overstory & midstory basal area), and plot centroid distance from the Deep Fork River (in meters). K_{sat} for the surface horizon was averaged with K_{sat} of the most restricting horizon below the surface.

2.3e Direct Gradient Analysis

"Direct Gradient Analysis" (DGA) was conducted to evaluate multiple environmental variables simultaneously as they influence species composition. With DGA not only are species analyzed and compared between each other simultaneously but plots, in terms of species composition, are compared as well along multiple environmental gradients which is then be expressed in two-dimensional space (Smilauer et al. 2014). Basically multiple dimensions were simultaneously analyzed, compared, and condensed. Within DGA multiple techniques were available depending on the distribution of species. Final choice of technique depended on whether to assume that the relationship between species and the environment was linear or unimodal; I choose unimodal distribution because this form of distribution is often seen in nature where a specific range of environmental gradients presents ideal conditions for species (Pausas et al. 2007). This leads to using Canonical Correspondence Analysis (CCA) which is able to indicate patterns of species composition through analysis of various combinations of environmental variables (Smilauer et al. 2014). For my examination, species composition was comprised of species observed in the overstory, and to express species abundance I used basal area of each measured stem; basal area was preferred over stem frequency because basal area gave an absolute measure of vegetation abundance (Allen et al. 2001). For the explanatory variables I used the texture and soil moisture of each soil horizon, as well as plot's distance from the Deep Fork River leading to a total of 9 explanatory variables.

CHAPTER III

RESULTS

3.1 Vegetation:

3.1a Overstory

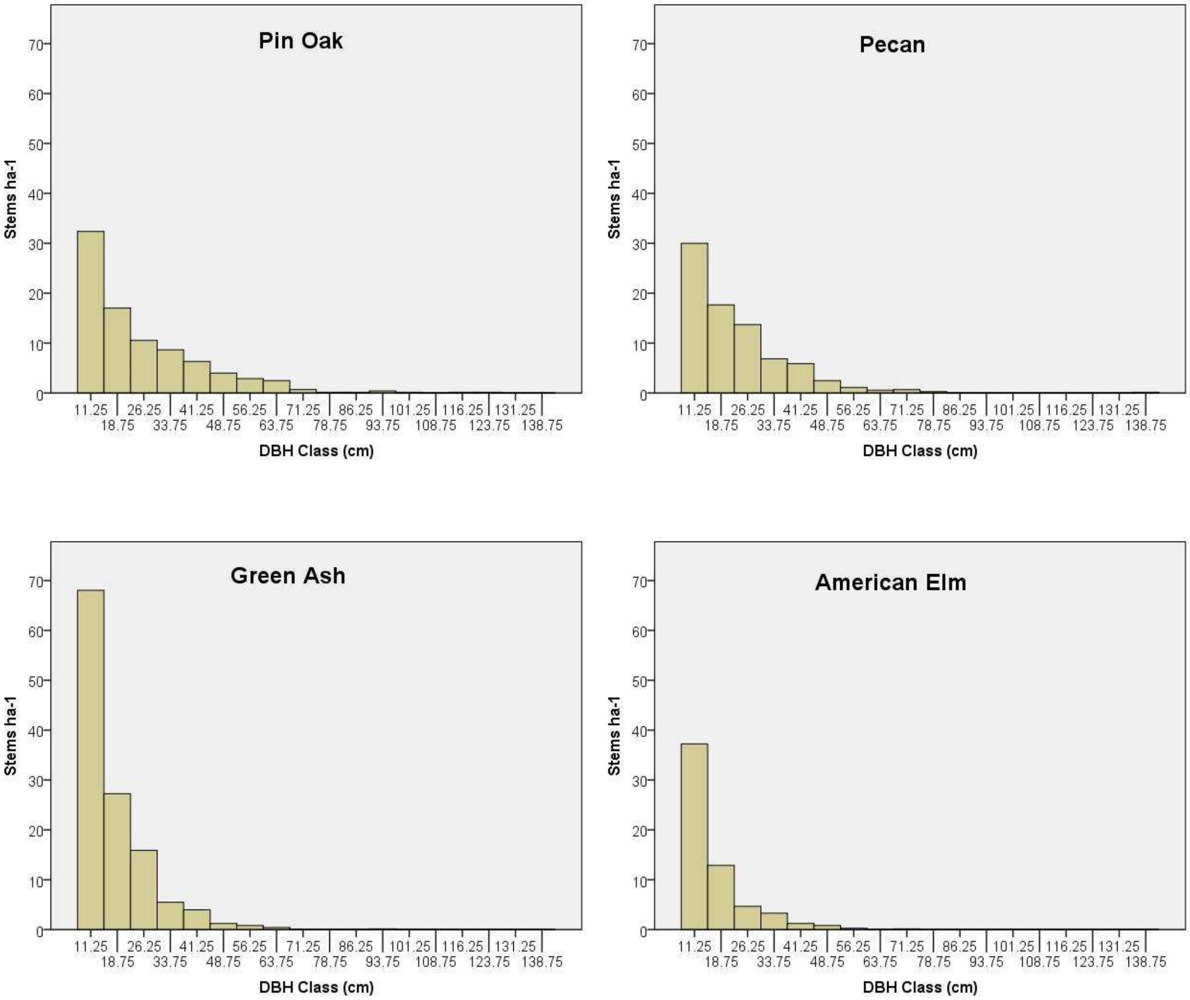
Mean basal area was calculated at 26.2 $m^2 ha^{-1}$, and 5 species alone contributed ≈65% of total basal area: pin oak (*Quercus palustris*), pecan (*Carya illinoensis*), green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), and sugarberry (*Celtis laevigata*). Pin oak had the highest basal area by a considerable margin. In fact, ≈26% of the overstory basal area alone was contributed by pin oak (Table 3). These same five species had the highest density in the overstory, with green ash and pin oak being the top species. Overstory density was determined at 600 stems ha^{-1}. The plots of stem density by DBH class showed a consistent pattern of large numbers of small trees with sharply decreasing numbers in the larger classes (Figure 3).

Table 3: Basal area and density with standard deviation of trees in overstory, midstory, and understory in DFNWR

Species	Overstory			Sapling density (stems ha^{-1})	Seedling density (seedlings ha^{-1})
	Basal area (m^{2}ha^{-1})	Mortality (%)	Density (stems ha^{-1})		
pin oak	6.32 ± 12.2	10.0	85 ± 132.5	162 ± 844.5	872 ± 2,165.5
pecan	4.39 ± 9.50	14.3	79 ± 134.5	125 ± 738.0	375 ± 842.8
green ash	3.78 ± 7.89	8.6	122 ± 257.3	395 ± 1,285.9	2,425 ± 2,478.3
American elm	1.63 ± 4.51	10.4	59 ± 94.0	167 ± 291.5	2,044 ± 2,235.1
sugarberry	0.926 ± 3.60	4.3	40 ± 86.4	97 ± 305.6	1,851 ± 2,238.8
deciduous holly	.0207 ± 1.07	9.1	3.0 ± 29.1	624 ± 1,478.9	1,615 ± 1,870.4

Measurements from the survey showed overwhelmingly that the majority of overstory species in the DFNWR were in excellent condition. Major species had at least 60% of stems classified as crown condition (CC) 1 or essentially in perfect health (Figure 4); pin oak, American elm, and sugarberry had >60% of stems assessed as CC 1. And all key species showed ≈80% of overstory stems at no worse than CC 2. Remaining species in the DFNWR displayed similar trends in overstory condition, 60% of stems classified as CC 1 and nearly 80% of stems no worse than CC 2.

Of the stems measured in the overstory, only 11.7% were dead. Some species were struggling in the canopy. Species with >25% overstory mortality included: chittamwood (*Bumelia* *lanuginosa*), hawthorne (*Crataegus sp.*), honey locust (*Gleditsia triacanthos*), mexican plum (*Prunus mexicana*), plum sp. (*Prunus sp.*) and post oak (*Quercus stellata*). But many of these species were scarce with overstory density at 1 stem ha^{-1} or lower, with the exception of post oak with overstory density of 32 stems ha^{-1}.



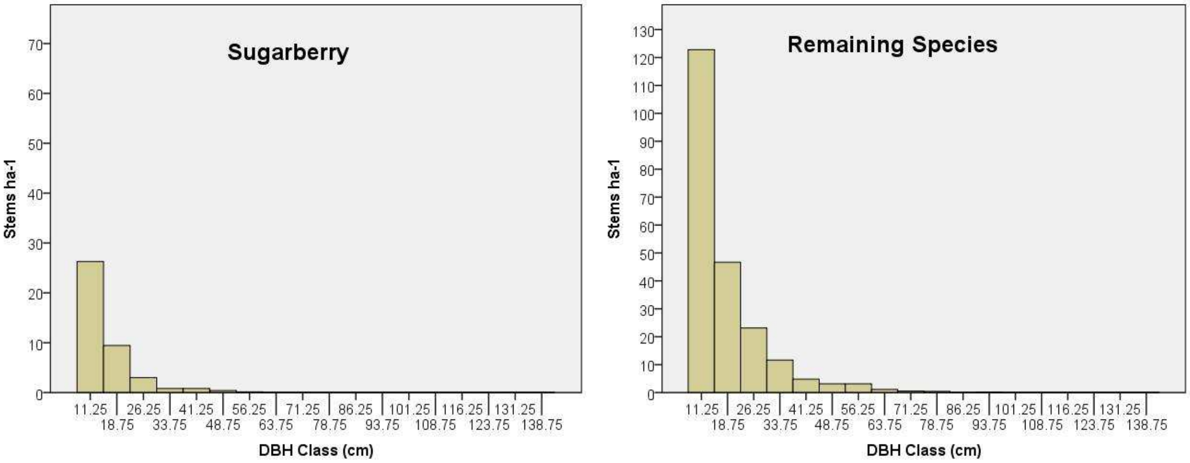
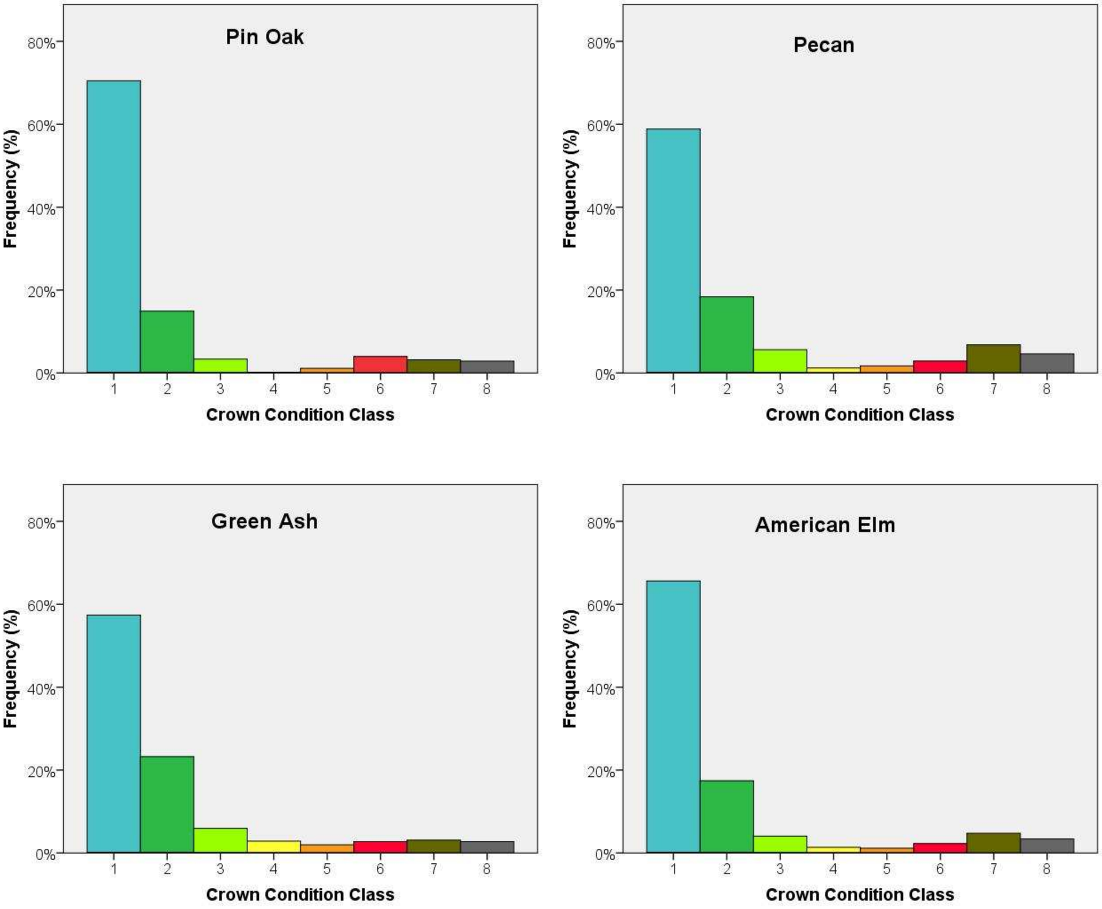


Figure 3: Frequency distribution of overstory trees in terms of trees ha^{-1} by diameter class for dominant species



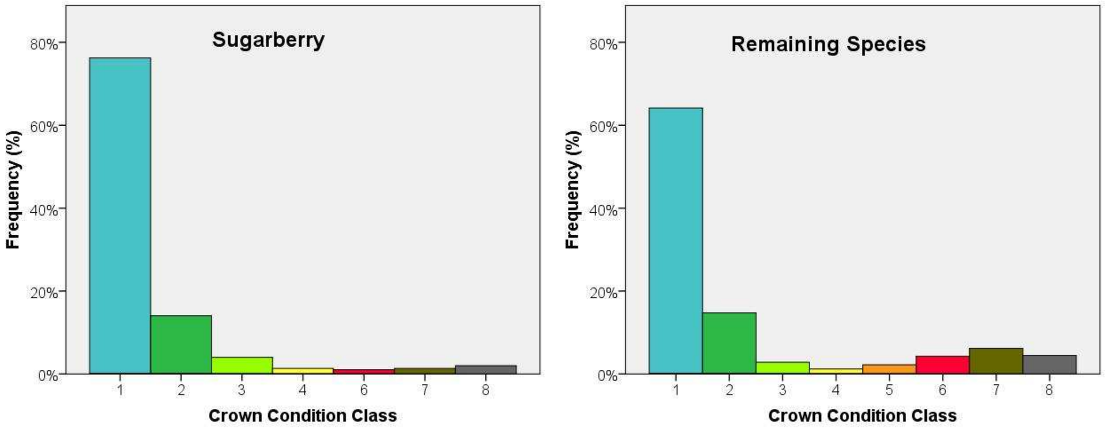


Figure 4: Distribution of crown condition for key species in DFNWR

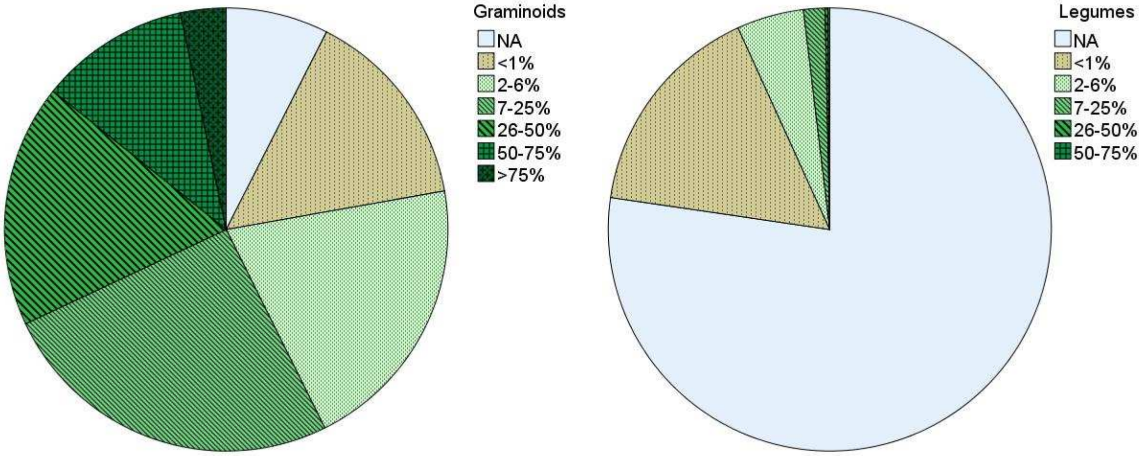
3.1b Midstory

Many of the same species that were abundant in the overstory were likewise abundant in the midstory. The principal differences being deciduous holly (*Ilex decidua*) which only contributed <0.1% of the overstory basal area was 21.5% of the midstory basal area followed closely by green ash at 19.2%. Elms (*Ulmus sp*.) collectively had the 3rd highest basal area. Pin oak was only 7.72% of the midstory basal area. Deciduous holly also had the highest density in the midstory. Green ash also had high density (Table 3). Additional abundant species observed in the midstory included: pecan and boxelder (*Acer negundo*). Measurements in the midstory yielded stem density at 2,365 stems ha^{-1}.

3.1c Understory

Overall the DFNWR showed abundant regeneration particularly with key species such as green ash, American elm, sugarberry, as well as deciduous holly. Pin oak showed adequate regeneration but was less prevalent in the understory compared to the midstory and overstory (Table 3); pin oak seedlings comprised only 6.42% of seedlings. Green ash was the most prolific species in the understory with a seedling density much higher than pin oak. Measurements showed total seedling density at 13,576 seedlings ha^{-1}.

For understory vegetation, graminoids and woody vegetation shared similar ground cover while there was more variation between legumes and forbs (Figure 5). Average cover class was the same for graminoids and woody vegetation, 7-25% ground cover. Legumes were not present in over 75% of subplots. Forbs were more prolific than legumes but average cover was 2-6%.



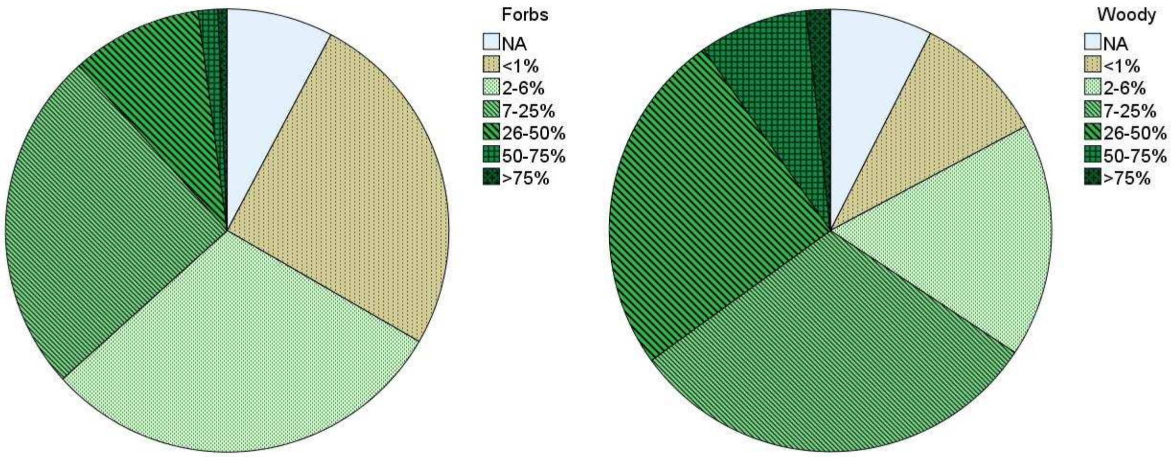
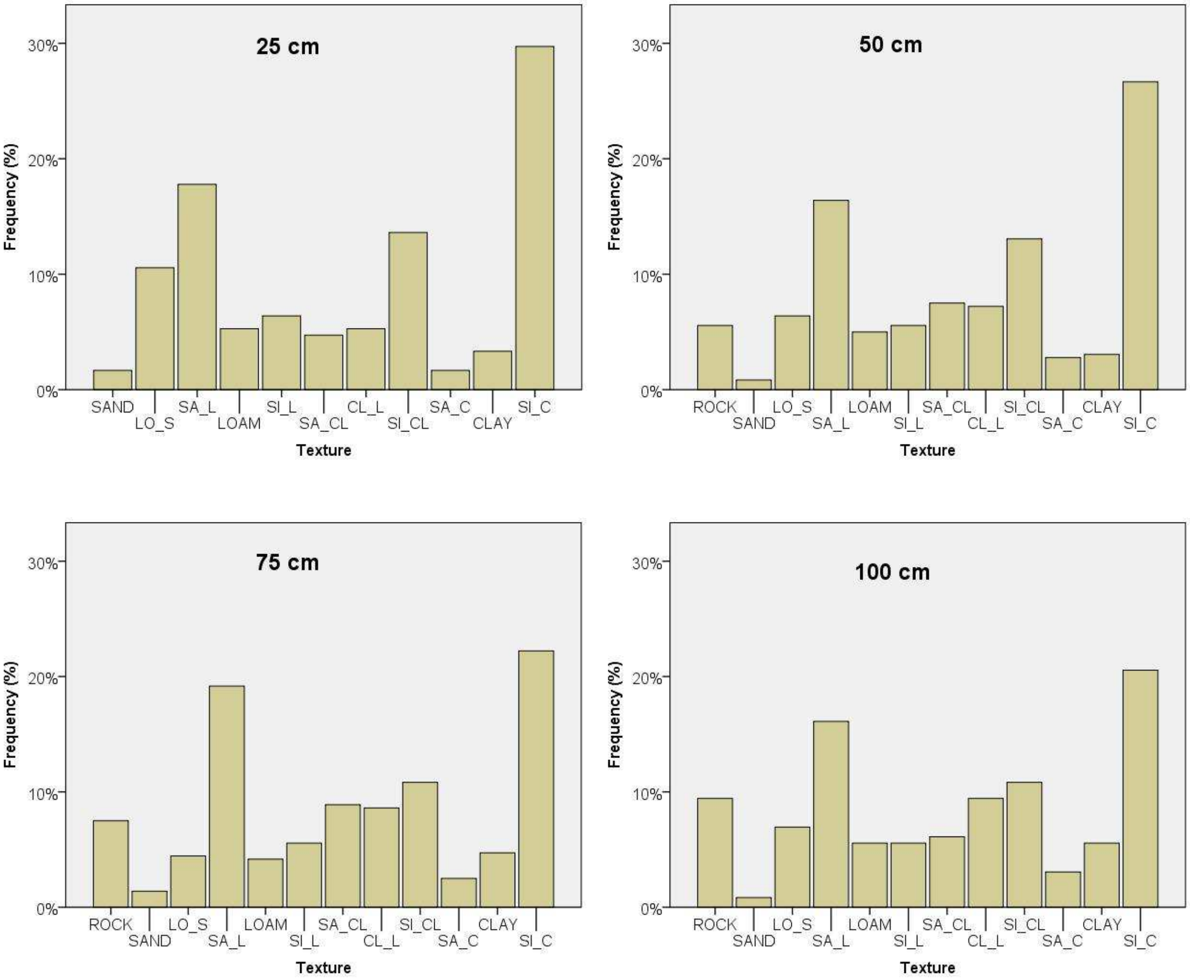


Figure 5: Distribution of cover class for ground vegetation

3.2 Soils:

3.2a Texture

Soil texture was similar at all depths, particularly with respect to loamy sand and silty clay soils. Silty clay soils represented 20-30% of all observations at each depth; loamy sand represented 15-20% of texture measurements at each depth (Figure 6). The "rock" soils specified the plots with shallower soil depth. The 50 cm depth recorded "rock" for 5% of observations, indicating a soil depth of approximately 25 cm. Rock was encountered at the 75 cm depth in approximately 7% of observations and at 100 cm in approximately 10% of observations. When converted to K_{sat}, the mean K_{sat} put the DFNWR soils in the Moderately-Low K_{sat} class where the relative rate of water infiltration in the soil was 0.1 to < 1.0 µm sec^{-1} or equivalently 0.036 to < 0.360 cm hr^{-1}. This indicated soils of the DFNWR drain slowly which was to be expected with clay rich soils.



Figures 6: Frequency (%) of soil textures at 25 cm, 50 cm, 75 cm, and 100 cm depths (Textures arranged left to right by decreasing grain size, Texture Code: LO_S=Loamy Sand, SA_L=Sandy Loam, SI_L=Silt Loam, SA_CL=Sandy Clay Loam, CL_L=Clay Loam, SI_CL=Silty Clay Loam, SA_C=Sandy Clay, SI_C=Silty Clay)

3.2b Hydromorphic Indicators

The soil moisture scale generated using depletion chroma and abundance for each plot showed the mean redoximorphic moisture at 11.44 with median redoximorphic moisture being 13, indicating that the soil was moderately saturated (Figure 7). Approximately 14% of plots had no depletions or hydromorphic indicators. The overall distribution of soil moisture scores in Figure 7 was bimodal, with peaks at 0 and 13.

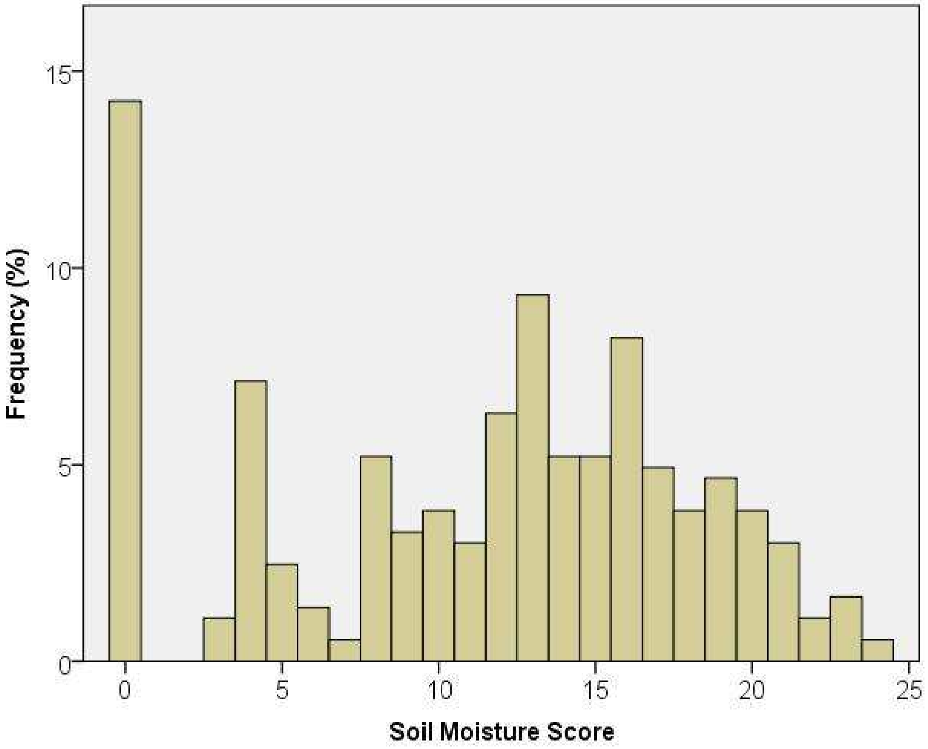


Figure 7: Frequency (%) of hydromorphic features derived from depletion observations (17-24=heavily saturated, 9-16=moderately saturated, and 0-8=unsaturated)

3.3 Environmental Flow Components:

Examination of EFC data showed there were very few periods of extreme low flow (Appendix 3). Small floods were common but at irregular intervals with infrequent large floods. There were fairly frequent high flow pulses between flood years. The 2006 “drought” year had periods of extreme low flow but the extreme low flows were not continuous and were relatively brief in duration (approximately 1-2 months). The longest period of extreme low flow in the 2000s was in June to November 2011. There were other long periods of extreme low flow that followed intermittently from 07/2012 to 02/2013. Regardless, these extreme low events were few and often brief. This supported the observations of the redoximorphic features of the soil, that DFNWR soils were moderately saturated.

3.4 Multiple Regressions:

Multiple regression analyses found no significant (p=0.05) relationship existed between pin oak crown condition and the environmental variables. Quadratic and cubic regressions were specifically applied; and when neither showed significant results, the dependent and independent variables were transformed using log-based transformations and entered into the models which still resulted in non-significant regression models.

3.5 Direct Gradient Analysis:

Explanatory variables in the CCA explained 20.8% of the variation observed in the species composition across the DFNWR. In the ordination diagram the first axis (p=.001), which accounted for 7.16% of the cumulative explained variation showed clear separation between bottomland species and more upland species such as black hickory (*Carya texana*, CATE) and post oak (QUST) (Figure 8). The second axis, which together with the first accounted for 9.84% of the explained variation, showed another separation between more riparian species such as river birch (*Betula nigra*, BENI) and sycamore (*Platanus occidentalis*, PLOC) and the remaining bottomland species. A Two Group-Variance Partitioning Analysis was conducted following

CCA, using soil texture in one group and the remaining explanatory variables in the other group. Results showed that of the variation accounted for by the explanatory variables, 67% is accounted for by the soil texture.

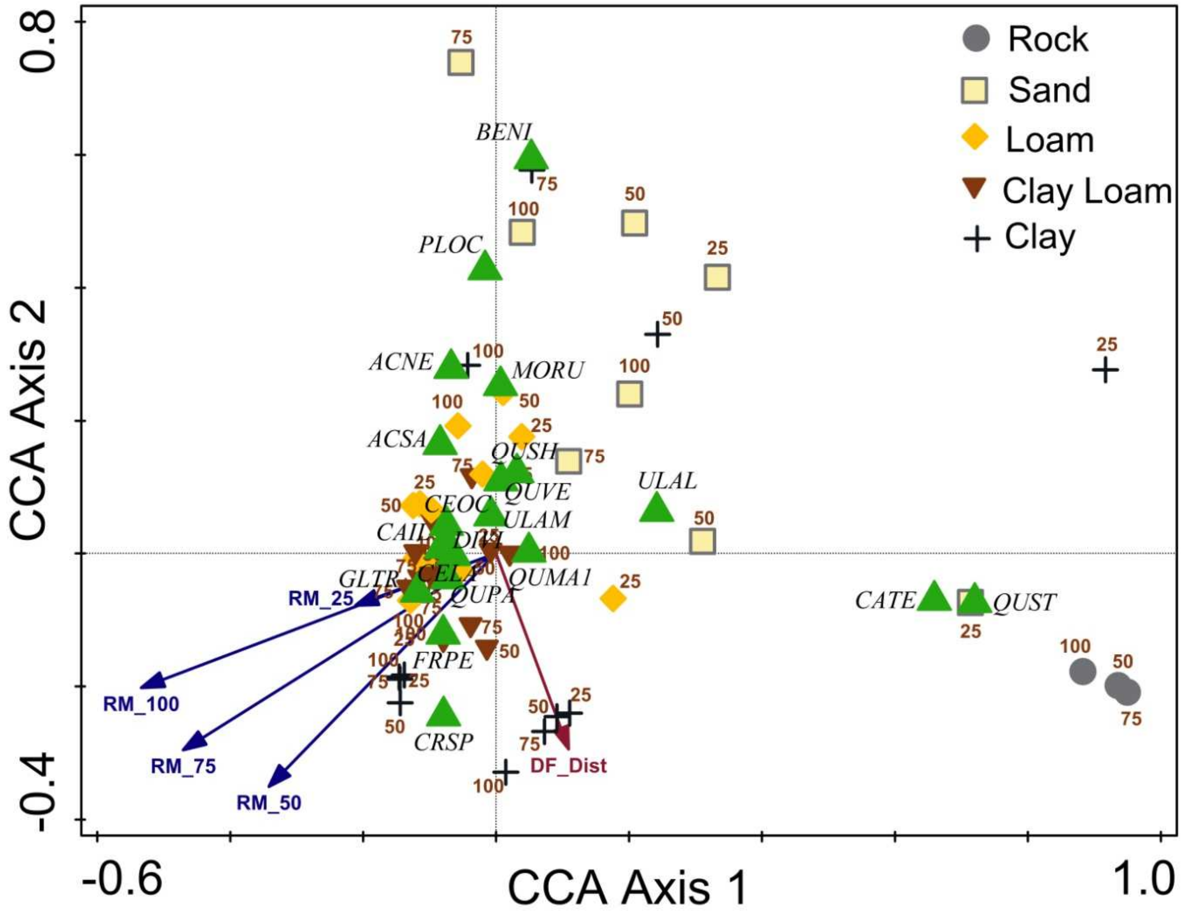


Figure 8: Ordination diagram from CCA[1]

(Symbols: Green triangles=species, blue & red arrows=environmental gradients for soil moisture at all depths and plot distance, other symbols represent soil textures and are labeled by soil depth)

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[1] For species identification see Appendix 1

CHAPTER IV

DISCUSSION

The most important finding of this study was there was no evidence of forest decline in the DFNWR bottomland hardwoods. Mortality was limited in the overstory and the principal species of concern, pin oak, had only 10% overstory mortality with abundant regeneration in the midstory and understory. In addition, there was no evidence of a relationship among environmental variables and overstory mortality. It was worth noting that soil texture had a strong influence on species composition according to CCA.

4.1 Multiple Regressions:

The lack of significant relationships between overstory health and the environmental variables does not indicate that the variables have no impact on the overstory at all. Utilization of resources and competition between individual trees are all key factors in tree population dynamics, particularly in terms of mortality (Waring 1987; Peet et al. 1987). However, the most likely reasons for the lack of success in the regression to explain forest decline is due to the low level of overstory mortality and narrow range of values in certain variables. Approximately 70% of all pin oak stems were in the highest crown condition class and only 10% of the stems were dead. Overstory crown condition had a range of 1-8 while dependent variables such K_{sat} had a range of only 0-4 while plot distance had a maximum value of 3,465 meters. Although there was some variability in the degrees of flooding, it was apparently not enough to generate high levels of mortality. As an example, elevation was initially considered as a potential independent variable, but lidar imagery of the floodplain along the Deep Fork River showed topography as relatively even.

4.2 Direct Gradient Analysis:

DCA showed a recurring association of species to soils. Black hickory and post oak lined up with "rock"/thinner soils in ordination space. The majority of the bottomland species shared a similar distribution with more clay rich soils in ordination space. Soil is the foundation of every ecosystem, the physio-chemical nature of soil impacts: root growth, water retention, cation-exchange capacity (soil nutrition), pH, aeration, nitrogen cycle, etc. all which can heavily influence plant composition (Raven et al. 2005; Schaetzl et al. 2005).

Soil moisture derived from redoximorphic features and plot distance from the river had little impact on species composition. No species or species group aligned on those gradients. One possibility is that using redoximorphic features in the soil may not have been an accurate way to generalize soil moisture, which could explain why river birch was located at the opposite end of the ordination diagram in respect to soil moisture. River birch is a riparian species that would be expected at the extreme wet end of any moisture gradient. Distance from the river showed no clear impact on the composition of species but did seem to impact the distribution of certain soils. Clay soils at all four horizons in the ordination diagram were the farthest from the river.

This finding appears to be consistent with stream flow velocity which would be lower and carry only small particles far from the main channel during floods (Schaetzl et al. 2005).

4.3 DFNWR Forest Health:

Results did not show any evidence of forest decline, in contrast to anecdotal accounts of decline from the USFWS. The survey showed abundant species diversity with a total of 51 tree species recorded which include several bottomland species: pin oak, sugarberry, American elm, green ash, and sycamore (Allen et al. 2001). According to the Society of American Foresters (SAF) there are 16 forest cover types associated with bottomland hardwoods (Allen et al. 2001), and based on species abundance and geographical location the DFNWR forests most closely resemble SAF Forest Cover 93 (sugarberry-American elm-green ash). Though oddly enough pin oak is not listed as an associate species, and according to the Silvics of North America pin oak is only associated with pin oak-sweetgum forests though not a single sweetgum (*Liquidambar styraciflua*) was observed in the DFNWR (Allen et al. 2001; Burns et al. 1990).

In addition the Deep Fork bottomlands showed excellent health and productivity and high quality habitat for wildlife. Observations showed most DFNWR species had excellent crown health with >60% of stems in CC 1 (Figure 4). Ideally basal area for the overstory of mature bottomland hardwoods should be roughly 25 m^2ha^{-1} (Rudis 1995); I found mean total basal area was 26.2 m^2ha^{-1}. There was also clear indication of regeneration with total seedling density estimated at 13,576 seedlings ha^{-1}, especially among key bottomland species (Table 3). Of the 51 species recorded 11 showed no signs of seedling regeneration, all of which were scarce in DFNWR.

Species without seedling regeneration included: river birch, button bush (*Cephalanthus occidentalis*), white ash (*Fraxinus americana*), kentucky coffeetree (*Gymnocladus dioicus*), osage orange (*Maclura pomifera*), cottonwood (*Populus deltoides*), bradford pear (*Pyrus calleryana*), blackjack oak (*Quercus marilandica*), carolina buckthorn (*Rhamnus caroliniana*), soapberry (*Sapindus drummondii*), and sparkleberry (*Vaccinium arboretum*). Several species in the DFNWR bottomland hardwoods act as critical food sources (Table 4) for the 149 species of birds known to reside at DFNWR (U.S. Fish and Wildlife Service 2014b).

Overall mortality was 11.7% which included trees in CC 6-8. It seems reasonable to assume trees remained standing for ten years to get to CC 8. To accumulate the mortality in CC 6-8 over a ten-year period implies an annual morality rate of about 1% which seems normal for an uneven-aged stand. Gap percent can be used as a proxy for mortality to compare to results of the current study. In healthy eastern deciduous forests the gap percent ranges from 9.5% (Runkle 1982) to 4.4% (Barden 1989) to 2.5-2.8% (Cho et al. 1991). Annual rate of gap production would be much smaller, because several years would be required to fill gaps. The majority of species showed very little mortality. Six species had mortality >25%, 5 of which are scarce in the DFNWR. It appears mortality in the bottomland hardwoods of the DFNWR was not excessive.

A potential threat to the dominance of pin oak is the abundance of deciduous holly in the midstory and understory where it ranked 1st and 2nd respectively in density. While it was rare for deciduous holly to reach the canopy stage, it is a prolific woody invader in the reforestation of abandoned fields and can suppress regeneration of important overstory species such as pin oak (USDA Forest Service 2015a; Lockhart et al. 2004). Deciduous holly can be treated with a variety of techniques such as stem injections with herbicide and shearing (USDA Forest Service 2015a). Although pin oak dominated the overstory and had a size distribution to support normal replacement of mortality of mature trees, there was some reason for concern in that green ash had more than twice the density of pin oak in the midstory, and three important canopy species (green ash, American elm, and sugarberry) had 2-3 times the seedling density as pin oak.

Table 4: Suitability of overstory/understory species as food and habitat for wildlife (Allen et al. 2001); "NA" means that insufficient data was available to determine suitability

Tree	Suitability to wildlife		
	Waterfowl	Deer/Turkey	Neotropical Migrants
green ash	low	low	NA
boxelder	low	high	NA
elm	medium	medium	medium
hackberry	low	low/medium	high
red mulberry	low	medium/high	high
pin oak	high	high	NA
persimmon	low	high	NA
sugarberry	low	low/medium	high

4.4 Pin Oak Management:

The pin oaks of the DFNWR were in excellent health with adequate regeneration and were present in 54% of the plots across the refuge. This makes restoration, reforestation, and establishing regeneration unnecessary. To optimize the health and abundance of pin oak will only require management of existing stands (Lockhart et al. 2004; Allen et al. 2001) or more specifically ecological enhancement. A variety of techniques are available which are narrowed down by the fact that DBH class distributions (Figure 3) indicated uneven aged stands in the DFNWR. This limits silviculture treatments to single-tree selection and group selection (Allen et al. 2001; Hicks et al. 2004). With single-tree selection harvesting, individual mature trees are selectively removed while group selection aims to create larger openings. Given that pin oak demonstrates high shade intolerance (Lockhart et al. 2004; Allen et al. 2001; Burns et al. 1990) it would be advantageous to create sufficient openings that give oak the best possible chance for growth and development. Because there was a deficiency of pin oak in the midstory and understory, it is especially important to create openings that provide enough light for successful regeneration of pin oak.

For successful enhancement, the two principal challenges that will have to be addressed are: natural woody invasion by shade tolerant species, and domination of the midstory and understory by deciduous holly. From literature review there was constant mention that any form of thinning in bottomland hardwoods tends to favor shade-tolerant species (Allen et al. 2001; Hicks et al. 2004). One study of the reforestation of an abandoned field along the edge of bottomland hardwoods showed that elms, ash, and sugarberry accounted for 85.1% of all naturally invading saplings (McCoy et al. 2002). Deciduous holly was a prolific midstory and understory species; it often colonizes an area in the aftermath of fire with the potential of suppressing timber regeneration (USDA Forest service 2015a). In a study to see if thinning coupled with fertilizer treatments could aid in developing bottomland regeneration found that deciduous holly comprised a sizeable share of seedlings and saplings in the largest size classes, further indicating that without intervention deciduous holly would be detrimental to oak seedling establishment (Lockhart et al. 2004).

For practical application, group selection should be done in pin oak stands where there is clear indication of regeneration. The gaps created should be no greater than 0.1 hectare and the trees to be cleared (excluding oak) should only consist of trees that are located in dominant and co-dominant positions in the canopy to maximize light availability (Hicks et al. 2004; Lockhart et al. 2004). For timing, clearing should be done in the dormant season to limit the impact of the disturbance; it would also be ideal to control any residual stems prior to the next growing season (Clatterbuck et al. 1993). If deciduous holly is present then the suggested method is slashing; while this may not be as effective as herbicide treatments, slashing is preferred because not only will it limit the return of deciduous holly, the resulting sprouts can provide browse for deer which in turn further aids in limiting the establishment of deciduous holly (USDA Forest Service 2015a). The cuttings should be left on site to create a litter layer to help in oak establishment (USDA Forest Service 2015b). The site should be revisited 3 years after treatment to evaluate oak return and determine if additional thinning is required (Clatterbuck et al. 1993). The number of gaps to be generated will be determined by USFWS staff depending on resources available as well as the ecological needs of the refuge.

Given the severity of the recent epidemic of the emerald ash borer (EAB) (Gandhi and Herms 2010, Kovacs et al. 2010) and the prominence of green ash in the DFNWR it is necessary to mention the possible consequences of EAB for management efforts of USFWS and respective state agencies. In terms of immediate impacts to the bottomland hardwoods, the green ash would likely be replaced by sugarberry (Hicks et al. 2004) which was one of the prominent bottomland species; but given that other species such as pecan and American elm were more prominent in the overstory and understory (Table 2) it would take time for sugarberry to fill the ecological niche of green ash. But it is the long term implications that are more worrisome; the probability and severity of change due to EAB is largely unknown (Telander et al. 2015). It is however widely considered that changes to forest hydrology would be affected; one study found that black ash (*Fraxinus nigra*) in wetland forests have variable impacts on evapotranspiration depending on soil moisture conditions and the loss of ash would have the greatest impact on wetter sites, which could alter species composition even to the point of potential conversion to marsh-like habitat (Telander et al. 2015). As previously stated, the probability and severity of changes are unknown, to make any assertion to the impact of EAB in the DFNWR would walk the fine line between responsible management and the myth of "The Carbon Copy" or that species composition is predictable (Hilderbrand et al. 2005). This is not meant to induce alarm but only to further emphasize the need for continued monitoring and adaptive management to the continuing changes and needs of the DFNWR.

CHAPTER V

CONCLUSION

The findings of this research have provided knowledge to support the goals of the USFWS Comprehensive Conservation Plan for DFNWR:

- Protection, restoration, and maintenance of the bottomland hardwood forest community,
- Development of a database of pertinent scientific information regarding Refuge habitats and wildlife.

The diverse blend of bottomland species found in the DFNWR was characteristic of the sugarberry-American elm-green ash forest type (SAF 93) (Allen et al. 2001). Pin oak was the dominant species which had excellent health and appeared to be regenerating. Mortality was limited in the canopy and only a few, mostly scarce, species were experiencing high levels of mortality. With the absence of any noticeable decline, no particular factors in the environment could be determined in connection with forest degradation. The CCA revealed that among all environmental variables, soil texture, had the most important impact on species composition in the bottomlands. These findings should contribute to the basis for long-term, adaptive, and effective management based on the ecological characteristics of the DFNWR which satisfy the goals of USFWS and ODWC.

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APPENDICES

APPENDIX 1: DFNWR overstory basal area, mortality and density, sapling density, and regeneration density. Mean ± standard deviation

Common Name	Scientific Name	Symbol	Overstory			Sapling Density (stems ha^{-1})	Regeneration Density (seedlings ha^{-1})
			Basal Area (m^{2}ha^{-1})	Mortality (%)	Density (stems ha^{-1})		
boxelder	*Acer negundo*	ACNE	0.264 ± 3.49	3.8	11 ± 42.9	104 ± 587.1	586 ± 1,842.6
silver maple	*Acer saccharinum*	ACSA	0.454 ± 13.4	10.6	6 ± 30.0	11 ± 137.5	41 ± 412.3
river birch	*Betula nigra*	BENI	0.659 ± 12.5	21.4	11 ± 57.7	<1 ± 13.9	0
chittamwood	*Bumelia lanuginosa*	BULA	.0111 ± 1.79	25.0	<1 ± 6.4	2 ± 41.6	68 ± 448.7
hornbeam	*Carpinus*	CACA	0	0	0	<1 ± 13.9	7 ± 130.9

	caroliniana						
pignut hickory	*Carya glabra*	CAGL	.0699 ± 2.55	0	2 ± 17.7	11 ± 156.5	61 ± 567.8
pecan	*Carya illinoensis*	CAIL	4.39 ± 9.50	14.3	79 ± 134.5	125 ± 738.0	375 ± 842.8
black hickory	*Carya texana*	CATE	0.302 ± 4.73	13.4	11 ± 57.1	24 ± 178.8	211 ± 1,034.8
redbud	*Cercis canadensis*	CECA	.00924 ± .701	20.0	<1 ± 6.9	16 ± 124.3	82 ± 483.3
sugarberry	*Celtis laevigata*	CELA	0.926 ± 3.60	4.3	40 ± 86.4	97 ± 305.6	1851 ± 2,238.8
hackberry	*Celtis occidentalis*	CEOC	0.111 ± 1.95	8.1	5 ± 26.5	15 ± 92.6	409 ± 1,448.1

button bush	*Cephalanthus occidentalis*	CEOC1	.00673	0	<1 ± 5.2	0	0
dogwood	*Cornus florida*	COFL	.00179 ± .065	0	<1 ± 3.7	96 ± 455.0	355 ± 936.5
hawthorne	*Crataegus sp.*	CRSP	0.130 ± 1.67	28.7	15 ± 80.3	38 ± 248.6	54 ± 487.2
persimmon	*Diospyros virginiana*	DIVI	0.262 ± 1.72	7.0	17 ± 57.9	44 ± 240.3	266 ± 877.4
swamp-privet	*Forestiera acuminate*	FOAC	.00207 ± .016	0	<1 ± 3.7	37 ± 225.3	443 ± 1,011.0
white ash	*Fraxinus americana*	FRAM	0	0	0	2 ± 41.6	0
green ash	*Fraxinus pennsylvanica*	FRPE	3.78 ± 7.89	8.6	122 ± 257.3	395 ± 1,285.9	2425 ± 2,478.3
honey locust	*Gleditsia triacanthos*	GLTR	0.125 ± 1.70	29.3	8 ± 42.2	15 ± 143.2	109 ± 575.6
kentucky coffeetree	*Gymnocladus dioicus*	GYDI	.0266 ± 4.05	0	<1 ± 6.4	3 ± 27.6	0
deciduous holly	*Ilex decidua*	ILDE	.0207 ± 1.07	9.1	3 ± 29.1	624 ± 1,478.9	1615 ± 1,870.4
black walnut	*Juglans nigra*	JUNI	.0745 ± 3.25	0	2 ± 15.3	8 ± 64.4	14 ± 184.8
eastern red cedar	*Juniperus virginiana*	JUVI	.00987 ± .606	0	<1 ± 5.2	5 ± 45.7	7 ± 130.9
osage orange	*Maclura pomifera*	MAPO	.0298 ± 2.48	8.3	2 ± 16.0	3 ± 33.9	0

red mulberry	*Morus rubra*	MORU	0.213 ± 1.94	2.9	9 ± 29.8	3 ± 30.8	7 ± 130.9
black gum	*Nyssa sylvatica*	NYSY	0	0	0	10 ± 109.5	48 ± 505.2
sycamore	*Platanus occidentalis*	PLOC	0.481 ± 10.6	12.5	5 ± 30.1	2 ± 30.9	7 ± 130.9
cottonwood	*Populus deltoides*	PODE	0.336 ± 10.0	23.1	2 ± 13.4	0	0
mexican plum	*Prunus Mexicana*	PRME	.00294 ± .081	33.3	<1 ± 5.8	<1 ± 13.9	54 ± 665.9
wild cherry	*Prunus serotina*	PRSE	.00370 ± .158	0	<1 ± 4.5	13 ± 146.8	68 ± 485.5
plum	*Prunus sp.*	PRSP	.00927 ± .741	62.5	1 ± 14.2	2 ± 30.9	48 ± 276.7
bradford pear	*Pyrus calleryana*	PYCA	.000682	0	<1 ± 2.6	0	0
bur oak	*Quercus macrocarpa*	QUMA1	0.424 ± 4.82	16.9	9 ± 34.1	17 ± 110.2	184 ± 859.3
blackjack oak	*Quercus marilandica*	QUMA2	.0668 ± 3.82	7.7	2 ±9.9	1 ± 27.7	0
swamp chestnut	*Quercus michauxii*	QUMI	.00525	0	<1 ± 2.6	0	7 ± 130.9
chinqaupin oak	*Quercus muehlenbergii*	QUMU	.000665	0	<1 ± 2.6	1 ± 27.7	7 ± 130.9
water oak	*Quercus nigra*	QUNI	0	0	0	0	7 ±130.9
pin oak	*Quercus palustris*	QUPA	6.32 ± 12.2	10.0	85 ± 132.5	162 ± 844.5	872 ± 2,165.5
red oak	*Quercus rubra*	QURU	0.173 ± 6.58	15.0	3 ± 16.2	5 ± 60.3	61 ± 625.4
shumard oak	*Quercus*	QUSH	0.261 ± 6.77	4.2	6 ± 43.6	9 ± 68.7	34 ± 391.6

	shumardii						
post oak	*Quercus stellata*	QUST	1.31 ± 8.16	26.7	32 ± 121.6	21 ± 335.0	197 ± 969.1
black oak	*Quercus velutina*	QUVE	0.365 ± 7.08	20.0	5 ± 28.7	9 ± 75.2	95 ± 661.2
carolina buckthorn	*Rhamnus caroliniana*	RHCA	.00129	0	<1 ± 2.6	0	0
smooth sumac	*Rhus glabra*	RHGL	0	0	0	<1 ± 13.9	7 ± 130.9
black locust	*Robinia pseudoacacia*	ROPS	.0401 ± 2.04	0	2 ± 13.4	35 ± 600.4	7 ± 130.9
soapberry	*Sapindus drummondii*	SADR	.000788	0	<1 ± 2.6	0	0
black willow	*Salix nigra*	SANI	0.268 ± 8.89	14.6	6 ± 43.9	0	7 ± 130.9
winged elm	*Ulmus alata*	ULAL	0.522 ± 3.02	5.8	33 ± 84.2	171 ± 585.7	463 ± 1,643.6
American elm	*Ulmus americana*	ULAM	1.63 ± 4.51	10.4	59 ± 94.0	167 ± 291.5	2044 ± 2,235.1
sparkleberry	*Vaccinium arboreum*	VAAR	0	0	0	<1 ± 13.9	0
rusty blackhaw	*Viburnum rufidulum*	VIRU	0	0	0	1 ± 27.7	54 ± 410.7

APPENDIX 2: Distribution of biotic and abiotic measurements in Arcmap

Figure	**Measurements**	**Description**
1	Total basal area	The total BA was organized into classes using Scott's Rule[2] (class width = $3.5sn^{-1/3}$). For symbolism, plots are represented by circles and the size of the circle represents the class. Plots are also divided into different colors; with plots below the threshold of 25 $m^2\ ha^{-1}$ being orange, at threshold yellow, and plots exceeding the threshold are green (Burt el al. 2009).
2	K_{sat}	There were plots that were in between classes that were rounded up to the next nearest class. Distribution of classes in ArcMap was done using the Jenks Method (Burt el al. 2009). The lower the K_{sat} class, the less water that can move through the soil.
3	Soil moisture from redoximorphic features	Soil moisture scores range from 0-24 where 0-8 the soil is scarcely moist, 9-16 soil is moderately moist, and 17-24 the soil is severely damp. For symbolism, the plots are color coded depending on class/wetness; the darker the color, the wetter the soil.

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[2] s=standard deviation, n=number of cases

Figure 1

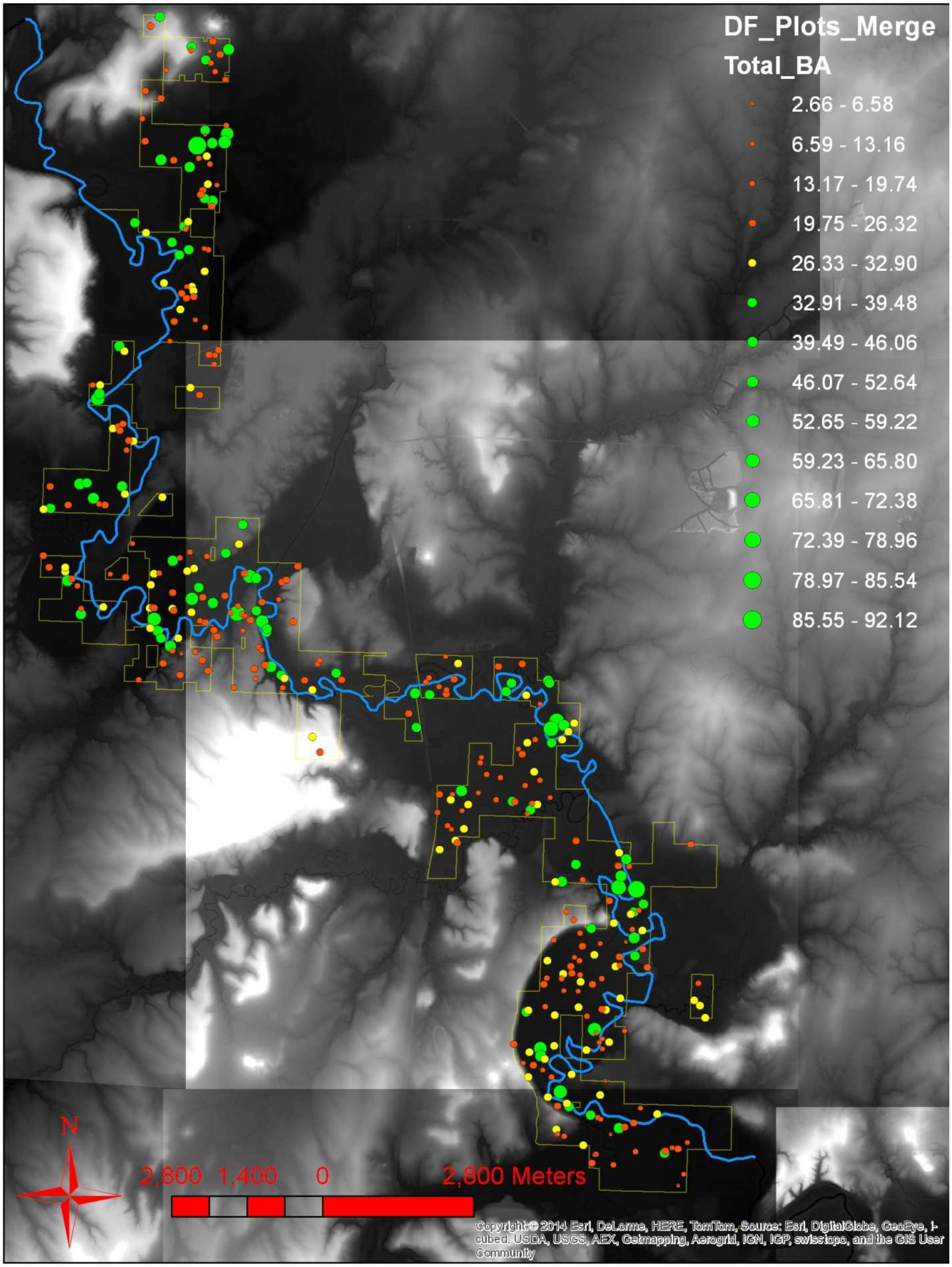

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Figure 2

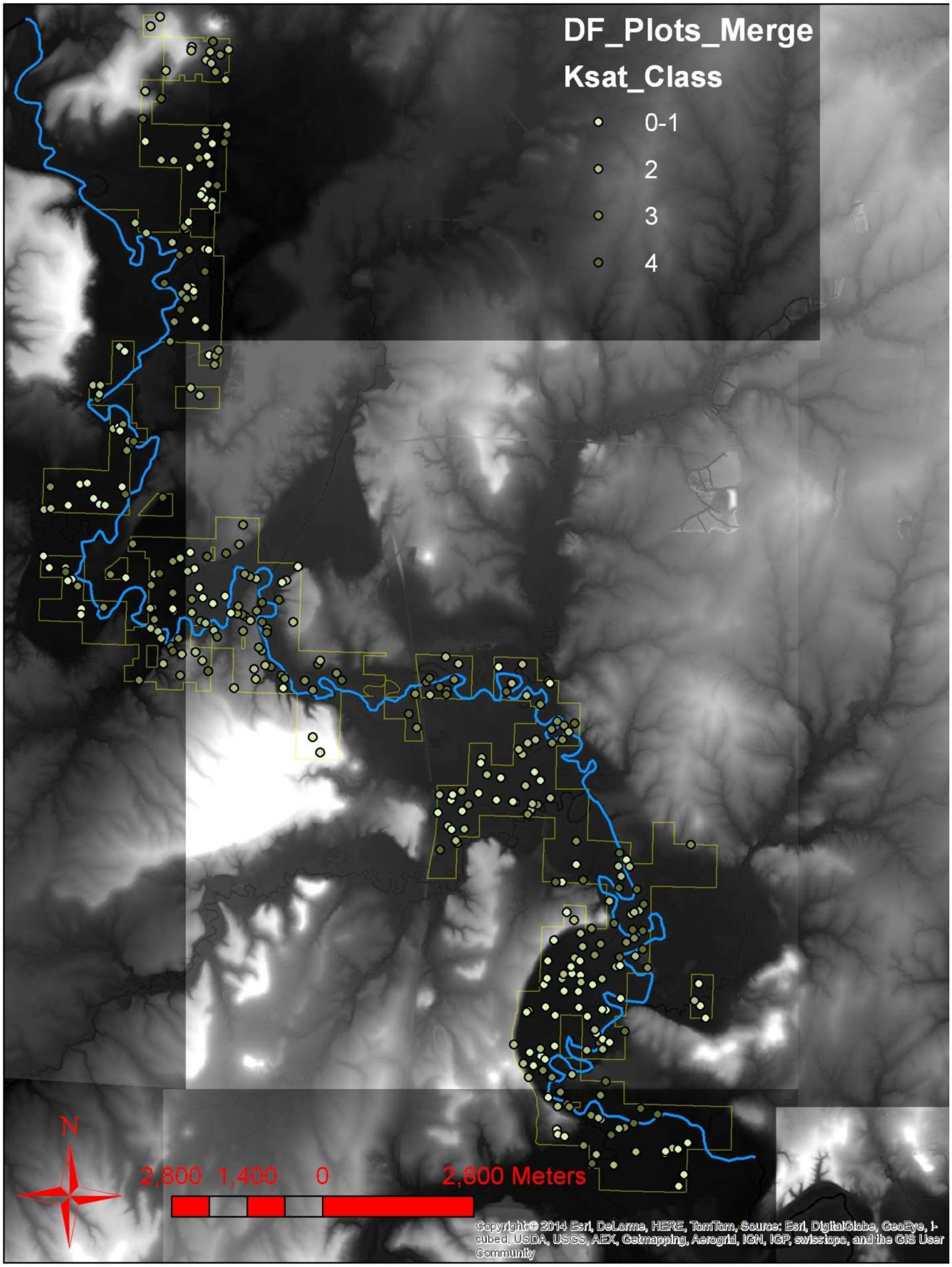
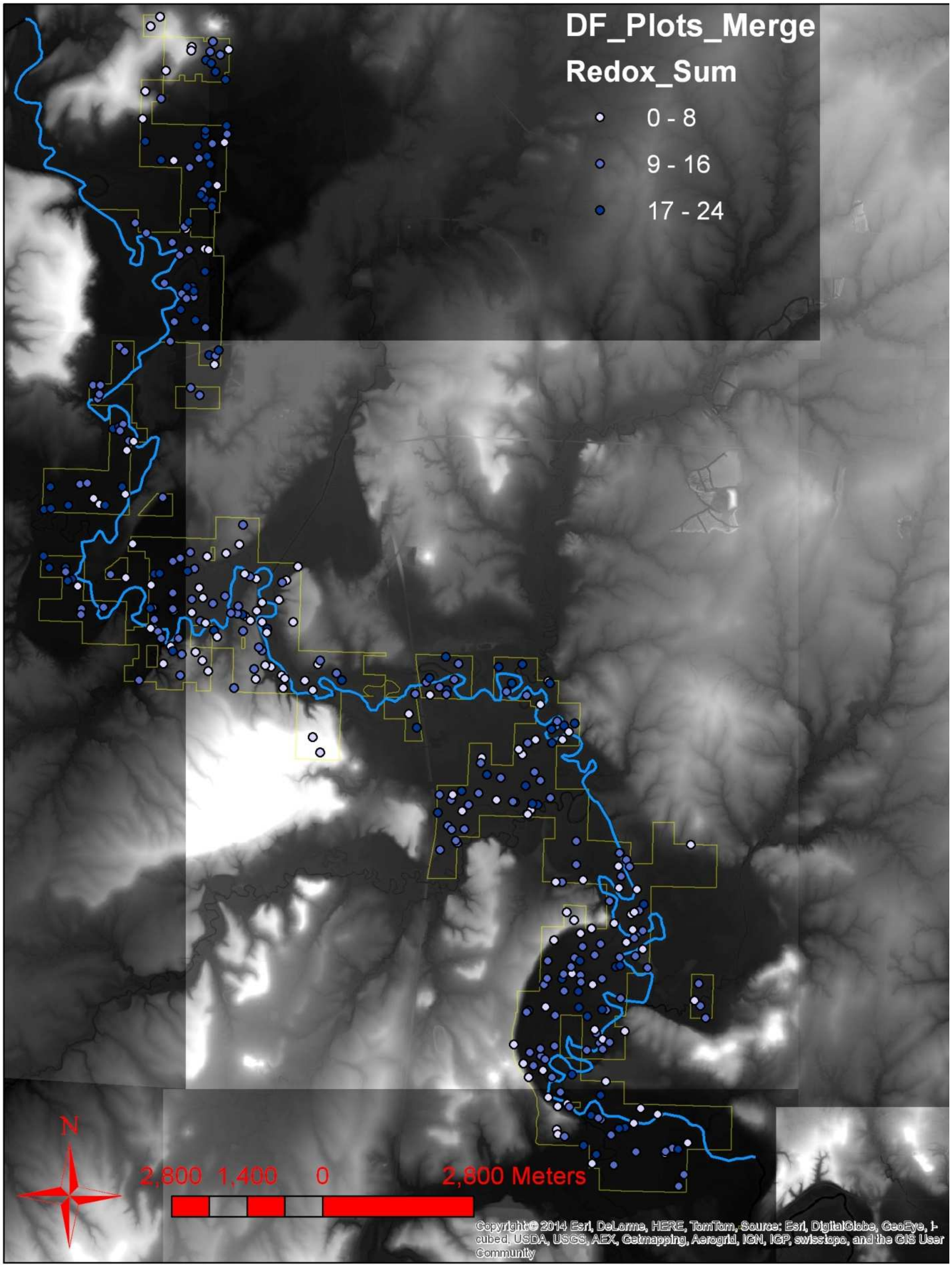

DF_Plots_Merge
Ksat_Class
● 0-1
● 2
● 3
● 4
N
2,800 1,400 0 2,800 Meters
Copyright:© 2014 Esri, DeLorme, HERE, TomTom, Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3


DF_Plots_Merge
Redox_Sum
0 - 8
9 - 16
17 - 24
N
2,800 1,400 0 2,800 Meters
Copyright:© 2014 Esri, DeLorme, HERE, TomTom, Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

APPENDIX 3: Environmental flow components of the Deep Fork River[3]

EFC	**Symbol**	**Ecological Influences**	**Criteria[4]**
Extreme Low Flows	Red	• Enable recruitment of certain floodplain species • Purge invasive, introduced species from aquatic and riparian communities	<10%
Low Flows	Green	• Normal moisture availability in the time between wet seasons	<50%
High Flow Pulses	Blue	• Shape physical character of river channel, including pools, riffles • Prevent riparian vegetation from encroaching into channel • Restore normal water quality conditions are prolonged low flows, flushing away waste products and pollutants	>75%
Small Floods	Bright Green	• Recharge floodplain water table • Maintain diversity in floodplain forest types through prolonged inundation (i.e. different plant species have different tolerances) • Control distribution and abundance or plants on floodplain • Deposit nutrients on floodplain	High flow with peak flow >2year return interval
Large Floods	Orange	• Create sites for recruitment of colonizing plants • Shape physical habitats of floodplain • Purge invasive, introduced species from aquatic and riparian communities • Disburse seeds and fruits of riparian plants • Provide plant seedlings with prolonged access to soil moisture	High flow with peak flow >10year return interval

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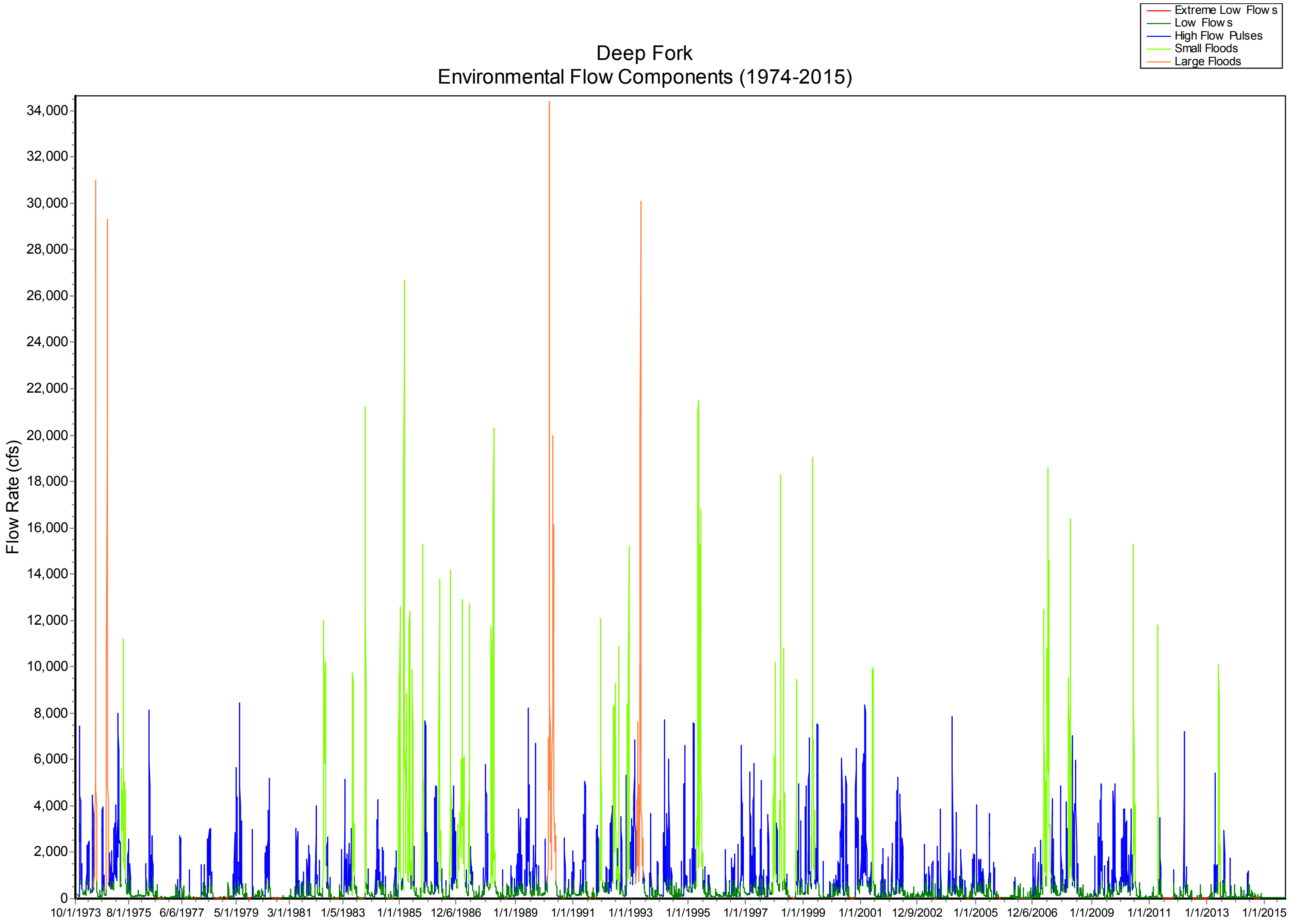
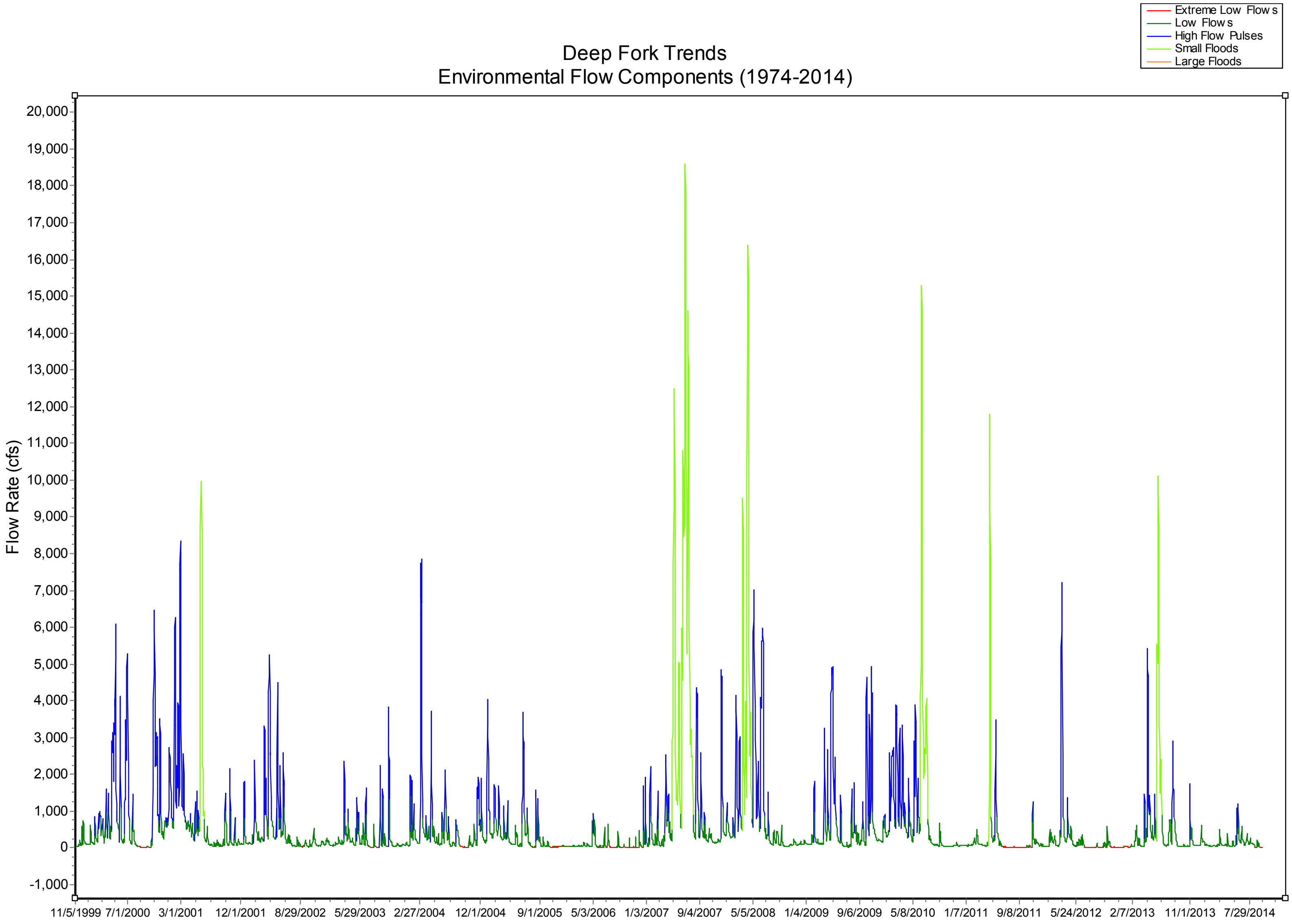
[3] EFC defined by The Nature Conservancy

[4] Percentile of Daily Flow for the period (1973-2014)

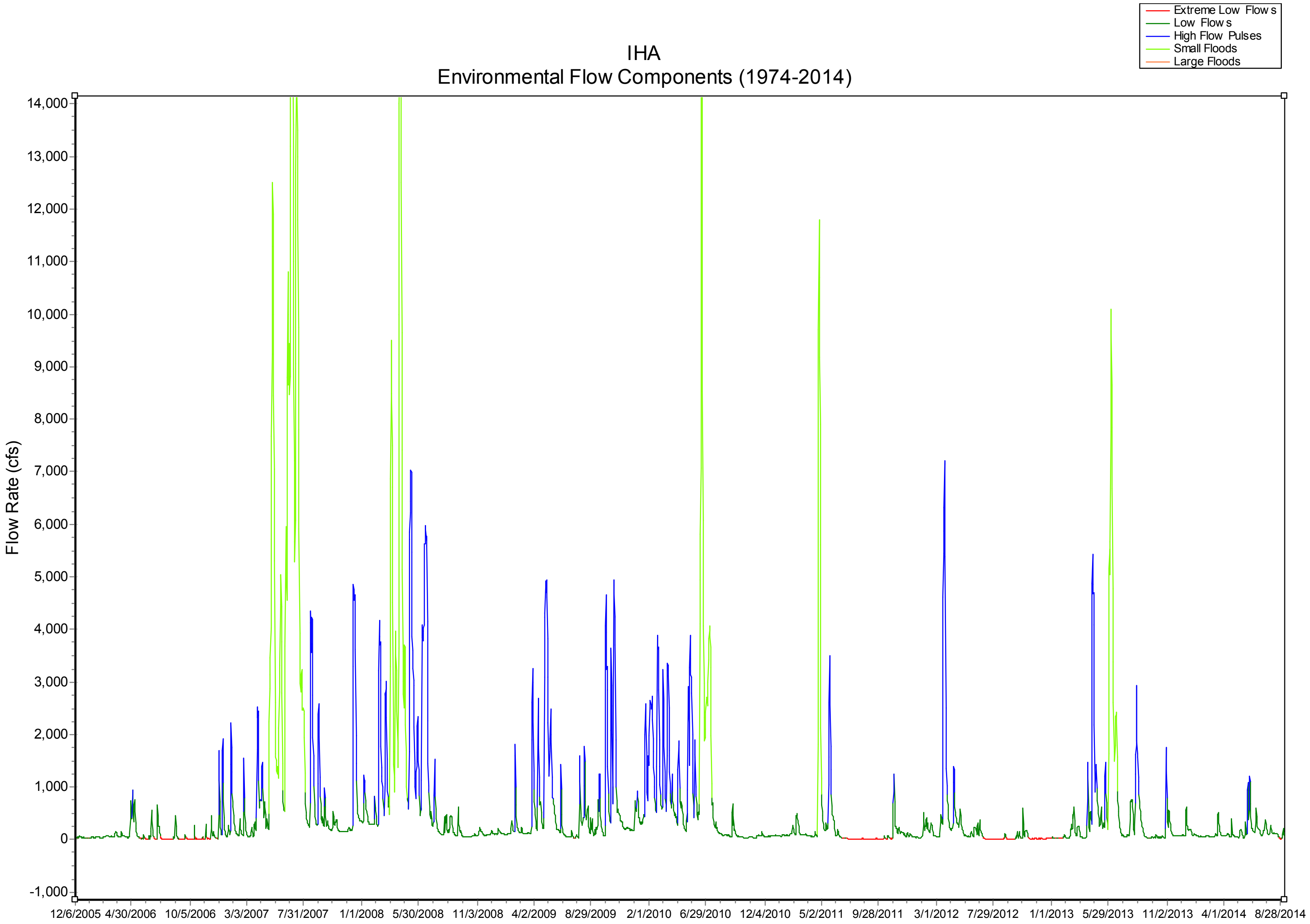
1974-2014


Deep Fork
Environmental Flow Components (1974-2015)
Extreme Low Flows
Low Flows
High Flow Pulses
Small Floods
Large Floods
Flow Rate (cfs)
34,000
32,000
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
10/1/1973
8/1/1975
6/6/1977
5/1/1979
3/1/1981
1/5/1983
1/1/1985
12/6/1986
1/1/1989
1/1/1991
1/1/1993
1/1/1995
1/1/1997
1/1/1999
1/1/2001
12/9/2002
1/1/2005
12/6/2006
1/1/2009
1/1/2011
1/1/2013
1/1/2015

2000-2014


Extreme Low Flows
Low Flows
High Flow Pulses
Small Floods
Large Floods
Deep Fork Trends
Environmental Flow Components (1974-2014)
Flow Rate (cfs)
20,000
19,000
18,000
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
11/5/1999
7/1/2000
3/1/2001
12/1/2001
8/29/2002
5/29/2003
2/27/2004
12/1/2004
9/1/2005
5/3/2006
1/3/2007
9/4/2007
5/5/2008
1/4/2009
9/6/2009
5/8/2010
1/7/2011
9/8/2011
5/24/2012
2/7/2013
11/1/2013
7/29/2014

2006-2014


Extreme Low Flows
Low Flows
High Flow Pulses
Small Floods
Large Floods
IHA
Environmental Flow Components (1974-2014)
Flow Rate (cfs)
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
12/6/2005
4/30/2006
10/5/2006
3/3/2007
7/31/2007
1/1/2008
5/30/2008
11/3/2008
4/2/2009
8/29/2009
2/1/2010
6/29/2010
12/4/2010
5/2/2011
9/28/2011
3/1/2012
7/29/2012
1/1/2013
5/29/2013
11/2/2013
4/1/2014
8/28/2014

Douglas Andrew Sides

Candidate for the Degree of

Master of Science

Thesis: BIOTIC AND ABIOTIC FACTORS AS INDICATORS OF BOTTOMLAND HARDWOOD HEALTH AND THEIR POTENTIAL USE FOR ECOSYSTEM MANAGEMENT

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Completed the requirements for the Bachelor of Science in Biology at Linfield College, McMinnville, OR in 2009.

Experience:

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- Oversaw the implementation of site-specific environmental mitigation measures and agency stipulations for telecommunication construction project, including daily field inspection reports
- Assisted senior field staff with the evaluation of potential issues and concerns ahead of construction activities

Great Basin Institute, BLM Elko Office, Elko, NV *Sage Grouse Technician*, 4/4/11-10/14/11

- Assessed 150 acres of rangeland using AIM (Assessment, Inventory, and Monitoring) Strategy including collection of gap intercept and line point intercept data, and reference photos
- Performed qualitative assessments on 100 lentic sites and 33.2 miles of lotic areas using PFC (Proper Functioning Condition)