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Evaluation of the three-dimensional patterns and ecological impacts of the invasive Old World climbing fern (Lygodium microphyllum)

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EVALUATION OF THE THREE-DIMENSIONAL PATTERNS AND ECOLOGICAL IMPACTS OF THE INVASIVE OLD WORLD CLIMBING FERN (*Lygodium microphyllum*)

by

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ABSTRACT

Invasion by non-native species has had significant ecological and economic impacts on a global scale. In the state of Florida, Old World climbing fern (*Lygodium microphyllum*) is an invasive plant listed by FLEPPC as a category one invader with significant ecological impacts that threaten native plant diversity. This species relies on existing vegetative structures for support to climb into the forest canopy and forms dense mats that cover tree crowns. This subsequently affects the resources available to other species present. Quantifying the structural changes due to the presence of this species has proved logistically difficult, especially on a large spatial scale.

Airborne LiDAR (Light Detection And Ranging) technology is a form of remote sensing that measures the elevation of surfaces over a site. In this study I utilized LiDAR to calculate various forest structure metrics at Jonathan Dickinson State Park (JDSP) in Hobe Sound, Florida across various management frequencies and densities of Old World climbing fern. These data were used to quantify the degree to which this invasive species alters forest structure across these two gradients. I also recorded species composition in the field to relate how Old World climbing fern impacts native plant diversity. Structural measurements including average canopy height, height of median energy (HOME), rugosity, canopy openness, and vertical structural diversity (LHDI) were calculated for a total of three hundred 0.25ha sites stratified by invasion density and management frequency.

Using a combination of univariate and multivariate statistical analyses I found that the presence of Old World Climbing fern altered the physical structure of the forest communities it invades. Higher percent cover of Old World climbing fern decreased structural diversity while increased management effort was found to mitigate those impacts. The management for Old World Climbing fern was also found to impact both species richness and diversity at JDSP. I also demonstrated that there were several species that were not found and others that were more common in the presence of Old World climbing fern and that there was a relationship between management and what species were present. The results show that both Old World climbing fern and the management practices used to control it have had significant ecological impacts on the natural communities in South Florida.

Dedicated to my Grandmother, who instilled in me the love of flowers. I miss you.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
HOME	Height of Median Energy
JDSP	Jonathan Dickinson State Park
LHDI	LiDAR-derived Height Diversity Index
LiDAR	Light Detection and Ranging
MRPP	Multiple Response Permutation Procedure
NMS	Non-metric Multidimensional Scaling
OWCF	Old World climbing fern (*Lygodium microphyllum*)

CHAPTER ONE: GENERAL INTRODUCTION

Introduction

Following habitat loss, invasion by non-native or nonindigenous species has been regarded as the second largest driver of the global biodiversity loss (McKinney and Lockwood, 1999; Levine, 2000; Mooney et al, 2005). While introductions of non-native species have happened repeatedly throughout history, the rate at which they occur has burgeoned exponentially due to increased transportation and global trade (Vitousek et al., 1996; McCullough et al., 2006). With a greater number of introductions, there is greater threat of invasion as well as increased management costs. The United States government spends an estimated cost of 120 billion dollars annually on invasive species management and prevention alone including 27 billion dollars on control measures for well-established species (Pimentel et al., 2005).

This issue of invasion by non-native species has increased in prominence due to the growing concern surrounding global climate change. Factors such as altered microclimates, higher nitrogen levels in soils, increased atmospheric carbon dioxide and changing precipitation levels have been shown to cause range shifts, contractions, and in the case of invasive climbing plants large expansions (Parmesan and Yohe, 2003). Specifically, elevated levels of atmospheric carbon dioxide have been found to increase the biomass and distribution of plant species with invasive species exhibiting a particularly strong correlation between increased carbon dioxide and increased biomass (Kimball et al., 1993; Ziska, 2003). This response is consistently attributed to the greater phenotypic plasticity possessed by non-native invasive species (Putz and Holbrook, 1991; Schweitzer and Larson, 1999; Daehler, 2003). With increased carbon dioxide levels, invasive climbing plant species have also been shown to outcompete native species for resources, such as water and soil nutrients (Hely and Roxburgh, 2005; Smith et al., 2010).

Invasive climbing plant species also have been found to adapt faster to other changing environmental factors and in turn expand their non-native ranges (Hellmann et al., 2008; Rahel and Olden, 2008; Smith et al., 2010; Clements and Ditommaso, 2011). With changing temperatures, there have been documented significant phenological changes in plant species and with native plants displaying later flowering than nonnative species. Earlier flowering allows nonnative plants to outcompete native species for resources (Dukes and Mooney, 1999; Fridley, 2012). In the case of non-native herbaceous climbing plants specifically, there has been significant increases in distribution and biomass with changing climate, and according to model predictions these populations are estimated to spread further with increasing temperatures (Bradley, 2009; Bradley et al., 2010; Gallagher et al., 2010; Lemke et al., 2011; Wang et al., 2011). This is also attributed to the phenotypic plasticity that is displayed by non-native plants when establishing themselves in novel areas and with this increased plasticity, invasive climbing plants adapt and expand faster compared to less plastic native plants (Putz and Holbrook, 1991; Schweitzer and Larson, 1999). This plasticity coupled with and in response to climate change, may even facilitate movement into previously invasion resistant lands and communities (Broennimann et al., 2007).

The environmental impacts of invasive climbing plants vary in their introduced areas and include changes in natural fire regime, soil nutrient levels, and resource allocation (D’Antonio and Vitousek, 1992). This in turn can lead to ecosystem-wide effects and changes in species composition (Mack et al., 2000; Dukes and Mooney, 2004). These changes have been identified as explanations of how invading climbing plants displace native species and cause significant declines in species richness and abundance across taxa in invaded areas. The ability to adapt quickly in response to climate change and the possible impacts on native species is a large concern for biologists and land managers as management may become more costly and eradication more unlikely.

Subtropical Florida is in an ideal location to study species invasion compared to the rest of the United States as it is prone to biological invasions by climbing plants. In addition, transient traffic through Florida is large since it attracts visitors from around the world. It has fifteen seaports, twenty-seven tradeports for air freight, and is noted for its large and extensive wildlife and horticultural plant imports. Certain regions in Florida have experienced vast reductions in native or endemic species due to non-native climbing plant population explosions. Investigating the impacts of some invasive species remains difficult due to lack of information of how these species interact with native species (Gurevitch and Padilla, 2004; Davis et al., 2011). However, in the case of herbaceous invasive climbing plants, the effects of competition between native and non-native species are well documented. This category of non-native plants has been shown to alter primary productivity and resource allocation in Florida's natural areas invaded by outcompeting native vegetation (Nauman, 1993; Gordon, 1998; Fujisaki, et al., 2010; Minogue et al., 2010).

In Florida, there are several species of non-native climbing plants that threaten the native vegetation and overall biodiversity including Japanese climbing fern (*Lygodium* *japonicum*), Old World climbing fern (*Lygodium microphyllum*), kudzu (*Pueraria montana*), and air potato (*Dioscorea bulbifera*). These species are all listed by the Florida Exotic Pest Plant Council as category one invaders, which are non-native species with significant ecological and economic impacts in the state of Florida (FLEPPC, 2011). Category one invasive climbers typically invade high disturbance areas and edges, such as roads or trails, which are created by habitat fragmentation. These species rely on native vegetation, such as bald cypress and pine stands, for structural support to climb into the canopy and restrict the amount of sunlight that is available for understory plants (Hutchinson and Langeland 2011). In doing so, invasive climbing plants act as ecosystem engineers by altering the canopy structure (i.e., affecting subcanopy radiation regime) and nutrient levels which ultimately affect species composition and overall biodiversity (Schweitzer and Larson, 1999).

In many cases, the result of an invasion by a climbing species is the replacement of canopy vegetation and creation of large stands or monocultures of that invader altering the physical characteristics of a natural community. The organization of the physical attributes of a community is referred to as structure (Noss, 1990). These physical attributes include species density, species biomass, canopy openness, and habitat complexity (Noss, 1990). Vegetative structure is an important factor in determining the health of an ecosystem and structural complexity has been shown to be correlated with higher biodiversity in natural systems (MacArthur and MacArthur, 1961; Lindenmayer and Franklin, 2002; Zellweger et al 2013). Invasion by a climbing non-native plant can then be considered a disturbance that impacts both vegetation and community structure. With climate change, there is growing concern regarding how these species will respond and how that response will impact Florida ecosystems.

Current invasive species programs in Florida focus on species that are already well established and have large ranges in the state, such as Japanese climbing fern, and on removal and potential of eradication with similar treatment types applied across different climbing plants. Treatment types include manual removal or “weeding,” prescribed burns, and herbicide treatments. Another large component of management strategies for invasive climbers is to prevent future spread. There are differences, however, in the climbing patterns and structural/ecological impacts among these species, which may influence the effectiveness of various management practices (Schweitzer and Larson, 1999). The lack of information regarding how these plants change forest structure coupled with the threat of expansion due to climate change makes management of growing populations challenging as different species may respond differently to the same environmental pressure. For example, prescribed burns aimed at eradicating some invasive climbers may be rendered less effective for species that penetrate the canopy, by creating high heat canopy fires, which is detrimental to native vegetation (FLEPPC 2001).

LiDAR (Light Detection and Ranging) analysis can assist in addressing those gaps in understanding regarding invasive climbing plants and how they impact forest structure. Measuring forest structure in the field is both labor and time intensive and may not provide the amount of detail or information needed to understand how forest structure differs between sites. Airborne LiDAR is a form of remote sensing that consists of an airplane equipped with a laser scanner and sensor, global positioning system and navigation system (Turner et al 2003; Parker and Russ 2004, Listopad et al, 2011). The laser scanner pulses light over an area of interest and once the light encounters a reflective surface such as a branch, leaf, or ground, it is returned to the laser sensor which then measures the intensity of the light received as well as the distance to the reflective surface. Each point is then recorded and distributed into a three dimensional point cloud. From this point cloud we can then derive several forest structure measurements that would describe the physical attributes of a forest stand. The National Ecological Observatory Network (NEON) is currently utilizing LiDAR in order to monitor impacts of anthropogenic disturbances, climate change, as well as invasive species at a continental scale (NEON, Inc., 2011). LiDAR can be used help to illustrate the interactions between an invasive climbing plant and native species, such as shading by the invader and changes in canopy openness and biomass, and also quantify the extent to which they alter community structure.

In this study I examine the structural changes in forest canopy due to an invasive climbing plant species, Old World climbing fern, and compare those structural differences across a gradient of invasion densities and management frequencies. Due to the pervasive impact of this species on canopy structure in natural areas we would expect to find significant changes in ecosystem structure due to Old World climbing fern. This study was also aimed at examining the impacts on plant species richness and abundance in areas invaded by Old World climbing fern. Understanding these interactions between native and non-native species and their impacts on forest physical and community structure can assist in understanding the overall impact of a nonindigenous climbing plant species and help to determine appropriate control measures to decrease future management cost and effort.

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CHAPTER TWO: RELATING OLD WORLD CLIMBING FERN (*Lygodium microphyllum*) INVASION DENSITY AND MANAGEMENT FREQUENCY TO FOREST CANOPY STRUCTURE

Introduction

A common measure of the health of an ecosystem is through determining the diversity and organization of physical structures present (Tilman 1994; Lam et al., 2014; Muller et al., 2014). A diverse vegetation structure in particular has been found to be correlated with high levels of biodiversity (MacArthur and MacArthur, 1961; Lindenmayer and Franklin, 2002; Zellweger et al., 2013). Historical examples of relating forest structure to biodiversity is found in studies on the tropics. Vegetation structure, in addition to other spatial conditions, can also greatly influence the ecological processes and the biotic and abiotic composition of a given area (Drake and Weishampel, 2000). For example, changes in forest structure can influence the frequency and intensity of disturbance (Rieman and Clayton, 1997). Complexity of vegetation structure has been shown to be correlated with diversity in both faunal and floral species and is also closely related to the amount of energy available in a system. In energy rich areas the relationship between structural diversity and available energy both work to drive biodiversity across the landscape (Verschuyl et al 2008). The influence of structural diversity on overall biodiversity has been shown to be strongest in energy rich systems (Verschuyl et al 2008). This pattern has been demonstrated in studies on bird species distributions and may apply to other taxa (Verschuyl et al 2008).

There are several sources of change in forest structure. Historical alteration of forest structure has occurred due to natural occurrences such as hurricanes, tornadoes, climate change, natural fires, etc. While these events still occur modern changes in forest structure are also due to anthropogenic activities, fire suppression, and invasion by non-native species. The costs of non-native invasive species include decreased biodiversity due to altered species composition and can lead to mass extinctions of native and endemic species by nonnative predators, such as the Nile Perch and the brown tree snake invasions (Fritts and Rodda, 1998; Wiles et al., 2003; Pringle, 2005; Goudsward et al., 2008;). Certain regions within the state of Florida have experienced great reductions in native or endemic species due to non-natives plant population explosions.

There is growing concern surrounding the impacts of invasive species on native species and natural communities due to altered environmental conditions caused by global climate change. Previous studies have found that the same qualities that influence a species' ability to invade a new area successfully also contributes to its ability to adapt to changing climate (Hellmann et al., 2008; Rahel and Olden, 2008; Smith et al., 2010; Clements and Ditommaso, 2011). These characteristics such as a broad environmental tolerance, fast reproductive rate, easy dispersal, etc. can contribute to an invasive species' ability to outperform native species in changing climates. Changes in phenology, such as earlier flowering, can assist non-native plants in outcompeting native plants for pollination services (Dukes and Mooney, 1999; Fridley, 2012). This phenotypic plasticity displayed by invasive species gives land managers and biologists reason for concern about the continued and possibly sped up spread of the distribution of invasive species. Population and spatial models have demonstrated that with higher temperatures and atmospheric carbon, both predicted by the Intergovernmental Panel on Climate Change (IPCC, 2013) to exponentially increase over the next century that invasive species populations are also expected to increase (Gallagher et al., 2010; Lemke et al., 2011; Wang et al., 2011). With the threat of increased distributions of invasive species, more information is needed in order to determine exactly how these species are impacting the areas in which they invade, both in terms of biodiversity as well as structurally.

Describing exactly how invasive plant species impact forest structure has been challenging due to limitations in the information available on how exotic species interact with native species (Davis et al., 2011). In order to appropriately address the questions surrounding how invasive species alter forest structure and what those changes mean for Florida ecosystems there needs to be a method of accurately estimating structure measurements. Logistically this remains difficult on a large spatial scale. The implementation of broad scale remote sensing techniques can assist in addressing those fundamental questions about the three dimensional structure of forested lands invaded by non-native species.

LiDAR (Light Detection and Ranging) is a form of remote sensing that is used to make high resolution elevation measurements on a broad spatial scale. This fine scale dataset allows for the calculation of various spatial statistics and previous studies have utilized this technique for accurately estimating vertical structure of forests (Lefsky et al, 2002; Drake et al, 2003; Asner et al 2008a,b; Listopad et al, 2011, Pekin et al., 2012). Using this technique is ideal for providing much needed insight into how forest structure differs due to invasive plant species and what implications this may have on Florida's ecosystems.

Study Species and Area

Old World climbing fern (*Lygodium microphyllum*) is an invasive fern species that was introduced to Florida in 1958 through a South Florida plant nursery as an ornamental plant. Its native range includes parts of Asia, Africa and Australia, but has become established in the southern half of the Florida peninsula (Pemberton, 1998). Old World climbing fern (OWCF) is a perennial evergreen plant; however, in much of its introduced range there is some die off in the winter months due to dry conditions (FLEPPC, 2011). Much like other climbing invasive plants, such as air potato (*Dioscorea bulbifera*) or kudzu (*Pueraria montana*), OWCF has a creeping growth pattern and grows through the canopy utilizing the structure of existing vegetation and is dependent on preexisting structures for vertical growth (Hutchinson and Langeland, 2011a). Once in the canopy, the fern forms a dense rachis mat that reduces the amount of sunlight that is available for understory plants and ultimately replaces canopy vegetation; this behavior has led to areas invaded by OWCF to become monocultures, decreasing local biodiversity.

OWCF invades many different land cover types including bald cypress, pine-flatwood, swamps, mangroves, and scrub ecosystems (Pemberton and Ferriter, 1998). In addition to outcompeting native plants, OWCF also can act as a fuel ladder to the canopy. The main rachis of the ferns can maintain high intensity fires at very high temperatures which travel through the dense mats of vegetation to the native canopy species (Stocker et al., 2008). Many Florida ecosystems are naturally pyrogenic and this transport of fire to the canopy can be extremely negative for the native vegetation, such as long leaf pines which cannot handle high intensity canopy fires. OWCF is currently listed as a category one invasive species in the state of Florida by the Florida Exotic Pest Plant Council, due to its ecological and economic impacts, and it is illegal to purchase or sell OWCF in the state (FLEPPC, 2011).

Management programs statewide by various authorities incorporate several different methodologies, including prescribed burns, herbicide, mechanical removal, biological control agents, and combinations of these methods (Hutchinson et al., 2007; Boughton and Pemberton, 2009; Hutchinson et al., 2010; Hutchinson and Langeland, 2011). Though some methods have been found to be more effective than others, no combination of treatments has been found to completely inhibit the growth of OWCF; the species quickly regenerates after a period of dormancy due to the fact that the rhizome, or underground stem, of the fern is typically not targeted in management practices (FLEPPC, 2011).

Located in southeastern Florida, Jonathan Dickinson State Park (JDSP) encompasses just over 4450 ha of natural areas which include several Florida communities, from endangered mangroves and swamps to pine flatwoods. The most prevalent land cover type in the park is palustrine forested wetlands, which are distinguished by canopy trees, such as Bald Cypress (*Taxodium distichum*) and Slash Pine (*Pinus elliottii*), with heights of over six meters and have about thirty percent canopy cover. The park is home to approximately 130 nonnative species of plants, including OWCF, varying in the degree of impact on native plant communities from benign to high impact species (Rossmanith, 2011). OWCF has been found in the park since the 1970's (FLEPPC, 2001). Within the park, OWCF typically invades forested and emergent wetland systems, though it is also found as small patches in scrub systems as well.

Management for OWCF has been conducted since 2000 and has yielded large reductions of the vine in the treated areas. Park managers have used herbicide, prescribed fires, manual removal, as well as biological control through the use of native moth herbivore, *Neomusotima conspurcatalisas*, as means to control this species. Logistic restraints, however have limited the eradication effort with several areas of the park currently left untreated (Rossmanith, 2012). Management zones within the park are delineated by times that they are burned and each zone is composed of several different land cover classes.

Figure 1: OWCF invasion site within JDSP. The fern is utilizing the pine stand for structural support.

Methods

Identification of Invasion Sites Using Aerial Imagery

In order to identify possible invasion sites, I acquired historical aerial imagery (2004-2012) from the Florida Department of Transportation (FL DOT Surveying and Mapping), the National Oceanic and Atmospheric Administration (NOAA Digital Coast) and the Martin County government (Table 1). These years also correspond with the time that JDSP managers began official monitoring of non-native species. The images were also constrained to early spring which encompasses the growing season of OWCF. I georeferenced the imagery then subjected them to a supervised classification using the ENVI extension in ArcGIS (ESRI, 2011).

Supervised classifications utilize the spectral signatures from imagery to identify potential regions of interest with the same spectral signature. This technique has been used previously with high resolution satellite imagery for measuring the spatial distribution of OWCF at Loxahatchee National Wildlife Refuge (LNWR) and was found to be successful in determining patterns of spread over time (Wu et al., 2006). I used ground based inventory data available through the Florida Natural Areas Inventory (FNAI, 2007) to select reference sites for spectral signatures within JDSP of documented invasion sites. The metadata supplied by FNAI classified invasion sites as: (1) containing a single plant, (2) scattered plants or clumps, (3) linearly scattered, (4) scattered dense patches, (5) dominant cover, or (6) a dense monoculture which was indicative of sites with greater than 50% canopy cover of OWCF. I further reduced these classes into three separate density classes: high, medium, and low by combining the FNAI classes. Zones classified as containing anywhere from a single plant to several plants (i.e., categories 1 and 2) were considered low density. Zones with dense or linearly scattered patches (i.e., categories 3 and 4) defined the medium invasion density class while zones that were classified as dense monocultures or dominant cover (i.e., categories 5 and 6) of OWCF defined the high invasion density class. The supervised classification procedure was repeated for every year from 2004 through 2012 and was checked for accuracy in the field for the most recent available aerial imagery. Accuracy of the supervised classification was determined by selecting random coordinate points within ArcGIS and assigning invasion density in the field. All of the randomly selected points corresponded correctly with the supervised classification values assigned.

Table 1: Source and acquisition dates for aerial imagery used for classification

Source	Acquisition date	Resolution
FDOT, Martin County, FL	01/2005	1 foot
NOAA, Martin county, FL	04/2006	1 foot
	No imagery available	
	No imagery available	
Martin County, FL	01/2009	1 foot
Martin County, FL	01/2010	1 foot
Martin County, FL	01/2011	0.5 foot
Martin County, FL	03/2012	1 foot
Martin County, FL	01/2013	0.5 foot

LiDAR Acquisition and Derived Canopy Metrics

LiDAR is an active form of remote sensing that is used to measure the elevation of surfaces over a site (Turner et al., 2003). Light is pulsed over a landscape and a sensor measures the distance to the target and the intensity of the return signal from the reflective surface. Reflective surfaces could be architectural sources, such as buildings and bridges, or environmental sources, such as tree branches and leaves. The data are represented as point clouds with points distributed in three dimensional space and georeferenced using Global Positioning Satellites (GPS) (Figure 2). From these volumetric (x,y,z) data clouds, 3-D or topographic ground surface maps are created by extracting the last returns or canopy surface maps by the first returns or upper elevation points (Angelo et al., 2010; Listopad, 2011).

Previous studies have applied LiDAR to demonstrate impacts on forest structure by invasive vegetation in tropical and subtropical forests and found that LiDAR was able to accurately convey forest structure characteristics of an invasion by non-native tree species and estimate the effectiveness of various control methods (Asner, et al., 2008a,b; ; Huang and Asner, 2009, Pekin et al., 2012). This technique, however, has not been previously applied towards describing the impact of invasive vine species.

LiDAR was flown by the Florida Department of Emergency Management in 2007 in order to determine the impacts of hurricane surge on coastal areas following several severe hurricanes in 2004 and 2005. Flights were conducted from August 31 through October 11, 2007 for a total of 181 flight lines. JDSP fell within the boundaries of these flight patterns this data set was compared to field surveys in order to ensure both vertical and horizontal accuracy. The point cloud and digital elevation model has a horizontal resolution of 1.25 m and a vertical resolution of approximately 0.18 m.

Sites were selected from palustrine forested wetlands using a stratified random procedure in ArcGIS 10.1. Sites were restricted to the palustrine forested wetland land cover class due to the lack of sufficient canopy vegetation in the other land cover classes within JDSP. The random point coordinates generated in ArcGIS were then stratified according to invasion density in 2007: high (n=100), medium (n=100), or low (n=100) and management frequency classes for a total of 300 sites (Figure 3). The frequency of management for OWCF was determined from when documented treatment for invasive plants first began in 2004 to 2007 when the LiDAR data were collected. The frequency ranged from having (1) never been treated (2) treated once, (3) twice, or (4) incidentally (i.e., treated irregularly but more than twice).

Each LiDAR sample consisted of a 0.25 ha circular plot. This size was chosen because the average size of an invaded site within JDSP is about 0.25 km^2 and using quarter hectare plots allowed for several, non-overlapping plots to be randomly placed within these sites. Using these data, I calculated various forest measurements that describe the three-dimensional structure of the forest across the invasion density gradient as well as between different management frequencies including average canopy height, height of median energy (HOME), vertical structural diversity (LHDI), rugosity, and canopy openness (Table 2).

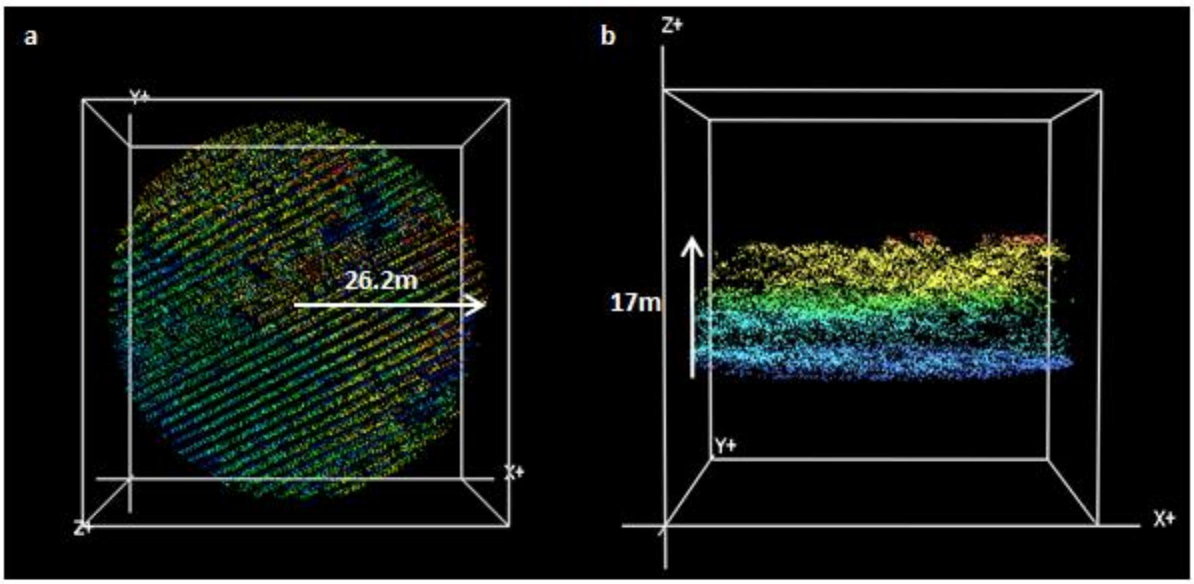

Figure 2: Top down (a) and cross section (b) views of a 0.25 ha LiDAR point cloud from an example site located within the high invasion density class. The coloration indicates the height of a particular point from the ground.

Table 2: List of plot categories and LiDAR-derived forest structure measurements.

Categories	Structural Measurements
Invasion Density	Average Canopy Height
Management Frequency	Height of Median Energy (HOME)
	Canopy Openness
	LiDAR-derived Height Diversity Index (LHDI)
	Standard Deviation of Canopy Height (Rugosity)

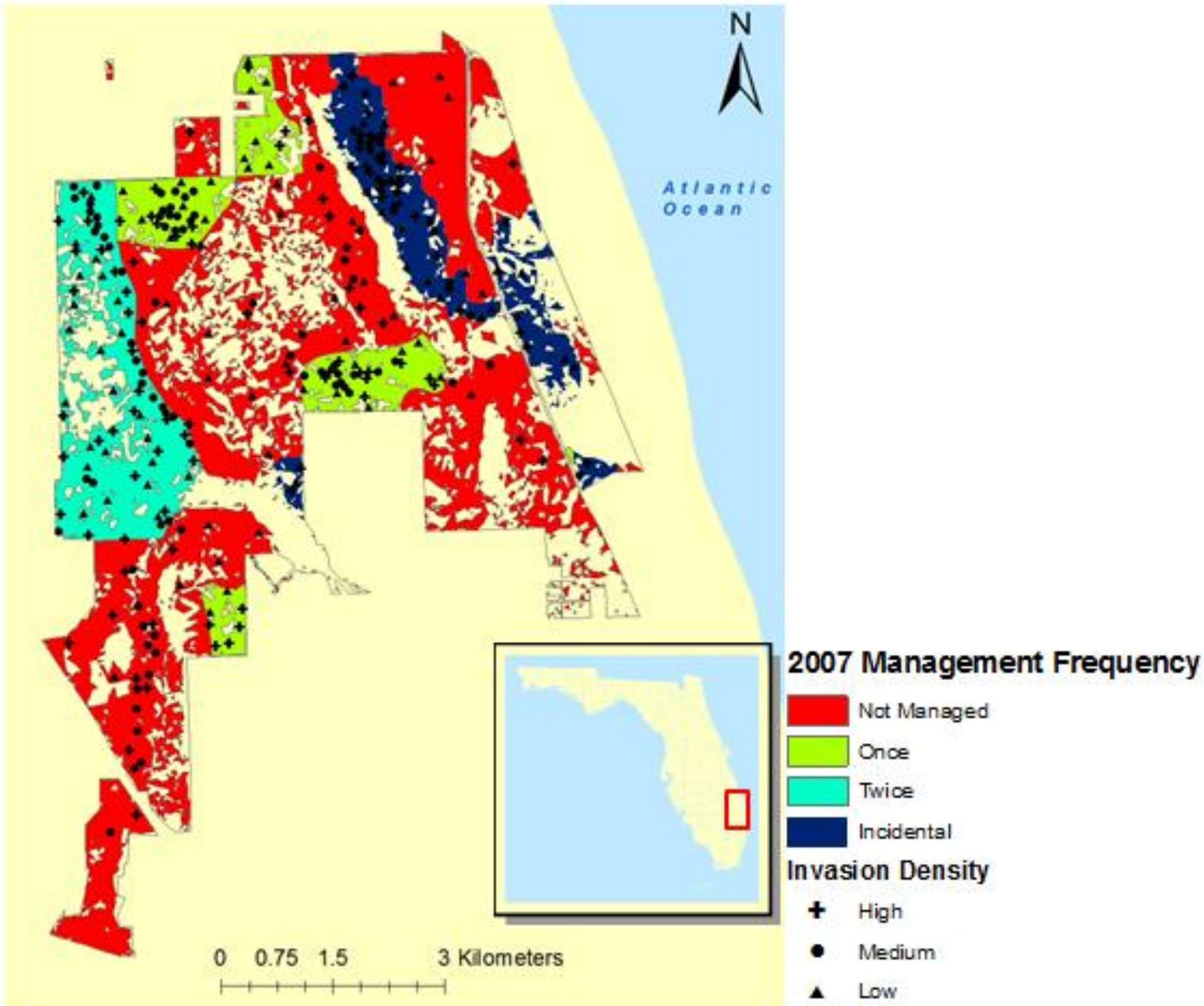

Figure 3: Map of LiDAR plot locations at JDSP near Hobe Sound, FL stratified by invasion density and management frequency.

Forest canopy structure provides insight into the health of a community or ecosystem (Lindenmayer and Franklin, 2002). Diverse canopy structure has been shown to lead to greater primary productivity and biodiversity (MacArthur and MacArthur 1961, Lefsky et al 2002). Vegetation height at each site was calculated by subtracting ground surface DEM from the canopy DEM. In order to measure vertical forest structure, elevation data from the LiDAR point cloud was binned according to their height relative to the ground in one meter bins at a

10x10m horizontal resolution, using the Fusion LiDAR analysis software (McGaughey, 2012) developed by the United States Forest Service (Figure 4). The average canopy height was measured by calculating the average height of the points in the first height bin which was representative of canopy structures. The density of points within each height bin class was then calculated to estimate vertical structure at each site.

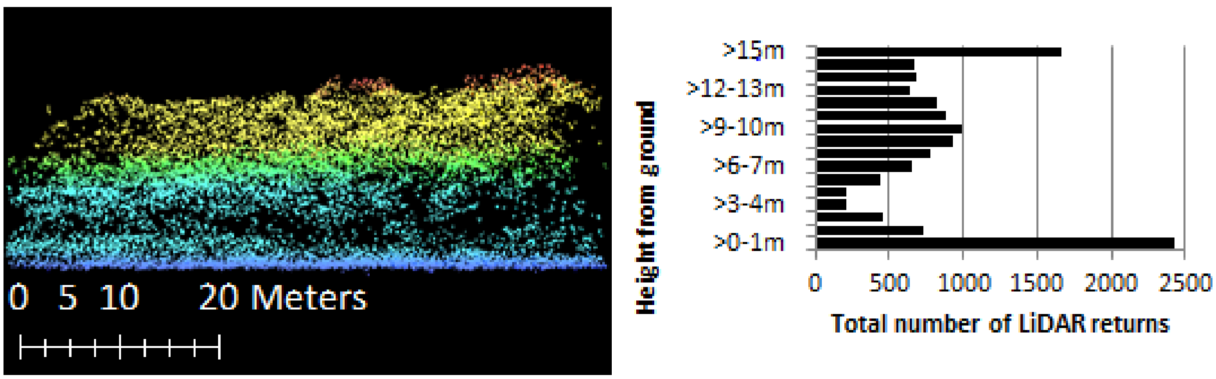

Figure 4: Example of LiDAR-derived point cloud and distribution of LiDAR returns in height bins.

Due to OWCF's climbing nature and how it forms dense mats in the canopy, an appropriate measure of how forest structure is altered by this species is through the measurement of how open canopy cover is in invaded areas compared to uninvaded areas. Canopy openness was measured for each plot using the predetermined height bins (Figure 5). To calculate canopy openness, I divided the total number of elevation points that fall within the last bin (ground points) by the total number of points within all remaining height bins for that plot (Drake et al., 2002; Müller et al., 2010). A small value for this measurement is indicative of a closed canopy whereas a relatively larger number would be indicative of an open canopy.

The height of median energy or HOME metric is derived from the LiDAR DEM by determining the median height value for a given site (Figure 5). HOME is influenced by the degree of canopy openness with open canopy sites exhibiting lower HOME values than relatively closed canopy sites due to a higher percentage of the overall reflected energy being from ground or last returns (Drake et al., 2003). This value gave an estimation of structural differences along the invasion gradient and accounted for differences in canopy openness and vertical structure within each plot.

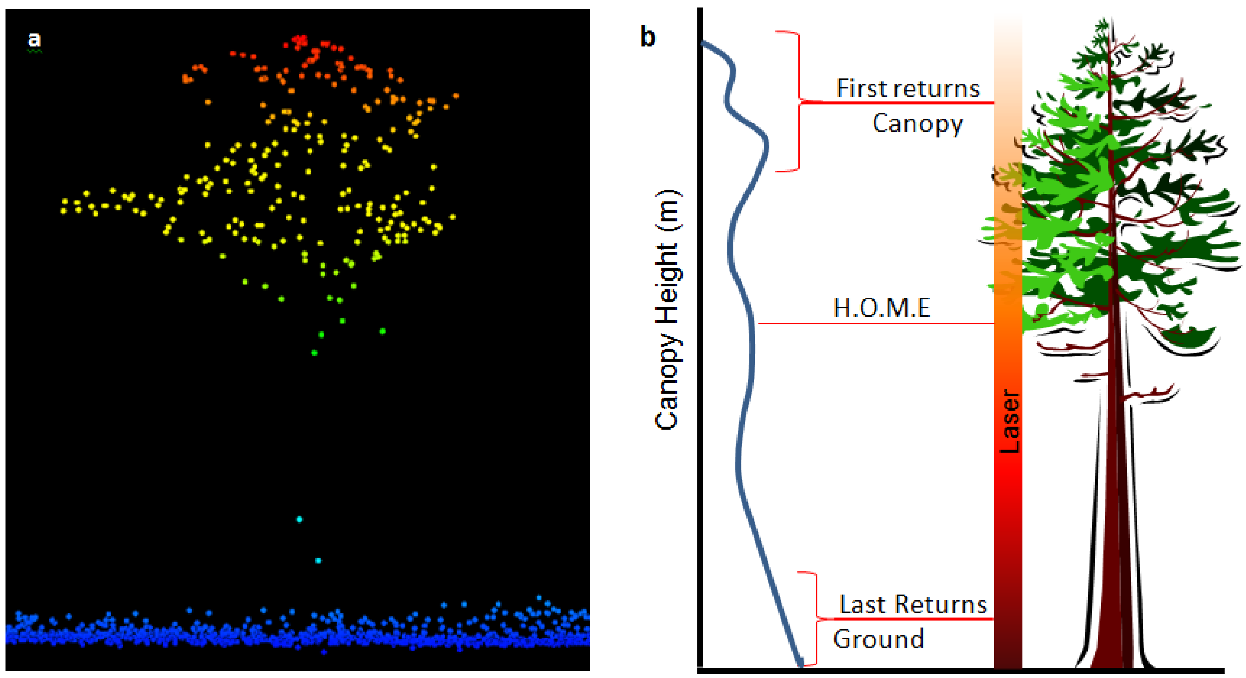

Figure 5: (a) Example of a LiDAR-derived DEM and (b) diagram of LiDAR metrics.

The roughness or bumpiness of a forest canopy is known as rugosity and forests with a diverse vertical structure have been found to have higher values of rugosity. The amount of diversity in vertical structure has previously been found to be correlated with the productivity of a forest stand, with older, high rugosity forests absorbing more solar energy than younger, low rugosity forest stands (MacArthur and MacArthur 1961, Lefsky et al 2002, Parker and Russ, 2004). Rugosity was measured by calculating the standard deviation of the height values for a site (Parker and Russ, 2004, Ogunjemiyo et al., 2005).

Vertical structure diversity was estimated through the LiDAR-derived Height Diversity Index (LHDI) which is measured using the height bin classifications by determining the proportion of points within each height bin class for a plot (Listopad et al., 2011). Previous studies have calculated LHDI as a modification of the Shannon Weiner Diversity index to calculate Foliage Height Diversity (MacArthur and MacArthur,1961;Listopad et al., 2011). I further modified this equation to estimate vertical structural diversity by using the Jost diversity index (Jost 2006). This index differs from traditional diversity indices in that it determines the effective number of species in a community, or in the case of LiDAR measurements, the effective number of height bins, this value served as a proxy for structural biodiversity potential at each site.

Statistical Analyses

Following the supervised classification methodology, the total area of each density category was calculated in ArcGIS for years with available aerial imagery (Figure 6). This process was limited to management zones that were never managed for invasive plants. The analysis was limited to these areas in order to avoid any impact that management may have had on the distribution of OWCF. The yearly values were then subjected to regression analysis in order to determine how the distribution of infestations has changed in terms of patch area over time. This was used as a means to determine how effective OWCF has been in spreading through these areas.

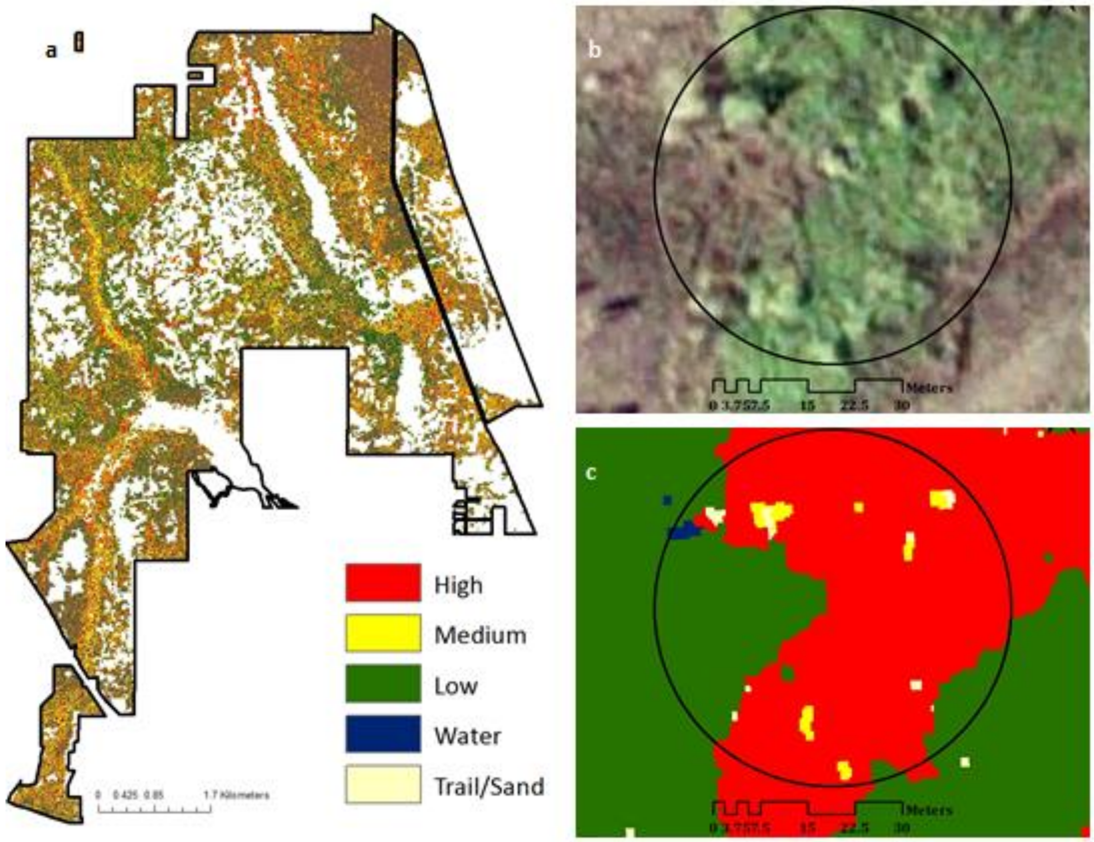

Figure 6: Supervised classification for the year 2006(a) and an example of a 0.25 ha plot's aerial imagery (b) and corresponding classification scheme(c).

I first checked for significant differences for all the LiDAR-derived forest metrics across both invasion density and management frequency categories using one-way analysis of variance (ANOVA). I then analyzed the data using a nested ANOVA design. Invasion density was nested within management frequencies. A nested design was chosen as the spatial arrangement of management frequency within the park, which was clumped into distinct regions, to avoid pseudoreplication. Comparisons across management frequencies and invasion categories were accomplished using a perMANOVA design in PC-ORD (McCune and Grace, 2002). The perMANOVA test statistic looks at the simultaneous response of multiple variables to multiple factors and is a non-parametric test of variance which is ideal for analyzing LiDAR data, as most LiDAR datasets are not normally distributed.

For the first perMANOVA analysis, I used invasion density as my factor and chose the Sorensen distance measure which is suitable for ecological datasets in order to calculate the distance matrix derived from the forest structure variables (McCune and Grace, 2002). For the second perMANOVA, I used management frequency as my factor and a distance matrix calculated using the Sorensen distance measure. There were a total of 999 permutations for each run.

In addition to the perMANOVA analysis, Non-metric Multidimensional Scaling (NMS) was used to test for patterns within the LiDAR-derived forestry metrics associated with both invasion density and management frequency for OWCF. This method of ordination is suitable for analyzing LiDAR datasets as this test does not require that data be normally distributed. The NMS analysis was processed in PC-ORD starting with random coordinates using the 'slow and thorough' autopilot mode. The NMS was run once for the 75 unmanaged plots in order to determine if invasion density caused any patterns in forest structure independent of any management efforts. The same procedure was then run on all 300 plots to detect any patterns caused by management frequency.

Results

The results from the regression analysis were shown not to be significant for determining trends in patch dynamics over time. The total area of patches in non-managed zones at JDSP indicated as highly invaded by OWCF through the supervised classification increased from 2005 to 2010 and then decreased in 2011 (Figure 7). The total area of patches that was deemed as moderately (25-50% cover) invaded by OWCF decreased from 2005 to 2010 and increased in 2011 (Figure 7). The total area of patches within the lowest invasion density class did not follow any particular trend (Appendix).

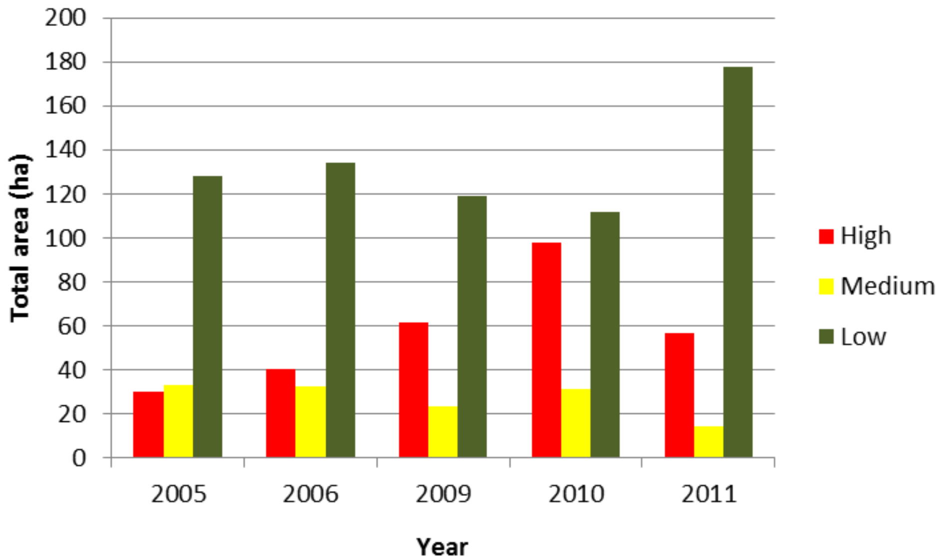

Figure 7: Total area in hectares of the high, medium, and low invasion density classes as determined by supervised classification by year.

Before running the one-way ANOVA, I checked for correlations between different LiDAR-derived metrics (Table 3). This was crucial as these metrics are measured from a single data set and the value of one metric may be dependent on the value of another. For example, a plot with lower values for canopy openness will typically display lower values for vertical structural diversity; hence these values are inversely correlated (Table 3). The Height of Median Energy metric (HOME) is also strongly influenced by how open a canopy is. Plots that have larger values for canopy openness, with more light available to understory structures, will have lower HOME values (Table 3).

Table 3: Correlation coefficients between all five LiDAR metrics.

	LHDI	HOME	Average canopy height	Rugosity	Canopy Openness
LHDI	1	0.471	0.405	0.480	-0.704
HOME		1	0.860	0.813	-0.325
Average canopy height			1	0.752	-0.271
Rugosity				1	-0.402
Canopy Openness					1

The results from the one-way ANOVA indicated that for all five LiDAR-derived forest structure metrics, a significant proportion of the variation was explained by invasion density. The same was also true for management frequency with the exception of canopy openness ($p = 0.2435$). Figures 8 and 9 describe the distribution of the values across invasion densities and management frequencies, respectively. I followed these analyses with a nested ANOVA. This test indicated that for the LiDAR-derived metrics both management frequency and invasion density described a significant proportion of the variance in the data ($p<0.0001$, Figures 10 and 11).

a a b c a a b a

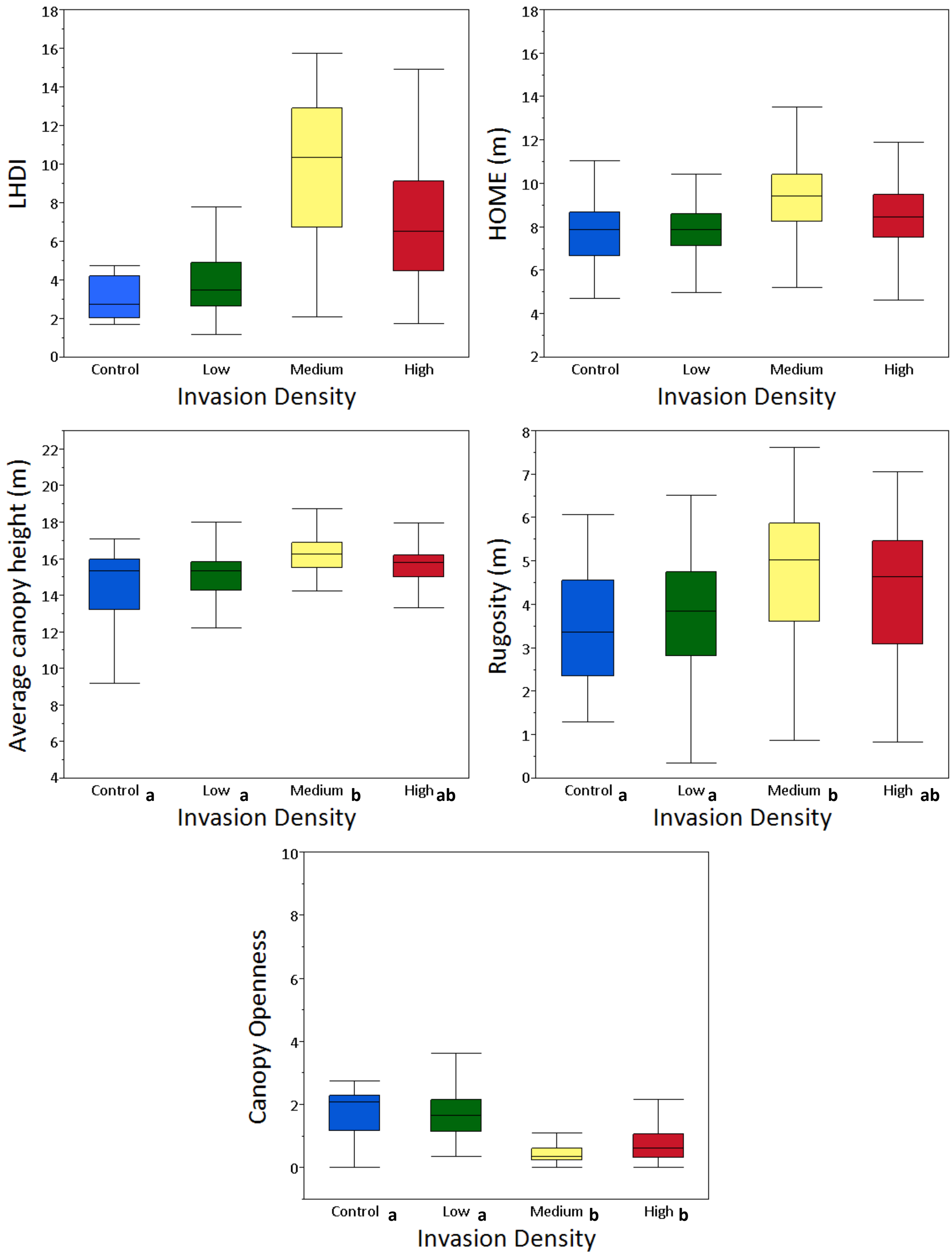

Figure 8: Boxplots describing the distribution of values across the invasion density gradient compared to control plots for LiDAR-derived metrics of unmanaged plots. Categories designated by different letters (a/b) are significantly different from one another.

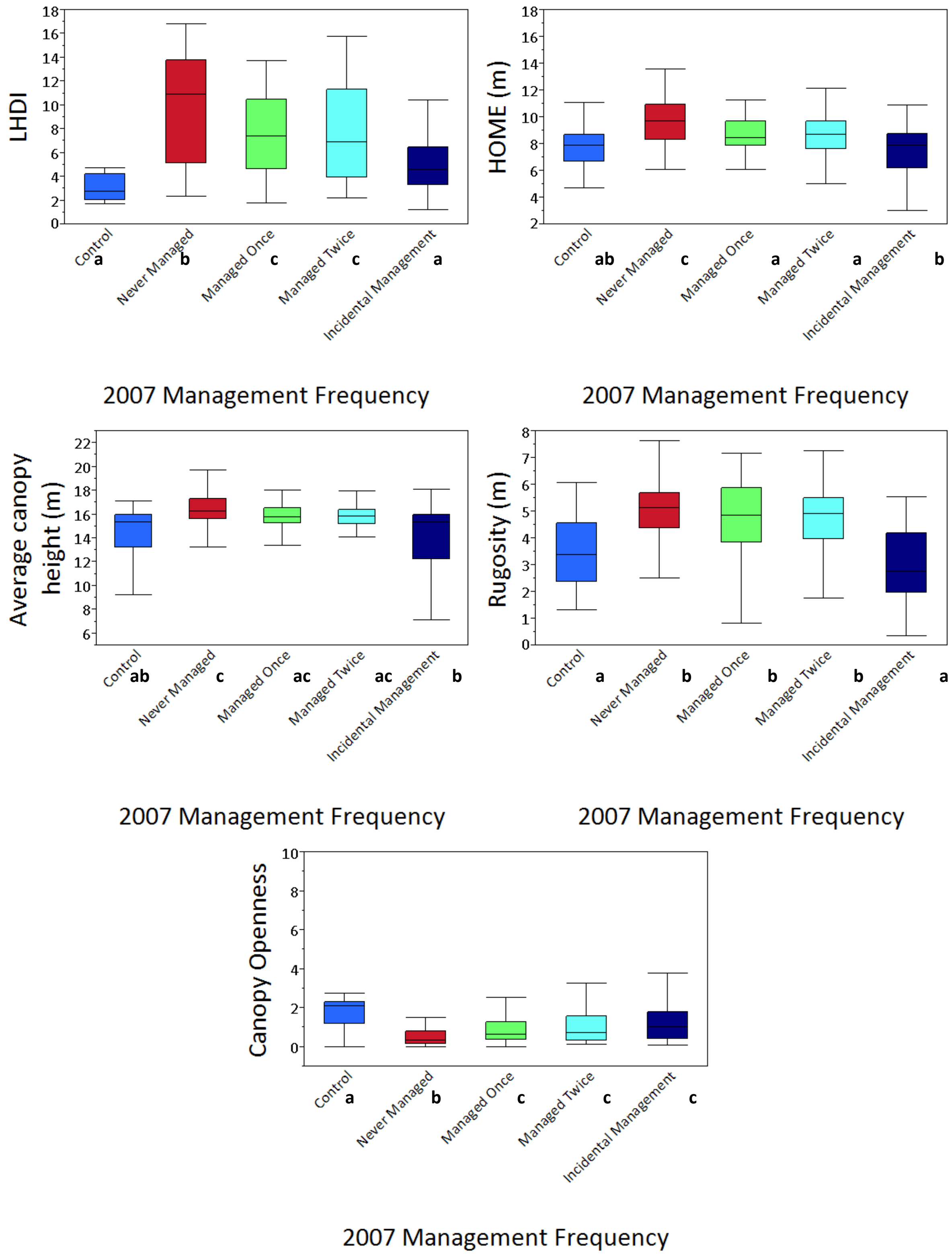

Figure 9: Boxplots describing the distribution of LiDAR-derived metric values across various management frequencies compared to control plots of all 300 plots. Categories designated by different letters (a/b/c) are significantly different from one another

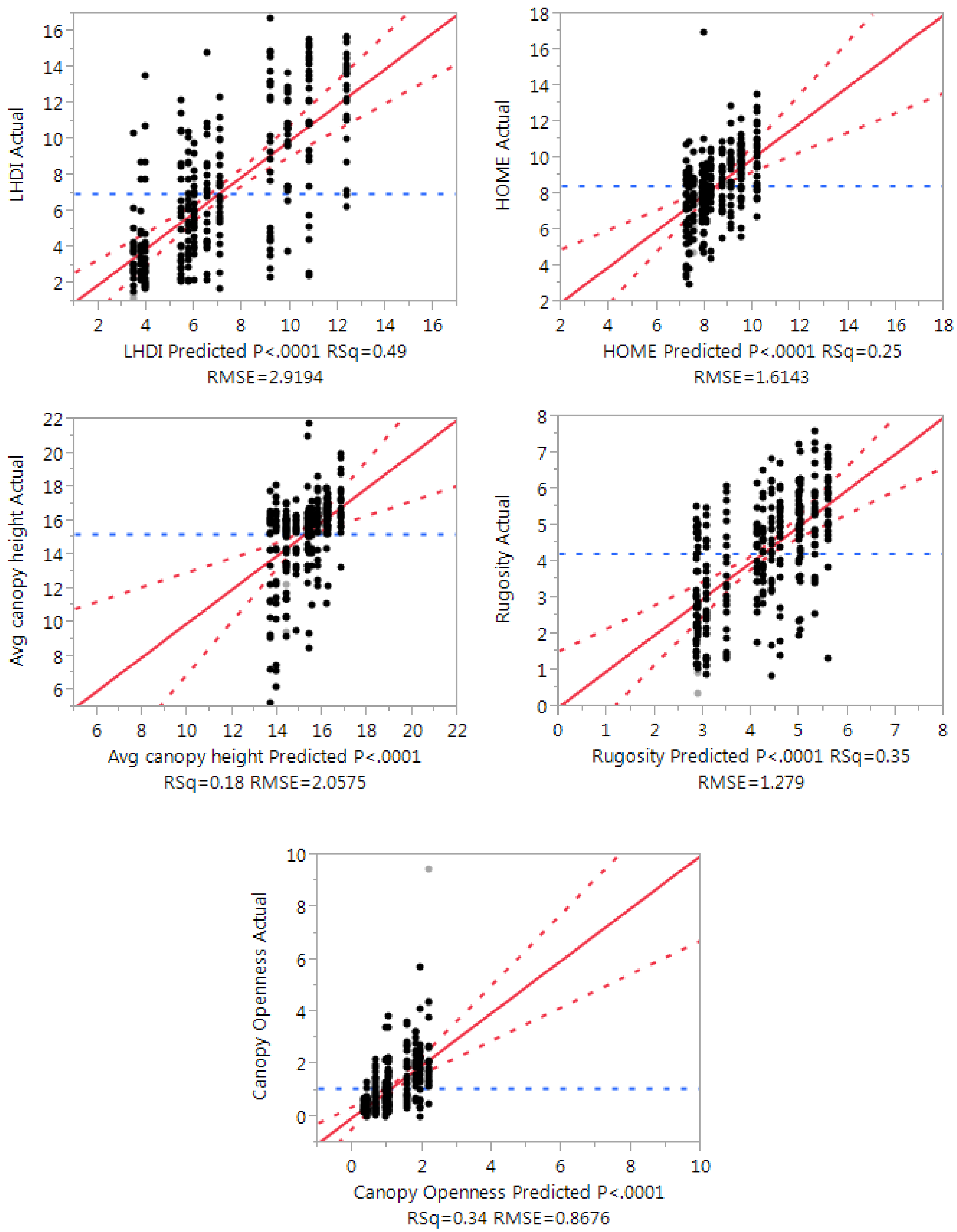

Figure 10: Results from the nested ANOVA for all five LiDAR-derived forest metrics. Plots of varying invasion densities were nested within the four management frequencies at JDSP. Dashed red lines indicate 95% confidence intervals whereas the solid line indicates the best line fit for the data. The blue line represents the average value for the particular metric across all plots.

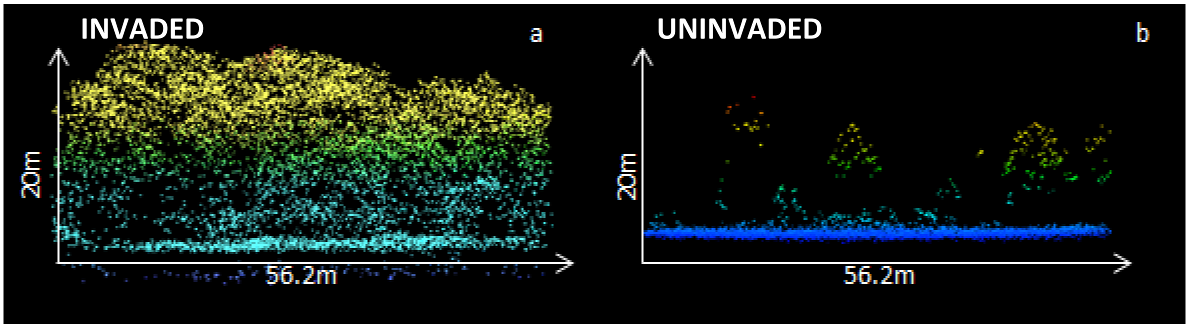

Figure 11: Example of a point cloud of 0.25 ha circular plot for a densely invaded site (a) compared to a site completely devoid (b) of OWCF. Sites with a higher percent cover of OWCF exhibited relatively smaller values for the LiDAR-derived metrics.

The results of the one-way perMANOVA using invasion density as the categorical factor show that there were significant differences ($p<0.001$) for the LiDAR-derived metrics between the three invasion density classes, i.e., high, medium, and low (Figure 8, Table 4). The one-way perMANOVA with management frequency held as the categorical factor also indicated that management frequency explained a significant proportion ($p<0.001$) of the variance for the LiDAR-derived metrics (Table 5).

Table 4: Results from the 1-way perMANOVA constructed from the LiDAR-derived metrics in PC-ORD using invasion density as the factor.

Source	DF	SS	MS	F	P
Invasion	2	1.0458	0.52289	34.162	<0.001
Residual	297	4.5459	1.53E-02		
Total	299	5.5917			

Table 5: Results from the 1-way perMANOVA constructed from the LiDAR derived metrics in PC-ORD using management as the factor.

Source	DF	SS	MS	F	P
Mgmt Freq	3	0.60296	0.20099	11.925	<0.001
Residual	296	4.5459	1.69E-02		
Total	299	5.5917			

The result of the NMS ordination procedure of unmanaged plots stabilized at a 2-dimensional solution with a stress of 8.07. The first axis explained most of the variance in the data at 89.7%, while the second axis described 8.9%. The first axis was highly negatively correlated with canopy openness (Table 7, Figure 12) and positively correlated with the other four forestry metrics whereas the second axis is positively correlated with canopy openness. When separated by invasion density there is a substantial amount of overlap between the classes, with low invasion density plots falling out at the lower end of axis 1 (Figure 12).

Table 6: Loadings for the two-dimensional Non-Metric Multidimensional Scaling (NMS) ordination

Metric	**Axis 1 Loadings**	**Axis 2 Loadings**
LHDI	0.479	-0.103
HOME	0.167	0.051
Average Canopy Height	0.100	0.022
Rugosity	0.268	0.046
Canopy Openness	-0.729	0.141

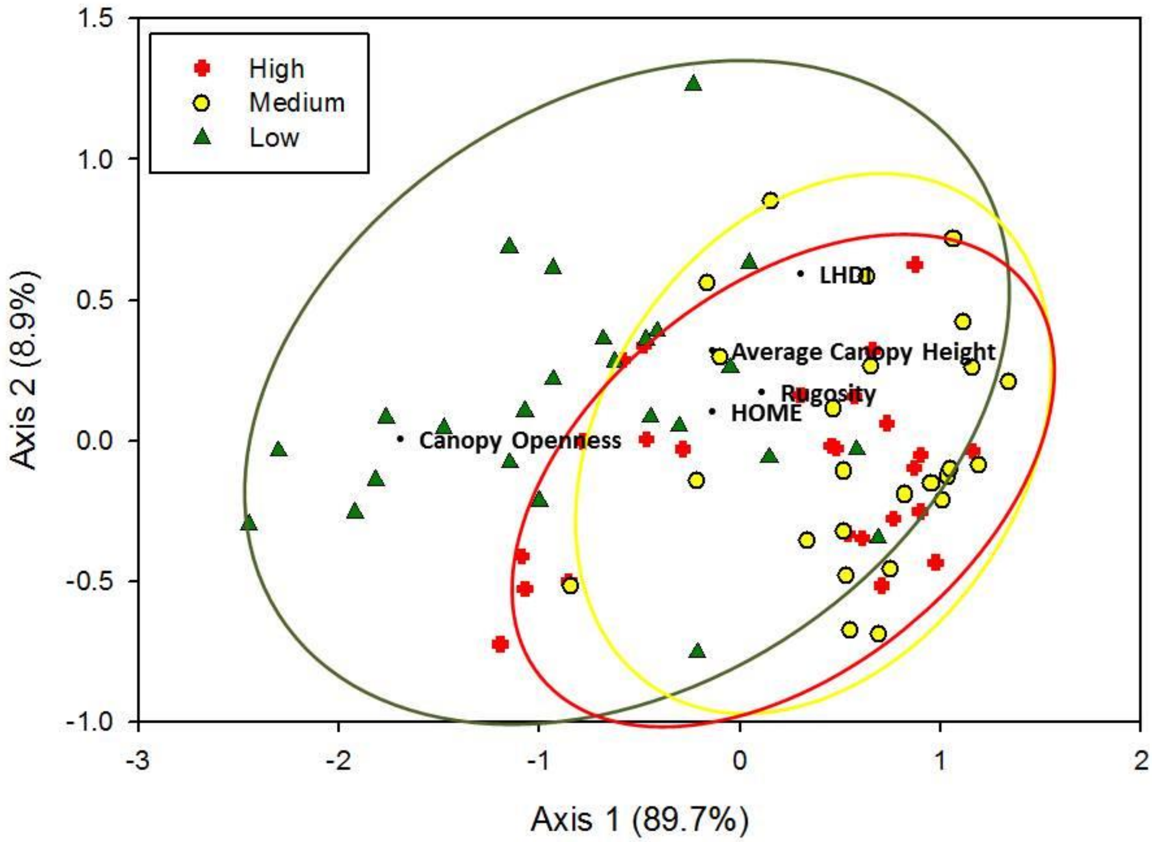

Figure 12: NMS ordination of the 75 unmanaged remotely sensed plots. Ellipses indicate invasion density. The average position of the LiDAR-derived forest metrics are indicated by blue dots.

The result of the NMS ordination procedure of all 300 remotely sensed plots stabilized at 2-dimensional solution with a stress of 7.424. The first axis explained most of the variance in the data at 83%, while the second axis described only 14%. The first axis was highly positively correlated with canopy openness (Table 7, Figure 13) and negatively correlated with the other four forestry metrics whereas the second axis was positively correlated with vertical structural diversity. When separated by both invasion density and management frequency there was a substantial amount of overlap and no clear patterns were found with this ordination procedure between the not managed, managed once and managed twice frequency classes (Figure 13). The zones managed most frequently (incidental management) were separated from the other management frequencies along axis 1 (positively correlated with canopy openness). The zones that were never managed for OWCF held the lowest values for axis 1 which indicates that the values for canopy openness for these plots were lower than the other management frequencies. There was no clear distinction between zones managed once or twice.

Table 7: Loadings for the two-dimensional Non-metric Multidimensional Scaling (NMS) ordination.

Metric	Axis 1 Loadings	Axis 2 Loadings
LHDI	0.384	0.145
HOME	0.159	0.041
Average Canopy Height	0.107	0.032
Rugosity	0.265	0.043
Canopy Openness	0.524	-0.296

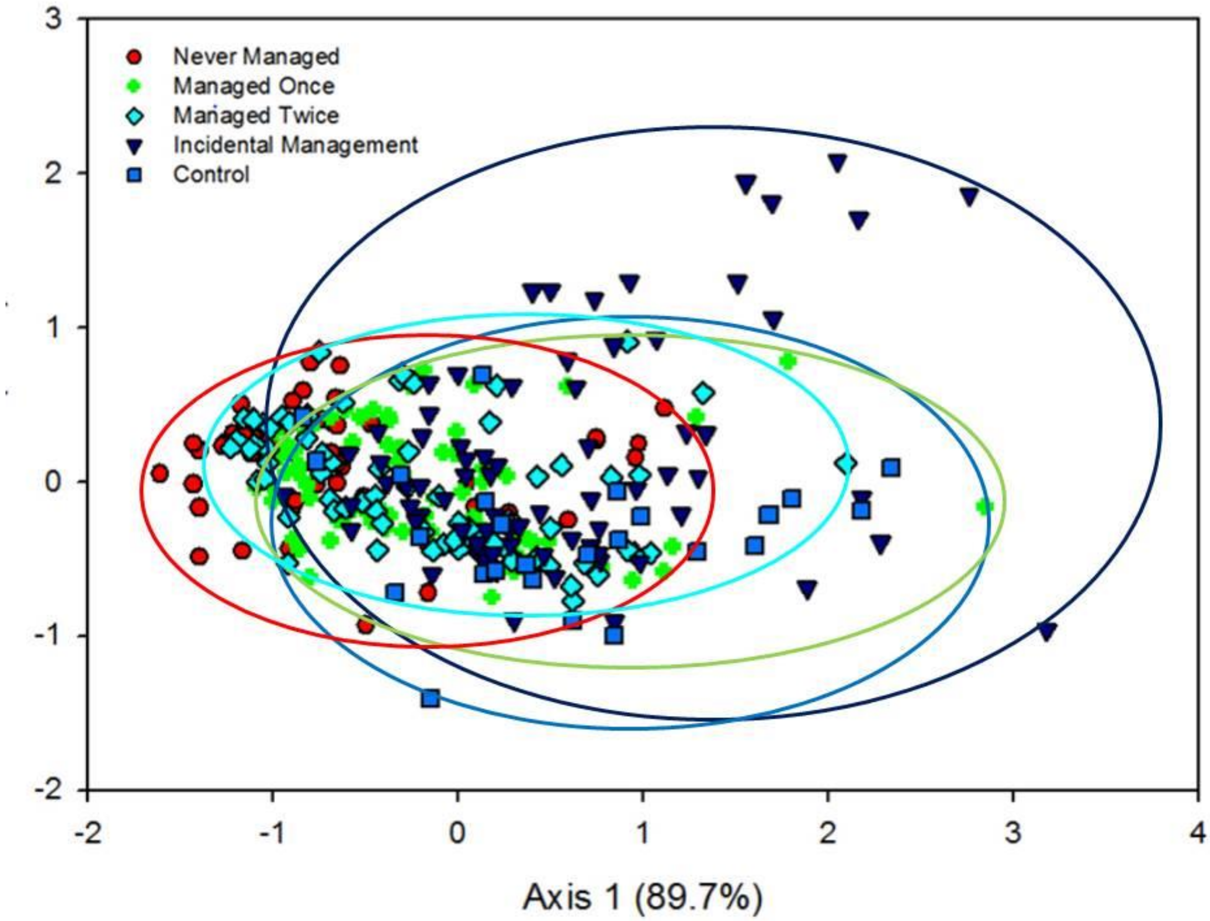

Figure 13: NMS ordination of the 300 remotely sensed plots. Ellipses indicate management frequency.

Discussion

The LiDAR analysis performed in this study indicated that both the invasion density and the frequency of management for invasive plants impact the forest structure within JDSP. The percent cover, or invasion density, of OWCF impacted all five LiDAR–derived metrics for the plots sampled. The ability of OWCF to utilize existing vegetation as structural support in addition to its rapid growth and regeneration alters the structure of the South Florida palustrine forested wetland from a relatively open canopy with a diverse vertical structure to that of a relatively closed and homogenous system.

As invasion density increased, the values for average canopy height, rugosity, height of median energy (HOME), and vertical structural diversity (LHDI) increased and the values for canopy openness decreased. The NMS ordination of unmanaged sites (Figure 12) showed that the plots with lower percent cover of OWCF exhibited larger values for canopy openness which is ideal for the persistence of the palustrine forested wetland system. Many of the faunal species found in the land cover class, e.g., the endangered Florida Scrub Jay (*Aphelocoma coerulescens*) prefer open canopy systems and with increasing densities of OWCF this value is greatly diminished, decreasing habitat availability for this and other species dependent on open canopies.

The LiDAR-derived height diversity index, which served as an approximation of the diversity of the heights and biodiversity potential within a plot, was significantly reduced due to higher concentrations of OWCF. This value has been shown to be an appropriate measure of ecological community health (Listopad et al., 2011). The more structurally diverse the habitat, the more niches are available for species to occupy. This pattern supports the anecdotal information from land managers about the impact of OWCF on South Florida wetland systems.

Conversely, increasing management frequency restores forest structure towards its native state for most of the LiDAR-derived metrics mitigating the effect of OWCF on plots managed more frequently, with the exception of canopy openness. From the NMS ordination, frequently managed sites had the highest canopy openness values whereas unmanaged sites had the lowest. Zones managed only once or twice had slightly higher values for canopy openness, however, were not statistically significant from the non-managed plots. This indicates that infrequent management may not be effective at mitigating the effects of invasion by OWCF.

Canopy openness, which indicates how much light, is available to understory and ground vegetation, was not shown to be greatly impacted by increased management effort. This may be due to a common process in which land managers treat for OWCF within JDSP. The most common form of management is herbicide application which kills and desiccates the aboveground biomass, but does not remove the rachis mat from canopy vegetation. This management practice may be the reason why canopy openness is not significantly altered by increased management frequency.

Herbicide treatment is a control mechanism typically used in conjunction with manual or mechanical removal in larger infestations. Workers will cut portions of the fern and a mixture of herbicide and water is sprayed on the leaflet surface and cross-section of the frond in order to enter the vascular tissues of the plant (Hutchinson and Langeland, 2006). There are several forms of herbicide that are frequently used against OWCF including Glyphosate, Imazapyr, and Metasulfuron-methyl (Minogue et al., 2010). The vascular tissues then work to transport the herbicide to other areas of the fern. The herbicide can be applied on the ground with spray bottles or aerially using an airplane to blanket large areas.

Manual removal and prescribed fire both are useful in removing biomass after herbicide application and preventing future spread in the right conditions (Van Loan, 2006). Manual removal, however, following herbicide application is both expensive and labor intensive. The use of prescribed burns is another method available to remove the rachis mat from the canopy however the presence of dead OWCF leads to high canopy fires which could result in the death of the cypress and pine that are the dominant canopy species at JDSP. Fire may also actually increase the ability of OWCF to spread by creating winds above the fire that transport the spores which can remain dormant until reaching moist soils (Wade et al., 2000).

Figure 14: Example of herbicide-treated invasion site with regeneration of OWCF on top on dead rachis mat**.**

LiDAR measurements were found to accurately depict how forest structure is impacted by OWCF. The publicly available data also allows for large scale sampling which is logistically difficult due to time, labor, and financial constraints. Though this study focused on just one natural area invaded by this species the use of image classification and LiDAR analysis could be extrapolated out to other areas and systems and could be used as a management tool across landscapes and regions. For example, this study demonstrated that both LHDI and canopy openness was shown to be strongly linked with higher invasion densities of OWCF, with more closed diverse canopies being associated with higher invasion density. These metric could be used as a way of identifying new or developing invasion sites of climbing species.

In the fifty years following the introduction of OWCF, the species has spread from one plant nursery to being a widespread, common species in most of south Florida (Pemberton and Ferriter, 1998). The rapid growth, strong dispersal ability, and high propagule pressure has helped it to establish in novel areas and alter open canopy wetlands to closed homogenous forest stands. The ability of OWCF to grow over native species and in a variety of different natural communities could have further impacts on biodiversity and primary productivity. The preservation of structural complexity contributes to heterogeneity in forested ecosystems and the effects of OWCF on that structure at JDSP impede that process. The impacts to native vegetation structure shown in this study could have further implications in terms of species composition not only for plant species but also for faunal species.

Managing for biodiversity is not clearly understood, however the concept of maintaining structure in a forested system is one that many land managers are able to easily understand and implement (Noss 1990). To promote biodiversity in the state of Florida there needs to be continued conservation of important habitat features. The best possible management plan for OWCF involves preventing these species from establishing in new areas. Drawing the line between invaded and non-invaded areas will help to control future spread. Preventing OWCF from establishing in new areas will decrease not only future economic costs of management, but more importantly it will decrease ecological impacts on native ecosystems. Providing education and becoming an advocate for invasive species management are critical components of a successful management strategy for Florida.

Appendix: Discussion of Aerial Imagery Results

The regression analysis, though not useful in predicting the year-to-year pattern in invasion density classes, did anecdotally provide insights into conditions related to patch expansion or contraction of OWCF. In 2010 the average annual precipitation for Martin County, FL was approximately 3.71 inches per month with both the wet and dry season being drier than average (SFWMD, 2011). Precipitation remained low in the early months (January-May) of 2011 decreasing to 1.906 inches (SFWMD). This lack of rainfall may explain the large decrease in area for the high and medium invasion density classes and increase in the low invasion density class. Areas that may have had a high density of OWCF in previous years would then appear to contain a lower density in 2011 due to desiccation. Imagery for 2011 was taken in January of 2011 before the wet season began and OWCF prefers wet conditions where spores are able to germinate quickly and successfully. Drier weather impedes the rapid growth exhibited by OWCF and much of the above ground can quickly become desiccated if water is not readily available.

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CHAPTER THREE: RELATING OLD WORLD CLIMBING FERN (*Lygodium microphyllum*) MANAGEMENT EFFORT TO PLANT DIVERSITY

Introduction

A diversity index is a common measure of the health of an ecosystem with a more diverse assemblage indicating a healthier system (Tilman, 1994; Chapin et al., 2000; Hooper et al., 2001; Loreau et al., 2001). Diversity is measured by determining how many species are present in a given area and how even that community assemblage is. Areas with more diverse communities are typically associated with greater primary productivity and potential ecosystem services (Tilman, 1994; Chapin et al., 2000; Hooper et al., 2001; Loreau et al., 2001). Currently there are several threats to biodiversity including, habitat degradation and fragmentation, overexploitation, invasive species, and climate change (Dobson et al., 1997; Dukes and Mooney, 1999; Sala et al., 2000). In particular invasion by non-native species and climate change had been shown to be strongly correlated (Dukes and Mooney, 1999; Dukes et al 2011; Fridley, 2012).

According to current Intergovernmental Panel on Climate Change (IPCC, 2013), the amount of carbon dioxide in the atmosphere and temperatures are increasing at an unprecedented rate. Some of these conditions can lead to changes in flowering time for plant species. Many native plants may not be able to adapt quickly enough to these changing conditions. These seemingly small changes in flowering can affect the growth and distribution of plants. Invasive plants, in particular, have been shown to favor changing climatic conditions and spread further (Porter et al., 2013; McGeoch et al., 2006, Willis et al., 2010) Invasive plants are expected to increase in size and spread into new areas due to the fact that they are able to utilize additional resources made available by climate change more readily than native species.

Invasion by non-native species is of ecological and economic concern and can cause losses in biodiversity on both a regional and global scale; however, there are discrepancies in terms of the magnitude of these impacts (McKinney and Lockwood, 1999; Sax et al.,, 2002; Sax and Gaines, 2003; Latimer et al., 2005). Invasive climbing plants, however, have been described as ecosystem engineers for the way these species change the structure of plant communities in areas in which they invade. These plants can lead to changes in the habitats in which they reside. Many rare native plants are also being displaced by these invaders. Invasive climbing plants are typically associated with higher canopy cover and lower understory cover in invaded sites, and with lower overall species richness compared to uninvaded sites (Hutchinson and Langeland, 2011).

Management costs for invasive species in the United States are estimated to be about 120 billion dollars annually (Pimentel et al., 2005). With the threat of increased spread due to climate change, these costs can be expected to rise and management may become more frequent and widespread. Management for invasive plants varies depending on the species and the system in which it invades. Traditional management practices include manual removal, such as weeding or plowing an area, herbicide application, as well as prescribed burns in naturally pyrogenic systems. Success of invasive species management differs across systems and there is not a standard in place in order to determine how effective a particular method is or at what frequency it should be conducted. Each of these practices themselves could also be considered a disturbance to natural areas and could potentially impact species richness and abundance.

While several studies have focused on the impacts of invasive plant species on biodiversity, very few have examined the effects of various management techniques on community structure (Flory, 2010; Jager and Kowarik, 2010; Kimball, et al., 2014). While understanding the biotic interactions that occur between native and non-native species is necessary for making effective management decisions, it is also crucial to understand the potential impacts that management for invasive species may have on community structure. Plant diversity can be used as a proxy in determining potential impacts on all taxa in areas managed for invasive plants. In this study, I aim to answer whether the presence of Old World climbing fern (*Lygodium microphyllum*) and the management efforts aimed at eradicating this species impacts the native plant diversity found at Jonathan Dickinson State Park (JDSP).

Previous studies have found that the competition imposed by OWCF for space has caused several native species, including some rare bromeliads, to experience declines in population numbers (Craddock Burks, 1996). Due to OWCF's ability to act as an ecosystem engineer by outcompeting native species for space, I expected that areas invaded by a non-native climbing plant will have lower plant diversity than uninvaded sites. I also expected that a decrease in diversity in invaded sites would be correlated with a decreased number of understory species present due to the change in the sub-canopy radiation regime with the presence of OWCF. In terms of management effort, I expected that the most frequently managed zones will have the largest values for both species richness and diversity.

Study Species

OWCF (*Lygodium microphyllum*) is a prime example of an invasive climbing species that is expected to spread with climate change. OWCF was introduced to the United States from East Asia and Australia in the mid-twentieth century. This perennial fern species was prized for its ornamental value and was used similarly to ivy for decorating gardens and landscapes. OWCF displays typical traits of a successful invasive species, such as easy dispersal, high propagule pressure, fast reproductive rate, rapid growth, and a tolerance for a wide variety of environments (Brown, 1984; Pemberton and Ferriter, 1998).

The leaflets of OWCF alternate between a non-fertile form with entire margins to a lobed fertile leaflet. There two rows of sporangia that line the small fertile leaflets. Each frond can then produce thousands of small, lightweight spores. In a previous study it was found that several hundred spores were caught per cubic meter per hour above a densely invaded stand of OWCF (Pemberton and Ferriter, 1998). The fern is able to spread easily and quickly through the spores which are easily transported by wind, water, and animals. Spores can remain dormant for long periods of time, up to about two years, and will germinate in moist soils and recently disturbed areas (Brown, 1984; Pemberton and Ferriter, 1998).

Figure 15: Example of the elongated frond of OWCF and the dense rachis mat created in the understory prior to ascending into the canopy.

After germination, OWCF creates large, dense mats of vegetation in the forest understory before proceeding into the canopy by climbing over other any existing structure (Figure 15 and 16). These vegetation mats are called rachis mats and are usually targeted in most management practices due to the shading effect that occurs when the fern enters the canopy (Hutchinson and Langeland, 2011). This subcanopy change in light availability threatens the understory vegetation present by reducing a crucial resource for growth and survival: sunlight. As OWCF is a perennial species, these rachis mats persist year round with drought and hard freezes being the only natural limiting factor in growth. If there is a lack of precipitation or unseasonably cold weather, the aboveground biomass of the fern desiccates and leaflets drop, but the physical structure of the rachis mat remains intact (Pemberton and Ferriter, 1998;

Minogue et al 2010). The fern will remain dormant for some time until conditions for growth are favorable and the plant then regenerates from an underground stem, or rhizome.

Figure 16: Two densely invaded sites with the understory completely covered by OWCF. The species then climbs existing vegetation by twining or wrapping itself around tree trunks.

The rhizome presents a problem in terms of management as they are not easily accessible, and in areas densely invaded by OWCF, there are a myriad of rhizomes in the soil. In fact, most management practices are unable to completely eradicate this species due to the fact that the rhizome is either not targeted in management practices or is difficult to access. Most herbicidal treatments are not transported down to the rhizome by plant tissues (Hutchinson et al., 2007; Hutchinson et al 2010; Hutchinson and Langeland, 2011).

Study Area and Management Practices

Jonathan Dickinson State Park (JDSP) is located in South Florida and was established in 1950. The park used to serve as a military camp and training center for radar systems. The park is home to several different natural communities and land cover classes. The park is also an important habitat for many vertebrate and invertebrate species and has been invaded with OWCF since the early 1960’s (Beckner, 1968). Management for invasive species has occurred sporadically throughout the park since the 1990’s, but had not been documented until 2004. Zones within the park are managed at different frequencies due to lack of funding or logistical reasons.

The first line of controlling the OWCF involves simple manual or mechanical removal. Manual removal is achieved by pulling or cutting the fern from the landscape, whereas mechanical removal involves machinery such bulldozers, chainsaws, and lawn mowers. This form of removal costs very little as the only costs attributed to it are wages of workers and equipment that can be utilized for other projects. In some cases there is no cost at all for labor. Invasive species round-ups are social gatherings designed around the removal of invaders by environmental groups such as the Florida Exotic Pest Plant Council and the Florida Native Plant society. There are Old World and Japanese climbing fern specific round-ups where groups of volunteers remove the ferns from natural areas. This concentrated effort helps to remove large amounts of the ferns’ above ground biomass. Manual and mechanical is most effective as an early detection/rapid response (EDRR) management practice. Early detection management concentrates on the small initial infestations in order to prevent the permanent establishment of the invader.

There are, however, limitations to the effectiveness of manual or mechanical removal of OWCF. The process of manually weeding can be cumbersome due to the anatomy and multiple branching growing patterns of this fern. The herbaceous nature of this plant makes the main rachis difficult to distinguish from branches. Roots can grow up to a meter long which makes extraction more difficult (Pemberton and Ferriter, 1998). When removing the ferns, land managers and volunteers also have to be knowledgeable about possibly dispersing spores and actually enlarging the area of infestation. Manual and mechanical removal is typically oriented around times that the plants are not fertile as to reduce this risk.

Herbicide treatment is a control mechanism typically used in conjunction with manual or mechanical removal in larger infestations. This method remains the most common type of eradication method utilized by land managers. Workers will cut portions of the fern and a mixture of herbicide and water is sprayed on the leaflet surface and cross-section of the frond in order to enter the vascular tissues of the plant (Hutchinson and Langeland, 2006). The vascular tissues then work to transport the herbicide to other areas of the fern. The herbicide can be applied on the ground with spray bottles or aerially using an airplane to blanket large areas.

A common problem that arises when using herbicidal treatment is that the biomass of the dead rachis mat remains in areas where treated and can still shade out other species. There is also the concern that OWCF can develop a form of resistance to certain herbicides. A University of Florida study examined the response of OWCF to several forms of herbicide and at different concentrations (Hutchinson and Langeland, 2006). They found that the effectiveness of the different herbicides were not statistically different, however when repeatedly using the same concentration that OWCF formed a resistance to that treatment. This study indicates that while different herbicides may be equally effective there has to be changes in the concentration so that the ferns do not become adapted to it.

Prescribed fires are also used to remove Old World and Japanese climbing fern from outcompeting and inhibiting growth of native species in these types of ecosystems. These two species have been known to change the fire ecology in areas where they have invaded (Boughton et al., 2011). This method is typically utilized as a last resort to rather large infestations when herbicide and manual removal are no longer feasible at such a large scale. The fern is typically cut and sprayed with herbicide before a prescribed burn is recommended as a treatment. Fire in these areas infested with non-native species is intended to allow native vegetation to refill the niche space left uninhabited. Fire, however, may actually increase the ability of Old World and Japanese climbing fern to disperse. For wind dispersed species, such as these, spores are sent up into winds and can remain dormant until the spore rests in moist soils (Pemberton and Ferriter, 1998).

Stocker et al. (2008) examined whether or not herbicide and fire combined treatments were effective at eradicating OWCF in South Florida. They found that initially the abundances of various native species were negatively impacted by the herbicide either by being killed or by becoming greatly reduced in biomass (Stocker et al., 2008). The native plants recovered after the study concluded.

Methods

Field Sampling

A random selection of the original 300, 0.25 ha remotely sensed sites from Chapter 2 was stratified by management frequency and selected prior to field sampling. The invasion category was assigned in the field. From 2004 JDSP management zones received invasive species treatment at varying frequencies from never receiving any management to being incidentally managed when needed. Management zones were grouped into one of four classes: (1) never managed, (2) managed one to three times, (3) four to six times, or (4) incidentally. Incidental management occurs frequently as needed throughout the park, but not regularly since 2004. I also noted whether OWCF was present in the plot and at what density. Density classes were based off of the Florida Natural Area's Inventory (FNAI) cover classes. The classes range from those containing a single plant to a dense monoculture of OWCF (FNAI, 2011). The classes designated by FNAI were further reduced to: low, medium, and high percent cover classes for rapid classification in the field. Low invasion density included areas with no OWCF to a few plants. Plots that were placed in the medium class had dense patches or linearly scattered distributions of OWCF, whereas the plots with greater than fifty percent cover of OWCF were noted as having a high density.

Plant species composition and relative abundance were measured in the field in order to determine the impact of OWCF on plant species diversity. Within each 0.25 ha plot selected from the LiDAR study, three 1x1m quadrats were haphazardly placed. Within each quadrat, plant species were identified, if possible, at the species level in the field. Voucher specimens were collected for any species that were not easily identified.

The following variables were measured for plants in each plot: species, individual plant height (cm), origin (native vs non-native), growth habit, and health (Table 9). The origin of a specimen determined whether it was a native or non-native species. Growth habit describes the form that a particular plant grows (e.g., tree, shrub, herb, forb, graminoid, etc). Noting the growth habit of a plant makes identification easier and helps to describe the plant community types present. Percent ground cover of each species present was also estimated within each quadrat (see Appendix Figure 1).

These data were then used to calculate the Jost Diversity index for each plot (Jost, 2006). Percent cover was used as a proxy for species abundance or number of individuals due to the prevalence of clonal species in most of the randomly selected plots. The presence of clonal species could skew diversity values if number of individuals was incorrectly measured. Species that were also non-native and classified as invasive were marked as such. To examine the impacts of invasive plants on native biodiversity I calculated species richness and diversity of native plant species only. I also noted at each plot if there was feral hog (*Sus scrofa*) rooting present and measured the distance to the nearest road which with ArcGIS using data layers provided by JDSP biologists. These variables were used to determine if the presence of OWCF and/or the plant diversity were correlated with common disturbances experienced within the park.

The number of plots sampled was based on sampling effort. Rarefaction curves were plotted as the number of plots by novel species. A rarefaction curve was created for all four unique plot categories (Gotelli and Colwell, 2001). When the curve leveled off and no new species were discovered for that plot category, I stopped sampling. This resulted in a total of 34 plots or 102 quadrats.

Table 8: Management zones stratified by the years managed for invasive species.

Management Class	Management Frequency	Zones Managed	Total # of zones	Total Area (ha)	Total # of quadrats
1	No Management:	A1, A7, A8, A9, A10, A11, AF, B1, B5, B6, B7, B9, B10, B16, B17, B20, B23, B24, B25, B26, C7, D5,F8, G8	24	909.98	12
2	Managed 1x:	A6, A3, A4, B2, B3, B21, B22, C3, C4, C6, C9, C10, D10	13	296.93	12
	Managed 2X:	A5, B4, B8, D2, D4, D6, D7, D8, D9, G3, G5, G6, H1, H2, H3, H4, I1, I2, I3, J1, J2, J3, J4, J5, K1, K2, K3, L1, L2, L3	30	876.81	
	Managed 3x:	E3, E4, E6, E7, E8, E9, E10, E11, E12, E13	10	897.39	
3	Managed 4x:	A2, C5, D1, D3, E5, E14, E15	7	476.15	39
	Managed 5x:	E2, F1, F2, F3, F4, F6, G7	7	722.47	
	Managed 6x:	E1, F5, F7, G1, G2, G4	2	66.86	
4	Incidental management:	B11, B12, B13, B14, B15, B18, B19, C1, C2	9	487.65	39

Table 9: List of field sampling plot categories and field measurements.

Dependent Variables	Independent Variables
Presence of OWCF	Species
Management Frequency	Percent Cover of each species present
Time since management	Number of individuals of each species
	Plant Height
	Origin
	Growth Habit
	Health

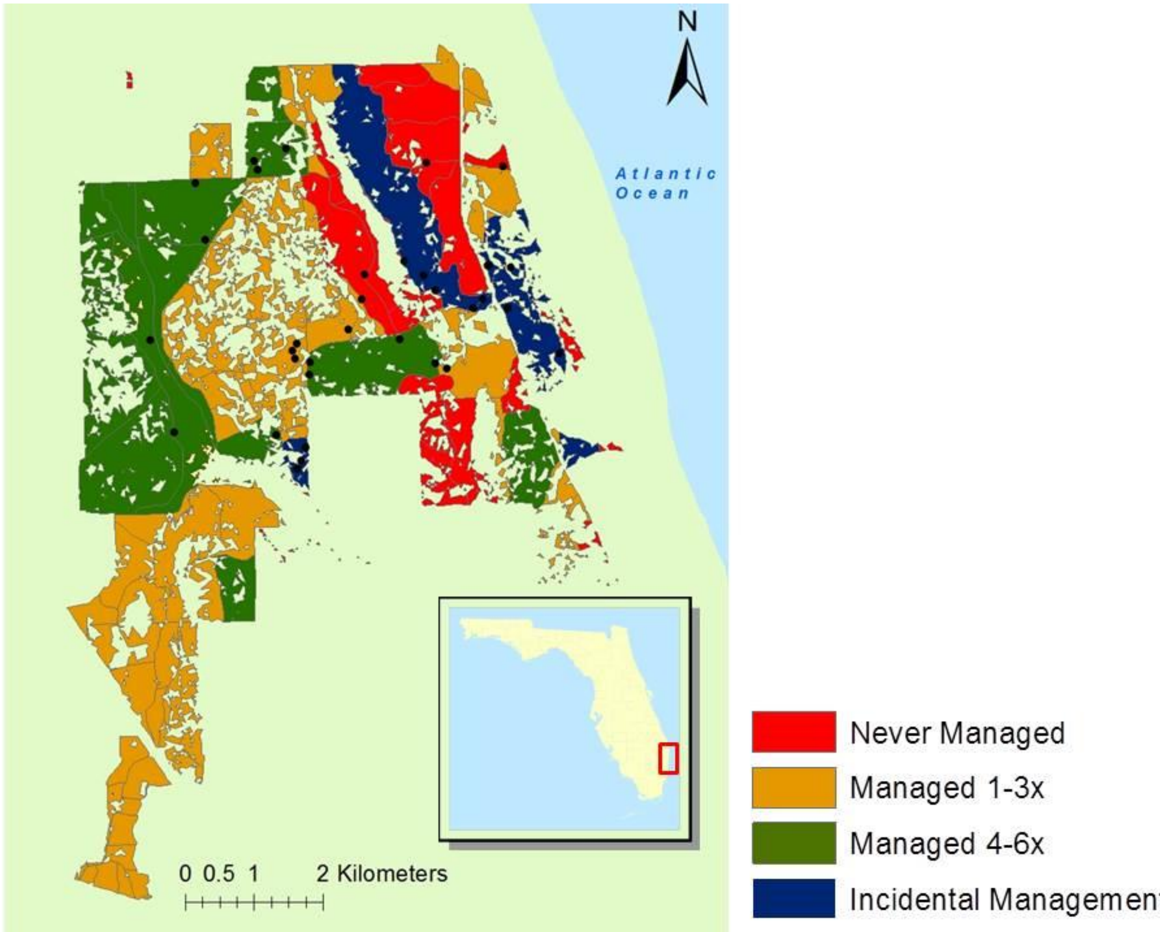

Figure 17: Map of the distribution of Management frequencies within JDSP through 2012.

Statistical Analysis

In order to determine which factors account for the most variance between sites, I first checked for significant differences across management frequency classes, invasion density, and with the presence/absence of OWCF for plant species richness and diversity using one-way analysis of variance (ANOVA). I also ran a regression analysis to determine if time since last management influenced species diversity in the field. I analyzed the plot dataset using a nested ANOVA. Presence of OWCF was nested within management frequencies. A nested design was used for this analysis because zones that are managed with the same frequency are spatially clumped throughout the park. Using a nested design avoids any pseudoreplication that could occur by assuming all the plots were independent samples. Within the Palustrine forested wetland system there are several plant community types. Plots were further stratified by plant community type in order to determine if the presence of OWCF had differing impacts across various community types. These data were analyzed using a one-way ANOVA with the presence/absence of OWCF as the independent variable and species richness and diversity as the dependent variables.

To compare community patterns across management frequencies, invasion categories, and plant community types the field data were analyzed using non-metric multidimensional scaling (NMS) and multi-response Permutation Procedure (MRPP) in PC-ORD (McCune and Grace, 2002). NMS, a multivariate ordination technique, was chosen to help to determine which factors and interactions between various factors influence species diversity. This technique was performed in PC-ORD using the "slow and thorough" mode.

Comparisons were also made across the different invasion stages and management frequencies by applying MRPP in PC-ORD. MRPP tests for the differences between groups of variables and were applied to determine if plant species composition is homogenous within individual invasion categories, management frequency, and plant community types. Values range up to 1 which is indicative of all plots within a management class or invasion category having the same exact species present. This value was used to determine how even species composition is distributed within each plot category. Indicator species analyses (ISV) were also conducted in PC-ORD. This process assigns an indicator value to every species (or genus) present and is used to determine correlations between that species being present and a particular management frequency class or plant community type. Large indicator values indicate a strong association of a species to a particular plot category.

Lastly, I ran a series of logistic ordinal and regression analyses to test if hog rooting, the distance from the nearest road, or distance to a water source influenced the presence of OWCF. The logistic test was appropriate for this type of analysis as presence and absence is a binary response. This was used to determine if disturbances within the park influences the diversity of plants within the park. Hog rooting is of interest as feral hogs are another invasive species in the state of Florida and are believed to create new spaces for other invasive species to invade by removing native plants and disturbing soils (Simberloff and Von Holle 1999).

Results

A total of 74 unique plant species were identified in the field plots (see Appendix). Species that were not able to be identified were listed under their respective genera. There were a total of eight such genera consisting of primarily grass species. The average species richness and Jost diversity were calculated for each plot. The distribution of these values across invasion density classes and in relation to the presence of OWCF is shown in Figures 18 and 19, respectively. These results were not significant, but they did display a trend with decreases in both species richness and abundance with increasing OWCF density. The distribution of species richness and diversity across the various management frequency classes is shown in Figure 20. The management frequency with the highest average species richness and diversity were the plots that were managed four to six times.

The results of the one-way ANOVA indicated that management frequency class explained a significant proportion (p<0.0001, p=0.003) of the variance in both species richness (Figure 21a, Table 10) and diversity (Figure 21b, Table 11), whereas the presence of OWCF alone could not account for the differences in diversity or species richness (p=0.112, p=0.144). The one-way ANOVA that used invasion density (low, medium, and high) as the dependent variable did not find significant differences for species richness (p=0.240) or diversity (p=0.407).

There were a total of three plant communities sampled: wet flatwoods, scrub, and strand swamp. For the wet flatwoods (Figures 22, Tables 12 and 13) and strand swamp (Figures 23, Tables 14 and 15) plant communities plots displayed lower values for both species richness and diversity when invaded by OWCF. This was not the case for scrub plots. These plots displayed higher values for both species richness and diversity with the presence of OWCF (Figure 24, Tables 16 and 17). The one-way ANOVAs by plant community type, however, indicated that these differences were not statistically significant.

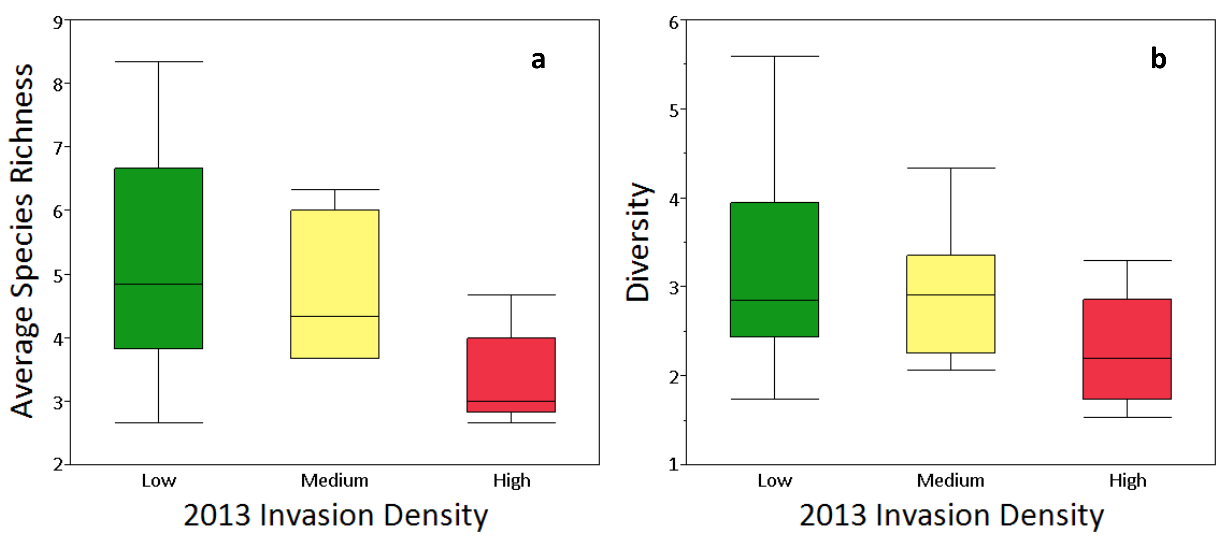

Figure 18: Box plots describing the distribution of total species richness (a) and diversity (b) values across an invasion gradient.

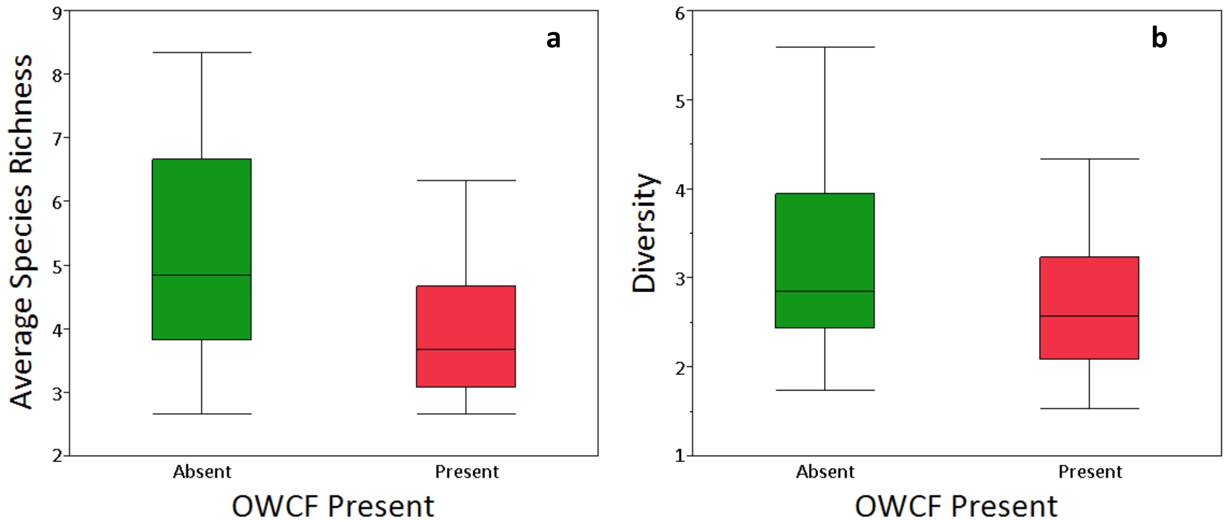

Figure 19: Box plots describing the distribution of native species richness (a) and diversity (b) for plots with and without OWCF present.

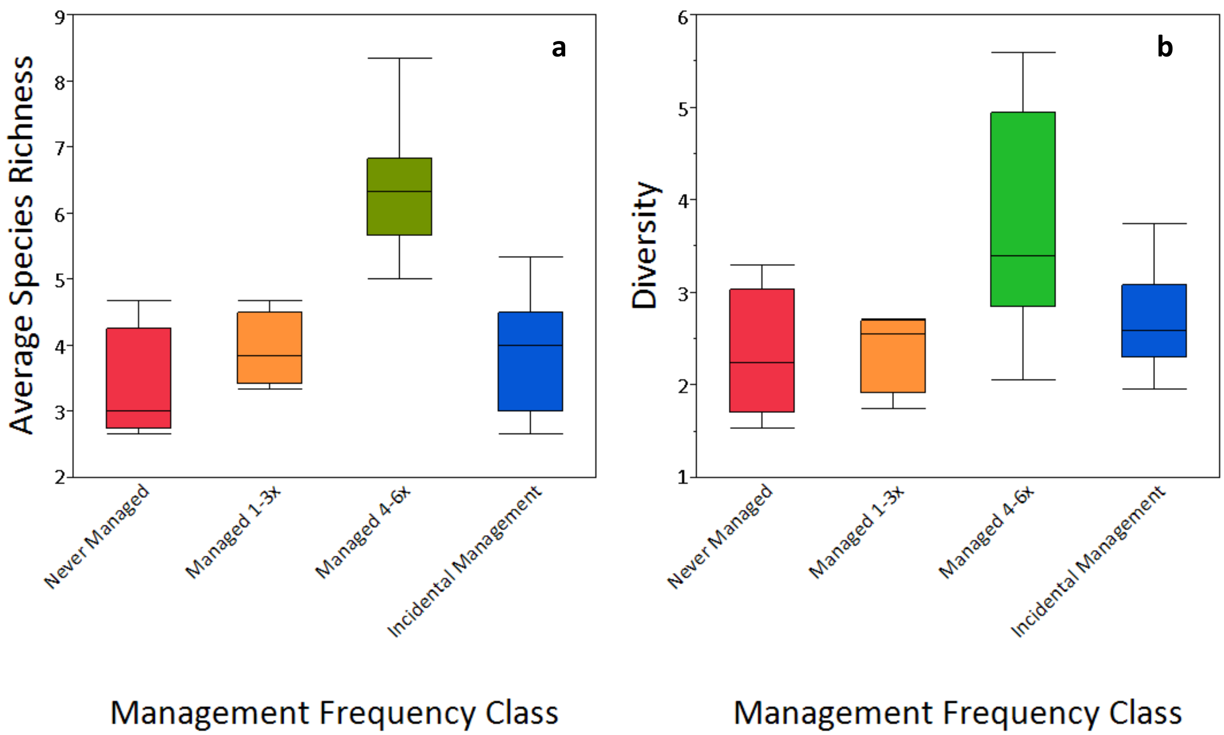

Figure 20: Box plots describing the distribution of native species richness (a) and diversity (b) for plots across various management frequency classes. Categories not designated by the same letter (a/b) are significantly different from one another.

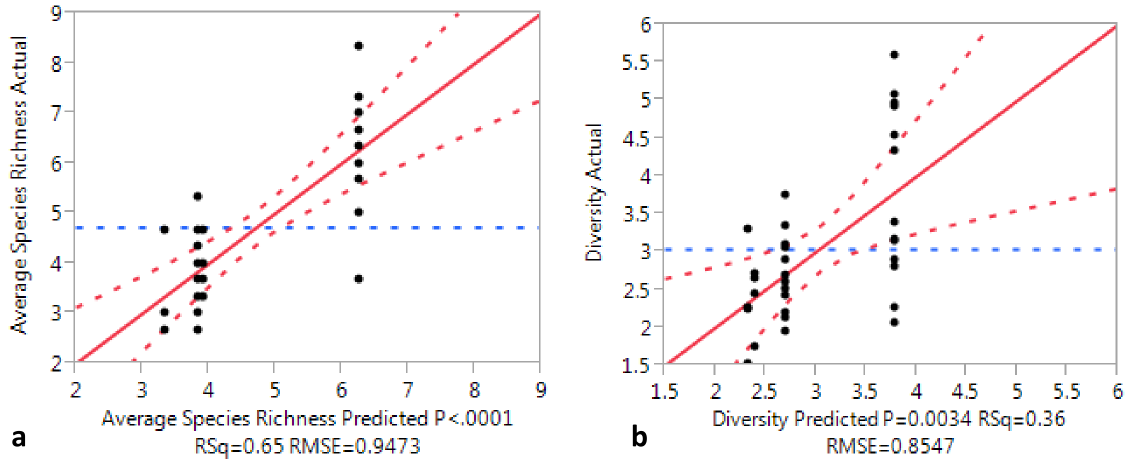

Figure 21: Results of the one-way ANOVA for (a) native plant species richness (p<0.0001) and (b) diversity (p=0.003) by management frequency class. Dashed lines indicate the 95% confidence interval, and solid red line indicates the best fit line for this data set. The blue line indicates the average value for species richness across all the field sampling plots.

Table 10: ANOVA table for native plant species richness by management frequency class.

Source	DF	SS	MS	F	P
Management class	3	50.886	16.962	18.902	<.0001
Error	30	26.921	0.897		
Total	33	77.807			

Table 11: ANOVA table for native plant diversity by management frequency class.

Source	DF	SS	MS	F	P
Management class	3	12.380	4.127	5.649	0.003
Error	30	21.918	0.731		
Total	33	34.298			

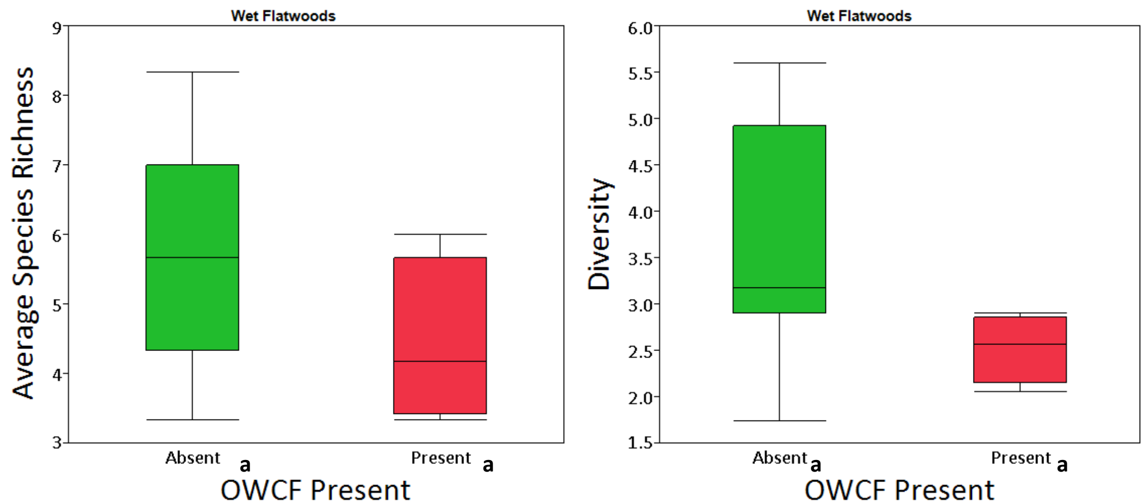

Figure 22: Results of the one-way ANOVA for species richness and diversity by the presence of OWCF in the wet flatwood plant community type. Categories not designated by the same letter (a/b) are significantly different from one another.

Table 12: ANOVA table for native plant species richness by the presence of OWCF by the presence of OWCF in the wet flatwood community type.

Source	DF	SS	MS	F	P
OWCF Presence	1	5.274	5.274	2.420	0.144
Error	13	28.326	2.179		
Total	14	33.600			

Table 13: ANOVA table for the native species diversity by the presence of OWCF in the wet flatwood community type.

Source	DF	SS	MS	F	P
OWCF Presence	1	3.116	3.116	2.905	0.112
Error	13	13.945	1.073		
Total	14	17.061			

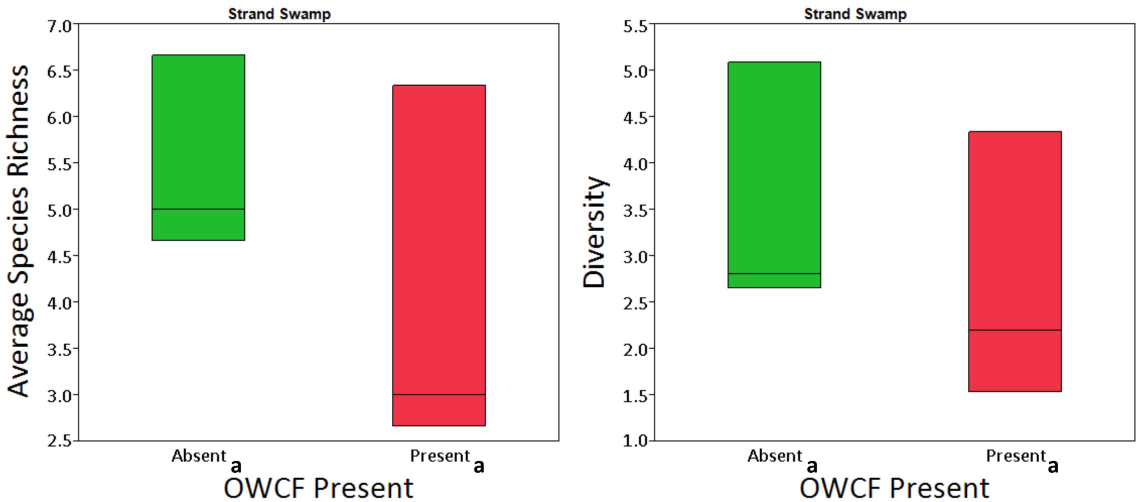

Figure 23: Results of the one-way ANOVA for species richness and diversity by the presence of OWCF in the strand swamp plant community type. Categories not designated by the same letter (a/b) are significantly different from one another.

Table 14: ANOVA table for native plant diversity by the presence of OWCF in the strand swamp plant community type.

Source	DF	SS	MS	F	P
OWCF Presence	1	3.130	3.130	1.190	0.337
Error	4	10.519	2.630		
Total	5	13.648			

Table 15: ANOVA table for native plant diversity by the presence of OWCF in the strand swamp plant community type.

Source	DF	SS	MS	F	P
OWCF Presence	1	1.032	1.032	0.515	0.513
Error	4	8.009	2.002		
Total	5	9.040			

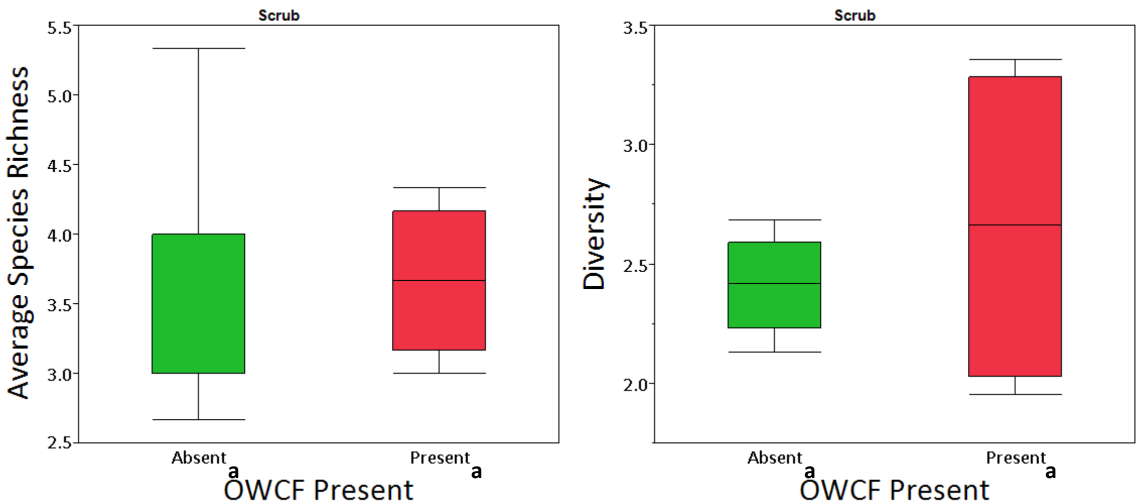

Table 16: ANOVA table for native plant diversity by the presence of OWCF in the scrub plant community type.

Source	DF	SS	MS	F	P
OWCF Presence	1	0.023	0.023	0.034	0.858
Error	9	6.159	0.684		
Total	10	6.182			

Table 17: ANOVA table for native plant diversity by the presence of OWCF in the scrub plant community type.

Source	DF	SS	MS	F	P
OWCF Presence	1	0.163	0.163	0.940	0.358
Error	9	1.559	0.173		
Total	10	1.722			

The nested ANOVA was structured with the presence/absence of OWCF nested within management frequency class. This test revealed significant differences between plots for species richness with a p-value of 0.0001 (Figure 24, Table 18) and diversity with a p-value of

<0.0001 (Figure 25, Table 19). The results of the regression analysis of diversity and species richness by time since management were not significant (p=0.47, p=0.84).

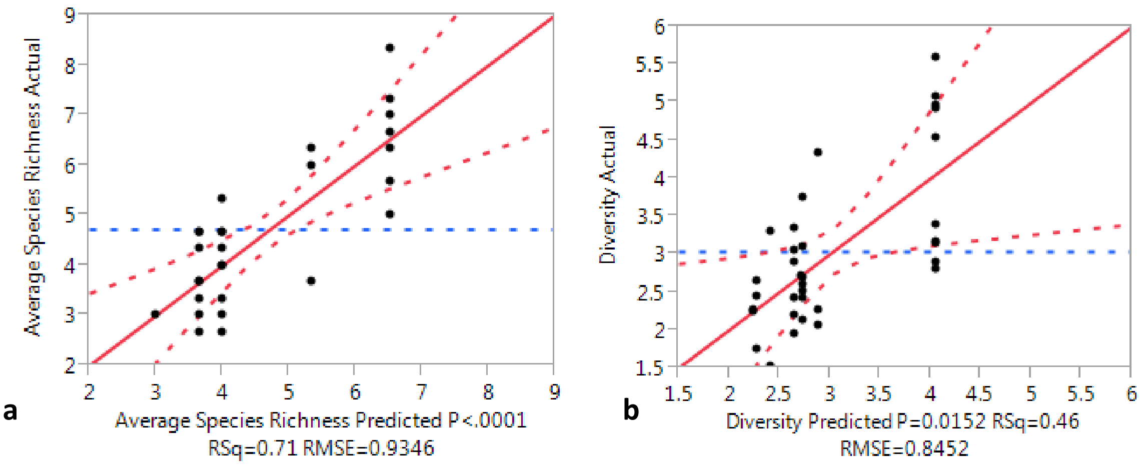

Figure 24: Results of the nested ANOVA for (a) plant species richness (p<0.0001) and (b) diversity (p=0.015) with presence of OWCF nested within management frequency class Dashed lines indicate the 95% confidence interval, and solid red line indicates the best fit line for this data set. The blue line indicates the average value for species richness across all the field sampling plots**.**

Table 18: Nested ANOVA table for native plant species richness by management frequency class and presence of OWCF (OWCF).

Source	DF	SS	MS	F	P
Management class(OWCF)	7	55.096	7.871	9.011	<0.0001
Error	26	22.711	0.874		
Total	33	77.807			

Table 19: Nested ANOVA table for plant diversity by management frequency class and presence of OWCF.

Source	DF	SS	MS	F	P
Management class (OWCF)	7	15.725	2.246	3.115	0.015
Error	26	18.573	0.714		
Total	33	34.298			

The result of the NMS ordination procedure of the plots stabilized at a 4-dimensional solution with a stress of 11.828 (see Appendix). Most of the variance was explained by the first axis at 30.1%, while the second, third, and fourth axes described 13.1%, 17.4%, and 9.7%, respectively. Plots that were either managed incidentally or at least four to six times had the greatest diversity of plant assemblages, whereas the plots that were never managed or only managed up to three times had fewer species present (Figure 26). There was however a significant amount of overlap in the species that were present in all four management classes (Figure 26). When separated by the presence or absence of OWCF the plots that contain OWCF have different species than the plot devoid of OWCF (Figure 28).

a)

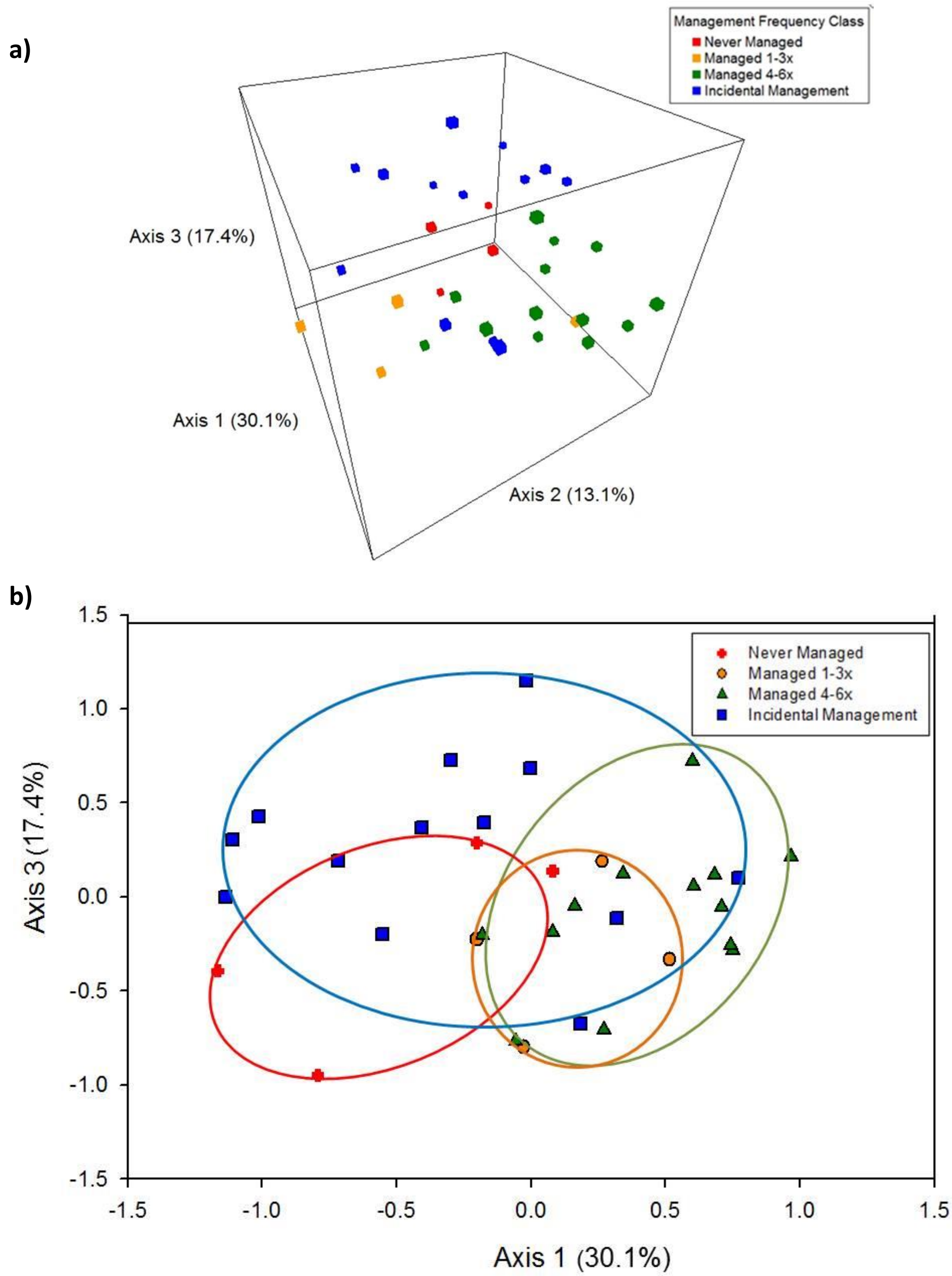

Figure 25: Results of the NMS ordination procedure with ellipses defining various grouping categories: (a) management frequency class in three dimensions and (b) in two dimensions. The placement of the points, which represent plots, along each axis is determined by the species present.

a)

b)

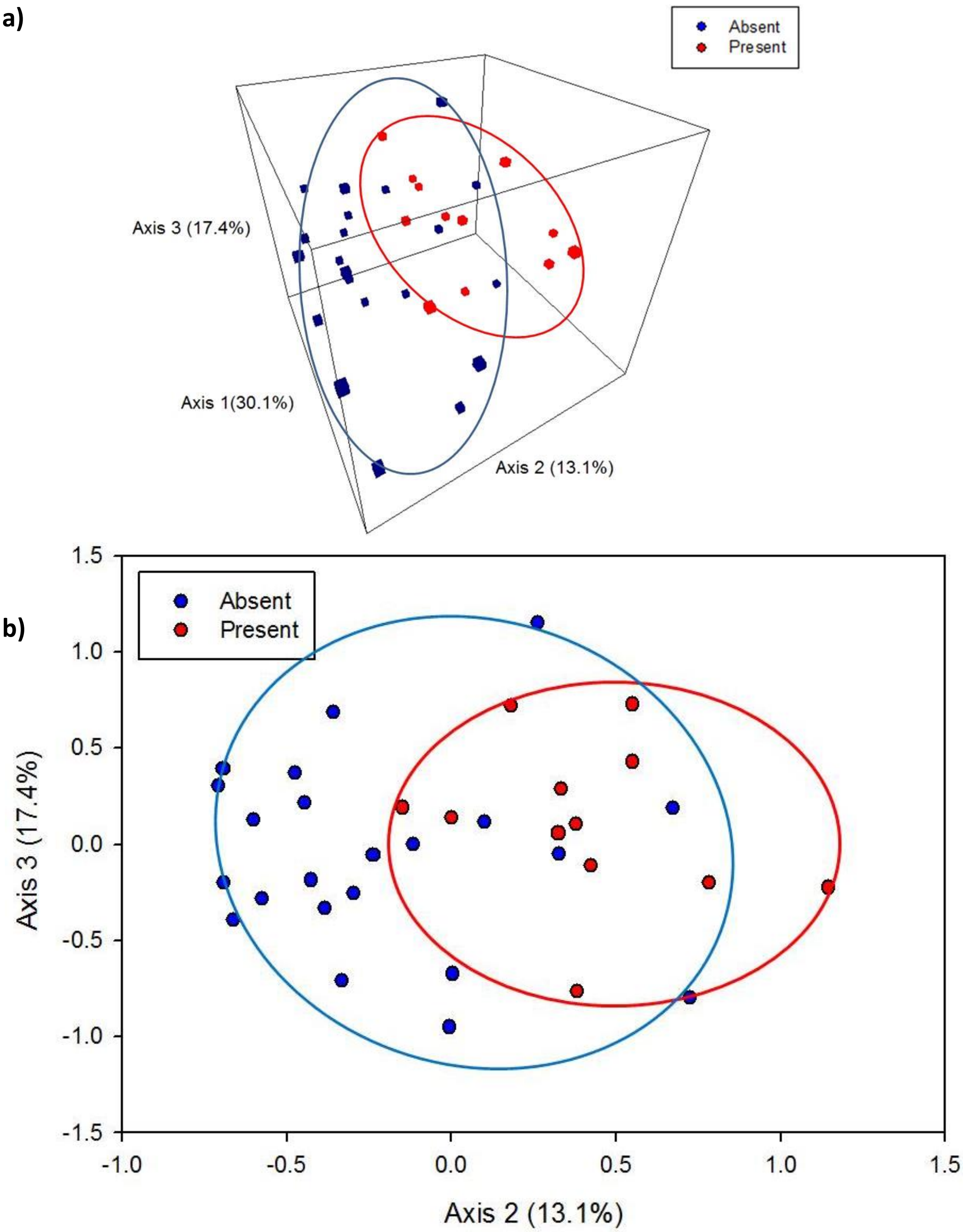

Figure 26: Results of the NMS ordination procedure with ellipses defining either the presence or absence of OWCF in (a) three dimensions, and (b) in two dimensions. The placement of the points, which represent plots, along each axis is determined by the species present.

The MRPP test was run by delineating group categories by both management frequency class and presence of OWCF in order to determine how plant species fall out within the plots. The MRPP allocates a value called the chance-corrected within-group agreement (A) that determines how homogenous a particular group is (McCune and Grace 2002). A value of 1 for A would be indicative of all the plots in the same category having the exact same species present (McCune and Grace 2002). Therefore, field sites with a more heterogeneous assemblage would have smaller values for A, with negative values indicating a very little overlap between plots of the same category (McCune and Grace 2002).

Within each management category the most homogenous was the non-managed plots, whereas the managed incidentally plots were the most heterogeneous containing the most diverse accumulation of plant species. Pairwise comparisons between all four management categories were made in order to determine how species compare between pairs of management classes. The results indicate that management classes three and four, which consist of the most frequently managed plots had the highest value for A at 0.046, which was significant ($p<0.0004$) (Table 20). The pair of management classes that had the least amount of overlap in species occurrences were management classes one and four (A=-0.007), however this comparison was not significant with a p-value of 0.658 (Table 20). Management frequency class one had received no treatment for OWCF whereas management frequency class four received incidental, or frequent management.

Table 20: Pairwise comparisons for species occurrences across various management frequency zones**.**

Pairwise Comparisons	A	p-value
3 vs. 4	0.046	0.0004
3 vs. 2	0.023	0.079
3 vs. 1	0.029	0.046
4 vs. 2	0.025	0.069
4 vs. 1	-0.007	0.658
2 vs. 1	0.031	0.150

The same MRPP procedure was run in PC-ORD using the presence of OWCF as the grouping variable. The pairwise comparison between these two groups determined a value of 0.024 for A. This comparison between groups was significant ($p<0.005$). The average A within each of the presence categories were 0.761 for plots with no OWCF and 0.745 for plots with OWCF indicating that the species present within each category was fairly homogenous within groups, but between categories, the species assemblages were different.

The indicator species analysis was then run to determine if the species present within the plots were indicators of any particular management frequency or presence class. This analysis was run twice, once for management frequency and another for presence of OWCF. The ISV indicated that there were several correlations between key species and management frequencies (Table 21). IV values range from 0 to 100 with a value of 100 indicating that a particular species belongs to a particular group with no error (McCune and Grace 2002). For the plots that were never managed, Sand Live Oak (*Quercus geminata*) was deemed an indicator species (IV=41.2) with a marginally significant p value of 0.058 for plots within the no management class. Dogfennel (*Eupatorium capillifolium*) was listed as an indicator species (IV= 48.8) for management frequency class 2, with a p-value of 0.023. The highest IV value found for a species in management frequency class 2 was 43.7 (p<0.025) and was assigned to Common carpetgrass (*Axonopus fissifolius)*. Chapman Oak (*Quercus chapmanii*) had the highest IV value (30.8) for management frequency class 4, however its value was not significant (p<0.124).

Table 21: Results from the indicator species analysis using management frequency as the grouping factor. Significant relationships are denoted in red. The species listed had IV values of > 25. All the indicator species were native.

Management Class	Species	Growth Habit	Observed IV Value	Randomized IV		p-value
				Mean	Std Dev	
1 - No management	*Quercus myrtifolia*	TR	28.3	18.8	10.7	0.208
	Quercus geminata	TR	41.2	22.2	9.08	0.058
	Sand Pine	TR	25.5	17.2	10.34	0.201
2 - Managed 1-3x	*Andropogon genus*	GR	33.2	23	8.78	0.182
	Eupatorium capillifolium	GR	48.8	17.4	10.39	0.023
	Ilex glabra	SH	28.1	25.8	7.84	0.343
	Vitis rotoundifolia	V	26.8	25.2	8.46	0.512
	Paspalum genus	GR	28.3	18.4	10.04	0.194
3 - Managed 4-6x	*Andropogon virginicus var glaucus*	GR	30.8	16.1	9.3	0.120
	Axonopus fissifolius	GR	43.7	22.8	9.15	0.025
	Lyonia lucida	SH	27.4	25.3	8.57	0.333
	Serenoa repens	SH	27.7	27.3	6.63	0.366
	Piloblephis rigida	FB	30.8	16.1	9.21	0.123
	Aristida stricta	GR	37.5	25.2	8.57	0.094
4 - Managed Incidentally >6	*Quercus chapmanii*	TR	30.8	16.1	9.27	0.124
	Quercus virginiana	TR	24.3	22.3	9.17	0.262
	Chamaecrista fasciculata	V	24.6	16.8	9.77	0.263

The indicator species analysis using OWCF presence as the grouping factor indicated that several species within each category could be considered indicator species. However, for plots that were devoid of Old World climbing only Wiregrass (*Aristida stricta*) with an IV value of 50.4 was found to be significant (Table 22). For zones with OWCF present, both Muscadine grape (*Vitis rotundifolia*) and Sword Fern (*Nephrolepis exaltata*) were identified as significant indicator species with IV values of 52.7 (p<0.021) and 37.6 respectively (p<0.015) (Table 22). This analysis was also run by plant community type for both wet flatwoods and scrub systems. The results of this analysis found that indicator species of whether OWCF was present or not within the wet flatwoods included common other pteridophytes, such as the sword and swamp ferns (Table 23). For scrub plots indicator species for plots with OWCF present included another herbaceous climbing vines, love vine and muscadine grape.

Table 22: Results from the indicator species analysis using the presence or absence of OWCF as a grouping factor.

OWCF	Species	Observed IV Value	Randomized IV Mean	Randomized IV Std Dev	p-value
Absent	*Eragrostis genus*	25.2	19.2	6.4	0.204
	Lyonia lucida	33.9	31.7	6.53	0.473
	Quercus geminata	29.1	23.9	6.8	0.246
	Pinus clausa	27.3	15.6	6.15	0.070
	Aristida stricta	50.4	31.8	6.57	0.030
Present	*Vitis rotundifolia*	52.7	31.9	6.67	0.021
	Nephrolepis exaltata	37.6	15.7	6.23	0.015

Table 23: Results from the indicator species analysis by plant community type for wet flatwoods.

OWCF	Species	Observed IV Value	Randomized IV Mean	Randomized IV Std Dev	p-value
Absent	*Eragrostis genus*	36.4	26.7	13.55	0.5089
	Lyonia lucida	35.6	44.8	10.92	1
	Pinus elliotti	36.4	26.8	13.35	0.5225
	Piloblephis rigida	36.4	26.9	13.27	0.5215
	Aristida stricta	54.1	44.7	10.57	0.2408
Present	*Taxodium distichum*	50	20.1	7.37	0.0572
	Serenoa repens	40.6	46.8	9.81	1
	Blechnum serrulatum	32.4	31.4	11.75	0.5419
	Nephrolepis exaltata	91.7	31.9	11.99	0.0028

Table 24: Indicator Species analysis by plant community type for scrub plots.

OWCF	Species	Observed IV Value	Randomized IV Mean	Randomized IV Std Dev	p-value
Absent	*Quercus virginiana*	42	47.3	10.55	1
	Quercus geminata	66.4	47.5	10.7	0.1958
	Pinus clausa	28.6	24.5	10.75	0.4901
	Aristida stricta	28.6	24.5	10.58	0.5011
	Vaccinium myrsinites	42.9	28.6	14.63	0.2352
Present	*Quercus Chapmanii*	31.8	34.9	12.2	0.5675
	Cassytha filiformis	38.9	28.7	14.64	0.4979
	Serenoa Repens	47.7	42.6	13.27	0.5427
	Vitis rotundifolia	63	35.7	13.05	0.0934

The logistic tests for determining whether common disturbances in the park were good indicators of the presence of OWCF were mixed. The ordinal logistic test for hog rooting was significant with a p-value of <0.001 (Figure 27), whereas the logistic regressions of time since management, distance from water, and distance from the nearest road were not significant.

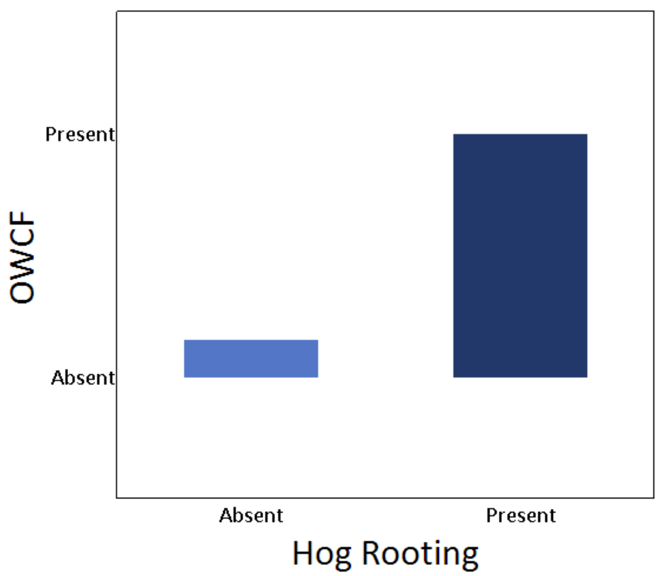

Figure 27: Figure 10: Logistic regression describing the relationship between hog rooting and the presence of OWCF.

Discussion

The results from the statistical analyses indicate that the frequency of management for OWCF and invasive plants in general does impact the diversity of plant species found at JDSP. Species richness and diversity increased as management frequency increased. Those zones which are treated four to six times had the highest values for species richness and diversity. Those zones were located by the western half of the park and along the main road. These zones are the most accessible by road or foot which makes management by park rangers or contractors easier.

On the other hand, the presence of OWCF alone does not determine the number of species or the diversity of the assemblage at any one site. There was a trend however, though not significant, in the diversity values across an invasion density (Figure 18). Plots with a higher density or percent cover of OWCF had lower values for both species richness and diversity while plots with no to little OWCF present had overall higher values for these two metrics. The one-way ANOVA for plant community type indicates that, while not significant, that there is decrease in native plant species richness and diversity in both wet systems: wet flatwoods and strand swamp. This pattern does not exist for the scrub sites. Sites with OWCF present demonstrated higher values for both metrics. Although this relationship is not statistically significant it may be due to fact that scrub systems typically hold shade tolerant species such as oaks. The rachis mat over the top of the understory would not impact these species as strongly as in sites with shade intolerant species as seen in a wet flatwoods community.

The nested ANOVA investigated the relationship between both the presence of OWCF and the frequency of management. The results indicated that while the presence of OWCF alone does not explain a significant amount of variation in plant diversity values across the landscape, when coupled with management frequency there were trends in how species richness and diversity are influenced in the park. The presence of OWCF had a bigger impact in zones of the park that had never been treated for invasive species by being allowed to spread and continue to grow. On the other hand, in those zones which have been treated multiple times since 2004, OWCF did not dominate over native species for both resources and space. Continued spraying and manual removal by the park has been successful at keeping this species at low enough levels that native plants are able to persist.

As indicated by the NMS, MRPP, and ISV the types of species present in a plot varies according to management effort as well as with the presence of OWCF. Sites where OWCF was absent displayed a wider assemblage of species across all management frequencies. There was a significant amount of overlap between the two groups; however, there are species that are present only in plots without OWCF and vice versa. The species most commonly found in sites with OWCF include hardy trees, such as oaks, and other fern species. There is a dearth in the number and variety of herbaceous species in these plots, whereas sites without OWCF have higher occurrences of herbaceous forb and grass species. This pattern may also be attributed to OWCF's preference in invading wet areas such as cypress domes and swamps. Although this species can invade and persist in a wide array of Florida communities areas with the highest invasion success in the park as well as in the state of Florida are wet or close to some water source. These communities are typically comprised of the indicator species determined by the ISV as well as other pteridophytes that prefer wet systems.

In terms of management effort, zones that were treated irregularly, but most frequently have the largest aggregation of different species, however the plots managed four to six times had the highest average for both species richness and diversity. Zones treated only a few times or not at all have fewer overall species present. This leads to the conclusion that frequent management allows for the establishment and persistence of species that may be excluded by the presence of OWCF; however, species richness and diversity did not significantly change with increased management efforts so this pattern of species occurrences may be due to fact that the species commonly excluded by OWCF are early successional species. Indicator species for zones treated for invasive species include grasses and forb species. These species are also common pioneer species that quickly become established after a disturbance such as management. Areas managed infrequently had more transitional species and a higher percent cover of OWCF, whereas the indicator species for zones that have never been treated consist of hardier shrub and tree species such as oaks. These woody species are less likely to compete directly with OWCF for resources until OWCF begins to ascend into the canopy. This is not the case for grasses and common forb species as when Old World begins forming a rachis mat in the understory they often die due to the lack of sunlight available. Frequent management helps to ensure that OWCF and other invasive plant species do not get to the size in which they begin to exclude these species, but too frequent of management may also exclude secondary successional species.

The presence of other disturbances, such as roads, had little to no effect on plant species diversity or the presence of OWCF. This may be attributed to OWCF's ability to efficiently disperse quickly and for long distances. Roads and trails may not provide as strong of a vector for transport as wind. There was a trend in the presence of hog rooting and the presence of OWCF however the logistic regression showed that the presence of rooting is not sufficient to determine if OWCF present. This may be due to an insufficient sample size with few plots with evidence of hog rooting. Feral hogs, an invasive species as well, have been shown in other systems to promote the establishment of other invasive plant species (Loope and Scowcroft 1985; Grice, 2006). It is possible, though not discernable from this study, that the removal of native herbaceous species by rooting provides additional resources by OWCF. Transport of spores by hogs, while not tested in this study, has been documented as common vectors of other invasive plants (Simberloff and Von Holle 1999).

Financial constraints make treating for invasive species a difficult task and so understanding which threshold of management effort has a significant impact on maintaining native plant biodiversity is vital to controlling not only the species itself, but also costs of management. This study has reinforced the importance of frequent management of natural areas, however since the plots that were treated incidentally had the most diverse assemblage it may not be necessary to apply treatments at regular intervals, but rather when needed. This may help to decrease overall costs of management. Utilizing different forms of management strategies, such as prescribed burns can also help to manage OWCF population size while jointly providing the fire needed to maintain the naturally pyrogenic communities at JDSP. Using both herbicide and prescribed burns delay the regeneration of OWCF after management and can allow formally excluded native species to recolonize those areas.

The majority of studies that have examined the impacts of OWCF on Florida communities have found that the invasive climber has lowered plant diversity through competition for resources and space. Management for invasive species remains an economic issue at the local, regional, and national scale. Past studies have looked at how management, in particular herbicide, has impacted native plants. These studies however have only focused on short term impacts directly after treatment. No study has taken into account how frequent management, a significant disturbance in itself, has impacted these same communities over long periods of time. This study has shown that while OWCF may influence community structure at JDSP, frequent management practices help to mitigate long-term impacts. The presence of one ornamental non-native species has altered both the plant species composition and management strategies for South Florida's natural areas.

Appendix: Field Sampling Quadrat Diagram and Species List

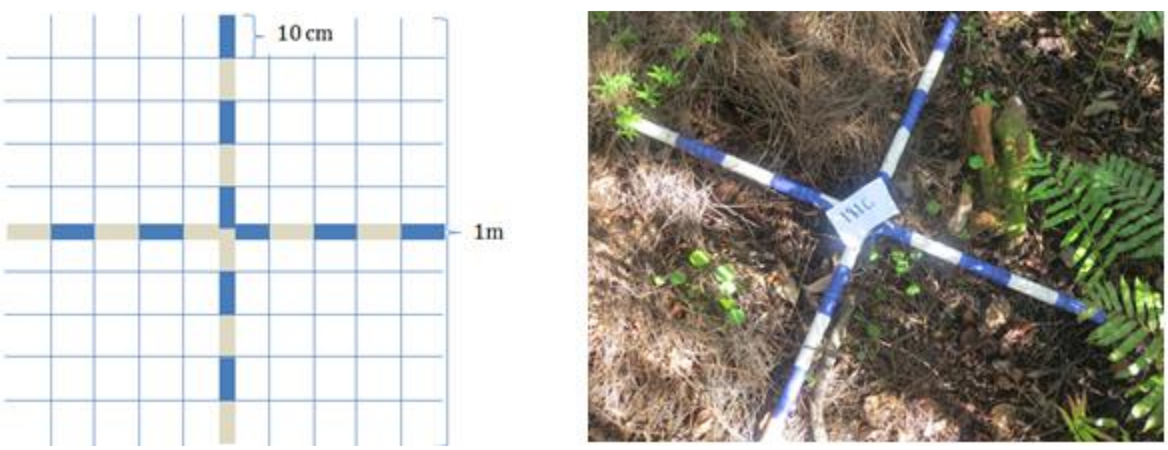

Figure 28: Example of PVC quadrat used in the field for estimating species percent cover.

Table 25: Species List. Non-native species are indicated by an asterisk.

Common Name	Scientific Name
American elm	*Ulmus americana*
Andropорgon genus	-
Aristida Genus	-
Bald-cypress	*Taxodium distichum*

Common Name	Scientific Name
Blue porterweed	*Stachytarpheta jamaicensis*
Cabbage palm	*Sabal Palmetto*
Camphorweed	*Heterotheca subaxillaris*
Capeweed	*Phyla nodiflora*
Carolina holly	*Ilex ambigua*
Chalky bluestem	*Andropogon virginicus var glaucus*
Chapman’s oak	*Quercus chapmanii*
Coinvine	*Dalbergia ecastaphyllum*
Common carpetgrass	*Axonopus fissifolius*
Dahoon holly	*Ilex cassine*
Dichanthelium genus	-
Digitaria genus	-
Dogfennel	*Eupatorium capillifolium*
Downy maiden fern	*Thelypteris dentata*
Earleaf greenbrier	*Smilax auriculata*
Eragrostis genus	
Falsefennel	*Eupatorium leptophyllum*
Fetterbush	*Lyonia lucida*
Florida false beardgrass	*Chrysopogon pauciflorus*
Florida rosemary	*Ceratiola ericoides*
Fourleaf vetch	*Vicia acutifolia*
Fourpetal pawpaw	*Asimina tetramera*
Gallberry	*Ilex glabra*
Giant leather fern	*Acrostichum danaeifolium*
Groundsel tree	*Baccharis halimifolia*
Helianthus Genus	-
Hypericum Genus	-
Innocence	*Houstonia procumbens*
Lacy bracken fern	*Pteridium aquilinum var caudatum*
Laurel oak	*Quercus laurifolia*
Lesser Florida spurge	*Euphorbia polyphylla*
Live oak	*Quercus virginiana*
Love vine	*Cassytha filiformis*
Manyflower marshpennywort	*Hydrocotyle umbellata*
Marlberry	*Ardisia escallonioides*
Muscadine grape	*Vitis rotundifolia*
Myrtle oak	*Quercus myrtifolia*
Narrowleaf blue-eyed grass	*Sisyrinchium angustifolium*
Netted pawpaw	*Asimina reticulata*
Old world climbing fern*	*Lygodium microphyllum*

Common Name	Scientific Name
Panicum genus	-
Partridge pea	*Chamaecrista fasciculata*
Paspalum Genus	-
Virginia creeper	*Parthenocissus quinquefolia*
Perforate reindeer lichen	*Cladonia perforata*
Piedmont black senna	*Seymeria pectinata*
Pricklypear	*Opuntia humifusa*
Red Bay	*Persea borbonia*
Rose myrtle*	*Rhodomyrtus tomentosa*
Rubbervine	*Rhabdadenia biflora*
Rusty Lyonia	*Lyonia ferruginea*
Salicornia Genus	-
Sand live oak	*Quercus geminata*
Sand Pine	*Pinus Clausa*
Saw Palmetto	*Serenoa repens*
Shiny blueberry	*Vaccinium myrsinites*
Shoestring fern	*Vittaria lineata*
Silverling	*Baccharis glomeruliflora*
Skyflower	*Hydrolea corymbosa*
Slash Pine	*Pinus elliotti*
Slender clubmoss	*Lycopodiella caroliniana*
Slender sandbur	*Cenchrus gracillimus*
St John's-wort	*Hypericum tenuifolium*
Succulent grass	
Swamp bay	*Persea palustris*
Swamp fern	*Blechnum serrulatum*
Sword fern	*Nephrolepis exaltata*
Tarflower	*Bejaria racemosa*
Tuberous grasspink	*Calopogon tuberosus*
Turkey oak	*Quercus laevis*
Showy Milkwort	*Polygala violaceae*
Septicweed	*Senna occidentalis*
Climbing aster	*Symphyotrichum carolinianum*
Wax Myrtle	*Myrica cerifera*
White sweetclover*	*Melilotus albus*
Wild pennyroyal	*Piloblephis rigida*
Wiregrass	*Aristida stricta*
Yellow milkwort	*Polygala rugelii*

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CHAPTER FOUR: GENERAL CONCLUSION

The state of Florida is in a unique position in terms of invasion by non-native species with higher than average invasion success (Schmitz, 2007). This can be attributed to the fact that Florida has a greater number of non-native species introductions than other states due to high levels of trade through our many tradeports and shipping ports and human movement through tourism and visitors to the state. The number of vectors available for which species are introduced to the state leads to species having a greater propagule pressure. Higher propagule pressure coupled with numerous vectors of transport contributes to non-native species having a higher rate of invasion success (Reaser et al. 2008).

As one of the successful invaders in the past half-century in the state of Florida Old World climbing fern has significantly impacted the communities and systems in which it has invaded. Understanding the structural impacts of OWCF it crucial in ensuring that land managers and biologists can determine the appropriate type of management as well as to have a clearer picture of how this species impacts Florida systems. The thick, dense rachis mats created by OWCF, as well as its ability to climb over other existing structures, causes this species to have larger impacts then other invasive understory species. Forest stands with greater vertical structural diversity are considered healthier systems than stands with a lower diversity of vegetation structures.

The ability of OWCF to alter forest structure from a relatively open canopy to a closed and homogenous system indicates the magnitude of its influence in the areas in which it invades. By performing as both an understory strata species as well as a canopy cover species OWCF has demonstrated its ability to act as an ecosystem engineer by altering forest and canopy structure in natural areas as well as the community of the native species that are present. In chapter two, I demonstrated that in the case of areas invaded by OWCF structural diversity is greatly reduced by the presence of this species.

In order to successfully manage Florida's natural areas and promote biodiversity there needs to be an effective management practices for maintaining vegetative complexity. A key component of any successful invasive species management program is to understand both the biotic and abiotic impacts of the target species as well as the management practice used to control them. This study has shown that OWCF poses a significant risk to Florida's wetland systems by altering that structure. Understanding which methodologies of management are most successful at eradicating or slowing the spread of invasive species remains to be in major obstacle for land managers.

There are significant limiting factors in terms of the management effort that is possible for natural areas. These include logistic financial as well as time restraints. Management for OWCF, especially manual herbicidal treatments, requires a large amount of manpower. The cost of that manpower as well as the cost of herbicide is also significant. Even with a large workforce for areas densely invaded by OWCF with the plant extending from the understory to the canopy it is very difficult to remove or kill off a significant proportion of this plant. This highlights the importance of understanding how effective management techniques are at varying frequencies in order to determine the optimal amount of management effort is successful at controlling invasive species.

Eradication seems very unlikely for OWCF due to its high propagule pressure, fast dispersal, and high tolerance for a wide variety of environmental factors. However, previous studies have found that using a variety of different herbicide treatments as well as frequently treating areas invaded leads to greater management success in terms of controlling population size and possibly eradicating OWCF from natural areas. Promoting native biodiversity in natural areas is also crucial for the work against invasive species. In chapter three, I presented evidence that while overall plant diversity and species richness did not significantly change with the presence of OWCF, its presence and the management effort, used to control the population at JDSP did alter the species present. It is essential that in conjunction with management for invasive species that land managers are sure to include overall restoration management techniques such as prescribed burns. The best management plan for OWCF and other high impact invasive species is an early detection rapid response to help prevent establishment in novel areas and continued spread.

In the light of increasing globalization and changing climate the invasion by non-native species is becoming progressively prevalent. To successfully promote habitat diversity and in turn biodiversity, there must be monitoring of species present, their function in the community, and the physical structure of a system (Noss, 1990). Understanding these components along with the impacts of non-native species in invaded areas allows for a broader understanding of the landscape and how to effectively manage it.

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