ANALYSIS OF KISSIMMEE RIVER FLOODPLAIN SEED DISPERSAL FOR VEGETATION COMMUNITY RESTORATION

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Scott Markwith, Department of Geosciences, and has been approved by the members of his supervisory committee. It was submitted to the faculty of the Charles E. Schmidt College of Science and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

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This research examined the influence of hydrochory (seed dispersal via water), anemochory (seed dispersal via wind), and zoochory (seed dispersal by animals) on the re-establishment of the important floodplain vegetation communities of the Kissimmee River floodplain. Fifty-eight seed species were identified from 19,849 and 43,894 seeds trapped in hydrochory traps in sites north and south of Oak Creek, respectively. Seeds trapped by anemochory were measurable but were found to be far less important than hydrochory, while results showed no evidence of zoochory. The sampling month showed significant effects in ANOVA for hydrochory seed density/trap, hydrochory species richness, anemochory seed density/trap, species richness in standing vegetation, standing vegetation axis 1 and 2, hydrochory seed pool axis 2, and both maximum and mean wind speed; however, the directional relationship to Oak Creek showed significant effects for hydrochory species diversity, species richness in standing vegetation, standing vegetation axis 3, hydrochory seed pool axis 1, and both maximum and mean wind speed; while site type showed significant effects for hydrochory seed density/trap, species richness in standing vegetation, and both hydrochory seed pool axis 1 and 2. A Kruskal-Wallis Non-parametric test showed significant effects for site type, month and directional relationship to Oak Creek for water depth and standing vegetation. Water velocity sampling and a seed mimic release experiment showed minimal water and seed movement in the floodplain, indicating that seed may not disperse far from the parent plant via hydrochory. Seeds typical of species found in broadleaf marsh communities were found in high densities in hydrochory traps south of Oak Creek, but were not found in traps north of Oak Creek. A number of interacting factors, e.g. hydrology, lack of remnants, seed phenology, etc, are limiting the dispersal of broadleaf marsh species north of Oak Creek, delaying range, expansion, and further community restoration. Upstream seed dispersal could be very effective in BLM restoration efforts and should be further evaluated.

ANALYSIS OF KISSIMMEE RIVER FLOODPLAIN SEED DISPERSAL FOR VEGETATION COMMUNITY RESTORATION

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INTRODUCTION

Levin et al. (2003) described dispersal as “the unidirectional movement of an organism away from its place of birth”. The dispersal of plant seeds by water, wind, and animals in aquatic systems has gained attention because it has implications for flow regulation, restoration, climate change, and the spread of non-native species (Nilsson et al., 2010). The existence of multiple dispersal vectors is a common phenomenon in the majority of plant communities (Ozinga et al., 2004), and the establishment of vegetation communities may be reflective of available propagule sources in riparian areas (Neef and Baldwin, 2005; Moggridge and Gurnell, 2010; Malanson, 1993; Barrat-Segretain, 1996). Seed dispersal studies include capturing seeds in traps (Levin et al., 2003; Greene and Calogeropoulos, 2002) and direct observations of species to understand different types of movement over time (Levin et al., 2003; Watkinson, 1978). Seed dispersal studies can also be used to give advanced warning of invasive or non-native species colonization in a region (Neef and Baldwin, 2005).

Generally, average wetland size is decreasing and wetlands are becoming fragmented due to anthropogenic disturbances (Soons et al., 2006; Jansson et al., 2000; Hooftman et al., 2003; Soons et al., 2005). Despite the fact that there is a considerable amount of research on seed dispersal, there is a shortage of research concerning the relationship between ecological restoration and seed movement. Further research is needed to understand the interactions between seed dispersal, anthropogenic disturbance, wetland restoration, and community change.

Hydrochory

Hydrochory is the movement of seeds by water, either floating, submerged in flowing water, or with the help of floating vessels. In recent years our knowledge about hydrochory and its roles in population and community ecology have increased (Nilsson et al., 2010). Wetland species can be dispersed by several different mechanisms; however, dispersal by water is the primary vector for wetland systems (Neef and Baldwin, 2005). For riparian plants, channelization, such as the C-38 canal on the Kissimmee River in Florida, obstructs dispersal by separating the river and the wetland zones. This can lead to a decrease in species richness in riparian zones, and it is unknown if this can be reversed with canal backfilling and restoration of lateral connectivity.

Numerous examples illustrate the importance of hydrochory in riparian zones. Experiments by Merritt et al. (2010) provide evidence that water dispersal of seeds influences dynamics of colonization and can be important for the long-term development of communities in floodplain areas. They also concluded that hydrochory contributes to variability among sites, enhances species richness over time, and can play an important role in meta-population dynamics of plant communities. Jansson et al. (2005) found that hydrochory increased the number of colonizing species by 40%-200% per year and resulted in more diverse plant communities after three years of succession. Griffith and Forseth (2002) found that 94% of water-dispersed seeds caught in their traps fell and were dispersed only 0.5 meters from the mother plant, whereas Merritt et al. (2010) reported that hydrochores (and seed mimics) were dispersed anywhere from 6 km up to 152 km. Borchensius (2002) conducted experiments in floodplain areas of the Amazon River and concluded that seed dispersal was greatest when water depth was greatest.

Anemochory

In wetlands, anemochory, the movement of seeds by wind, is often overlooked due to hydrochory's dominance. However, anemochory plays a key role in dispersing small and lightweight seeds (Neef and Baldwin, 2005; DeVlaming and Proctor, 1968; Fenner, 1985; Soons, 2006). Wind can transport large numbers of seeds over long distances, and unlike water, can disperse seeds in all directions and areas not connected by surface water (Soons, 2006). Soons (2006) conducted an experiment to compare wind and water dispersal, and results showed that wind dispersed seeds to a wider range of sites; however, the wind-dispersed seeds reached the sites in lower densities than the hydrochorous seeds. Various experiments have shown that wind can be a very effective long distance seed disperser when conditions are ideal (Ozinga, 2004); however, gravity, wind speed, turbulence and specific adaptations of seeds for anemochory are all factors that influence seed movement (Kuparinen, 2006; Soons, 2006).

Zoochory (Ichthyochory and Avichory)

As early as Darwin (1859) and Ridley (1930), scientists have recognized that animals, including birds and fish, are frequent seed dispersers in aquatic environments (Cook, 1988; Barrat-Segretain, 1996). The different mechanisms of dispersal by fish and birds include internal dispersal and involuntarily dispersal on their fur or feathers (Neef and Baldwin, 2005; Vittoz and Engler, 2007). The probability of internal zoochorous seed dispersal depends on probabilities of seed availability, seed ingestion by the animal, seed survival, and seed viability after gut passage (Pollux, 2007).

Similar to dispersal by wind, birds can disperse seeds (avichory) in areas that are not connected hydrologically to the river (Adams et. al., 2007). Adams et al. (2007) and Clark (1999) found that some birds have been documented to disperse seeds up to 10 kilometers, while Pollux (2005 and 2007) found that seeds were kept in mallard guts for up to 60 hours. Adams et al. (2007) also found that seeds found in the feces of Cedar Waxwings do not have reduced germination rates.

Research shows that fish can disperse seeds (ichthyochory), influencing riparian vegetation dynamics (Correa et al., 2007). Fish migrations can extend over hundreds of kilometers (Kubitzki and Ziburski, 1994) and seeds can stay in the intestines and stomach for up to a week (Kubitzki and Ziburski, 1994; Goulding, 1980). A number of studies have involved catching catfish and dissecting the intestines and stomach of the fish to find what species of seeds were eaten and their condition (Kubitzki and Ziburski, 1994; Adam et al., 2007; Pollux et al., 2006). Seeds that passed through the intestinal tract of various fish had no effect on the viability of seeds (Kubitzki and Ziburski, 1994; Pollux et al., 2006), and in one study even helped germinate the seeds faster (Correa et al., 2007).

The Kissimmee River

The Kissimmee River is located in central Florida between Lake Kissimmee and Lake Okeechobee. Due to historical flooding in this region and the desire for development, Congress authorized a project to channelize the river in the 1950's and a 90 km long flood control canal (C-38) was completed in 1971. Ecological damage was observed even before construction of the canal was complete. One year after construction was completed, the potential for restoration of the Kissimmee River was discussed. Physical effects and other disturbances of channelization such as reduced floodplain wetlands, degraded fish and wildlife resources, invasion by exotic vegetation and grazing from cows significantly transformed plant communities (U.S. Army Corps of Engineers, 1991). Prior to channelization, wetland plant communities such as broadleaf marsh (BLM, 46% of the floodplain including upstream of sampling sites), wet prairie (WP, 21%), and wetland shrub (WS, 13%) were all dominant, and shortly after channelization were replaced by upland vegetation and pasture (Carnal and Bousquin, 2005). By 1996 (25 years after channelization), these three once-dominant plant communities were reduced to 7% (BLM), 11% (WP), and 9% (WS). Along with the loss of almost 8000 hectares (almost 20,000 acres) of wetlands and substantial loss of wildlife, there was also a drastic decline in water quality.

Kissimmee River restoration efforts began in 1999 by backfilling the canal with the goal of restoring ecological function, biological communities, and the hydrological system to historical conditions (Fig. 1). Being one of the largest river restoration projects in the world, the effort will take about 15 years to complete with a cost of $578 million. The South Florida Water Management District expects floodplain wetlands to recover to at least 80% of the floodplain area after water depth, extent, duration, and frequency of floodplain inundation are restored in response to backfilling of the C-38 canal and reconnection of remnant river channels (Carnal and Bousquin, 2005). Seed dispersal, vegetative reproduction of remnant communities, and germination of viable seed banks are hypothesized mechanisms for wetland vegetation recovery (Carnal, 2005). However, recovery of the broadleaf marsh (BLM), wet prairie (WP), and wetland shrub (WS) communities has been slow where the C-38 canal has already been backfilled (Spencer and Bousquin, In press). Possible hypotheses concerning restoration delay to this point follow from the processes expected to induce recovery, and include:

1) Current hydrology is not conducive to reestablishment and persistence of longer-hydroperiod wetland vegetation (BLM). Bousquin et al. (2005) and Williams et al. (2005) indicated that wetland plant communities will depend in part on implementation of the headwaters revitalization water regulation schedule so that water releases mimic historic hydroperiods. At this point this schedule has not been implemented.

2) Competition from an invasive shrub species, *Ludwigia peruviana*, is inhibiting native marsh recovery. Spencer and Bousquin (In press) speculate that *L. peruviana* may have a competitive advantage due to inappropriate hydrologic conditions within a large section of the restored floodplain. An additional issue may be the extraordinary seed production of this invasive. Jacobs et al. (1994) found in a wetland in Sydney, Australia that *L. peruviana* produced ~450,000 seeds/m^2, and ~65,000 seeds/m^2 were found in the soil seed bank.

3) A lack of a viable seed bank. Wetzel et al. (2001) found that especially for the BLM and WS sites, but also within WP, re-establishment of the former vegetation may require propagule dispersal from off-site sources because a viable seed bank is absent.

4) A lack of remnant communities to contribute to vegetative reproduction through much of the restored floodplain. Channelization reduced floodplain wetlands from 80% to 29% of the floodplain area (BLM 46% to 7%, WP 21% to 13%, WS 13% to 8%) (Carnal and Bousquin, 2005). These wetland remnants are severely fragmented by large swaths of converted upland communities; and they may struggle to colonize floodplain wetlands distant from potential source locations. In such cases natural seed dispersal may be needed to facilitate colonization of impacted wetlands in jump dispersal/stepping stone fashion, from which colonizers may begin to spread further by seed or vegetatively.

5) Seeds of the expected species are not being dispersed into the floodplain wetlands from remnant communities. Information on this hypothesis is currently lacking and the contribution of this process to community recovery is not understood.

OBJECTIVES

This research examines the dispersal processes influencing the establishment of recognized important floodplain vegetation communities of the Kissimmee River. This information will help inform future Kissimmee River hydrologic management and adaptive management, and explain how seed dispersal may influence vegetation restoration now and in the future. Following are specific research questions:

- Are the dominant and defining species of BLM being dispersed from remnant locations into wet prairie and wetland shrub communities where BLM can establish and expand its range?
- Are hydrochory, zoochory, and anemochory dispersing seeds of the dominant and defining species of BLM, WP, and WS communities?
- Are these dispersal mechanisms transporting invasive species?
- What are the volume, pattern, and rate of seed movement within the seed shadow of remnant vegetation communities in the floodplain?
- What is the seed phenology for the characteristic species from the floodplain communities and how do these patterns relate to the probability of water flow, wind events and bird migration patterns?

METHODS

Field Sampling and Data Collection

Sampling locations were located in the reach of the Kissimmee River called Pool C, where most of the C-38 canal was backfilled by Phase I construction in 2001, in the floodplain north and south of the confluence of Oak Creek. The approximate area upstream and downstream of the confluence of Oak Creek appears to be a break point between the southern section of the Phase I floodplain impacted hydrologically by a backwater effect of the S-65C water control structure and dominated by WS, and the northern section of the floodplain dominated by WP (Spencer and Bousquin, In press). The 4 sampling locations farthest north of the Oak Creek confluence were located in large contiguous areas of *Panicum hemitomon* dominated WP, and 4 sampling locations were placed in the WS and WS/*Ludwigia peruviana* dominated areas close to and south of the Oak Creek confluence (Figure 2). Each sampling location was composed of 2 study plots within remnant BLM (except location 1, where all 6 study plots were identified as BLM), 2 study plots in areas of *Panicum hemitomon*-dominated WP or WS directly within the seed shadow (area receiving dispersed seeds from plants of the remnant BLM), and 2 study plots outside of the seed shadow of the remnant BLM. Thus, there were 8 sampling locations that contained 6 study plots, for a total of 20 BLM study plots, 14 BLM seed shadow study plots, and 14 WP non-seed shadow study plots. Two additional sampling locations were located in contiguous areas of *Panicum hemitomon*-dominated WP and *Ludwigia peruviana*-dominated WS, one plot in each, that were not within BLM remnants or within their seed shadow. These sites were designed to determine if seeds of BLM species were found in areas remote from BLM remnants and dominated by competitors.

Sampling took place every 3 months over a one-year period. Hydrochory, anemochory, and avichory were sampled concurrently for a two-week period every three months. Ichthyochory sampling occurred as an individual event at each plot at a single point in time. Anemochory and avichory sampling were possible year round given site accessibility; however, hydrochory, ichthyochory, and other sampling based on the presence of water did not take place at any location that was not appropriately flooded during any sampling period.

Each study plot consisted of one PVC stake to which one hydrochory trap and one anemochory trap was affixed. Floating hydrochory seed trap design was based upon Middleton (1995) with minor variation (see Figure 3A for schematic of seed trap design). Traps were constructed from standard 2 gallon buckets with the bases cut out, nylon mesh fabric liners with hole sizes 0.71 mm^2 to capture seeds (Industrial Netting part # NN1500), flotation devices (sections of styrofoam noodles), and attached by rope to permanently located PVC stakes so that the traps could reorient with changes in water level and flow direction. The anemochory traps were constructed of a wind deflector to channel seeds into the traps, and a frame structure holding a coconut fiber mat, for seed trapping, facing 360 degrees and attached 2 meters above the ground/peat surface to the same stake as the hydrochory trap (Figure 4) (designed after Neff and Baldwin, 2005). Both trap types were deployed once every three months for a two-week period. After two weeks the traps were collected and transported back to Dr. Markwith's Biogeography Lab on the Boca Raton campus of Florida Atlantic University for seed extraction, processing, and identification.

Zoochory was sampled adjacent to the hydrochory/anemochory trap plots. Avichory sampling was conducted with fecal traps attached to 2-meter high artificial perches. A single artificial perch with fecal trap was placed at each study plot for a period of two weeks every 3 months. Perches were constructed of PVC pipe with a short horizontal pipe capping the top. Fecal traps were constructed from a plastic shoebox attached 1.5 meters above the ground/peat surface, open end facing up and containing nylon mesh fabric liners of the same composition as the hydrochory traps (Figures 3B and 4). Ichthyochory sampling was conducted using a 1 $meter^3$ throw trap with 0.71 mm^2 nylon mesh sides (after Kushlan, 1981), from which all fish were extracted using a dip-net, anesthetized in ice water, identified to species and measured (after Glenn and Arrington, 2005), and decapitated. Avichory traps and fish samples were transported back to Dr. Markwith's Biogeography Lab on the Boca Raton campus of Florida Atlantic University for seed extraction from feces or fish digestive tracts, processing, and identification.

Identification of the collected seeds was performed to characterize species diversity of the seed pool and patterns of individual species. Seeds too small to be identified with the naked eye were examined for diagnostic traits under a Leica S6 D microscope and a digital image captured with a Leica DFC295 3.1 megapixel digital camera. Seeds were visually sorted and identified using a seed key. A comprehensive seed key for aquatic/riparian species was developed using herbarium specimen, online resources, and field identification.

Trapping naturally floating seeds provides evidence of quantity, composition, and diversity of seeds being moved; however, rate of movement is not addressed. Experiments were conducted to examine dispersal rate, distance, and spatial pattern of the hydrochory transport vector. A seed mimic was recognizably marked with water resistant paint and released adjacent to all study plots (except plots lacking water) during the July 2011 sampling period (100 seeds released at each location). Collection of released seeds began after 24 hours elapsed from the input of seeds. Any painted seeds encountered within the study area were recorded and distance and direction from the release point measured, and the context of its location recorded (i.e. floating or trapped by vegetation or some other friction element).

Flow velocity was measured 0.2 m upstream from the stake at each hydrochory trap location when the hydrochory traps were deployed. Velocity was measured using a SonTek/YSI Flowtracker Handheld-ADV Acoustic Doppler Velocity meter. Flow readings were taken just below the surface, 2.5 cm depth. Water depth was also recorded at same locations as water velocity readings. Wind velocity and direction were also recorded when the anemochory traps were deployed using a portable anemometer (Kestrel 4500 Weather Tracker).

Aquatic vegetation adjacent to the seed traps was sampled every 3 months to identify individual species and percent cover of each. A 2 m x 0.5 m sampling frame was used. The long side was positioned parallel to the dominant flow direction, and the downstream short side was anchored to the seed trap stake. The sampling frame was only anchored to each stake and vegetation sampled only after the hydrochory trap was collected to avoid influencing seed sampling. Standing vegetation for the sampling month of November was not included due to inconsistent application of the sampling protocol in that month

Seed phenology was examined by field observation during seed trap sampling. A representative sample of the most common species (5 individuals per species) in the BLM and WP communities and dominant invasive species (Table 1) were tagged and monitored to track the range of fruit/seed maturation timing for each species. The tagged plants were located in proximity to the sampling locations.

Statistical and Data Analysis

A number of common parameters were calculated and statistical tests conducted to address the research objectives. Following is a breakdown of variables that were directly measured or calculated based on empirical data every sampling period, for which descriptive statistics (e.g. means and standard deviations per study plot type, etc…) were calculated per sampling period and for the entire year of sampling:

- Seed traps (hydrochory, anemochory, and avichory) and ichthyochory trap throws, each of which was an observational unit:
    - Seed Specific Variables: species richness, Shannon diversity index, and total seed density in hydrochory and anemochory traps. Hydrochory seeds/trap was log transformed, and anemochory seeds/trap was log and power transformed to achieve a normal distribution for these variables. Observations with zero values were excluded from hydrochory species richness and hydrochory species diversity.
    - Dispersal Vector and Environmental Parameters: water depth, flow velocity, wind speed (mean and maximum), number of fish collected, fish species richness, proportion and species of fish containing seeds, and length of fish. Mean wind and maximum wind speeds were both power transformed to achieve a normal distribution for these variables.
- Experimental seed release analysis, each located marked seed was treated as an observational unit: distance of travel, direction of travel, rate of seed movement, percent retrieved seeds trapped by standing vegetation, and percent of seeds that sank.
- Standing vegetation parameters, each quadrat was the observational unit: total percent cover, species richness, and the percent cover of BLM, WP, and WS characteristic species and invasive species.

- Seed Phenology, each monitored individual plant was the observational unit: total number of fruits, and number of mature fruits releasing seeds.

Non-metric Multidimensional Scaling (NMS) was conducted to examine the species composition patterns of the hydrochory seed pool and standing vegetation over the entire year. For each analysis the following conditions were maintained: a) NMS was first run in autopilot mode to determine the best dimensionality for the analysis, in each case the 3-dimensional solution was best, b) maximum number of iterations was 500, c) starting coordinates were random, and d) 250 runs with real data and 250 runs with randomized data. For the seed pool analysis, seed density/trap was summed per species over the 12-month sampling period; traps containing seeds of species in less than 5% of the traps were excluded. A second matrix was included with the seed pool analysis that contained water depth, water velocity, wind speed, wind direction, and vegetation percent cover. For the standing vegetation NMS analysis, species found in less than 5% of the vegetation quadrats were excluded. A second matrix was included with the standing vegetation analysis that contained water depth, water velocity, wind speed, wind direction, vegetation percent cover, and vegetation species richness. Axis scores were categorized by site type (i.e. BLM, seed shadow, non-seed shadow), sampling location in relation to the confluence with Oak Creek (i.e. 4 farthest north locations vs. 4 farthest south locations), and sampling month, and visualized using 2D joint plots.

ANOVA (Analysis of Variance) was conducted to test the seed specific, dispersal vector, and environmental variables listed above for significant differences among site type, sampling month, and relationship to the confluence with Oak Creek as appropriate. A Shapiro-Wilk test for normality was used, and the variables that did not meet the normality assumption of an ANOVA were tested with the Kruskal-Wallis Non-Parametric test for significant differences among site types, month, and relationship to the confluence of Oak Creek. Variables that could not be normalized included: anemochory species richness, anemochory species diversity, water depth, water velocity, wind direction, standing vegetation percent cover, standing vegetation NMS axis 1, and hydrochory NMS axis 3.

Ordinary Least Squared Multivariate Linear Regression analysis was used to examine the relationship between independent and dependent variables. Dependent variables for the analysis included the variables listed above under the seed specific variables from the seed traps and axis scores from the NMS analysis of the seed pool. The independent variables included the dispersal vector and environmental variables from the trap locations as well as those standing vegetation parameters listed above.

RESULTS

Over the 12-month study, a total of 58 different species of seed were collected from the hydrochory traps. There were 19,849 seeds collected from 39 different species north of Oak Creek and 43,894 seeds found from 49 different species in the south. A total of 63,743 seeds were collected in hydrochory traps over the entire sampling period, and the month with the greatest mean seed density/trap was July (Figure 5a). Outside of the random plots, non-seed shadow sites north of Oak Creek had the greatest mean seed density/trap, while seed shadow sites south of Oak Creek had the greatest seed density/trap (Table 2). ANOVA on hydrochory seed density/trap indicated a significant effect of sampling month, site type, the interaction of site type and relationship to Oak Creek, and the interaction of site type, relationship to Oak Creek, and sampling month (Table 3).

The overall mean species richness in the hydrochory seed pool showed a peak in July with 6.42 species/trap, and a low in April with 1.68 species/trap. Seed shadow sites south of Oak Creek had both the highest mean species richness (6.92) and highest mean Shannon-Weiner Diversity Index (0.96) for hydrochory seed traps (Table 2). The single hydrochory trap with the greatest species richness was a BLM site at location 3 in November with 19 species. ANOVA on hydrochory species richness indicated a significant effect of sampling month and the interaction of sampling month and relationship to Oak Creek (Table 3). ANOVA on hydrochory species diversity indicated a significant effect of relationship to Oak Creek, the interaction of the sampling month and relationship to Oak Creek, and the interaction of the sampling month, site type, and relationship to Oak Creek (Table 3).

There were 35 different species of seed collected from anemochory traps. A total of 1,127 seeds were found from 30 different species north of Oak Creek and 1,318 seeds found from 25 different species south of Oak Creek, summing to a total of 2,445 anemochory seeds over the entire sampling period. The month with the greatest mean seed density/trap was November (Figure 5a). Outside of the random plots, BLM sites south of Oak Creek had the highest mean seeds per trap (Table 4). ANOVA on anemochory seed density/trap indicated that only the effect of sampling month was significant (Table 3).

The overall mean species richness in the anemochory seed pool peaked in November with 3.3 species/trap, and a low in April with 0.26 species/trap (Figure 5b). Non-seed shadow sites south of Oak Creek had both the highest mean species richness (1.96) and highest mean Shannon-Weiner Diversity Index (0.49) for anemochory seed traps (Table 4). The single anemochory trap with the greatest species richness was a BLM site at location 7 in November with 9 species. A Shapiro-Wilk test indicated the normality assumption of ANOVA was not met by the anemochory species richness and anemochory species diversity variables or the variables transformed. A Kruskal-Wallis

Non-parametric test on these two variables was conducted and month had a significant effect at the $p < 0.01$ level on both variables (Table 5). Site type and relationship to Oak Creek were not significant effects on either.

There were 27 different plant seed species collected from avichory traps. A total of 294 seeds were found from 21 different species north of Oak Creek and 281 seeds found from 18 different species south of Oak Creek, summing to a total of 575 avichory seeds over the entire sampling period. There were eight different traps in which bird feces was found; however, none of these seeds were found in bird's feces. Many of the seeds found in these traps arrived by wind transport because of obvious anemochory adaptations. These wind-born seeds are not reported with the anemochory data and are clearly not due to avichory. Bird observations took place on two separate days in July 2011. 5 different bird species were documented flying around or standing near avichory perches, however no birds were seen using the perch on the avichory trap.

Ichthyochory sampling could only be conducted in the sampling month of July, which was the only month where the water was deep enough in the floodplain. There was a total of 19 fish from 3 different species caught in the throw traps (Table 6). The size of the fish caught ranged anywhere from less than 10mm to 40mm. No seeds were found in the fishes' digestive tracts.

The seed release experiment was only conducted in the sampling month of July because many areas had no water in the dry season sampling months, and some areas were even dry in the wet season. 100 wooden seed mimics were released at 7 of 10 locations in July (Table 9). Seed mimics moved in only 4 out of 7 locations. Seed mimics traveled northeast at 2 locations, both north and south at another, and at the other they moved southeast of the release point. Location 3 had the greatest mean distance traveled, 45.72cm, with a dispersal rate over the 24-hour period of 0.00053cm/s. More than 50% of the released seed mimics sank in 6 of 7 sites and 100% of all recovered seed mimics were found trapped in vegetation.

Seed phenology was observed over the 12-month sampling period by monitoring mature individuals from the 8 most common species in the BLM, WS, and WP communities. All species bore fruit in the month of November except *Salix caroliniana* (Table 10). *Cephalanthus occidentalis* was the only species bearing fruit in every sampling period, and *Ludwigia peruviana* had the greatest mean number of mature fruits. The invasive species, *Ludwigia peruviana* and *Scirpus cubensis*, both produced fruit in 3 out of 4 sampling periods.

The phenology of seeds actively dispersing in the seed pool and collected in hydrochory traps indicates species-specific variation by month. In the sites north of Oak Creek the peak seed dispersal period was in the April and July sampling months. The dominant seed pool species at this time included seeds of *Rumex crispus, Eupatorium capillifolnum, Polygonum punctatum,* and *Echinochloa walteri.* In the sites south of Oak Creek the peak seed dispersal period was in the July and November sampling months, and included *Scirpus cubensis, Ludwigia leptocarpa, Ptilimnium capillaceum,* *Cephalanthus occidentalis, Polygonum punctatum, Saggitaria lancifolia, Sacciolepis striata, Salix caroliniana, Rumex crispus, Hydrocoytle umbellata, Hydrocoytle ranunculoides,* and *Cyperus spp.*

The following invasive species were found in both the hydrochory and anemochory seed traps throughout the entire study area over the 12-month sampling period: *Rumex crispus, Scirpus cubensis, Centella asiatica, Paspalum notatum, Urochloa subquadripara,* and *Myriophyllum* spp. Exceptions include: *Urochloa subquadripara* was the only invasive species found in just the anemochory traps north of Oak Creek and only in November and January, and *Paspalum notatum* was only found in April north of Oak Creek. *Rumex crispus* was the dominant invasive species in the floating seed pool both north and south of Oak Creek, with a total of 11,669 seeds documented. *Rumex crispus* accounted for 92% of hydrochory seeds in April (9,191 out of 9,951 total). Other invasive species, such as *Hydrilla verticillata, Eichhornia crassipes,* and *Ludwigia peruviana*, were not found in the seed pool but were present in the standing vegetation.

Water depth varies annually and seasonally in accordance with Florida's yearly wet and dry seasons and the results from this study are specific to this sampling year. The maximum mean water depth was 0.13m south of Oak Creek in November (Figure 6A). Many areas north of Oak Creek had no water in the dry season, but some were dry even in the wet season. The water depth variable did not meet the normality assumption from a Shapiro-Wilk test. A Kruskal-Wallis Non-parametric test on water depth showed significant effects of site type and month at the $p < 0.05$ level, and relationship to Oak

Creek had a significant effect at the $p = 0.0001$ level (Table 5). Mean water velocity was very low across the floodplain, with the only recorded velocities occurring in the wet season months of November and July at sites south of Oak Creek (Figure 6B). Water velocity readings north of Oak Creek were largely unavailable due to lack of water, but velocities were usually 0 cm/s when water was present.

Mean wind speed varied throughout the 12-month sampling period. The maximum mean wind speed was 2.72 m/s in November, north of Oak Creek (Figure 6C). The sites north of Oak Creek had a higher mean wind speed (2.28 m/s) than sites south of Oak Creek (1.41 m/s). ANOVA on both maximum and mean wind speed indicate that sampling month, relationship to Oak Creek, and the interaction of sampling month and relationship to Oak Creek had significant effects (Table 3). A Kruskal-Wallis Non-parametric test showed significant effect of month on wind direction at the $p < 0.01$ level (Table 5).

Mean percent cover of standing vegetation was roughly equivalent north and south of Oak Creek and among site types (Table 7). The month with the greatest mean percent cover was April (87% north of Oak Creek, 84% south of Oak Creek). A Kruskal-Wallis Non-parametric test showed a significant effect of only month on standing vegetation percent cover at the $p < 0.05$ level (Table 5). Mean species richness in the standing vegetation was greater south of Oak Creek (4.0) than north of Oak Creek (3.0) (Table 7). BLM sites south of Oak Creek had the greatest mean species richness in the standing vegetation (4.29). ANOVA on species richness in the standing vegetation indicated that sampling month, site type, and relationship to Oak Creek were significant effects (Table 3).

The final stress of the three-dimensional Non-metric Multidimensional Scaling (NMS) analysis of the hydrochory seed pool was 16.12; final instability was 0.0006; and axis 1 had an $r^2 = 0.167$, axis 2 had an $r^2 = 0.136$, and axis 3 had an $r^2 = 0.197$, for a total r^2 of 0.50. Scatter plots of the NMS axis scores show groupings between plots north and south of Oak Creek (Figure 7) and based on sampling month (Figure 8). However, groups of plots are not visibly discernible when categorized by site type (Figure 9). ANOVA results confirm significant differences north and south of Oak Creek on axis 1 and among months on axis 2 scores (Table 3). Even though visible groups were not apparent, site type had a significant effect on both axis 1 and axis 2. The Kruskal-Wallis Non-parametric test showed significant effects of month and relationship to Oak Creek on axis 3 at the $p < 0.01$ level (Table 5). The interaction of sampling month and relationship to Oak Creek, and the interaction of site type and relationship to Oak Creek were both significant effects on axis 2 (Table 3).

The final stress of the three-dimensional NMS analysis on standing vegetation was 18.19; the final instability was 0.00001; and axis 1 had an $r^2 = 0.242$, axis 2 had an $r^2 = 0.223$, and axis 3 had an $r^2 = 0.285$, for a total r^2 of 0.75. Groupings are visibly apparent among plots north and south of Oak Creek, but with substantial overlap (Figure 10), and ANOVA on axis 3 scores confirm significant differences (Table 3). A clear pattern of groups based on sampling month was present, and ANOVA on axis 2 and axis

3 scores confirm significant differences between sampling months. There were no apparent groupings in the scatter plots categorized by site type (Figure 12), and site type was not a significant effect in the ANOVA analysis on the axis scores, but the Kruskal-Wallis Non-parametric test on Axis 1 scores showed site type, month and relationship to Oak Creek were significant effects (Table 5).

Ordinary Least Squared Multivariate Linear Regression analysis was used to examine the relationship between dependent and independent variables (Table 11). Anemochory seed density/trap was significantly and positively related to sampling month and site type. Hydrochory NMS axis 1 was significantly and positively related to the relationship to Oak Creek and negatively related to site type. Hydrochory NMS axis 2 was significantly and negatively related to both mean wind speed and relationship to Oak Creek. Regression analysis was performed on hydrochory seed density/trap, and axis 2 and 3 scores from the standing vegetation, however the models did not result in significant global f-values or p-values and were not included in the Table 11.

DISCUSSION

This research demonstrates that although seeds of the defining wetland community species are dispersed by hydrochory and anemochory, the seed pool is not homogenous and in many instances species of these communities are not being dispersed to locations where they can expand their range and facilitate further community restoration. Prior to channelization, BLM communities were found in areas upstream of the sampling locations and upstream transplant of BLM species was not necessary (Figure 2). Re-colonization of BLM species at sites north of Oak Creek may be hindered due to a number of factors, e.g. lack of remnants, hydrology, seed phenology, etc. The co-occurrence of these multiple processes and patterns, and their slow, asynchronous, or un-restored nature may produce a poor rate of community restoration that may need to be monitored at the decade to century scale.

The seed pool in the Kissimmee River floodplain varied spatially among locations north and south of Oak Creek and temporally over the sampling year. Seeds of the typical species from BLM communities were not found in hydrochory traps in sites north of Oak Creek; however, they were found in relatively high densities south of Oak Creek. This pattern largely reflects that of the standing vegetation. Broadleaf marsh species require longer hydroperiods than wet prairie and wetland shrub communities, and a regular dearth of water found in northern sites is a hypothetical contributor to the absence of BLM plants north of Oak Creek (Carnal and Bousquin, 2005). Without the presence of a seed source or a vector for dispersal, i.e. water, there can be little expansion of BLM. Greater water depths south of Oak Creek were associated with hydrochory traps with greater mean species richness than sites north of Oak Creek. Similar to the findings of Borchsenius (2002) and Boedeltje et al. (2004), the seed density and composition varied temporally with variability in water depth. Jansson et al. (2005) experimentally tested how hydrochory affects species richness in riparian systems; species richness in flooded plots was 40-200% greater than the non-flooded plots.

Water velocity in the floodplain was very slow and often un-measurable, while the dispersal rate from the seed mimic experiments was also very slow and trapping by emergent vegetation was prevalent. Restoration from remnant BLM communities could take a very long time because dispersal to new sites is so slow. Water velocity sampling and the seed mimic release experiment show little water and seed movement among sites in the floodplain, which means that seedlings in the study areas do not disperse very far from the parent plant. The seed release experiment also shows that the dense vegetation and woody debris in the Kissimmee River floodplain study area can slow or even stop the dispersal rate of waterborne propagules. Schneider and Sharitz's (1988) seed release experiments similarly show that experimentally released seeds were concentrated against trees and other emergent substrates.

Due to the dominant direction of water flow from north to south, seeds have trouble moving upstream via hydrochory from source remnants in the south. According to Pollux et al. (2007), recent studies show that upstream dispersal can occur in many plant species through wind, birds, and other means. However, similar to the research described herein, Schneider and Sharitz (1988) found greater species richness and seed density in hydrochory compared to anemochory traps. There is only a small subset of species with "wind-dispersed" adaptations compared to the entire seed pool (Merritt et al., 2010). In addition, wind-dispersed seeds may land on the water and be secondarily dispersed by hydrochory, creating an overlap in species composition, as the anemochory seed pool is ultimately a subset of the richer hydrochory seed pool (Merritt et al., 2010). Anemochory exhibited a relatively poor ability to disperse seeds of any type, including BLM species, and avichory and ichthyochory provided no evidence of effectiveness. Thus, upstream dispersal may be rare, and a potential drag on the restoration process.

Seed phenology of *Pontederia cordata* and *Saggitaria lancifolia* in late wet season and winter is not conducive to long-term hydrochory because of water drawdown with dry season onset. On the other hand, seed availability for *Cephalanthus occidentalis* throughout the wet and dry seasons may allow this species to disperse more effectively and advantageously when hydrological conditions are appropriate. Seed phenology of *Rumex crispus* in late dry season and wet season dispersed these invasive plant seeds via hydrochory throughout much of the floodplain, and greatly affected the total number of trapped seeds in the April sampling month. The combination of the seed phenology and wet season flooding resulted in the greatest hydrochory species richness and total seeds found in the July sampling month. The hydrochory seed pool for the sampling months of January and April showed greater mean seeds/trap than November, however, species richness was low, resulting in a few select species dominating the seed pool in those months.

Although the trapped seed pool reflects the established vegetation to an extent, the relationship between the two is not perfect. Seeds of several broadleaf marsh and wet prairie species common in the standing vegetation were observed in the seed pool (e.g., *Polygonum punctatum, Cyperus* spp., *Hydrocoytle umbellata, Saggitaria lancifolia,* and *Panicum hemitomon),* but seeds of other common broadleaf marsh and wet prairie species were rare or absent from the seed traps (e.g., *Pontederia cordata, Diodia virginiana, Leersia hexandra, Paspalum dissectum, Rynchospora inundata,* and *Eleocharis* spp.). The reasons some of these species' seeds were not trapped include sinking seeds (*Pontederia cordata*, personal communication with Dr. Markwith; *Eichornia crassipes,* Washington State Department of Ecology, 1994), dominance of vegetative reproduction (*Diodia virginana*, Breeden and Brosnan, 2010; *Eichornia crassipes*, and *Lemna* spp., Mkandawire and Dudel, 2007), sampling error (*Ludwigia peruviana*), and asynchronous sampling with seed phenology.

Pekas (2010) concluded that plant communities dominated by perennial species usually have relatively low standing vegetation-seed pool similarities. Merritt and Wohl (2006) similarly found weak associations between local standing vegetation and hydrochorous seed samples along free-flowing rivers. Nilsson et al. (2010) suggests that water can disperse both vegetative and generative propagules. Boedeltje et al. (2004) showed that vegetative dispersal can occur over a longer dispersal period than generative dispersal, and frequently appears in species that cannot form a substantial seed bank. We did not attempt to measure vegetative dispersal in the Kissimmee River floodplain, but this may be an important mode of dispersal for many aquatic plants within the restoration.

Seed dispersal studies can provide advanced warning of possible colonization by invasive or non-native species (Neef and Baldwin, 2005), and many invasive species are found in the dispersing seed pool in the Kissimmee River floodplain. However, many invasives are already established in the standing vegetation, e.g., *Ludwigia peruviana, Eichornia crassipes, Hydrilla verticillata, Scirpus cubensis, Rumex crispus,* and *Myriophyllum* spp. Seeds of some invasive plants are not necessarily dispersed by water, e.g. *Urochloa subquadripara* was only found in the anemochory traps, and species such as *Myriophyllum* spp. are dispersed by vegetative fragments (Nilsson et al., 2010). *Ludwigia peruviana* was not observed in the hydrochory traps because of a systematic sampling error caused by the seeds being smaller than the liner mesh size.

Restoration Implications

Research conducted by Helfield et al. (2007), indicates that hydrochory has enormous potential as a mechanism for restoration of degraded riparian sites. Restoration of the natural hydrologic regime is required so that phenology and water flows co-occur to transport propagules into suitable sites, and greater water depths re-establish connections between land and water (Nilsson et al., 2010; Helfield et al., 2007). Nilsson et al. (2010) further states that incorporating natural establishment through hydrochory can have a higher yield and greater spatially extensive benefits than active restoration through planting or broadcasting seeds to restore wetland vegetation. However, reduced plant populations from habitat loss and fragmentation can reduce seed production and seed quality in wetland plants. In such cases, management should focus on maintaining the size of the existing native plant populations so that more seeds can be produced and dispersed (Soons, 2006). In some cases restoration of hydrochory may introduce and speed up the spread of undesirable species, therefore, cautious planning is necessary.

Restoration tactics often involve disturbances that generate opportunities for germination of seeds and regeneration of vegetation. These methods are also used to manage the current vegetation and prescribe the vegetation response to restoration (Pekas, 2010). In areas where restoration of BLM and WP vegetation communities is desired, eradication of the invasive species *Ludwigia peruviana* by methods such as chemical control, mechanical control, or prescribed fire, followed by increased managed water depths could help bring back the historical vegetation communities. Chemical control with herbicide was used in the Kissimmee River Restoration Project, however there were no detectable reductions in the vegetation four months after use (Carnal, 2005; Bousquin, unpublished data). Mechanical control has reduced vegetation through the mechanical removal of substrate, floating mats, and plants (Carnal, 2005). Prescribed fire has reduced woody shrubs and enhanced the vegetation mosaic in wetlands; however there are potential negative impacts such as an increase in vegetative reproduction (Miller et al., 1998). Carnal (2005) states that increased inundation of the floodplain will eliminate shrub species that are intolerant of flooding. Furthermore, initial high flows will eliminate much of the non-native and floating/mat-forming species, however flow must be maintained so that species suited for varying water levels and continuous flow become dominant. A higher cover of emergent native species could result from a decrease in floating, mat-forming and invasive species. Until the vegetation community structure stabilizes, monitoring in the Kissimmee River floodplain should continue and include adaptive management strategies to more thoroughly understand and change the system.

CONCLUSION

There is still much to learn about hydrochory, anemochory, and zoochory in the Kissimmee River floodplain and their roles in the restoration of this and other damaged floodplain ecosystems. One particular inconclusive point is whether the dispersal phenology maintains a correlation with seasonal water depth and velocity variation in years where the magnitudes of wet and dry season contrast. Second, further studies should focus on improving ichthyochory and avichory sampling strategies, which could provide a better understanding of the influences of these dispersal vectors in the Kissimmee River floodplain. Greater water depths during the wet season, as well as increased sampling frequency could improve future ichthyochory results. Alterations in the design of the avichory trap should include natural characteristics in order to better replicate a floodplain landscape.

Patterns of hydrochory in sites north of Oak Creek differed from the sites south of Oak Creek, with typical BLM species rarely found in the seed pool of the northern sites. The effectiveness of upstream seed dispersal for facilitating BLM restoration in areas north of Oak Creek should be further evaluated. This study supports other wetland research concluding that hydrochory can affect the population dynamics, geographic distribution, and persistence of floodplain communities (Merritt et al., 2010; Nilsson et al., 2010). The success rate of restoration efforts is directly influenced by seed dispersal vectors, and proper management of the system relies on understanding the interactions between hydrochory, anemochory, and zoochory with other biotic and abiotic patterns and processes.

Table 1: Most common species found in each vegetation community that was included in the phenology sampling.

Species	Plant Community Group
Pontederia cordata	BLM
Sagittaria lancifolia	BLM
Ludwigia peruviana	Invasive, especially in BLM
Panicum hemitomon	Long-hydroperiod WP
Rhynchospora spp.	WP
Scirpus spp.	WP
Salix caroliniana	WS
Cephalanthus occidentalis	BLM-BB, WS

Table 2: Means ± standard deviations for hydrochory traps north and south of Oak Creek over the 12-month sampling period for total seeds/trap, species richness, and seed Shannon-Wiener Diversity Index.

	Total Seed Density/Trap	Species Richness	Shannon Diversity
North Oak Creek			
BLM	100.13 ± 178.34	3.66 ± 4.03	0.52 ± 0.62
SS	58.59 ± 145.95	1.25 ± 2.78	0.14 ± 0.32
NSS	423.47 ± 1154.22	1.84 ± 3.73	0.10 ± 0.26
South Oak Creek			
BLM	362.92 ± 745.64	5.85 ± 5.29	0.80 ± 0.72
SS	395.83 ± 669.47	6.92 ± 5.59	0.96 ± 0.75
NSS	225.04 ± 468.70	3.96 ± 5.31	0.45 ± 0.65
Random Plots			
RP	304.75 ± 554.28	2.75 ± 3.20	0.49 ± 0.65
RL	2893.25 ± 5762.52	5.00 ± 5.77	0.56 ± 0.77

Table 3: ANOVA p values for hydrochory seeds, hydrochory species diversity, anemochory seeds, maximum wind, mean wind, vegetation species richness, standing vegetation axis 2 and axis 3, and hydrochory NMS axis 1 and axis 2 over the 12-month sampling period. P-values were reported for each test. Independent variables include month of sampling, site type (BLM, SS, NSS), Oak Creek (north or south of Oak Creek), and interaction effects.

	Month	**Site Type**	**Oak Creek**	**Month × SiteType**	**Month × OakCreek**	**SiteType × OakCreek**	**Month × SiteType × OakCreek**
Hydrochory Seed Density/Trap	0.0034**	0.0403*	0.2325	0.3609	0.1025	0.0067**	0.0041**
Hydrochory Species Richness	0.0005**	0.6718	0.3424	0.1620	0.0045**	0.2815	0.6676
Hydrochory Species Diversity	0.1479	0.0874	0.0105**	0.8084	0.0409*	0.1185	0.0100**
Anemochory Seed Density/Trap	0.0000**	0.0748	0.4460	0.4426	0.5012	0.3687	0.6337
Max Wind Speed	0.0000**	0.6512	0.0000**	0.7988	0.0000**	0.1010	0.5403
Mean Wind Speed	0.0000**	0.6362	0.0000**	0.9234	0.0002**	0.1575	0.7261
Vegetative Species Richness	0.0000**	0.0266*	0.0000**	0.2672	0.5418	0.2040	0.3958
Standing Vegetation NMS Axis 2	0.0041**	0.1364	0.2544	0.1910	0.8208	0.4173	0.7113
Standing Vegetation NMS Axis 3	0.0463*	0.3702	0.0001**	0.8182	0.7772	0.1281	0.7539
Hydrochory NMS Axis 1	0.8789	0.0015**	0.0002**	0.1423	0.2988	0.7445	0.7542
Hydrochory NMS Axis 2	0.0000**	0.0086**	0.5063	0.3898	0.0203*	0.0172**	0.8060

* Significant at the $p < 0.05$ level
** Significant at the $p < 0.01$ level

Table 4: Means ± standard deviations for anemochory traps over the 12-month sampling period for total seed density/trap, species richness, and seed Shannon-Wiener Diversity Index.

	Total Seed Density/Trap	Species Richness	Shannon Diversity
North Oak Creek			
BLM	13.38 ± 25.16	1.91 ± 2.29	0.38 ± 0.5
SS	6.41 ± 13.56	1.47 ± 1.92	0.29 ± 0.49
NSS	8.13 ± 13.32	1.41 ± 1.81	0.29 ± 0.43
South Oak Creek			
BLM	21.23 ± 77.14	1.79 ± 1.61	0.41 ± 0.49
SS	8.29 ± 6.29	1.88 ± 2.05	0.46 ± 0.61
NSS	7.25 ± 9.98	1.96 ± 1.81	0.49 ± 0.53
Random Plots			
RP	58.5 ± 109.76	1.75 ± 2.22	0.37 ± 0.74
RL	4.25 ± 6.13	1.25 ± 1.5	0.37 ± 0.44

Table 5: Kruskal-Wallis Non-Parametric test for significance. P-values reported for each variable.

Kruskal-Wallis Test	**Site Type**	**Month**	**Oak Creek**
"Non-Parametric Test"		**P-Values**	
Anemochory Species Richness	0.8737	0.0001**	0.1611
Anemochory Species Diversity	0.9448	0.0001**	0.1310
Water Depth	0.0259*	0.0274*	0.0001**
Water Velocity	0.9995	0.2147	0.4976
Wind Direction	0.9877	0.0001**	0.1595
Standing Vegetation Percent Cover	0.7324	0.0306*	0.5464
Standing Vegetation NMS Axis 1	0.0479*	0.0001**	0.0001**
Hydrochory NMS Axis 3	0.1103	0.0001**	0.0001**

* Significant at the p < 0.05 level

** Significant at the p < 0.01 level

Table 6: Summary table for Ichthyochory throw traps. Occurred only in the July sampling period due to lack of water in other sampling months. (- = No data).

Location	Sample Date	# Fish Collected	Species Richness	Type of Fish	Length (mm)	Proportion of Fish with Seeds
L1	7/10/11	0	0	-	-	-
L2	7/10/11	2	1	Mosquito Fish	25 mm	0
				Mosquito Fish	18 mm	0
L3	7/10/11	0	0	-	-	-
L4	7/10/11	0	0	-	-	-
L5	7/10/11	2	2	Sailfin Catfish	40 mm	0
				Mosquito Fish	20 mm	0
L6	7/10/11	0	0	-	-	-
L7	7/10/11	12	2	Sailfin Catfish	22 mm	0
				Mosquito Fish	< 10 mm	0
				Mosquito Fish	< 10 mm	0
				Mosquito Fish	< 10 mm	0
				Mosquito Fish	< 10 mm	0
				Sailfin Catfish	25 mm	0
				Sailfin Catfish	23 mm	0
				Sailfin Catfish	20 mm	0
				Sailfin Catfish	22 mm	0
				Sailfin Catfish	21 mm	0
				Sailfin Catfish	23 mm	0
				Mosquito Fish	10 mm	0
L8	7/10/11	3	2	Mosquito Fish	31 mm	0
				Golden Top Minnow	15 mm	0
				Golden Top Minnow	16 mm	0

Table 7: Mean total percent cover and species richness for standing vegetation north and south of Oak Creek, as well as in the different sites.

	% Total Cover	Species Richness
North of Oak Creek	80.0%	3.0
BLM	77.0%	3.4
SS	79.2%	2.8
NSS	78.9%	2.6
South of Oak Creek	78.0%	4.0
BLM	73.8%	4.3
SS	77.2%	4.1
NSS	73.2%	3.6
Random Plots		
RP	71.0%	4.0
RL	70.0%	3.3

Table 8: Mean percent cover for standing vegetation on the 8 most common species in the BLM-BB and WP communities.

	P. cordata	*S. latifolia*	*L. peruviana*	*P. hemitomon*	*Rhynchospora* spp.	*Scirpus* spp.	*S. caroliniana*	*C. occidentalis*
North Oak Creek								
BLM	0.42%	3.75%	0%	26.00%	0.29%	1.04%	0%	0%
SS	0%	0.04%	0%	41.04%	0%	0%	0%	0.08%
NSS	0.92%	0%	0%	31.15%	0%	0.63%	0.33%	0%
South Oak Creek								
BLM	0.21%	9.88%	4.79%	10.92%	0%	1.25%	0.63%	4.38%
SS	0.08%	5.65%	5.08%	10.00%	0%	0%	0%	10.75%
NSS	0%	0%	0.63%	2.50%	0%	0%	5.54%	7.71%
Random Plots								
RP	0%	1.25%	0%	1.5%	0%	0%	0%	0%
RL	0%	0%	0%	0%	0%	0%	0%	18.8%

Table 9: Summary table for Seed Release data. Occurred only in the July sampling month due to lack of water in other sampling months. (L = Location, RL = Random Ludwigia site, RP = Random Panicum site) (- = No data)

Location	# Seeds Moved	Mean Distance (cm)	Rate of Moved Seeds (cm/s)	Direction Traveled	% Seeds Trapped in Vegetation	% Seeds that Sank
L1	17	22.05	0.00030	N/S	100%	75%
L2	10	15.24	0.00018	SE	100%	90%
L3	8	45.72	0.00053	NE	100%	25%
L4	10	12.70	0.00015	NE	100%	>50%
L5	0	0	0	0	100%	>50%
L6	0	0	0	0	100%	>50%
L7	-	-	-	-	-	-
L8	-	-	-	-	-	-
RP	-	-	-	-	-	-
RL	0	0	0	0	100%	90%

Table 10: Mean seed phenology for 8 most common species in the BLM-BB and WP communities. (BLM = Broad Leaf Marsh, NSS = Non-Seed Shadow, SS = Seed Shadow, RP = Random Panicum site).

Species	Sample Location	Total # Fruits	# Mature Fruits	Fruiting Months
P. cordata	L1 BLM1	0	0	November & January
	L1 SS1	0	0	
	L5 SS1	0.25	0	
	L5 BLM2	1.25	1.25	
	L5 BLM2	1.5	1.5	
S. Lancifolia	L1 BLM2	0	0	November
	L1 BLM1	5.5	5.5	
	L4 BLM1	4.25	4.25	
	L5 BLM2	1.5	0.25	
	L5 BLM1	7.5	7.5	
L. peruviana	L3 BLM1	26.5	22.25	November, January & April
	L3 BLM1	69.5	67.75	
	L3 BLM2	12.5	10.75	
	L1 BLM1	51.5	38	
	L1 BLM1	8	7.5	
P. hemitomon	L8 NSS1	0	0	November & April
	L8 NSS2	0	0	
	L7 NSS1	0	0	
	RP	0	0	
	L4 SS1	6.75	0	
Rhynchospora spp.	L6 NSS2	4	4	November
	L5 SS1	2.25	0	
	L4 BLM1	2.75	2.75	
	L5 NSS1	5.25	0	
	L5 NSS1	3.5	0	
Scirpus spp.	L8 BLM1	7.25	3.25	November, January & April
	L7 BLM2	19	0	
	L7 BLM2	0	0	
	L4 NSS2	2	2	
	L4 NSS2	0	0	
S. caroliniana	L3 SS2	112.5	0	January & April
	L3 NSS2	22.5	0	
	L3 NSS2	0	0	
	L4 NSS1	18	18	
	L4 NSS2	21.25	0	
C. occidentalis	L3 NSS1	7.25	6.5	November, January, April, & July
	L3 SS1	6	3	
	L4 SS1	14	0.25	
	L2 SS1	36	1.25	
	L2 NSS2	34.06	20.5	

Table 11: Regressions of anemochory seeds, hydrochory NMS axis 1 and 2 on independent variables that include water depth and velocity, mean wind speed, wind direction, vegetative species richness, month, north or south of Oak Creek, and site type. Coefficients, R^2, p-values and global f-values reported for each independent variable. The models reported all have significant global f-values.

	Anemochory Seed Density/Trap	**Hydrochory NMS Axis 1**	**Hydrochory NMS Axis 2**
Global F-Values	0.0067**	0.0012**	0.0000**
R^2 Values	0.3637	0.4086	0.527
Adj. R^2 Values	0.2480	0.3057	0.4447
Water Depth	1.0852	-1.0307	6.0026
Water Velocity	-50.815	-14.705	-107.60
Mean Wind Speed	0.2472	-0.0667	-1.2625*
Wind Direction	-0.0120	-0.0026	-0.3731**
Vegetative Species Richness	-0.0385	-0.0249	0.0801
Month	0.0795*	0.0111	-0.0830
Oak Creek	-0.3576	0.7274**	-0.0357
Site Type	0.2614*	-0.3017**	-0.5151

* Significant at the $p < 0.05$ level
** Significant at the $p < 0.01$ level


Figure 1: Photo of a section of the restored river with backfilled canal.

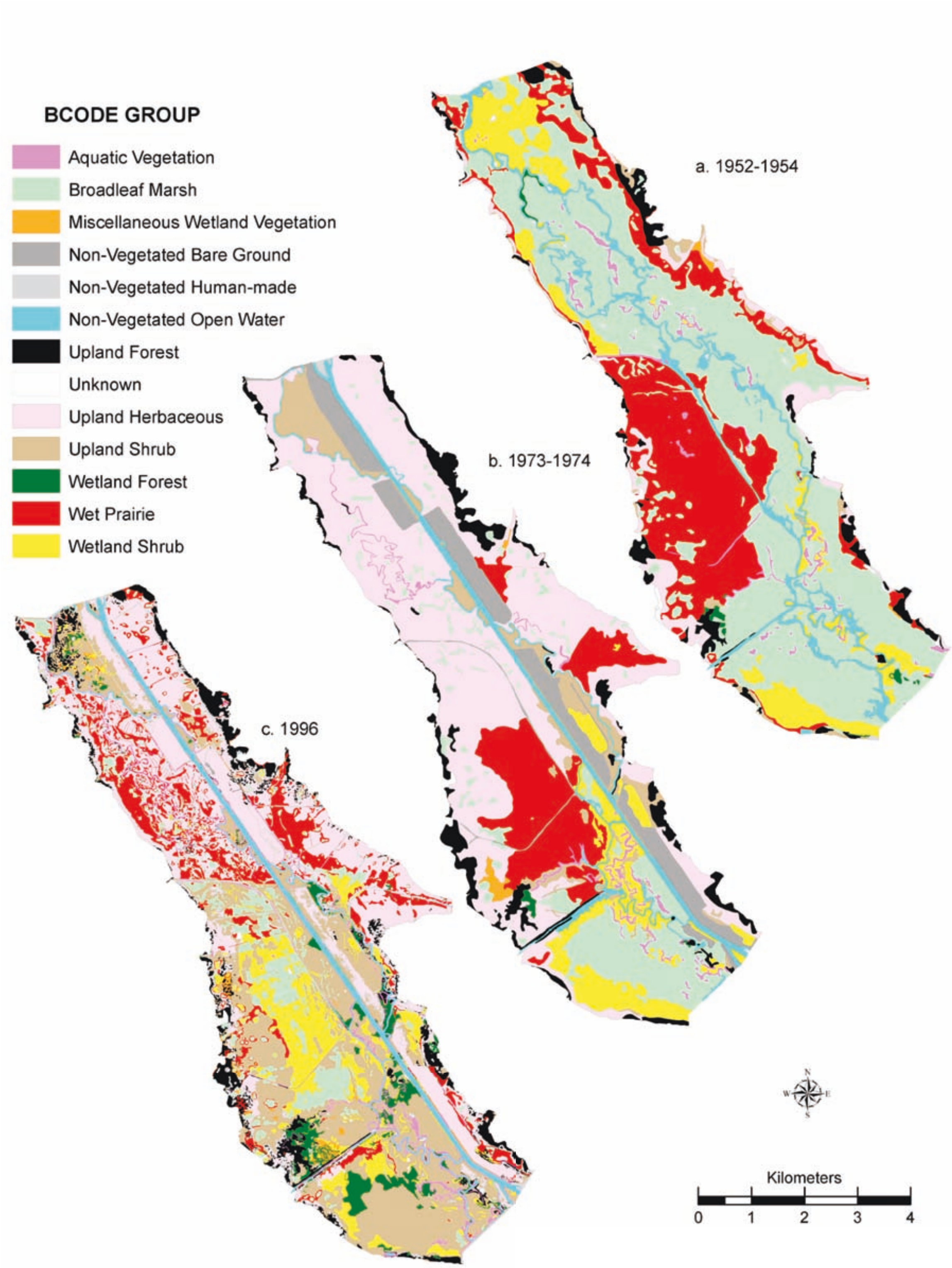


Figure 2. Vegetation maps of Pool C: (a) 1952-1954 (pre-channelization, reference period) (data from Pierce et al. 1982); (b) 1973-1974 (early post-channelization) (data from Milleson et al. 1980); and (c) 1996 (post-channelization, baseline period).

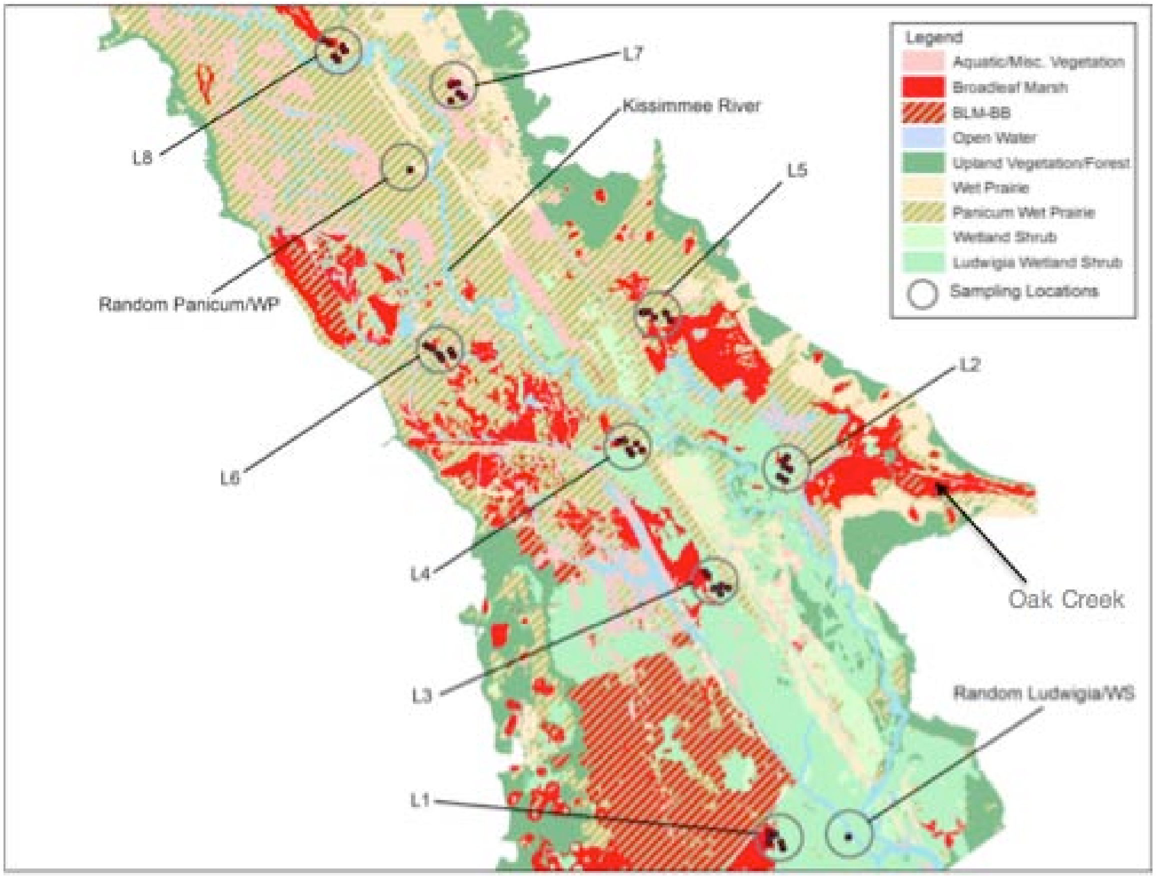


Figure 3: Vegetation map of Kissimmee River floodplain area Pool C and sampling locations.

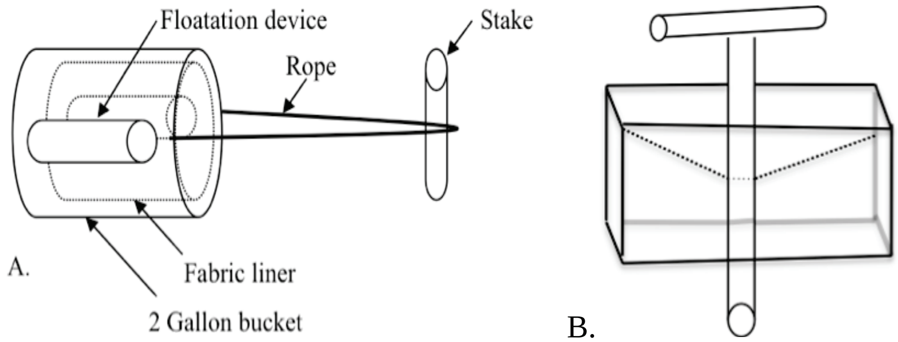


Figure 4: Schematic design of the A. hydrochory trap, and B. avichory trap.

Figure 5: Example of actual avichory (left) and anemochory (right) traps used in the Kissimmee River.

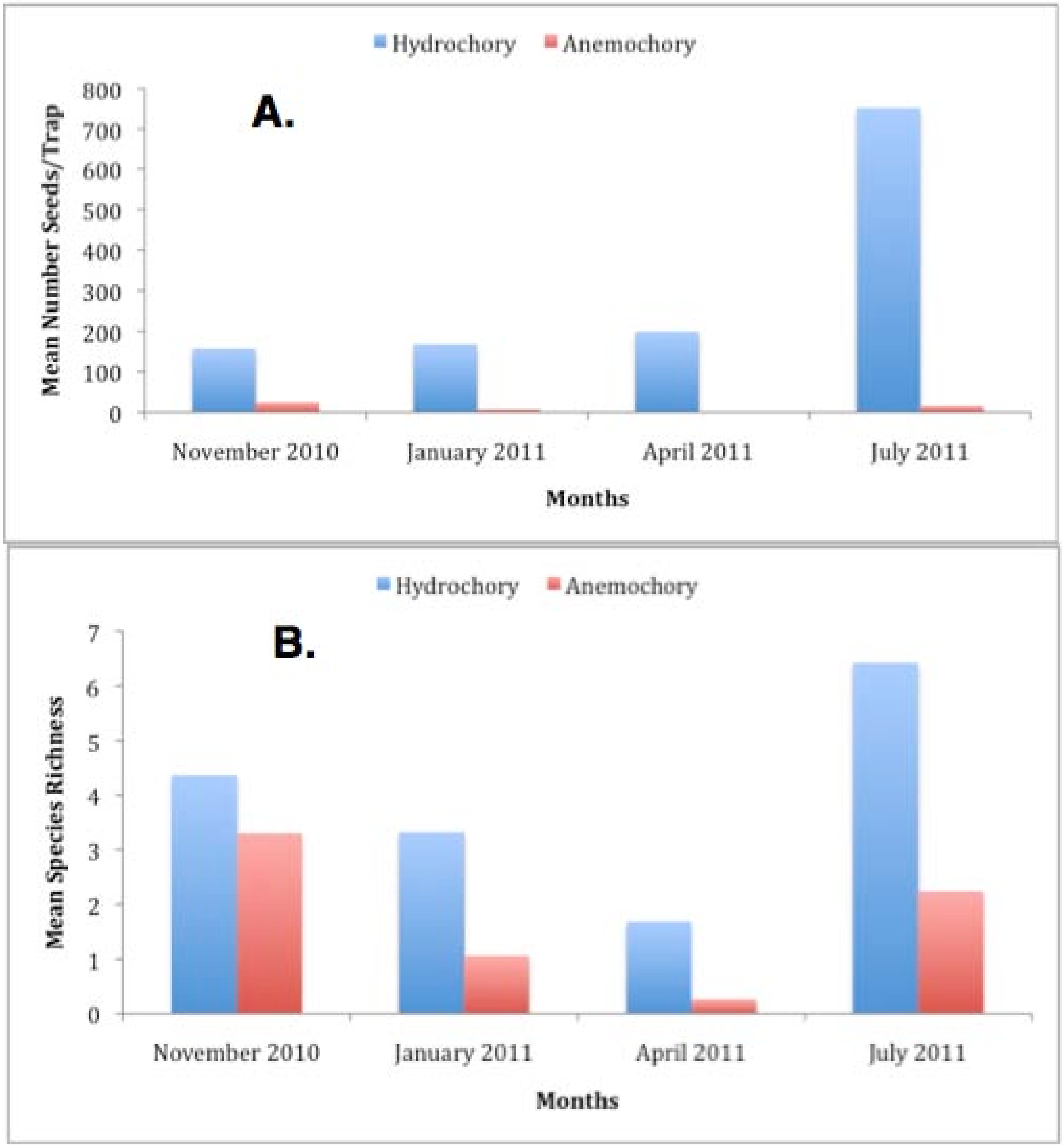


Figure 6: A) Mean number seeds/trap found by month for hydrochory and anemochory over the entire 12-month sampling period. B) Mean species richness by month for hydrochory and anemochory over the entire 12-month sampling period. Hydrochory seed traps are labeled blue and anemochory seed traps are labeled red.

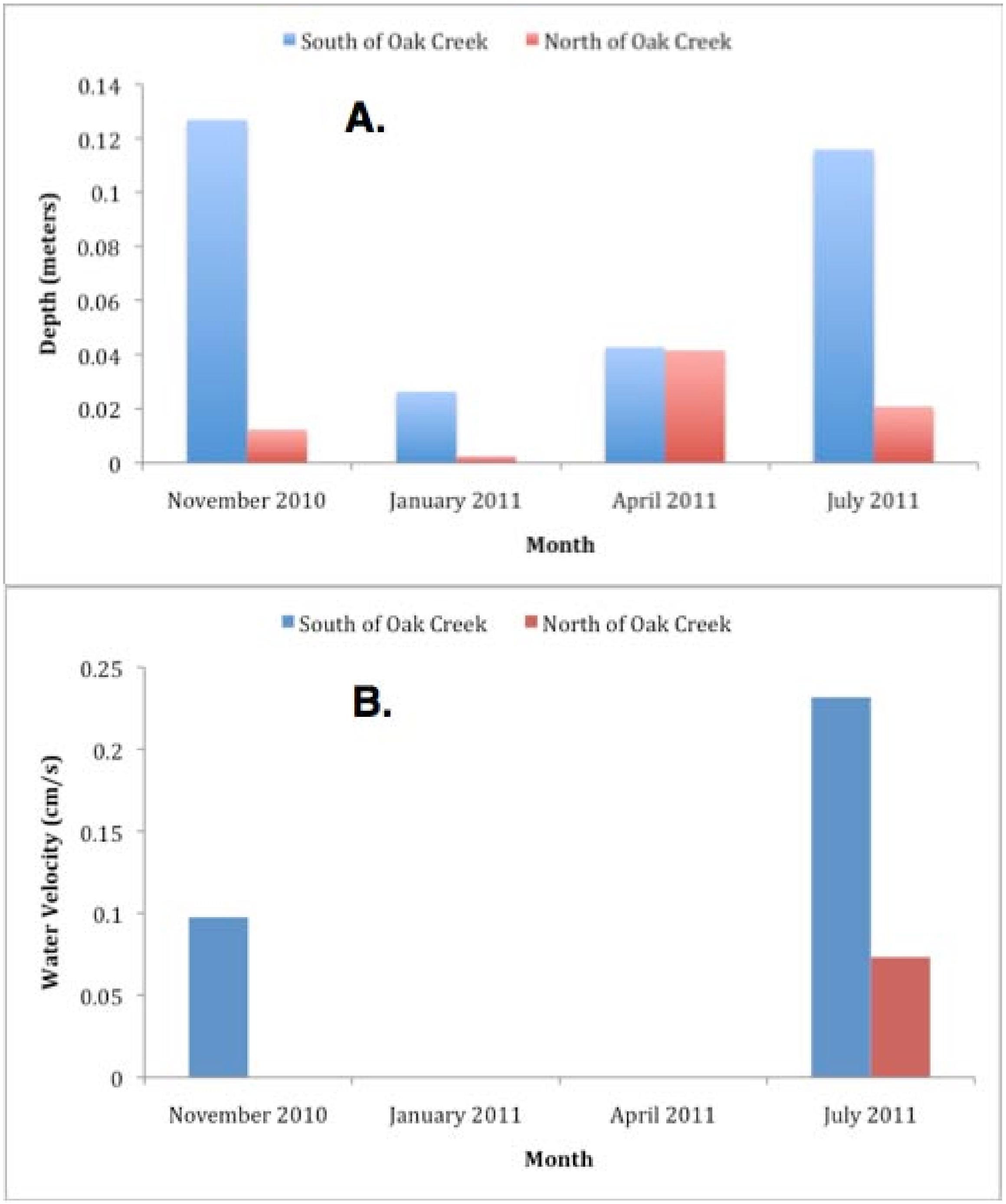
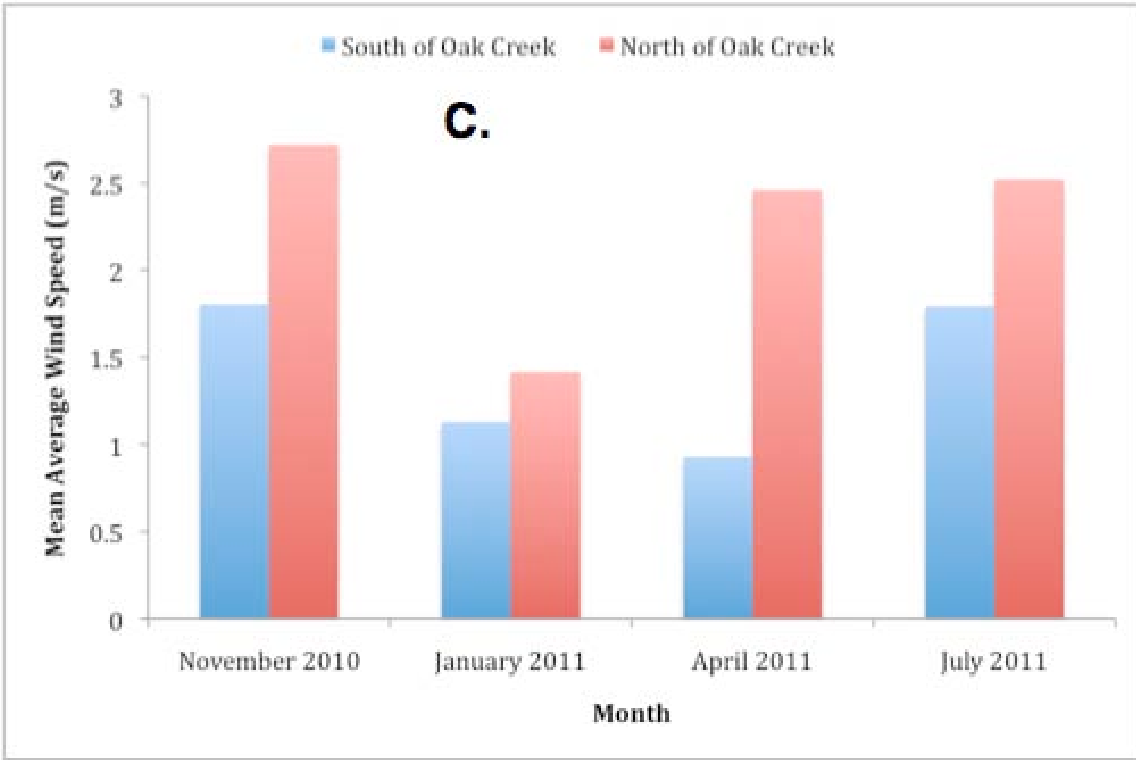


Figure 7: A) Mean water depths (meters) north and south of Oak Creek by month over the entire 12-month sampling period. B) Mean water velocities (cm/s) north or south of Oak Creek by month over the entire 12-month sampling period. Sites south of Oak Creek are labeled as blue, and sites north of Oak Creek are labeled as red.



C) Mean average wind speeds (m/s) north and south of Oak Creek by month. Sites south of Oak Creek are labeled as blue, and sites north of Oak Creek are labeled as red.

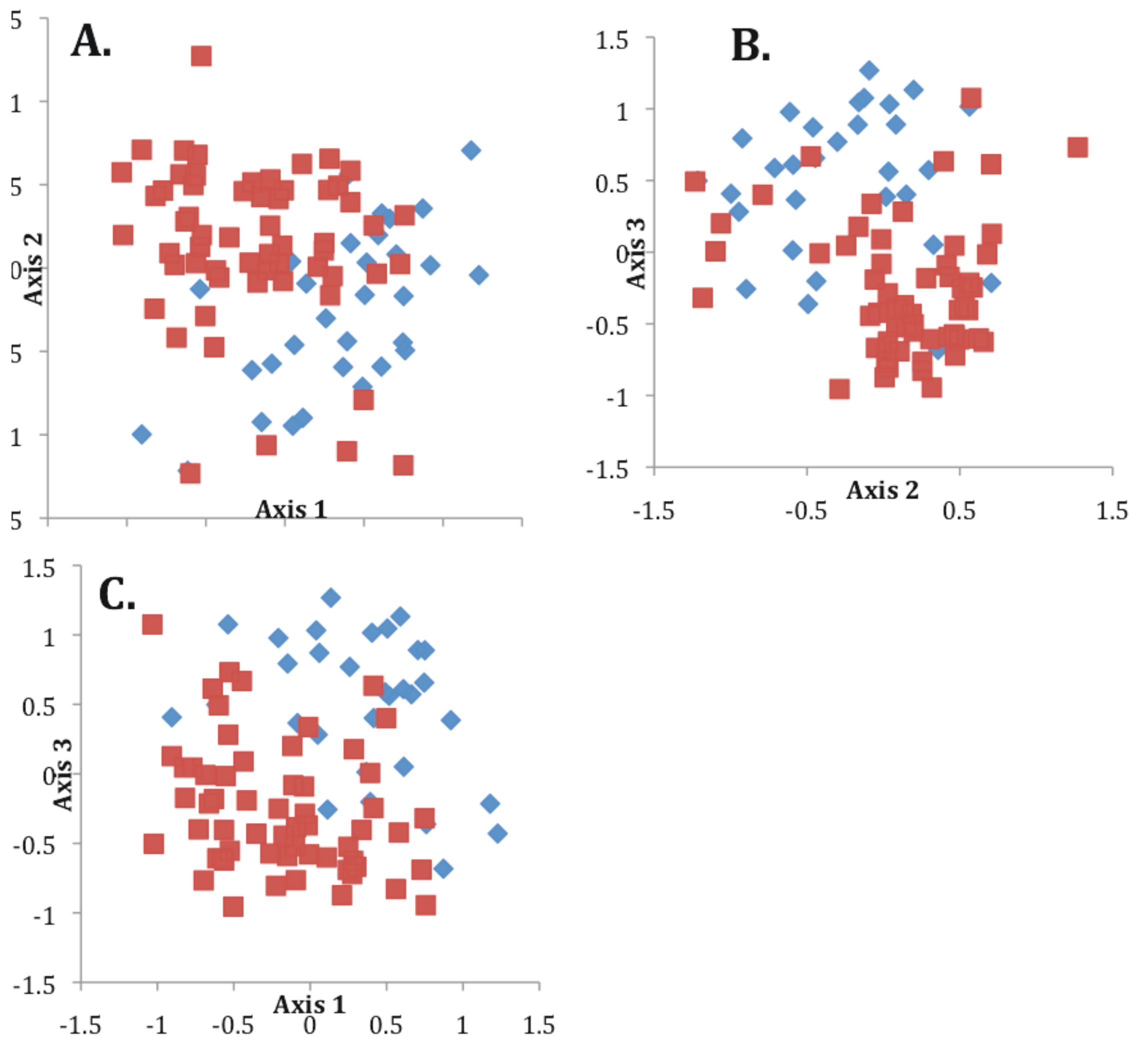


Figure 8: Non-metric Multidimensional Scaling (NMS) scatter plot for hydrochory seed pool composition categorized by relationships to Oak Creek: (A) Axis 1 vs. Axis 2 (B) Axis 2 vs. Axis 3 (C) Axis 1 vs. Axis 3. The diamond represents the north sites, and the square represents the south sites.

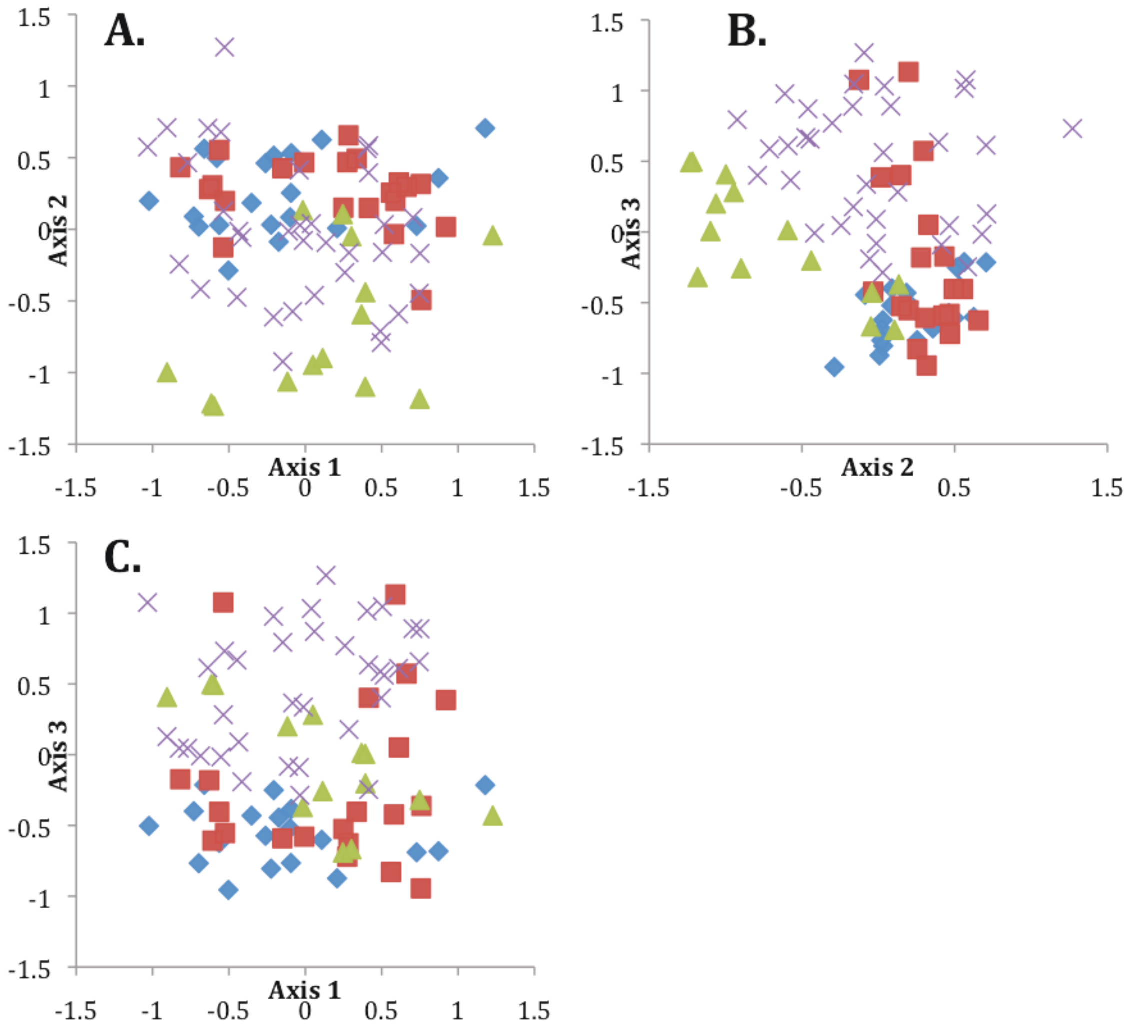


Figure 9: Non-metric Multidimensional Scaling (NMS) scatter plot for hydrochory seed pool composition categorized by sampling month: (A) Axis 1 vs. Axis 2 (B) Axis 2 vs. Axis 3 and (C) Axis 1 vs. Axis 3. The diamond represents November, square is January, triangle is April, and the ‘x’ symbol is July.

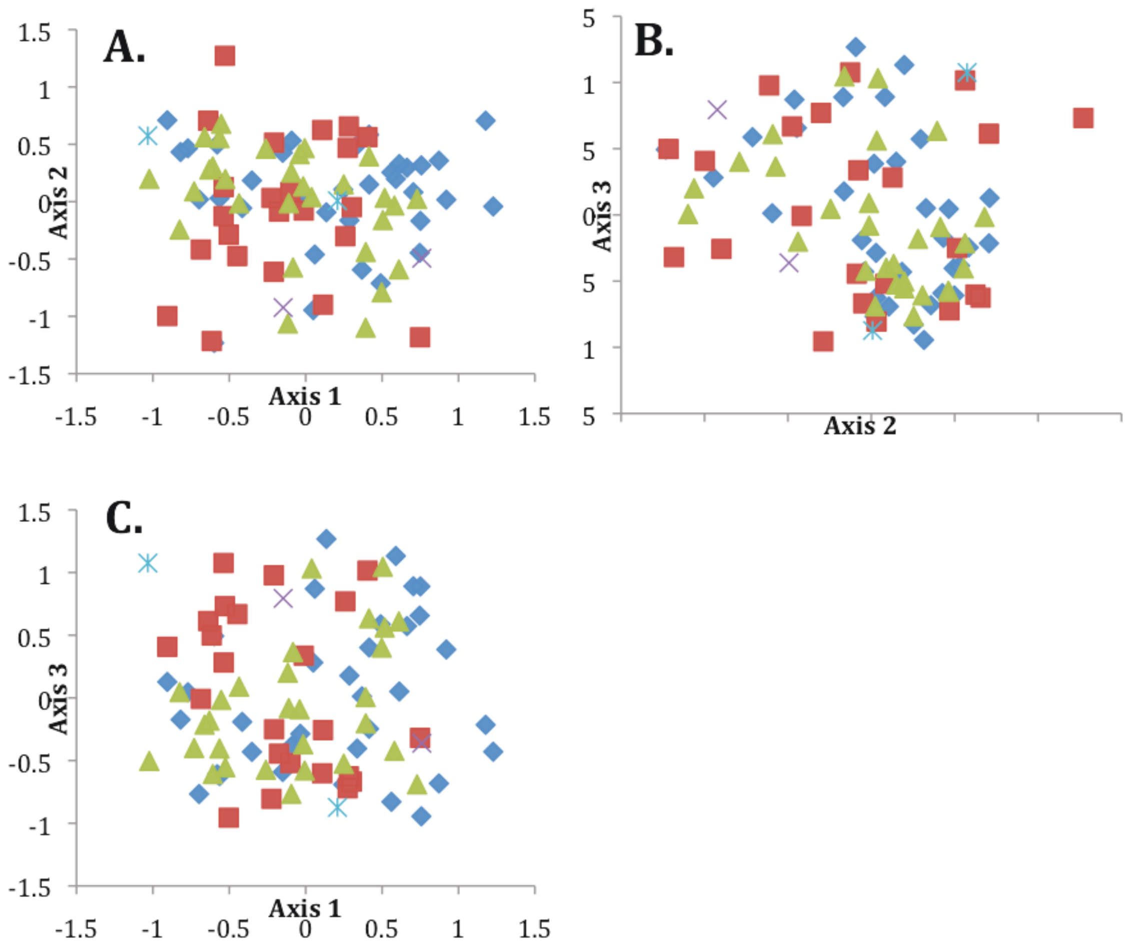


Figure 10: Non-metric Multidimensional Scaling (NMS) scatter plot for hydrochory seed pool composition categorized by site type: (A) Axis 1 vs. Axis 2 (B) Axis 2 vs. Axis 3 and (C) Axis 1 vs. Axis 3. The diamond represents BLM sites, square is Non-seed shadow sites, triangle is seed shadow sites, ‘x’ symbol is random Panicum site, and * symbol is random Ludwigia site.

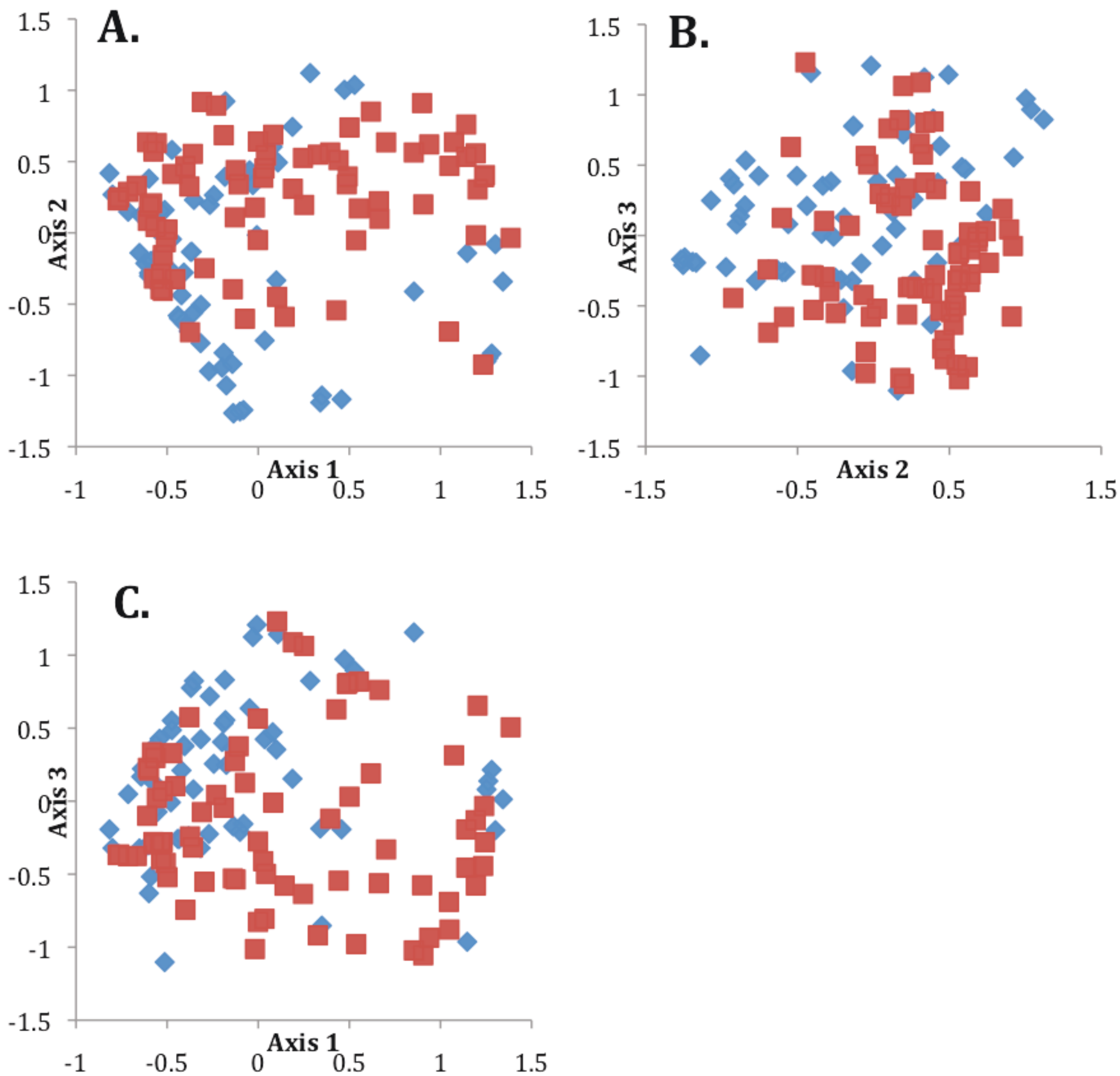


Figure 11: Non-metric Multidimensional Scaling (NMS) scatter plot for standing vegetation categorized by relationship to Oak Creek: (A) Axis 1 vs. Axis 2 (B) Axis 2 vs. Axis 3 and (C) Axis 1 vs. Axis 3. The diamond represents the sites north of Oak Creek, and the square represents the sites south of Oak Creek.

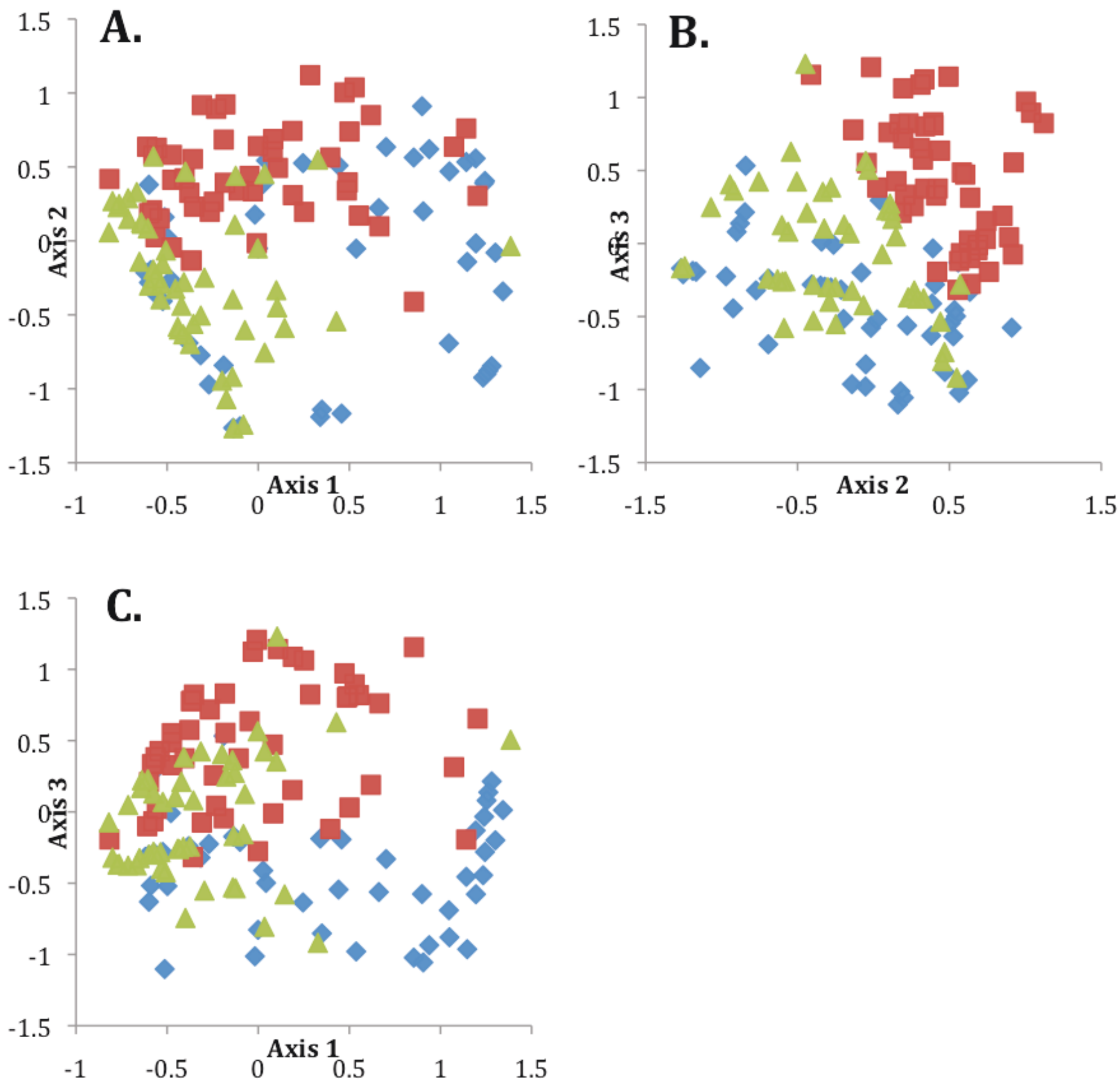


Figure 12: Non-metric Multidimensional Scaling (NMS) scatter plot for standing vegetation categorized by sampling month: (A) Axis 1 vs. Axis 2 (B) Axis 2 vs. Axis 3 and (C) Axis 1 vs. Axis 3. The diamond represents January, square is April, and the triangle is July.

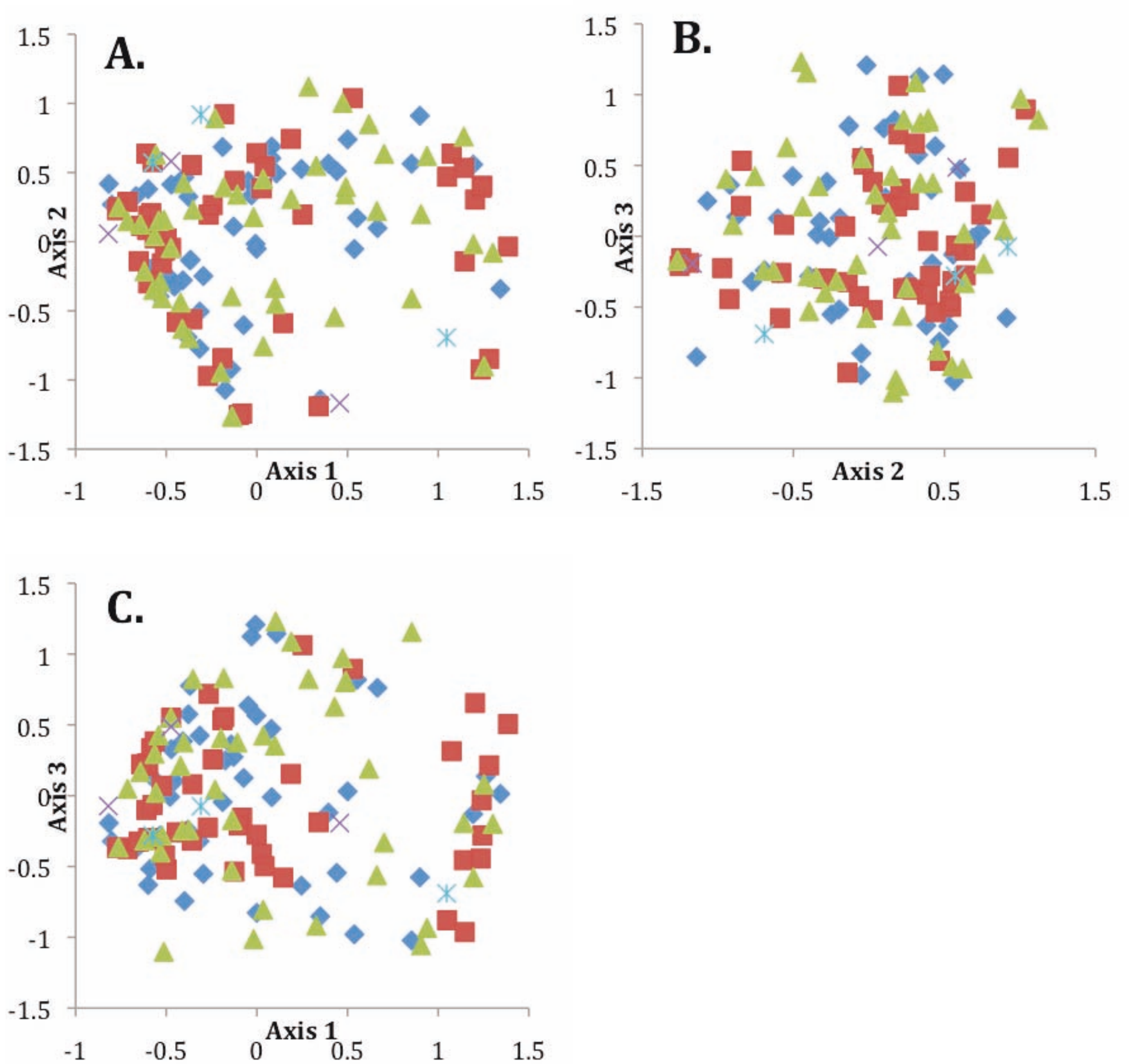


Figure 13: Non-metric Multidimensional Scaling (NMS) scatter plot for standing vegetation categorized by site type: (A) Axis 1 vs. Axis 2 (B) Axis 2 vs. Axis 3 and (C) Axis 1 vs. Axis 3. The diamond represents BLM sites, square is Non-seed shadow sites, triangle is seed shadow sites, 'x' symbol is random Panicum site, and * symbol is random Ludwigia site.

REFERENCES

Adams, S. B., P. B. Hamel, K. Connor, B. Burke, E. S. Gardiner and D.Wise. 2007. Potential Roles of Fish, Birds, and Water in Swamp Privet (*Forestiera acuminata*) Seed Dispersal. *Southeastern Naturalist* 6.4:669-682.

Barrat-Segretain M. H. 1996. Strategies of reproduction, dispersion and competition in river plants: a review. *Vegetation* 123:13–37.

Boedeltje G, J.P. Bakker, A. T. Brinke, J. M. Groenendael and M. Soesbergen. 2004. Dispersal phenology of hydrochorous plants in relation to discharge, seed release time and buoyancy of seeds: the flood pulse concept supported. *Journal of Ecology* 92:786–796.

Borchsenius, F. 2002. Spatial and Temporal Variation in Hydrochory in Amazonian Floodplain Forest. *BioTropica* 34.4:606-612.

Bousquin, S., D. H. Anderson, D. J. Colangelo and G. E. Williams. 2005. Chapter 1: Introduction to baseline studies of the channelized Kissimmee River. In: Volume I, Kissimmee River Restoration Studies, Establishing a baseline: Pre-restoration studies of the channelized Kissimmee River. SFWMD Technical Publication ERA 432.

Breeden, G., and J. T. Brosnan. 2010. Virgnia Buttonweed (*Diodia Virginiana*). *Turfgrass Science at the University of Tennessee*. Institute of Agriculture. Web. <http://www.tennesseeturfgrassweeds.org/admin/Lists/Fact%20Sheets/Attachments/9/W147.pdf>.

Carnal, L. 2005. Expectation 12: Areal coverage of floodplain wetlands. In: Volume II, Kissimmee River Restoration Studies, Defining success: Expectations for restoration of the Kissimmee River. SFWMD Technical Publication ERA 433.

Carnal, L. and S. G. Bousquin. 2005. Chapter 10, Areal coverage of floodplain plant communities in Pool C of the channelized Kissimmee River. In: Volume I, Kissimmee River Restoration Studies, Establishing a baseline: Pre-restoration studies of the channelized Kissimmee River. SFWMD Technical Publication ERA 432.

Clark, J.S., M. Silman, R. Kern, F. Macklin and J. HilleRisLambers. 1999. Seed dispersal near and far: Patterns across temperate and tropical forests. *Ecology* 80:1475-1494.

Cook, C.D.K. 1988. Dispersion in aquatic and amphibious vascular plants. *Plant Life in Aquatic and Amphibious Habitats* 179-190.

Correa, S. B., K. O. Winemiller, H. Lopez-Fernandez and M. Galetti. 2007. Evolutionary Perspectives on Seed Consumption and Dispersal by Fishes. *BioScience* 57.9:748-756.

Darwin C. 1859. On the Origin of Species by Means of Natural Selection. Murray, London, U.K.

DeVlaming, V. and V. W. Proctor. 1968. Dispersal of aquatic organisms: viability of seeds recovered from the droppings of captive killdeer and mallard ducks. *American Journal of Botany* 55:20–26.

Fenner, M. 1985. *Seed Ecology*. Chapman and Hall, London, UK.

Glenn, J. L. and D. A. Arrington. 2005. Chapter 13: Status of Fish Assemblages of the Kissimmee River Prior to Restoration: Baseline Conditions and Expectations for Restoration. In: Volume I, Kissimmee River Restoration Studies, Establishing a baseline: Pre-restoration studies of the channelized Kissimmee River. *SFWMD Technical Publication ERA* 432.

Goulding, M. 1980. The Fishes and the Forest. *University of California Press*, Berkley, California.

Greene D. F, and C. Calogeropoulos. 2002. Measuring and modeling seed dispersal of terrestrial plants. *Dispersal Ecology* 3–23.

Griffith, A. B., and I. N. Forseth. 2002. Primary and Secondary Seed Dispersal of a Rare, Tidal Wetland Annual, *Aeschynomene virginica*. *WETLANDS* 22.4:696-704.

Helfield, J. M., S. J. Capon, C. Nilsson, R. Jansson & D. Palm. 2007. Restoration of rivers used for timber floating: effects on riparian plant diversity. *Ecological Applications* 17:840–851.

Hooftman, D.A.P., M. van Kleunen and M. Diemer. 2003. Effects of habitat fragmentation on the fitness of two common wetland species: *Carex davalliana* and *Succisa pratensis*. *Oecologia* 134:350-359.

Jacobs, S. W. L., F. Perrett, G. R. Sainty, K. H. Bowmer and G. L. Jacobs. 1994. *Ludwigia peruviana* (Onagraceae) in the Botany Wetlands near Sydney, Australia. *Australian Journal of Marine and Freshwater Research* 45:1481–1490.

Jansson, R., C. Nilsson, M. Dynesius and E. Andersson. 2000. Effects of river regulation on river-margin vegetation: A comparison of eight boreal rivers. *Ecological Applications* 10:203-224.

Jansson, R., U. Zinko, D. M. Merritt and C. Nilsson. 2005. Hydrochory Increases Riparian Plant Species Richness: a Comparison between a Free-flowing and a Regulated River. *Journal of Ecology* 93:1094-1103.

Kubitzki, K. and A. Ziburski. 1994. Seed Dispersal in Floodplain Forests of Amazonia. *BioTropica* 26.1:30-43.

Kuparinen, A. 2006. Mechanistic models for wind dispersal. *TRENDS in Plant Science* 11.6:296-301.

Kushlan, J. A. 1981. Sampling characteristics of enclosure fish traps. *Transactions of the American Fisheries Society* 110:557-662.

Levin, S. A., H. C. Muller-Landau, R. Nathan and J. Chave. 2003. Ecology and Evolution of Seed Dispersal: A Theoretical Perspective. *Annual Review of Ecology Evolution and Systematics* 34:575-604.

Malanson, G. P. 1993. Riparian Landscapes. *Cambridge University Press*. Cambridge.

Merritt, D. M. and E. E. Wohl. 2006. Plant dispersal along rivers fragmented by dams. *River Research and Applications* 22:1-26.

Merritt, D. M., C. Nilsson and R. Jansson. 2010. Consequences of Propagule Dispersal and River Fragmentation for Riparian Plant Community Diversity and Interannual Turnover. *Ecological Society of America* 80.4:609-626.

Middleton, B. 1995. Sampling devices for the measurement of seed rain and hydrochory in rivers. *Bulletin of the Torrey Botanical Club* 122:152-155.

Miller, S. J., K. J. Ponzio, M. A. Lee, L. W. Keenan and S. R. Miller. 1998. The use of fire in wetland preservation and restoration: are there risks? *Tall Timbers Fire Ecology Conference Proceedings* 127-139.

Milleson, J. F., R. L. Goodrick, and J. A. Van Arman. 1980. Plant communities of the Kissimmee River Valley. Technical Publication 80-7. South Florida Water Management District, West Palm Beach, Florida, USA.

Mkandawire, M. and E. G. Dudel. 2007. Are *Lemna* spp. Effective Phytoremediation Agents? *Bioremediation, Biodiversity, and Bioavailability* 1:56-71.

Moggridge, H. L. and A. M. Gurnell. 2010. Hydrological Controls on the Transport and Deposition of Plant Propagules on Riparian Zones. *River Research and Applications* 26:512-527.

Neff, K.P. and A. H. Baldwin. 2005. Seed dispersal into wetlands: Techniques and results for a restored tidal freshwater marsh. *Wetlands* 25:392-404.

Nilsson, C., R. L. Brown, R. Jansson and D. M. Merritt. 2010. The Role of Hydrochory in Structuring Riparian and Wetland Vegetation. *Biological Reviews* 85.4:837-858.

Ozinga, W. A., R. M. Bekker, J. Schaminee and J. M. Van Groenendael. 2004. Dispersal Potential in Plant Communities Depends on Environmental Conditions. *Journal of Ecology* 92:767-777.

Pekas, K M. 2010. Seed Pool Dynamics of a Great Basin Sagebrush Community in the Context of Restoratio*n*. *Thesis*. Utah State University. Logan, Utah.

Pierce, G. J., A. B. Amerson, and L. R. Becker. 1982. Final Report: pre-1960 floodplain vegetation of the lower Kissimmee River Valley, Florida. Biological Services Report 82-3. U. S. Army Corps of Engineers, Jacksonville, Florida, USA.

Pollux B.J.A., L. Santamaria and N. J. Ouborg. 2005. Differences in endozoochorous dispersal between aquatic plant species, with reference to plant population persistence in rivers. *Freshwater Biology* 50:232-242.

Pollux, B J A., M. De Jong, A. Steegh, N. J. Ouborg, J. M. Van Groenendael and M. Klaassen. 2006. The Effect of Seed Morphology on the Potential Dispersal of Aquatic Macrophytes by the Common Carp (*Cyprinus carpio*). *Freshwater Biology* 51:2063-2071.

Pollux, B. J. A., N. J. Ouborg, J. M. Van Groenendael and M. Klaassen. 2007. Consequences of Intraspecific Seed-size Variation in *Sparganium Emersum* for Dispersal by Fish. *Functional Ecology* 21:1084-1091.

Ridley, H. N. 1930. The Dispersal of Plants Throughout the World. Reeve & Co., Ltd, Ashford, Kent, U.K.

Schneider, R. L. and R. R. Sharitz. 1988. Hydrochory and regeneration in a bald cypress water tupelo swamp forest. *Ecology* 69:1055-1063.

Soons, M. B. 2006. Wind Dispersal in Freshwater Wetlands: Knowledge for Conservation and Restoration. *Applied Vegetation Science* 9:271-278.

Soons, M.B., J. H. Messelink, E. Jongejans and G. W. Heil. 2005. Habitat fragmentation reduces grassland connectivity for both short-distance and long-distance wind-dispersed forbs. *Journal of Ecology* 93:1214-1225.

Spencer, L. J. and S. Bousquin. In press. Interim Responses of Wetland Vegetation to Phase I of the Kissimmee River Restoration Project: Comparisons of Vegetation Maps from Five Periods in the River's History. *Restoration Ecology*.

U.S. Army Corps of Engineers. 1991. Final integrated feasibility report and environmental impact statement environmental restoration Kissimmee River, Florida. U.S. Army Corps of Engineers. Jacksonville, Florida, USA.

Vittoz, P. and R. Engler. 2007. Seed Dispersal Distances: a Typology Based on Dispersal Modes and Plant Traits. *Botanica Helvetica* 117:109-124.

Washington State Department of Ecology. 1994. Non-Native Invasive Fresh Water Plants: Water Hyacinth. *Web*. <http://www.ecy.wa.gov/programs/wq/plants/weeds/aqua010.html>.

Watkinson, A. R. 1978. The demography of a sand dune annual: *Vulpia fasciculata*. III. The dispersal of seeds. *Journal of Ecology* 66:483-498.

Wetzel, P. R., A. G. van der Valk and L. A. Toth. 2001. Restoration of wetland vegetation on the Kissimmee River floodplain: potential role of seed banks. *Wetlands* 21:189-198.

Williams, G. E., J. W. Koebel, D. H. Anderson, S. G. Bousquin, D. J. Colangelo, J. L. Glenn, B. L. Jones, C. Carlson, L. Carnal and J. Jorge. 2005. Kissimmee River restoration and upper basin initiatives, Chapter 11. In: South Florida Environmental Report Volume I: The South Florida environment water year 2004. *SFWMD and FLDEP Technical Publication ERA* 432.