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Assessing Differences in the Wetland Functional Capacity of Wet Pine Flatwood Compensatory Mitigation Sites Managed with Prescribed Fire and Mechanical Mowing

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January 2024
Revised February 2024

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Final Technical Report (TR)

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Abstract

This report assesses the functional capacity of wet pine flatwood wetland habitats in the Gulf Coastal region of the United States, with a specific focus on compensatory mitigation sites maintained using mowing or prescribed fire, or both, as understory management strategies. The use of mowing in lieu of prescribed fire treatments has been proposed for a variety of reasons, including when mitigation sites are located near residential areas or where fires pose a risk to private property and public safety. This study evaluates the effects of mechanized mowing on ecosystem functions by using the hydrogeomorphic (HGM) wetland functional-assessment method to compare mitigation sites managed by mowing to sites managed by prescribed-fire regimes. Assessing mowing as a vegetation-control strategy in lieu of prescribed-fire regimes provides valuable information that can improve the design and management of wet pine flatwoods mitigation sites throughout portions of the southeastern United States, where this wetland class occurs.

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Preface

This report was revised 8 February 2024 for major corrections. It supersedes the previous version.

This study was conducted for the Wetlands Regulatory Assistance Program, US Army Engineer Research and Development Center–Environmental Laboratory (ERDC-EL), under 2022-ERD-0450-0001, "Assessing Differences in the Wetland Functional Capacity of Wet Pine Flatwood Compensatory Mitigation Sites Managed with Prescribed Fire and Mechanical Mowing," Funding Account Code U4390087, AMSCO Code 088893. The technical monitor was Mr. Kyle Gordon.

The work was performed by the Wetlands and Coastal Ecology Branch (EEW), ERDC-EL. At the time of publication, Ms. Patricia Tolley was acting branch chief, EEW, and Mr. Mark Farr was division chief, Ecosystem Evaluation and Engineering Division. The deputy director of ERDC-EL was Dr. Brandon J. Lafferty, and the director was Dr. Edmond J. Russo Jr.

Thanks to Mr. William deGravelles and Ms. Tiffany Hammond of The Nature Conservancy of Louisiana, Mr. Brandon Gaspard of US Army Corps of Engineers–New Orleans District, Ms. Becky Stowe of The Nature Conservancy of Mississippi, and Mr. Nick Goyette in-lieu-free land manager for coordinating access and providing information about the selected properties that helped the US Army Engineer Research and Development Center (ERDC) team complete the sampling required for this project.

Thanks to the Wetlands Regulatory Assistance Program and Program Manager Mr. Kyle Gordon for providing funding and coordinating the management of this project. Thanks to all land managers involved in the completion of this project by allowing the ERDC team access to their properties and providing information about the property itself. A special thanks to Mr. Will Tomlinson and Ms. Sydney Bufkin. Without their help, completion of this project would have been very difficult, if not impossible.

COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

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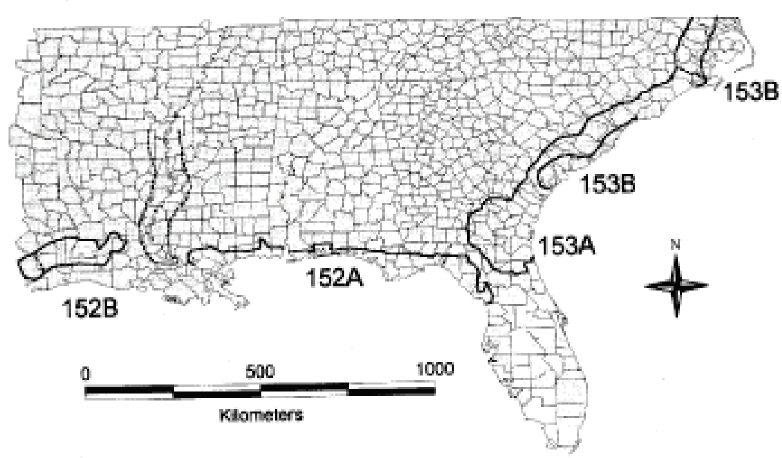
1 Introduction

Wet pine flatwoods occur across portions of the southeastern coastal plain region of the United States, including areas in Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Texas, and Virginia (Figure 1). Under natural conditions, these wetland ecosystems are characterized by three distinct vegetative strata. The herbaceous layer typically exhibits a wide variety of grasses, forbs, and occasionally palmetto; understory vegetation consists of sparse shrubs and hardwood saplings; and the canopy is typically dominated by a single species of pine tree. Healthy wet pine flatwood habitats exhibit herbaceous layers that contain very high species diversity, up to 40 species per square meter, in comparison to other habitat types (Peet and Allard 1993). These unique habitats, and many of the endemic species that use wet pine flats, evolved under periodic fire regimes that maintain a relatively low tree density and provide habitat for multiple pyrophytic plant species. Historically, lightning strikes ignited dead trees or other plant material, and Native and Indigenous Americans used fire to manage ecosystems to support subsistence activities (Means 1985; Platt et al. 1991). In the absence of fire, dense stands of woody vegetation develop and shade out characteristic wet pine flatwood species; increase evapotranspiration; and, over time, induce the conversion of wet pine flats to drier, lower quality, and less diverse habitat.

Figure 1. Reference domain for wet pine flatwoods. Numbers refer to major land resource areas mapped by USDA-SCS (1981, 111–13). (Image reproduced from Rheinhardt et al. 2002, 15. Public domain.)



Today, fire management plays a key role in maintaining fully functional wet pine flatwoods. As a result, ecosystem management approaches incorporate periodic prescribed burning to prevent woody encroachment and sustain the ecosystem functions provided by this wetland class. Many characteristic wet pine flatwood plant species require fire as a requisite aspect of their life cycles (Brewer 1999; Brewer 2001; Landers 1991; Means 1985; Platt et al. 1988). For example, *Pinus palustris* (longleaf pine) relies heavily on fire for growth and reproduction. During the early portion of the *P. palustris* life cycle, known as the *grass* stage, fire acts as a catalyst that triggers growth of the sapling, known as the *bolt* stage or *bolting*. The removal of herbaceous vegetation and leaf litter from the forest floor during fires also benefits *P. palustris* seedling establishment by reducing competition for resources (Landers 1991; Means 1985; Platt et al. 1988). Other plant species of wet pine flatwoods also rely on litter removal, smoke, or heat from fire for seedling germination (Brewer 1998; Brewer 1999; Baskin and Baskin 2001; Brewer 2001; Veldman et al. 2014). Additionally, periodic prescribed fires prevent the growth and invasion of many broadleaf shrubs and trees. Without periodic fires to prevent excess woody vegetation growth, shrubs and trees may produce enough shading to exclude the growth of other plants that rely on sparse canopies and unshaded ground typical of wet pine flatwood habitats (Brewer 1998; Brewer 1999; Veldman et al. 2014; Price 2018). Several species of herpetofauna and arthropods also rely on fire to perform or initiate key portions of their life cycles (Menges and Gordon 2010).

1.1 Background

While disturbance by fire is an important driver of wet pine flatwoods ecosystems, prescribed burning poses several persistent challenges for land managers. Safe implementation of prescribed fire requires adequate humidity and soil moisture, correct and consistent wind direction and speed, fire-lane establishment and maintenance, and experienced and well-outfitted burn crews. Public opinion of prescribed burning has declined in recent years (and in some regions) because of poor fire-control strategies, large antecedent fuel loads, and resultant accidental wildfires. Additionally, as residential areas and infrastructure increasingly encroach into rural areas and wildlands, challenges associated with conducting safe and secure prescribed burns adjacent to residential areas or infrastructure can impede or preclude natural-resource practitioners’ capacity to effectively use fire as an ecosystem-management strategy (Ryan et al. 2013).

In response to concerns about potential impacts of prescribed burning on residential areas and infrastructure, understory management is sometimes accomplished through mechanical mowing in lieu of prescribed fires to prevent the buildup of excess woody vegetation and maintain the low-density, open midcanopy characteristic of wet pine flatwoods. However, the long-term implications for this approach to managing vegetation on wet pine flatwoods compensatory mitigation sites remain unknown. While several studies investigate the benefits of mechanical mowing or chopping as a supplement to prescribed burns, there is a paucity of research assessing the effectiveness of understory mowing in lieu of prescribed burning as a long-term land-management strategy to sustain the functions performed by fire-dependent ecosystems (Luken 2005; Kirkman and Mitchell 2006).

One of the main disadvantages when considering the exclusion of prescribed fire as a management tool in wet pine flatwoods is the loss of direct and indirect influence of fire as a catalyst or progenitor of conditions important to the sustainability of a floral and faunal community that evolved in response to fire. The exclusion of periodic fires from wet pine flatwoods dominated by *P. palustris* can cause substantial negative effects on habitat structure over time (Menges and Gordon 2010). For example, without fire *P. palustris* seedlings do not progress from the grass stage to the bolt stage, extending the overall time spent in the early successional phase of its life cycle (Landers 1991; Means 1985; Platt et al. 1988). Establishment and rapid growth of broadleaf species in response to fire exclusion also cause senescence or reduced growth rates in *P. palustris* saplings via increased ground shading. Reduction in seedling establishment and decreased growth rates for pine species in these habitats alters canopy flora composition and forest health over multidecadal periods.

Another disadvantage of mowing in lieu of prescribed fire is that mowing deposits material into the leaf-litter layer, often resulting in thick mats of dead grasses, wood chips, and other vegetative debris. Unless removed, the material deposited by mowing can reduce the efficient establishment of new trees by preventing cones and seeds from reaching the soil surface to germinate (Brewer 1998; Brewer 1999; Kreye et al. 2014; Landers 1991; Means 1985; Platt et al. 1988; Veldman et al. 2014). Conversely, fire consumes leaf litter and other plant materials as a fuel source, resulting in a sparse layer of fresh particulate organic matter and detritus and the reduction of labile forest-floor cover that inhibits seed germination. There are also plant species (some endemic) found in pine flatwoods that rely on bare-soil exposure to initiate seed germination (Brewer 1998; Brewer 1999; Veldman et al. 2014). Leaf-litter accumulation can also become problematic when fuel stocks increase to levels that amplify the risk of catastrophic fire started by lightning or accidental ignition within the management area, placing nearby homes and infrastructure in harm's way.

Mechanical treatments can also lead to the loss of established pine seedlings during mowing. Pine seedlings at early stages have very sensitive apical meristems compared with competing broadleaf species. If the apical meristem is severely damaged or cut off, the sapling or seedling will not regenerate and will senesce. Mowing does not cause the same effect on many broadleaf plants and shrubs, which often readily resprout after cutting, potentially creating an understory unfavorable for the establishment or regrowth of key desirable plant species while enhancing conditions for non-target vegetation to become established at the site (Luken 2005, Watts et al. 2006; Gorman et al. 2013).

Mowing may also increase vulnerability to invasive-species encroachment. Considering the previously listed effects of excluding fire from wet pine flatwood sites, native-species growth may be restricted, and invasive species may outcompete the native species for limited resources and space. *Triadica sebifera* (Chinese tallow tree) is an invasive species commonly found throughout the Gulf Coast region and a likely species to invade vulnerable wet pine flatwood habitats. The life cycle and environmental tolerance of *T. sebifera* tree makes controlling the invasive species difficult, and eradicating it from affected areas is challenging following its establishment (Pattison and Mack 2008; Pattison and Mack 2009; Pile et al. 2017). Additionally, the seeds of non-native and nuisance species could be introduced into wet pine flatwood habitats on mower blades and other heavy equipment, increasing the risk of invasion.

Several studies investigated the potential benefits of mowing to control woody-species encroachment, and a few evaluated mechanical treatments as an alternative to prescribed fire. However, no studies have provided a comprehensive assessment of whether these two management approaches have different long-term effects on wetland functions. For example, Kirkman and Mitchell (2006) reported that herbaceous-layer species richness was enhanced by mowing, but that study only evaluated a single mowing event intended to alter a fire-management plan, not replace it. The study concluded the mowing disturbance increased herbaceous-species richness in the short term relative to untreated areas but did not assess mid- or long-term implications for the study area. Though limited in scope, a study by Luken (2005) examined mowed power-line corridors in South Carolina, reporting that mowing and clearing of litter material promoted the growth of several native carnivorous plants. However, those areas maintained by mowing in the absence of fire were prone to broadleaf shrub–species dominance. The study also noted that mowing and clearing of litter increased the number and density of graminoid species present relative to areas managed with fire.

Despite potential ecological limitations of using mowing in lieu of prescribed burning, mechanical management incurs a low risk of unintended consequences (for example, uncontrolled fire) in wet pine flatwoods located near residential areas or other infrastructure. Mowing may also be conducted with fewer restrictions relative to prescribed burns. For instance, mowing can be performed regardless of speed and direction of the wind and without consideration of relative humidity. Mowing also does not require maintenance or the establishment of bordered fire lanes. However, mowing must consider soil moisture content, as heavy equipment can induce rutting and soil compaction in wet pine flatwoods during wet periods. Also, the equipment may become entrapped in saturated or moist soils during wet periods.

A final consideration concerns the effect maintaining wet pine flatwoods with prescribed fire has on the location and spatial extent of these managed ecosystems. While not the focus of this report, policy makers and practitioners should consider that, generally, prescribed fire is more easily accomplished away from urban areas because of lower health and property-damage risks. This greater difficulty of carrying out prescribed burns near urban areas has important implications for how communities interact with their local environment, what types of ecosystems are present in their local environment, and which ecosystem functions and services are being provided to those communities. If high-quality wet pine flatwoods are restricted to rural areas to conduct sustained fire-based management, fewer communities will have the ability to access, understand, and appreciate these habitats. Further, because many wet pine flatwoods projects have been established as mitigation banks designed to offset unavoidable impacts to wetlands, the abundance of wet pine flatwoods may decrease near communities that can benefit from those wetlands and increases in rural areas or wildlands where there are fewer people to realize the benefits of those wetlands.

1.2 Objective

This technical report describes methods, results, associated recommendations, and opportunities for future research related to the use of prescribed fire and mowing to maintain wet pine flatwoods in the southeastern United States. The study used the hydrogeomorphic (HGM) wetland functional-assessment approach to investigate the influence of management strategies for wet pine flatwoods on the delivery of wetland functions.

1.3 Approach

The HGM wetland functional-assessment approach was developed by Brinson (1995) for application within the US Army Corps of Engineers (USACE) regulatory program, specifically to address the administration of the Clean Water Act* responsibilities assigned to the agency (Smith et al. 2013). The approach first classifies wetlands according to their dominant water source, hydrodynamics, and landscape position then determines the functional capacity of wetlands using readily observable and quantifiable measures (that is, indicators) of ecosystem structure that have been linked with the delivery of desirable ecosystem functions (for example, hydrology, habitat for plants and animals, biogeochemical cycling). The HGM method examines variables related to wetland functions and combines variables using empirical equations to deduce a wetland functional capacity index (FCI) score ranging from 0.0 (*absence of function*) to 1.0 (*fully functional*). In practice, HGM requires that users collect on-site and off-site variable metric data (for example, tree density, presence of indicator plant species) that is converted to variable subindex scores (that is, normalized to a 0.0–1.0 scale) and combined with other variable subindex scores to generate an FCI output. Rheinhardt et al. (2002) describes the variables and functions applicable to wet pine flat wetlands and provides details on the sampling scheme used throughout the development of this report.

* Federal Water Pollution Control Act of 1948, 33 U.S.C. §§ 1251–389 (2022). https://www.govinfo.gov/content/pkg/USCODE-2022-title33/pdf/USCODE-2022-title33-chap26.pdf.

2 Methods

2.1 Study Location and Site Selection

Sampling locations were selected along the Mississippi and Louisiana Gulf Coast according to the presence of wet pine flatwood habitat and accessibility (Figure 2). Sample plots are separated into four management categories: *unmanaged*, *burned-only*, *mowed-only*, and *burned-mowed*. The *burned-mowed* category refers to areas managed via a combination of burning and mowing. Two study locations managed by mowing were selected according to accessibility and past land-use patterns. These study locations are in-lieu-free (ILF) mitigation sites known as *South Forest Heights ILF* and *Middle School West ILF* (Figure 3).

Three study locations managed by prescribed fire were selected in Mississippi according to accessibility and past land-use patterns. The selected areas are managed by The Nature Conservancy (TNC) and include Old Fort Bayou Mitigation area, Old Fort Bayou Mitigation Bank Phase III, and Devil's Swamp Mitigation Bank (Figures 4 and 5). Old Fort Bayou Mitigation area also included a small section of forest that has remained unmanaged since TNC acquired the property.

Figure 2. Sampling locations in Louisiana and Mississippi. *Red polygons* are burned-only and burned-mowed locations. *Green polygons* (*inset*) are mowed-only locations.

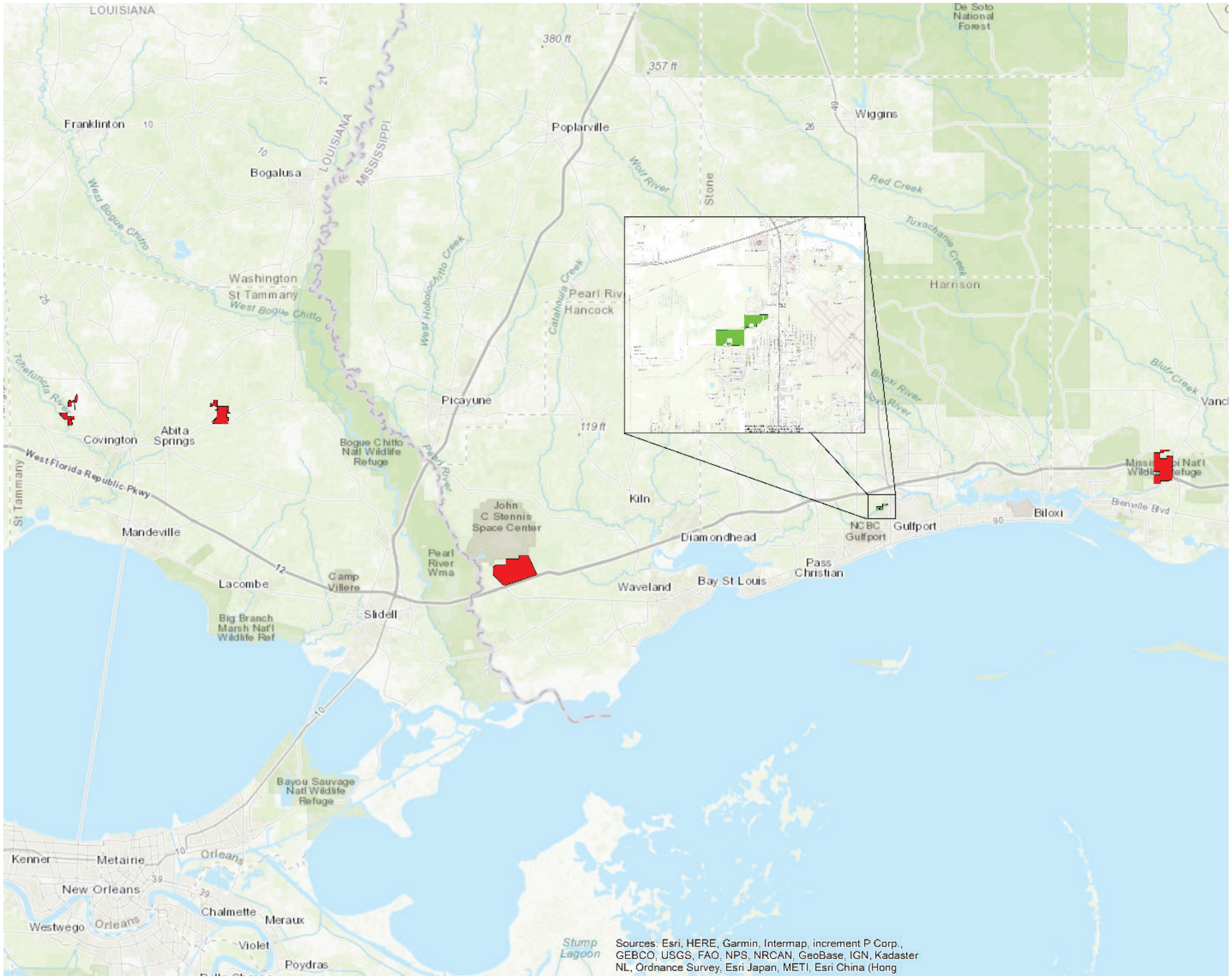


Figure 3. South Forest Heights ILF (in-lieu-free) and Middle School West ILF mitigation areas chosen as the sampling locations for wet pine flatwoods understory management via mowing. South Forest Heights ILF is an area of 20.29 ha with 0 ha of burn-managed area. A total of 3 hydrogeomorphic (HGM) sample points (mowed) were established at South Forest Heights ILF. Middle School West ILF is an area of 39.82 ha with 0 ha of burn-managed area. A total of 6 HGM sample sites (mowed) were established at Middle School West ILF.

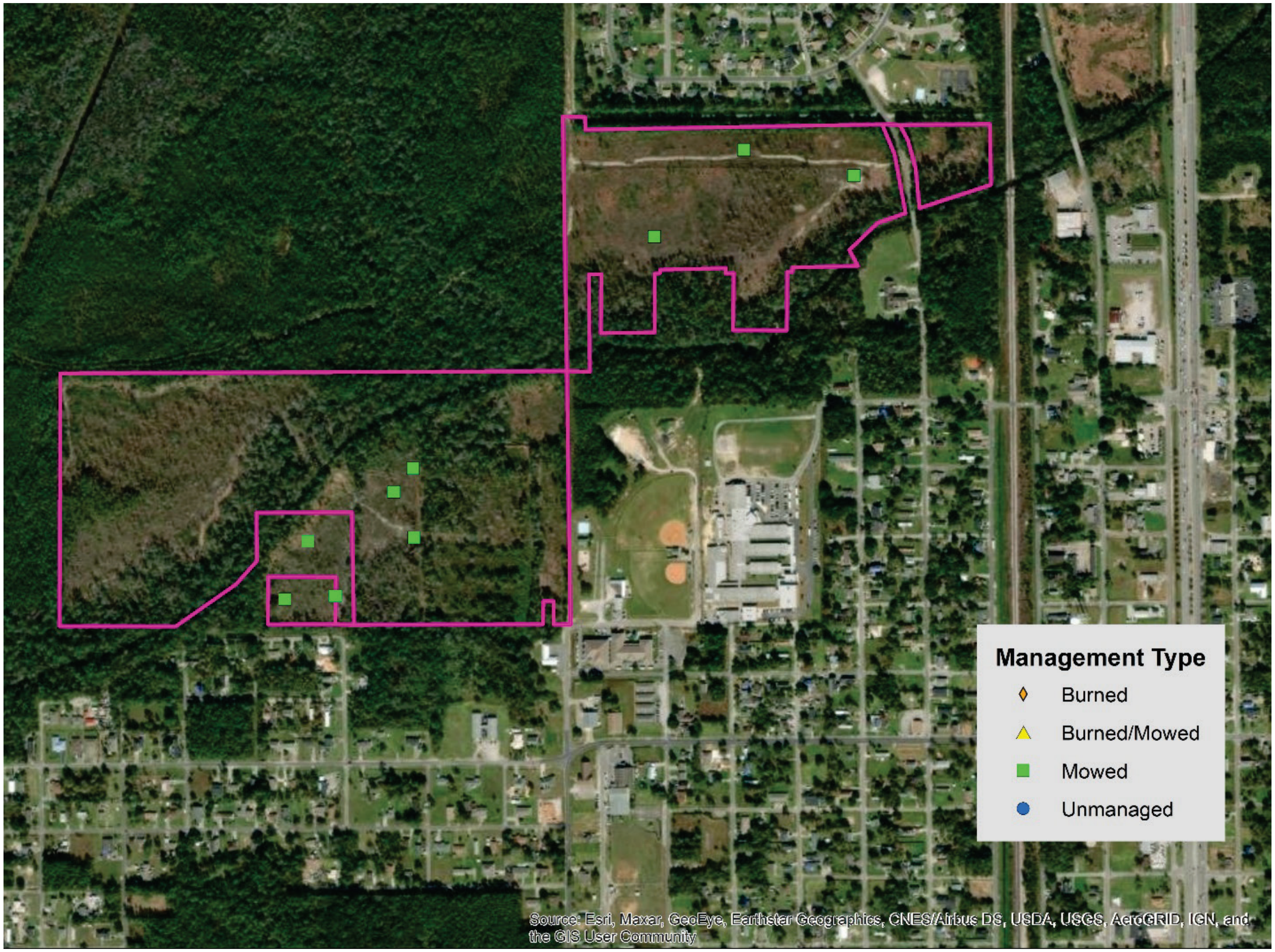


Figure 4. Old Fort Bayou and Old Fort Bayou Mitigation Bank Phase III areas chosen as sampling locations for wet pine flatwoods managed via prescribed fire, prescribed fire and mowing, and an unmanaged area. Old Fort Bayou is a mitigation bank with an area of 1,003.45 ha with 438 ha of burn-managed area. A total of 28 HGM sample points (22 burned, 3 burned-mowed, and 3 unmanaged) were established at Old Fort Bayou. Old Fort Bayou Phase III is a mitigation bank with an area of 43.11 ha with 26.29 ha of burn-managed area. A total of 2 HGM sample points (burned) were established at Old Fort Bayou Phase III.

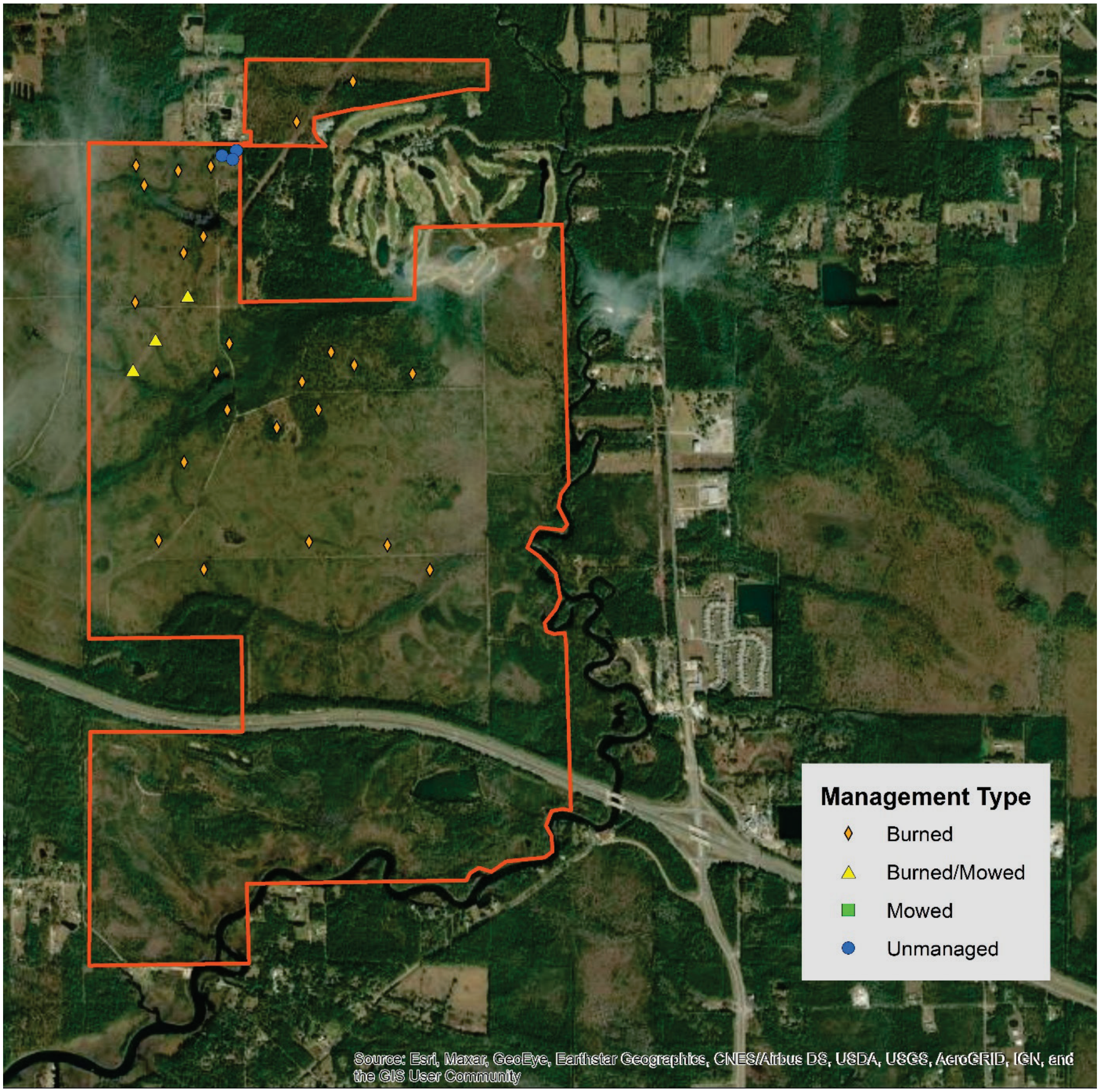
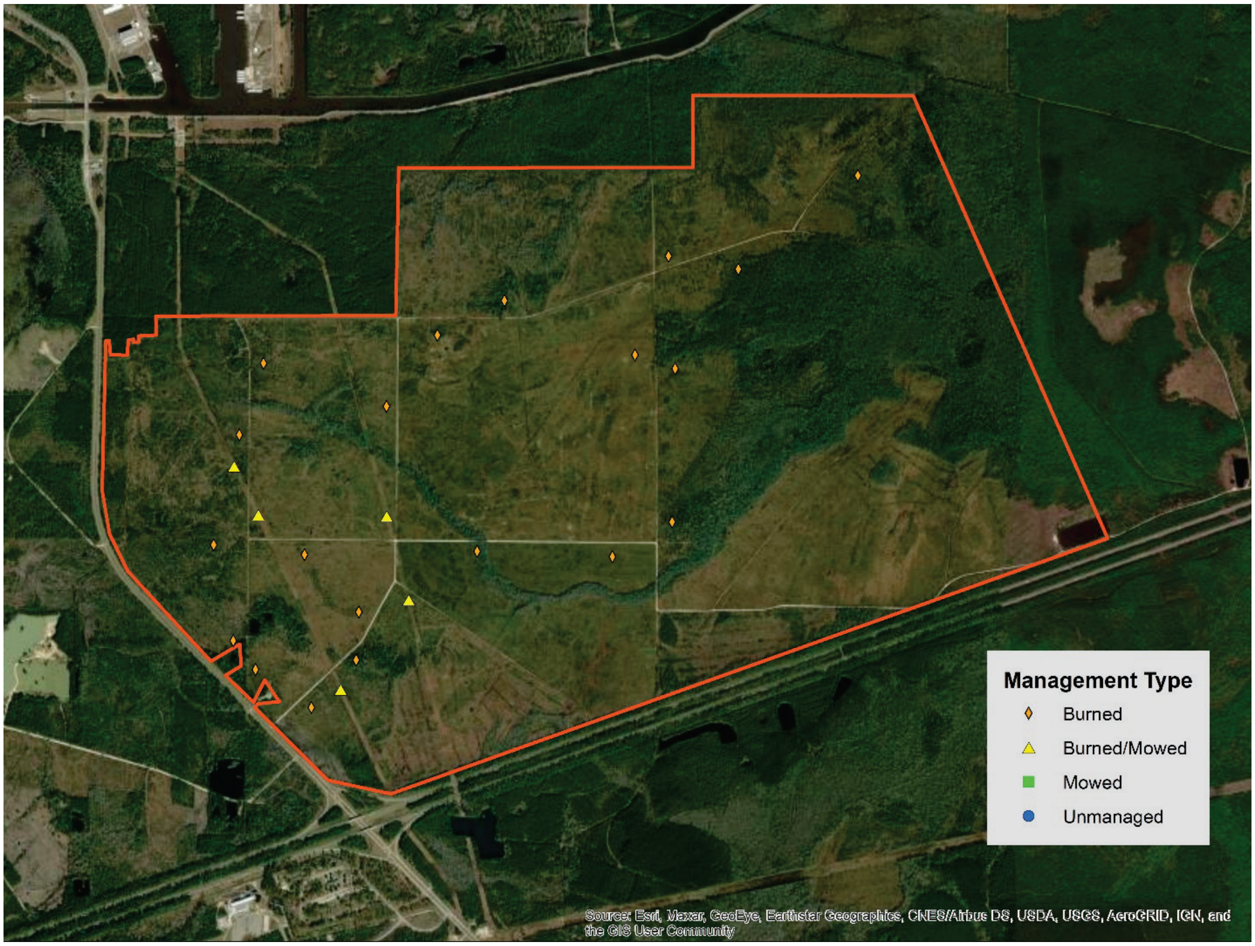


Figure 5. Devil's Swamp Mitigation Bank Phase I area was selected to sample wet pine flatwoods managed via prescribed fire and prescribed fire and mowing. Devil's Swamp is a mitigation bank with an area of 1,825.77 ha with 1,085.48 ha of burn-managed area. A total of 25 HGM sample points (20 burned and 5 burned-mowed) were established at Devil's Swamp Mitigation area.



In Louisiana, no mitigation banks are currently approved to use mowing as a management strategy, so no study locations of this type were available. Four study locations managed by prescribed fire were chosen in Louisiana wet pine flatwood mitigation areas, including Abita Creek (Figure 6), Lake Ramsay (Figure 7), Oaklawn, and Mossy Hill (Figure 8).

Figure 6. Abita Creek mitigation area was selected to sample wet pine flatwoods managed via prescribed fire. Abita Creek is a mitigation bank with an area of 383.23 ha with 195.8 ha of burned area. A total of 16 HGM sample points (14 burned and 2 burned-mowed) were established at Abita Creek.

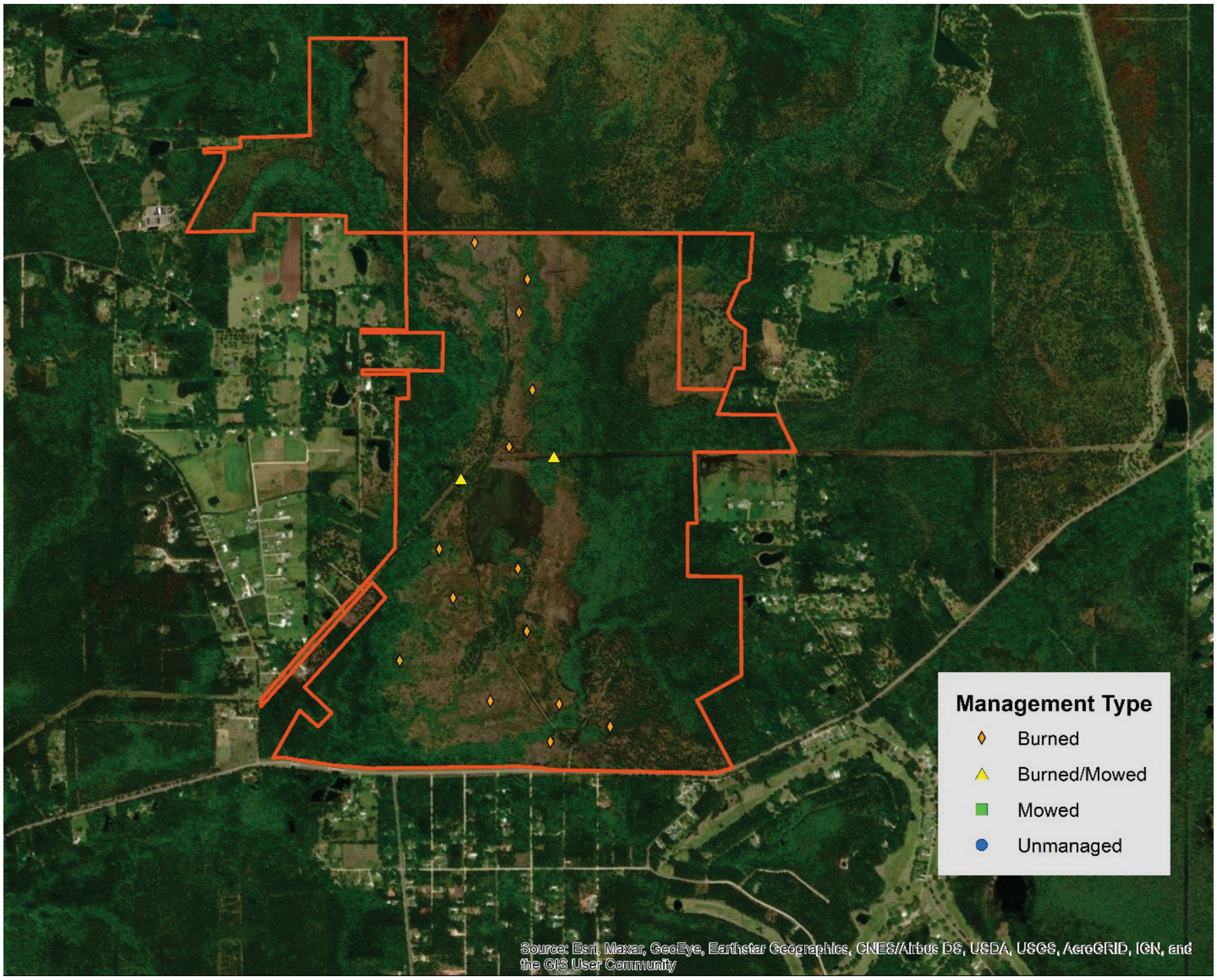


Figure 7. Lake Ramsay mitigation area was selected to sample wet pine flatwoods managed with prescribed fire. Lake Ramsay is a mitigation bank with an area of 201.27 ha with 114.41 ha of burned area. A total of 6 HGM sample points (burned) were established at Lake Ramsay.

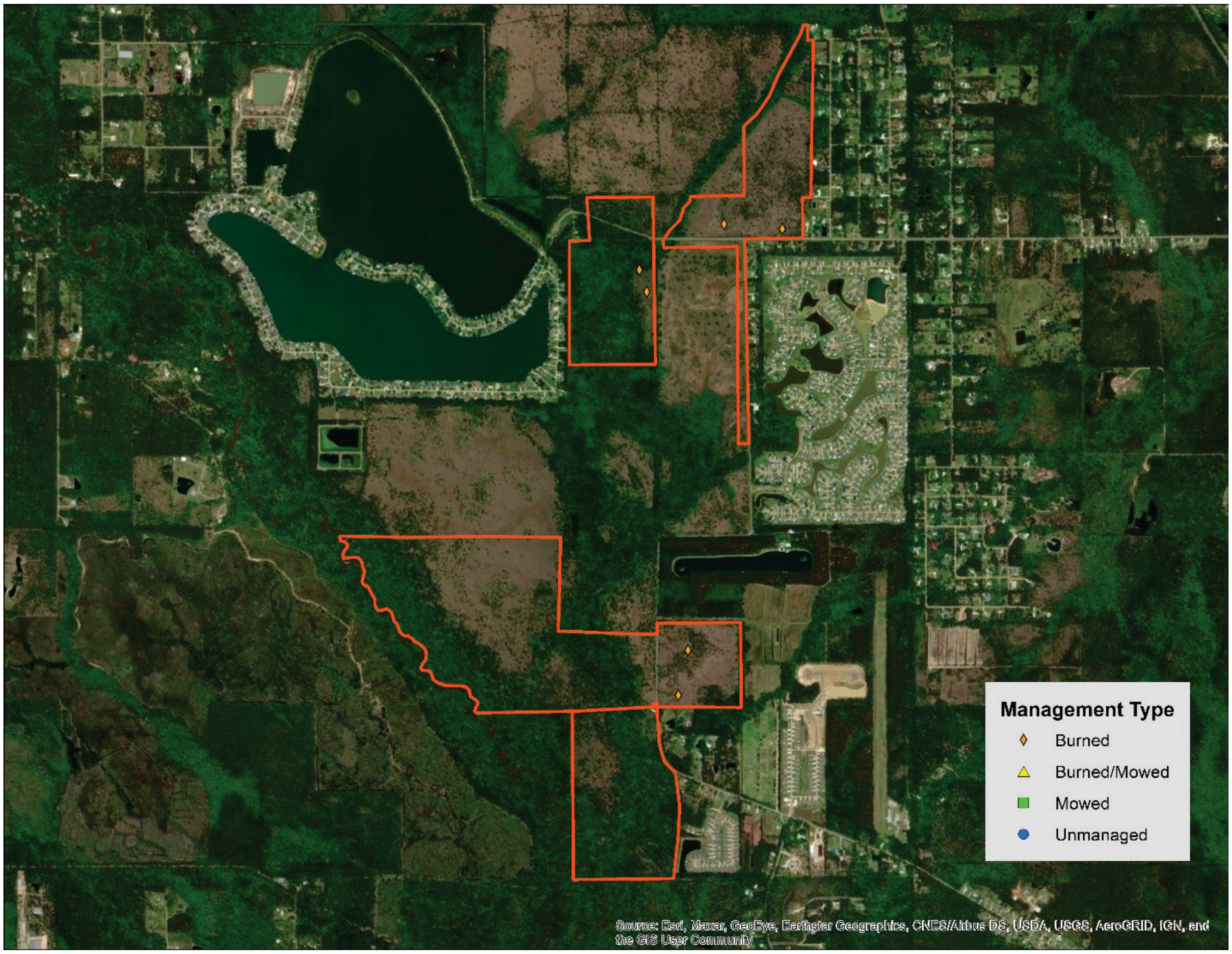
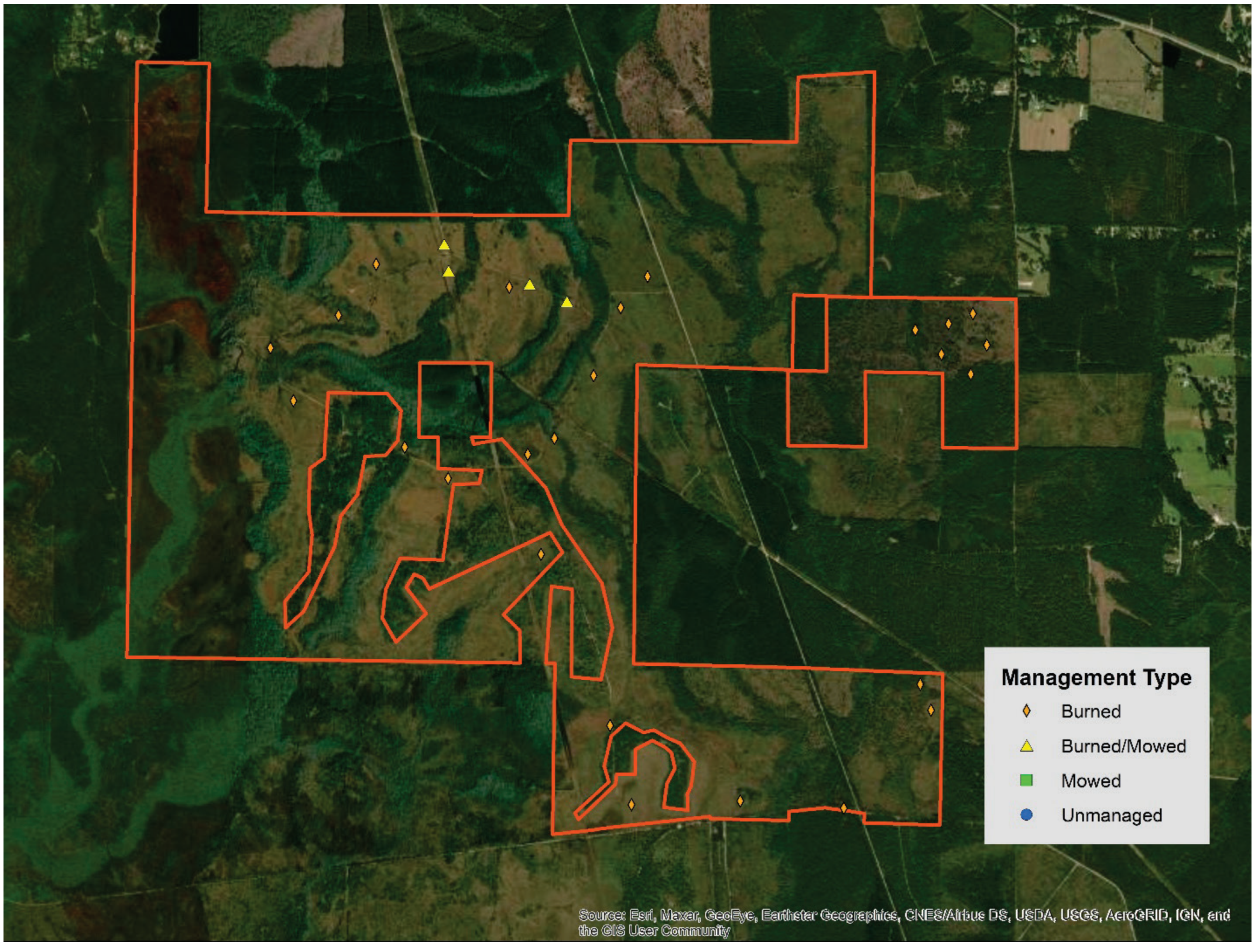


Figure 8. Mossy Hill and Oaklawn mitigation areas were selected to sample wet pine flatwoods managed with prescribed fire. Mossy Hill is a mitigation bank with an area of 928.67 ha with 686 ha of burned area. A total of 23 HGM sample points (19 burned and 4 burned-mowed) were established at Mossy Hill. Oaklawn is a mitigation bank with an area of 75.36 ha with 48.53 ha of burned area. A total of 6 HGM sample points (burned) were established at Oaklawn.



Across all study locations, 115 HGM research sample points were established, with 3 points located in unburned and unmanaged wet pine flatwoods, 9 points located in areas managed by mowing, 14 points located in areas managed by fire and mowing, and 89 points located in areas managed by prescribed burning. This distribution reflects the relative extent of land-use patterns within the study locations examined, and research sample points were selected to capture the range of conditions observed at each individual study location.

At study locations chosen as part of the prescribed-fire treatment group, several sample points were placed in areas where power-line or pipeline corridors crossed the area. This placement choice allowed for another treatment group, a combination of burned-mowed management to be added to this assessment for analysis. As a treatment group, the burned-mowed areas are typically mowed at least once yearly during maintenance of power lines and pipelines, with prescribed burns occurring less frequently. Finally, unmanaged sample points were also established, representing another treatment group.

2.2 Data Collection and Analysis

All sampling and analysis were conducted in accordance with the HGM approach guidebook by Rheinhardt et al. (2002). Therefore, each sample point was classified into the appropriate wetland subclass, and the requisite HGM variable metric data were collected accordingly (Table 1).

In total, HGM data were collected from 9 study locations across Mississippi and Louisiana, including 89 burned sample points, 14 burned-mowed sample points, 9 mowed sample points, and 3 unmanaged sample points. The distribution of study locations chosen is based on the presence of wet pine flatwoods habitat, access, and geographic distribution. Study locations within the burned and burned-mowed treatment groups displayed evidence of fire management (for example, charred tree trunks) and were assigned to the maximum landscape variable ($V_{LANDSCP}$) subindex score. Data entry used the automated data form associated with the guidebook that calculates each variable subindex score and all applicable FCI scores (Table 2).

The HGM approach is particularly useful in project-implementation scenarios where affected wetlands must be assessed and appropriate mitigation land area must be determined. Rheinhardt et al. (2002) include details on the calculation and rationale behind each one of the wetland FCIs examined for each HGM subclass being assessed. For example, $FCI_{HYDROLOGY}$ uses variables collected by geographic information system (GIS) and in the field to generate an FCI score representing the capacity of a wetland area to maintain the appropriate hydropatterns needed to support groundwater recharge, water-quality benefits, and delivery of wetland benefits associated with saturated or inundated landscapes. The FCI_{PLANTS} score reflects the wetland's ability to maintain characteristic floral communities and $FCI_{ANIMALS}$ the habitat suitability for characteristic fauna. The $FCI_{BIOGEOCHEM}$ score communicates the ability of the wetland to perform biological, geological, and chemical processes (for example, nutrient cycling) important to wet pine flat ecosystems.

Table 1. HGM variables used to calculate functional capacity index (FCI) scores by HGM subclass.

Collection Type	Description	Symbology	HGM Subclass		
GIS			**Bunchgrass and Pine**	**Cypress and Pine**	**Switch Cane and Pine**
Surface flow of water	Represents the level of alteration to surface flow of water across the wetland area	$V_{SURFFLOW}$	X	X	X
Surface water storage	Represents the level of alteration to surface-water storage capacity of the wetland area	$V_{STORAGE}$	X	X	X
Outflow of water	Represents the flow of water across the wetland in the down-gradient direction and any alterations that may alter the natural water-level regime	$V_{OUTFLOW}$	X	X	X
Inflow of water from an exogenous basin	Represents the proportional increase in water-table elevation via transport from other drainage basins	V_{INFLOW}	X	X	X
Area of contiguous fire-maintained landscape	Represents the contiguous area of the wetland managed by prescribed fire	$V_{LANDSCP}$	X	X	X
Field					
Evapotranspiration potential	Represents the potential loss of water to the atmosphere via evaporation and transpiration by plants	V_{ET}	X	X	X
Alteration of microtopography	Represents the integrity of natural microtopographical features in the wetland	V_{MICRO}	X	X	X
Alteration of soil porosity	Represents soil porosity, which affects the space available for subsurface water storage, and any alterations to soil porosity	V_{PORE}	X	X	X
Herbaceous indicator score	Represents the frequency of important indicator plant species occurrence within the wetland area	V_{HERB}	X	X	—
Native bunchgrass cover	Represents the abundance of native bunchgrass species occurring within the wetland area	V_{NBG}	X	X	—
Cover of sedges	Represents the abundance of sedge species occurring within the wetland area	V_{SEDGE}	—	X	—
Pine density	Represents the density of canopy-sized pines within the wetland area	V_{PINE}	—	—	X
Subcanopy density	Represents the density of woody subcanopy stems within the wetland area	V_{SUBC}	—	X	X

Note: GIS—geographic information system.

Table 1 (cont.). HGM variables used to calculate functional capacity index (FCI) scores by HGM subclass.

Collection Type	Description	Symbology	HGM Subclass		
Field			Bunchgrass and Pine	Cypress and Pine	Switch Cane and Pine
Physiognomic structure of pond cypress	Represents the contribution of pond cypress to the physiognomy of the wetland area	$V_{CYPRESS}$	–	X	–
Physiognomic structure of canopy longleaf and pond pine	Represents the contribution of canopy-sized longleaf and pond pine to the physiognomy of the wetland area	V_{LONGL}	–	–	X

Table 2. Functions assessed by this HGM method, how the functional capacity indices are calculated, and the related HGM subclass for each function.

FCI	Calculation	HGM Subclass		
		Bunchgrass and Pine	Cypress and Pine	Switch Cane and Pine
HYDROLOGY	$FCI_{HYDROLOGY} = MIN\left[V_{SURFFLOW}, V_{OUTFLOW}, V_{STORAGE}, V_{INFLOW}, \left(V_{ET} \times \left(\left(V_{MICRO} + V_{PORE}\right)/2\right)\right)^{1/2}\right]$	X	X	X
PLANTS	$FCI_{PLANTS} = MAX\left(V_{NBG}, V_{HERB}\right)$	X	–	–
PLANTS	$FCI_{PLANTS} = MAX\left[V_{NBG}, V_{HERB}, \left(V_{CYPRESS} \times \left(\left(V_{SEDGES} + V_{SUBC}\right)/2\right)\right)^{1/2}\right]$	–	X	–
PLANTS	$FCI_{PLANTS} = \left[V_{LONGL} \times \left(\left(V_{SUBC} + V_{PINES}\right)/2\right)\right]^{1/2}$	–	–	X
ANIMALS	$FCI_{ANIMALS} = \left(FCI_{PLANTS} \times V_{LANDSCP}\right)^{1/2}$	X	X	X
BIOGEOCHEM	$FCI_{BIOGEOCHEM} = \left(FCI_{HYDROLOGY} \times FCI_{PLANTS}\right)^{1/2}$	X	X	X

Data analysis used the R and Rstudio open-source statistical software packages (The R Foundation 2019; Posit 2023). Data normality was evaluated with the Shapiro-Wilk test. All data differed significantly from normal distributions, which prompted the use of nonparametric testing. Kruskal-Wallis rank-sum tests were used to assess the collected and computed data, including variable metric scores, variable subindex scores, and FCI scores. Kruskal-Wallis tests used habitat-management strategy (that is, burned, burned-mowed, mowed) as the group factor. Additionally, data were evaluated with study location as the group factor. Kruskal-Wallis rank-sum tests use an alpha of 0.05 to determine significant differences. Dunn posthoc tests were used to assess which group factors were significantly different. The Dunn posthoc tests apply an alpha of 0.025 to determine significant differences between groups. All Dunn posthoc test results can be viewed in the Appendix.

3 Results and Discussion

The study identified differences in wetland function based on both management strategy and location. The following sections discuss treatment effects, which are the major focus of the research, followed by a brief reporting of location effects. Individual variable metric scores important to the level of wetland function are highlighted to emphasize the effects of different management techniques on ecological outcomes.

3.1 Treatment Effects

The understory woody vegetation management strategies resulted in significantly different HGM assessment outcomes. Tables 3 and 4 report the variable metric scores, variable subindex scores, and FCI results for selected assessment elements organized by understory vegetation management approach. Note that unmanaged areas received lower scores than all managed wet pine flatwood locations, differences occurred across management strategies, and management strategy effects are reflected in wetland functional capacity outcomes.

Table 3. Mean and standard deviation of selected variable metric and variable subindex scores across treatment groups.

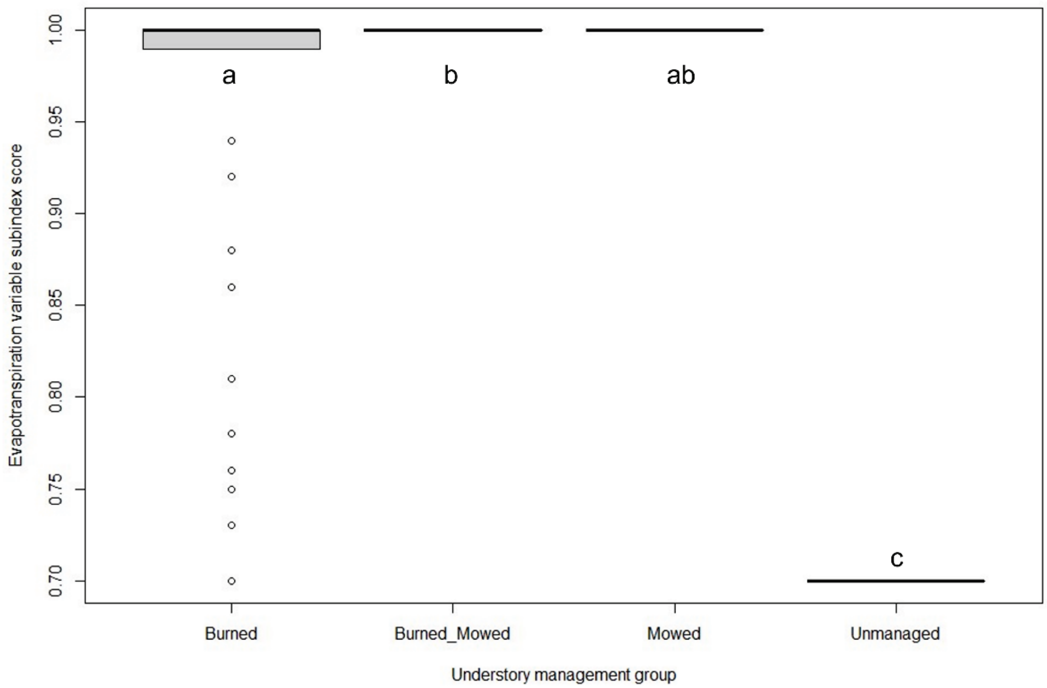
Treatment	Mean (Standard Deviation)					
	Indicator Species Score	Native Bunchgrass Cover (%)	V_{ET}	V_{MICRO}	V_{PORE}	$V_{LANDSCAPE}$
Unmanaged	0.0 (0.0)	0.0 (0.0)	0.7 (0.0)	1 (0.0)	1 (0.0)	0.05 (0.0)
Burned	3.09 (1.85)	32.53 (19.27)	0.95 (0.10)	0.99 (0.03)	0.99 (0.01)	0.95 (0.16)
Burned-mowed	4.21 (2.02)	46.07 (23.47)	1 (0.0)	0.90 (0.08)	0.92 (0.06)	1.00 (0.0)
Mowed	3.44 (2.96)	18.0 (12.79)	1 (0.0)	0.88 (0.13)	0.98 (0.06)	0.05 (0.0)

Table 4. Mean and standard deviation of FCI scores across treatment groups.

Treatment	Mean (Standard Deviation)				
	$FCI_{HYDROLOGY}$	FCI_{PLANTS}	$FCI_{ANIMALS}$	$FCI_{BIOGEOCHEM}$	FCI_{Avg}
Unmanaged	0.84 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.21 (0.0)
Burned	0.97 (0.06)	0.69 (0.27)	0.78 (0.21)	0.79 (0.21)	0.81 (0.17)
Burned-mowed	0.95 (0.04)	0.88 (0.20)	0.93 (0.12)	0.91 (0.12)	0.92 (0.11)
Mowed	0.96 (0.05)	0.70 (0.26)	0.18 (0.04)	0.80 (0.17)	0.66 (0.12)

For the Maintain Characteristic Water Level Regime function, three variable subindex scores (V_{ET}, V_{MICRO}, V_{PORE}) and the $FCI_{HYDROLOGY}$ outcomes were evaluated across treatment groups. Unmanaged sampling locations exhibited canopy closure and none to very little herbaceous, subcanopy, or midcanopy vegetation. All other treatment groups generally exhibited low canopy cover, high herbaceous vegetation cover, and sparse vegetation subcanopy and midcanopy strata. These vegetation characteristics represent an important factor in determining hydrologic functionality of a wet pine flatwood wetlands and determine the evapotranspiration variable subindex scores (V_{ET}) included in the HGM models. Significant differences in V_{ET} scores were observed between the unmanaged group and all other treatment groups and between the burned-only group and the burned-mowed group (Figure 9). The burned-only group exhibited high standard deviation compared with the other managed groups as a result of high habitat heterogeneity associated with the use of prescribed fire. Fuel loads and fire are not homogenous across managed areas, resulting in hot and cool zones where the fire intensity varies. Over extended periods of prescribed-burning regimes, the heterogeneity of vegetation decreases at large spatial scales. Conversely, the treatments that involve mowing reduce the height of all woody shrubs to the herbaceous layer, precluding the establishment of excess subcanopy and midcanopy strata vegetation. While differences exist between the management groups, the range of outcomes associated with V_{ET} reflect conditions indicative of highly functional, well-maintained wet pine flatwoods.

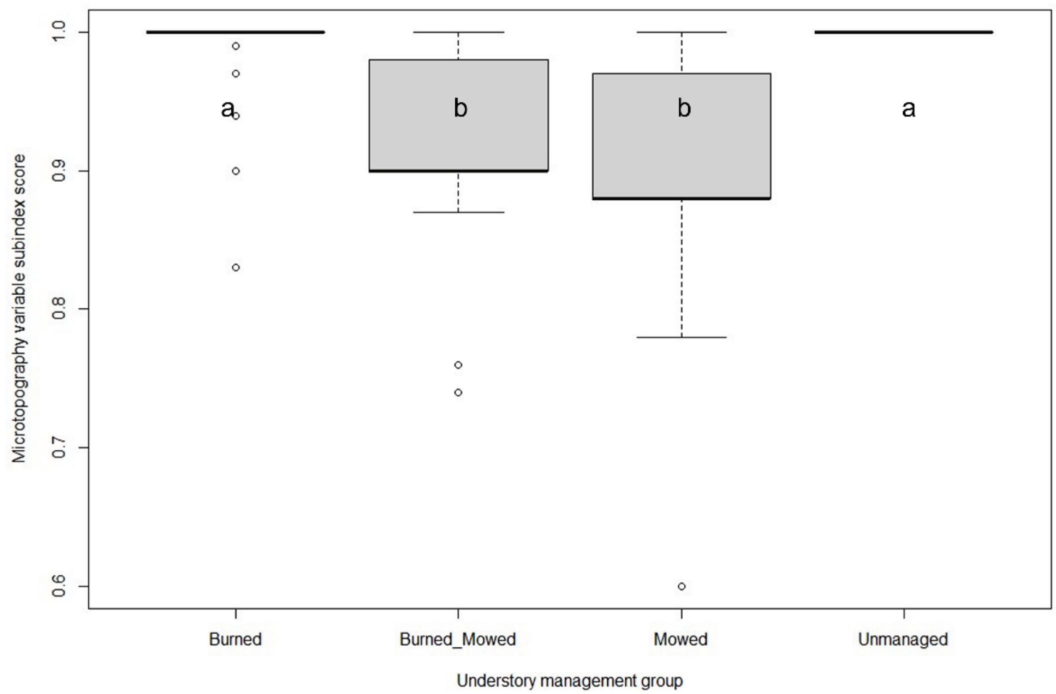
Figure 9. Box plot comparing average evapotranspiration potential (V_{ET}) variable scores for each management-strategy group. Box plot *bold* lines are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Tables 3 and A-1).



Soil disturbances were observed at a subset of sampling locations. Patterns of rutting and compaction were consistent within each treatment group. Unmanaged locations characterized by dense, woody vegetation had little to no disturbance from rutting or compaction because of the use of heavy machinery or animal usage (for example, grazing). Burned-only locations also had very little disturbance from rutting by machinery and only small amounts of rutting by animals, including readily observable game trails and feral-hog damage. Burned-mowed and mowed-only locations both exhibited rutting by machinery, from heavy equipment operations, and some rutting and wallowing from animals. Evidence of soil disturbances were most notable in low-lying areas where water accumulates, and soil saturation likely persists well into the growing season. Burned-mowed locations, all within power-line and pipeline corridors, exhibited more severe rutting than mowed-only locations, though rutting was found consistently at locations for both treatment groups. These soil disturbances were classified by severity and coverage and used to calculate alterations to microtopography (V_{MICRO}) and soil porosity (V_{PORE}) variable subindex scores. The subindex scores are important features used to determine the hydrological functionality of wet pine flatwood wetlands. There were significant differences in

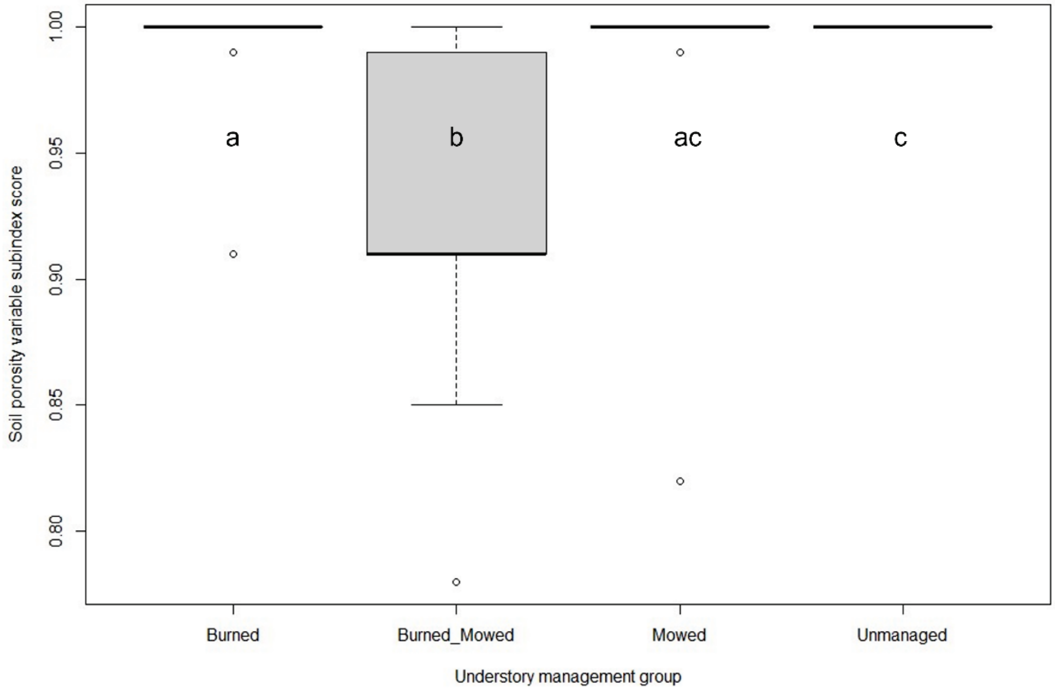
V_{MICRO} variable subindex scores between the burned-only group and the burned-mowed and mowed-only groups (Figure 10). These findings highlight how management regimes that include mowing can decrease functional-capacity outcomes as the result of rutting and soil compaction.

Figure 10. Box plot comparing average microtopographical alterations (V_{MICRO}) variable scores for each management-strategy group. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Tables 3 and A-2).



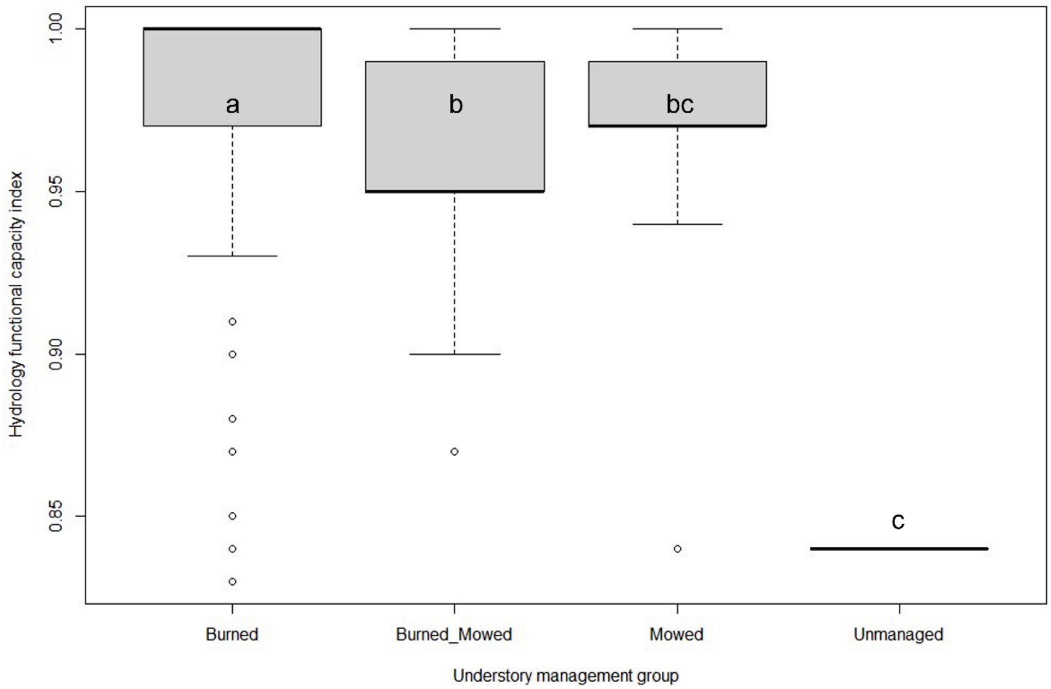
Significant differences in V_{PORE} variable subindex scores were detected between the burned-mowed group and every other group. The differences seen in Figure 11 are most likely due to the size of area being mowed at the burned-mowed study locations. Since all burned-mowed study locations were located within the right-of-way of power-line or pipeline corridors, the likelihood of more frequent mowing, repetitive treatments occurring at (typically) annual intervals, and larger (heavier) equipment usage likely explains why the average score for V_{PORE} variable is notably lower than all other treatment groups.

Figure 11. Box plot comparing the average soil porosity alterations (V_{PORE}) variable scores for each management-strategy group. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Tables 3 and A-3).



Using the variables described above, the $FCI_{HYDROLOGY}$ scores for each treatment group were calculated and compared. The treatment groups exhibited significantly different $FCI_{HYDROLOGY}$ outcomes. The burned-only group's $FCI_{HYDROLOGY}$ scores were significantly higher than the unmanaged areas and sample locations managed with mowing (Figure 12). The differences between areas using burned-only management and those incorporating mowing can be attributed to the alteration to soil microtopography and compaction associated with the use of mowing heavy equipment.

Figure 12. Box plot comparing the average hydrologic functional capacity ($FCI_{HYDROLOGY}$) function scores for each management-strategy group. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Table A-4).



3.1.1 Maintain Characteristic Plant Community (FCI_{PLANTS}) Function

For the maintain characteristic plant community (FCI_{PLANTS}) function, data for the average presence of indicator species and average percent coverage of native bunchgrasses (V_{NBG}) variable metric scores and the average FCI_{PLANTS} scores were analyzed by treatment group. Significant differences in V_{HERB} results were observed between the unmanaged group and all other groups and between the burned-only group and the burned-mowed group (Figure 13). Significant differences in V_{NBG} outcomes also occurred between management approaches that use fire (that is, burned-only and burned-mowed) and areas where fire has been excluded (Figure 14). The effects of excluding fire are readily observable when comparing the average V_{NBG} scores for each treatment: the mean V_{NBG} score for the mowed-only treatment was 18% cover, while the burned-mowed and burned-only treatments had mean V_{NBG} scores of 46% and 35.5%, respectively.

Figure 13. Box plot comparing the average indicator species presence (V_{HERB}) variable scores by management-strategy group. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Tables 3 and A-5).

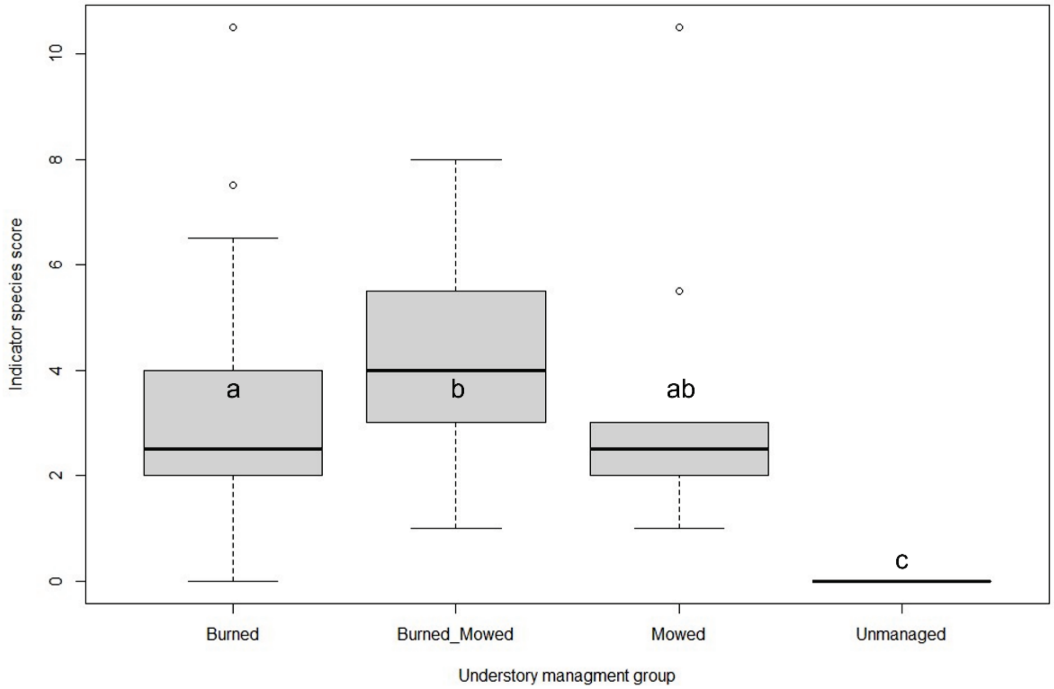
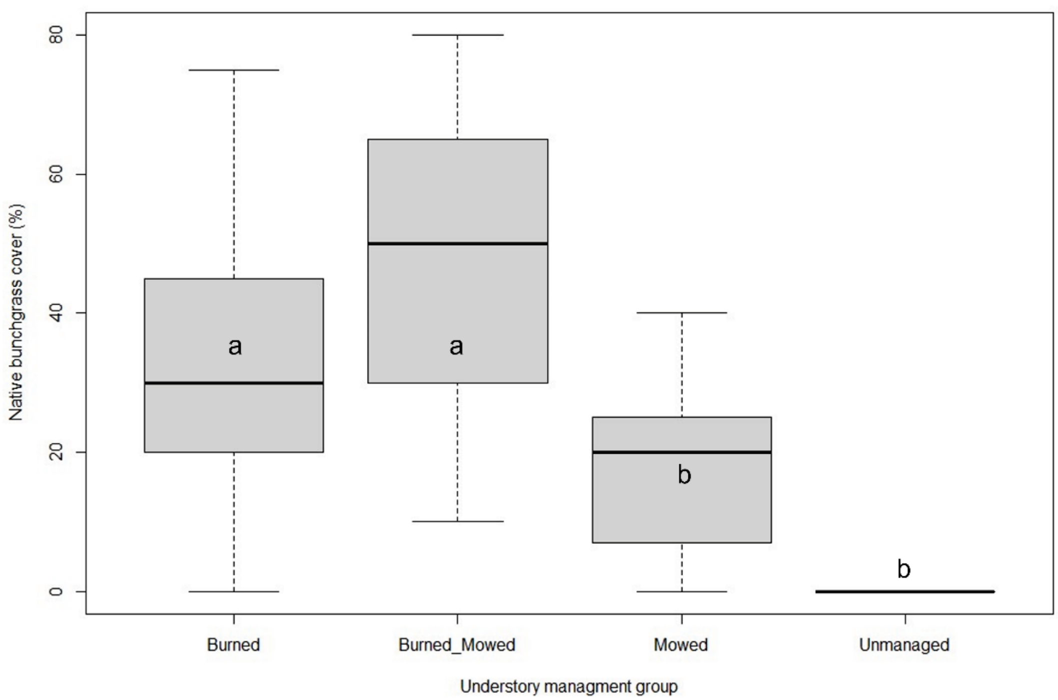
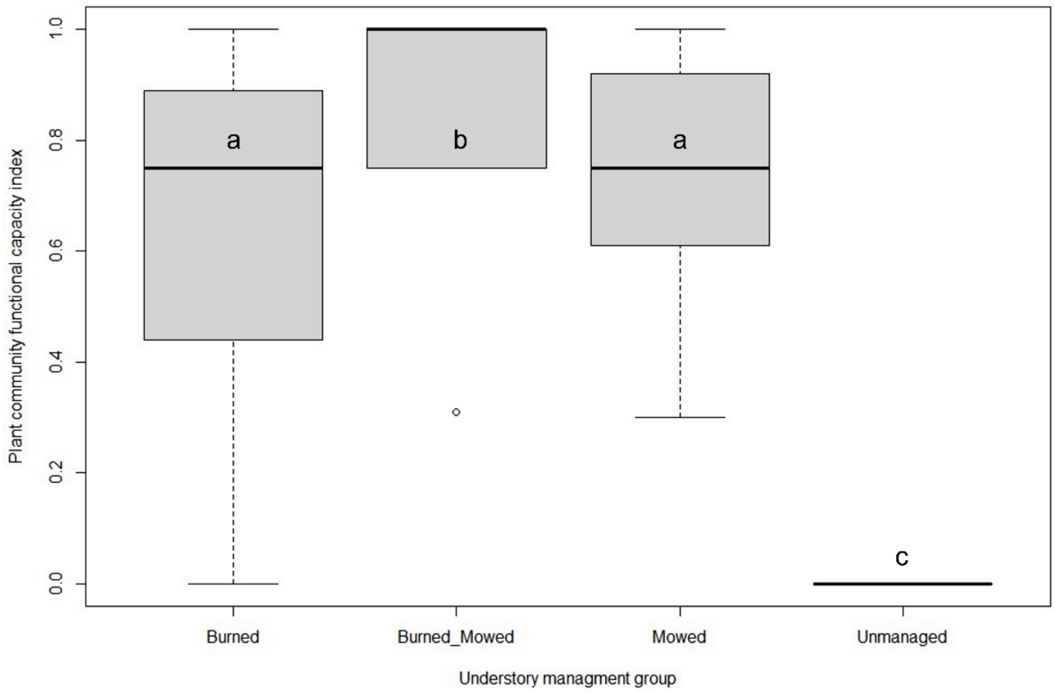


Figure 14. Box plot comparing average native bunchgrass cover (F_{NBG}) by management-strategy group. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Tables 3 and A-6).



There were significant differences in FCI_{PLANTS} scores between the unmanaged group and every other group, and between the burned-mowed group and every other group (Figure 15). The burned-mowed treatment group displayed a higher mean FCI_{PLANTS} score (0.88) than all other treatment groups (Figure 15). This finding aligns with other studies, including Kirkman and Mitchell (2006), which indicated conducting mowing prior to implementation of prescribed fires had a positive impact on habitat quality (Weekley et al. 2011). The increases in herbaceous vegetation diversity and quantity seen as a result of this combination of mowing and prescribed fire may also be attributed to other considerations. The fuel loading associated with mowing prior to a prescribed fire may induce an increase in fire residence time or burn homogeneity, or both, which likely increases prescribed-burn effectiveness. Increased fire residence time, while maintaining a low fire intensity, would cause more heat, smoke, and release of moisture—all of which are needed by certain plant species for germination or other key life-cycle requisites (Brewer 1998; Brewer 1999; Baskin and Baskin 2001; Brewer 2001; Veldman et al. 2014). Another potential factor driving the markedly higher FCI_{PLANTS} scores seen in the burned-mowed treatment group is an increased disturbance interval. Prescribed burning in wet pine flatwood habitats is typically conducted every 2–5 years to replicate the natural occurrence of fire. Since the sample points for the burned-mowed treatment group were located along power-line and pipeline corridors, the disturbance interval at these study locations is likely closer to 1–2 years between disturbance events (that is, mowing or fire). This combination of frequent disturbance precludes the establishment of canopy closure and encourages the growth of herbaceous species, including native bunchgrasses and pyrophytic vegetation. Though mowing has been shown to increase the prominence of broadleaf species (Luken 2005), the periodic burning likely suppresses any broadleaf species that try to establish along the power-line and pipeline corridors. These findings suggest that management regimes incorporating periodic prescribed burning in combination with regular mowing treatments conducted during periods of low soil moisture to prevent rutting and compacting promote fully functional wet pine flatwood ecosystems.

Figure 15. Box plot comparing average maintain characteristic plant community (FCI_{PLANTS}) function scores by management-strategy group. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Table A-7).



3.1.2 Maintain Characteristic Animal Community (FCI_{ANIMAL}) Function

For the maintain characteristic animal community ($FCI_{ANIMALS}$) function, one variable subindex score ($V_{LANDSCP}$) and $FCI_{ANIMALS}$ were analyzed. Significant differences in $V_{LANDSCP}$ scores were observed between the management strategies that used prescribed fires (that is, burned-only and burned-mowed) and those that did not (that is, unmanaged and mowed-only). The criteria for determining $V_{LANDSCP}$ scores is the extent of contiguous land area managed by prescribed fire (Figure 16). This criterion results in a $V_{LANDSCP}$ score of 0.0 for both the unmanaged and mowed-only treatment groups, as seen in Figure 17.

Figure 16. Graph illustrating subindex scoring for the $V_{LANDSCP}$ variable used in calculating the $FCI_{ANIMALS}$ score. (Image reproduced from Rheinhardt et al. 2002, 72. Public domain.)

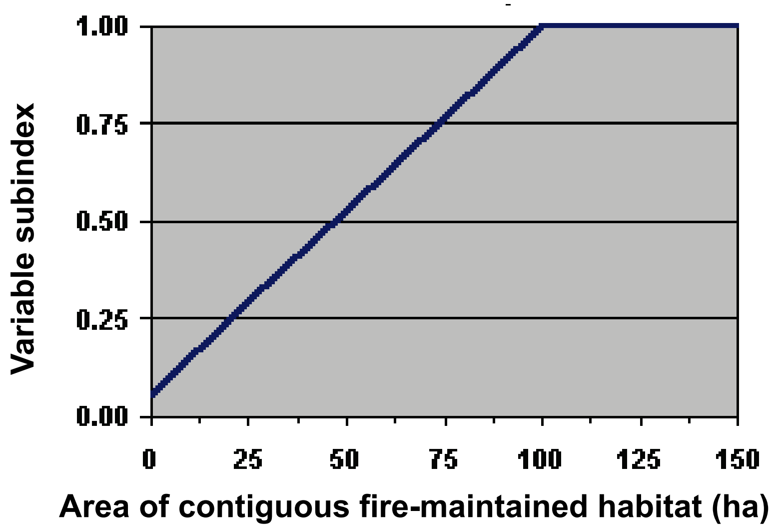
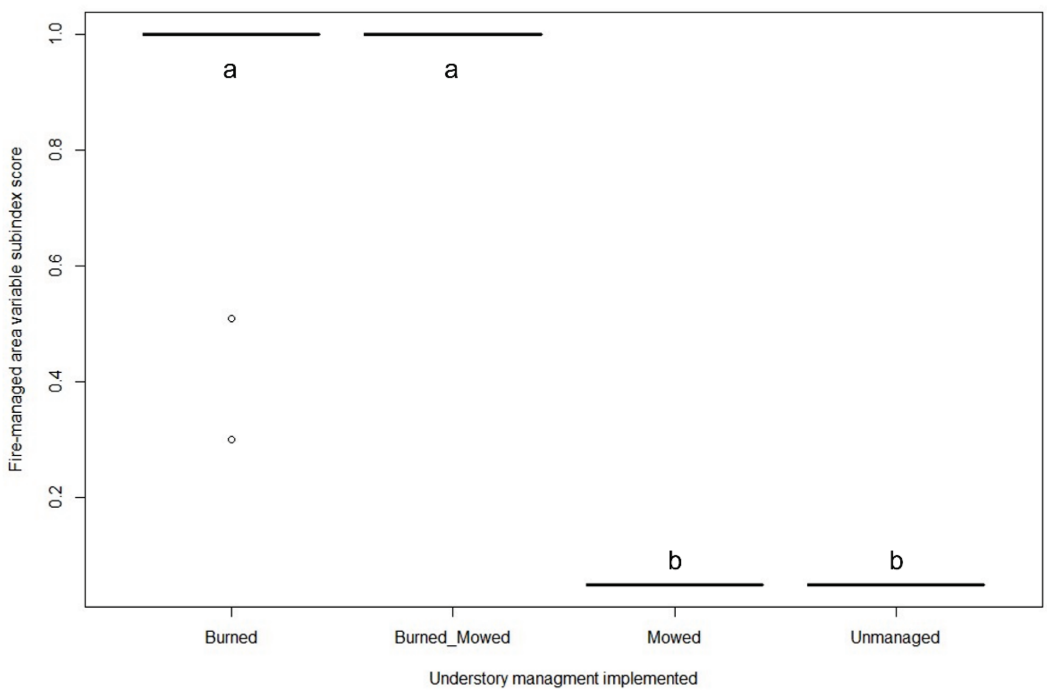


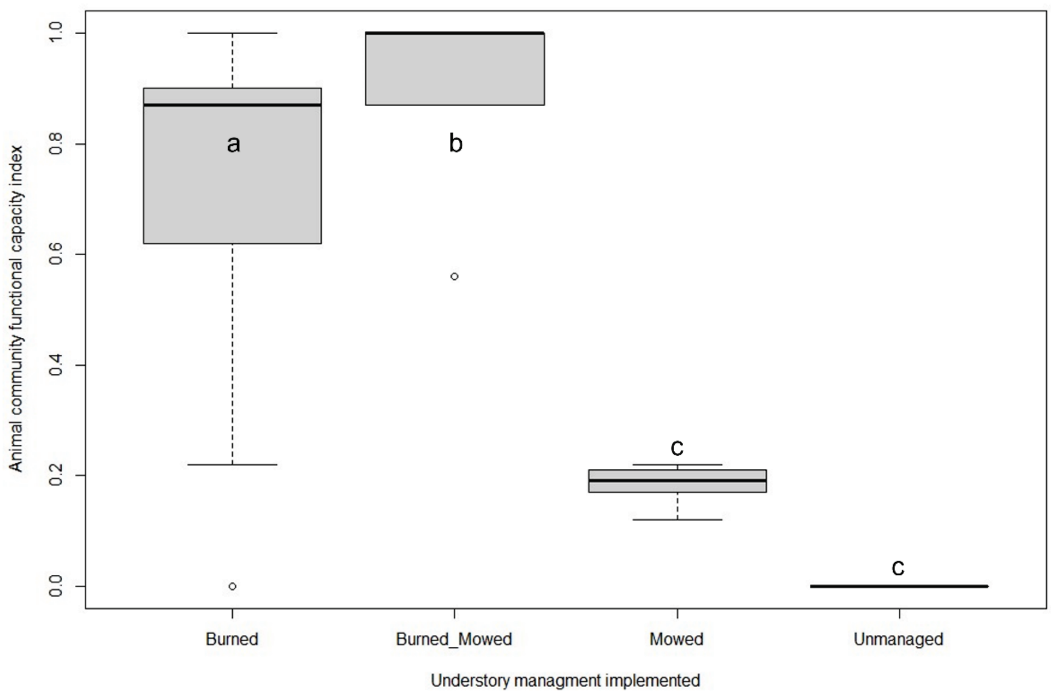
Figure 17. Box plot comparing average wetland area managed by fire ($V_{LANDSCP}$) variable scores by management-strategy group. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Tables 3 and A-8).



There were significant differences in $FCI_{ANIMALS}$ scores between the unmanaged group and the burned-only and burned-mowed groups, between the burned-only group and the burned-mowed and mowed-only groups, and between the burned-mowed group and the mowed-only group (Figure

18). $FCI_{ANIMALS}$ scores are calculated using the associated FCI_{PLANTS} scores and $V_{LANDSCP}$ scores. The significant differences seen in $FCI_{ANIMALS}$ scores between the two burned treatments and other treatments is due to their $V_{LANDSCP}$ scores, as outlined above. The observed differences between burned-only and burned-mowed $V_{LANDSCP}$ scores is an artifact of the power-line or pipeline corridors' location within large tracts managed with fire that extend well beyond the boundary of the corridor. This trait results in the corridors receiving high $V_{LANDSCP}$ variable subindex scores, and subsequently higher animal community FCI scores.

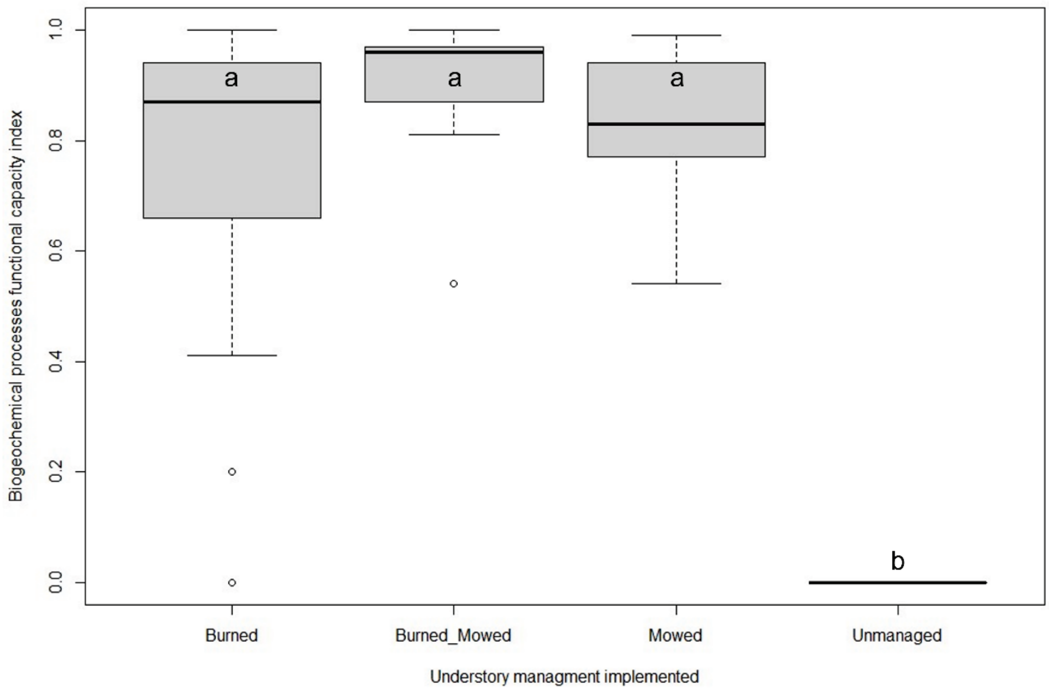
Figure 18. Box plot comparing the average maintain characteristic animal community ($FCI_{ANIMALS}$) function scores with management strategy as the groups. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Table A-9).



3.1.3 Maintain Characteristic Biogeochemical Processes ($FCI_{BIOGEOCHEM}$) Function

Significant differences in $FCI_{BIOGEOCHEM}$ scores were detected between the unmanaged group and all other groups (Figure 19). The $FCI_{HYDROLOGY}$ and FCI_{PLANTS} functional scores are incorporated into the calculation $FCI_{BIOGEOCHEM}$ scores, and as a result the conditions influencing $FCI_{BIOGEOCHEM}$ scores include the rutting and compaction from mowing activities ($FCI_{HYDROLOGY}$) discussed in Section 3.1 and the canopy closure and disturbance frequency effects (FCI_{PLANTS}).

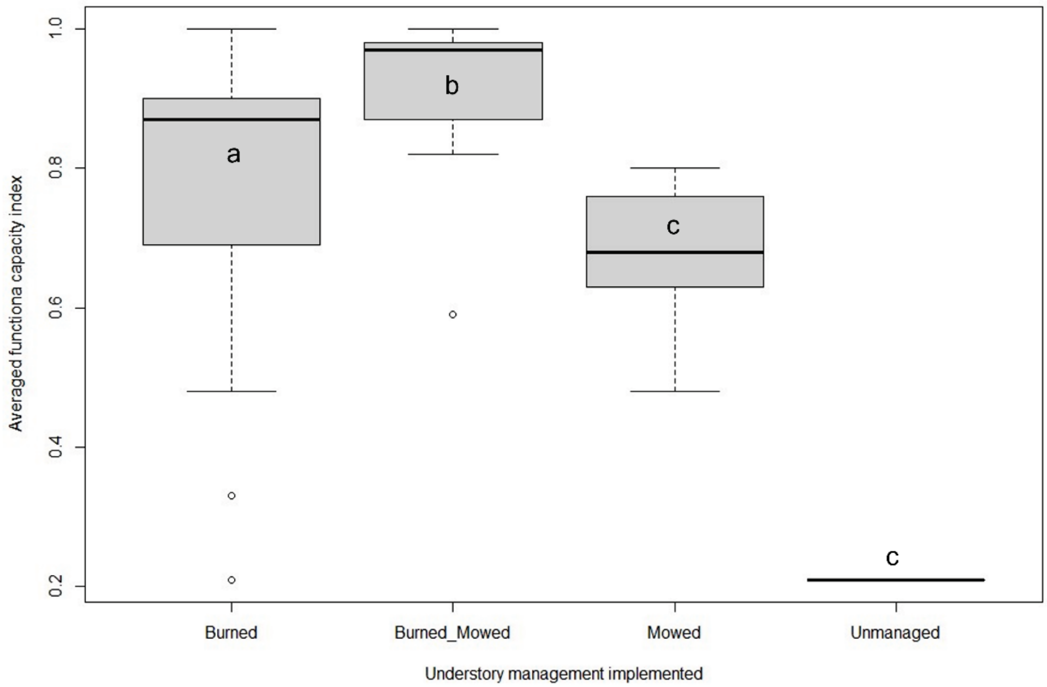
Figure 19. Box plot comparing average maintain characteristic biogeochemical processes ($FCI_{BIOGEOCHEM}$) scores with management-strategy groups. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Table A-10).



3.2 Average Functional Capacity Index (FCI) Scores

The average (FCI_{Avg}) scores are derived by taking the arithmetic mean of FCI scores for each treatment group. There were significant differences between all treatment groups except the unmanaged group and the mowed-only group. As seen in Figure 20, the burned-mowed group (0.92) had the highest average FCI score, followed closely by the burned-only group (0.81). While fire has been established as the preferred management approach, this finding further highlights the importance of fire for maintaining fully functional wet pine flats in agreement with the available literature (Baskin and Baskin 2001; Brewer 1998; Brewer 1999; Brewer 2001; Landers 1991; Means 1985; Platt et al. 1988; Veldman et al. 2014). Notably, it also suggests that mowing can play a role in these systems in combination with fire *if* it can be accomplished without inducing soil compaction or rutting. For example, areas that require disturbance can be burned during years where conditions allow, with dry season (that is, dry soil) mowing occurring during periods when prescribed fire is not feasible (for example, drought, unfavorable winds, limited burn-crew capacity).

Figure 20. Box plot comparing the overall wetland functional capacity (FCI_{Avg}) scores with management-strategy groups. Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Table A-11).



3.3 Site as Factor Group

Mean and standard deviation for FCI scores by sample locations are described in Table 5 below.

Table 5. Mean and standard deviation of each FCI score and average FCI score by site.

Site	Mean (Standard Deviation)				
	$FCI_{HYDROLOGY}$	FCI_{PLANTS}	$FCI_{ANIMALS}$	$FCI_{BIOGEOCHEM}$	FCI_{Avg}
Abita Creek	0.96 (0.06)	0.61 (0.27)	0.76 (0.20)	0.75 (0.21)	0.77 (0.17)
Devil's Swamp	0.98 (0.04)	0.83 (0.23)	0.89 (0.21)	0.88 (0.20)	0.89 (0.17)
Lake Ramsay	0.97 (0.05)	0.66 (0.24)	0.80 (0.16)	0.78 (0.16)	0.80 (0.14)
Middle School West ILF	0.95 (0.06)	0.71 (0.24)	0.18 (0.04)	0.81 (0.15)	0.66 (0.11)
Mossy Hill	0.97 (0.04)	0.73 (0.28)	0.84 (0.18)	0.82 (0.18)	0.84 (0.16)

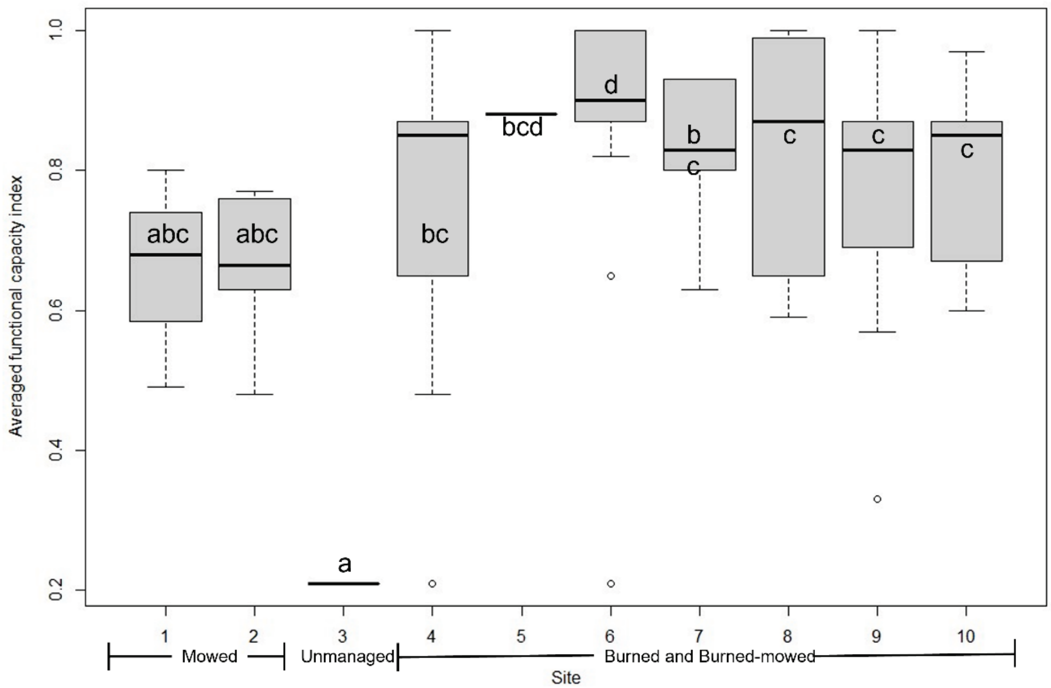
Table 5 (cont.). Mean and standard deviation of each FCI score and average FCI score by site.

Site	Mean (Standard Deviation)				
	$FCI_{HYDROLOGY}$	FCI_{PLANTS}	$FCI_{ANIMALS}$	$FCI_{BIOGEOCHEM}$	FCI_{Avg}
Oak Lawn	0.99 (0.02)	0.80 (0.21)	0.63 (0.09)	0.88 (0.13)	0.82 (0.11)
Old Fort Bayou	0.94 (0.07)	0.62 (0.27)	0.76 (0.23)	0.73 (0.23)	0.76 (0.19)
Old Fort Bayou (Unmanaged)	0.84 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.21 (0.0)
Old Fort Bayou Phase III	0.99 (0.0)	1.0 (0.0)	0.55 (0.0)	0.99 (0.0)	0.88 (0.0)
South Forrest Heights ILF	0.99 (0.01)	0.66 (0.35)	0.18 (0.05)	0.79 (0.22)	0.66 (0.16)

Significant differences were detected between study locations, with the unmanaged portion of Old Fort Bayou scoring the lowest of all areas examined (Figure 21). Though no significant difference was detected between the mowed-only study locations and most other areas (except Devil's Swamp and Mossy Hill), the FCI_{Avg} scores were lower than all locations that used prescribed burns for management.

These results indicate that two major issues that affect the function of wet pine flatwood wetland ecosystems exist when using mowing in lieu of prescribed fire, and these issues are reflected in the HGM assessment results. First, the exclusion of fire heavily affects the landscape-quality variable, which contributes to $FCI_{ANIMALS}$ scores. The exclusion of fire affects herbaceous plants that are used as indicator species for the HGM assessment, and many of the native herbaceous plant species of wet pine flatwoods require some aspect of the natural fire-disturbance regime to complete a part of their life cycle (Baskin and Baskin 2001; Brewer 1998; Brewer 1999; Brewer 2001; Landers 1991; Means 1985; Platt et al. 1988; Veldman et al. 2014). Second, the use of heavy machinery to conduct mowing operations negatively affects $FCI_{HYDROLOGY}$ scores through the alteration of microtopography and soil porosity via rutting and compaction. These alterations alter the hydrologic flow of water through wet pine flatwoods habitats. Creation of ruts across the habitat induces uneven pooling of surface water and affects the distribution of surface-water runoff across a wetland area. Compaction of the soil by machinery required for mowing can also alter soil porosity, negatively affecting surface-water infiltration rates and groundwater discharge-recharge dynamics.

Figure 21. Box plot comparing the average overall wetland functional capacity (FCI_{Avg}) score with site groups (1—South Forest Heights ILF; 2—Middle School West ILF; 3—Old Fort Bayou unmanaged, 4—Old Fort Bayou, 5—Old Fort Bayou Phase III, 6—Devil's Swamp, 7—Oaklawn, 8—Mossy Hill, 9—Abita Creek, 10—Lake Ramsay). Box plot *bold lines* are median values; *boxes* represent upper and lower quartiles; and *whiskers* represent 95% confidence intervals of median (full plaintext data in Table A-12).



The results presented herein also indicate that potential benefits likely exist in wet pine flatwoods when using a combined management approach that incorporates burning and mowing. FCI_{PLANTS} and $FCI_{ANIMALS}$ scores were highest in the burned-mowed treatment group because of increased disturbance intervals from frequent mowing of power-line and pipeline corridors in combination with potential additional fuel loading. Developing specific recommendations for ideal management recommendations will require further, more in-depth, studies to determine whether and how much benefit is gained through the combined management strategies, although several studies do report benefits (Kirkman and Mitchell 2006; Weekley et al. 2011). Notably, this concept highlights a potential conundrum for land managers. Does the benefit provided by mowing prior to a prescribed burn or at increased frequency compared with prescribed burning outweigh the risks of rutting and compaction caused by machinery to wet pine flatwoods habitats? Future studies with a larger geographic range of study locations, detailed management histories, and consistent management practice could answer this question. According to the available data, the best possible management strategies may include mechanical understory vegetation management during dry periods when compaction and rutting risks are minimized coupled with prescribed fire treatments during favorable conditions.

While some unanswered questions remain, the outcomes of this study may inform the selection of management strategies and monitoring of wet pine flatwoods. The results of this study, when coupled with existing literature, provide evidence that the use of prescribed fire, either alone or in combination with mowing, produces wetlands with higher FCI scores, and thus higher functioning wetlands, than unmanaged wet pine flatwoods and wet pine flatwoods managed through only mowing. The results also provide evidence that using a combination of prescribed fire and mowing in wet pine flatwoods may provide additional functional benefits beyond those only using prescribed fire. Uncertainties associated with management-strategy selection may be overcome by appropriate monitoring and adaptive management.

This study also highlights the ability of the existing wet pine flatwoods HGM model from Rheinhardt et al. (2002) to detect and quantify differences in functions of wetland-restoration and mitigation sites with differing management strategies. In addition to quantifying recovery trajectories and evaluating temporal changes (both short and long term) to wetland functions (Berkowitz 2019; Price and Berkowitz 2020), the results of this study provide insight into using HGM not only as a tool to assess impacts and mitigation associated with USACE permit actions but also a tool to monitor wetland-restoration and mitigation sites, inform adaptive-management actions, and support other mitigation decisions (for example, mitigation credit releases). Using HGM and its associated FCI calculators as the functional assessment method for this study also provided a user-friendly approach to rapid data collection and analysis.

4 Summary

The existing HGM assessment methodology provides valuable insight into the ecological functions of wet pine flatwoods wetlands, operates as intended, and delivers the best available tool to evaluate these ecosystems within the context of the USACE regulatory program for alternatives analyses, determination of compensatory-mitigation requirements, establishment of ecological-performance standards, monitoring requirements, adaptive-management actions, and other applications. Additionally, this technical report endorses the implementation of prescribed-fire management for wet pine flatwoods as the preferred methodology to support wetland functions in these ecosystems. Native bunchgrass cover, an indicator used to determine proper plant community and biodiverse habitat maintenance, was significantly higher in sample locations where prescribed fire was used. Hydrologic functions were negatively affected by mowing operations because of rutting and compaction from the machinery used to perform the mowing. However, periodic mowing conducted during periods of low soil moisture, in conjunction with prescribed fire, can provide an additional type of disturbance that supports higher levels of wetland function across a range of wet pine flatwood settings.

Notably, while strategies that incorporate prescribed burning as part of their management regime to maintain or reestablish wetland functions in wet pine flatwoods habitat are preferred, the use of mowing-only approaches to manage the understory is better for wetland functions than not implementing an understory-management strategy. This recommendation may warrant additional consideration in or near Environmental Justice communities that may be experiencing disproportionate and adverse human health and environmental effects due to air pollution, where prescribed burning may exacerbate air quality issues in these communities. On the other hand, this recommendation may benefit communities, including historically underrepresented communities, by increasing the ecological functions, goods, and services provided by wet pine flatwoods to residents at the urban-suburban-wildland interface and in other locations. Finally, Indigenous nations and Tribal governments may be interested in taking on the long-term management of wet pine flatwoods wetlands and applying Indigenous knowledge and Traditional ecological knowledge regarding the use of prescribed fire, including traditional techniques, to sustain desired plant and animal community composition and the provision of ecological functions, goods, and services.

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Appendix A: Posthoc Test Results Tables

This section includes the 12 management-comparison tables. The asterisks indicate statistically significant results (that is, $p \leq 0.025$, or an α level of 0.05/2).

Table A-1. Dunn posthoc test results for V_{ET}.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	−2.318008	(0.0102)*
Burned–Mowed	−1.905363	(0.0284)
Burned_Mowed–Mowed	0.000000	(0.5000)
Burned–Unmanaged	3.269529	(0.0005)*
Burned_Mowed–Unmanaged	4.064191	(0.0000)*
Mowed–Unmanaged	3.878513	(0.0001)*

Table A-2. Dunn posthoc test results for V_{MICRO}.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	5.194658	(0.0000)*
Burned–Mowed	4.321541	(0.0000)*
Burned_Mowed–Mowed	0.042261	(0.4831)
Burned–Unmanaged	−0.560362	(0.2876)
Burned_Mowed–Unmanaged	−2.864581	(0.0021)*
Mowed–Unmanaged	−2.760792	(0.0029)*

Table A-3. Dunn posthoc test results for V_{PORE}.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	7.609338	(0.0000)*
Burned–Mowed	1.557805	(0.0596)
Burned_Mowed–Mowed	−3.845326	(0.0001)*
Burned–Unmanaged	−0.157539	(0.4374)
Burned_Mowed–Unmanaged	−3.584152	(0.0002)*
Mowed–Unmanaged	−0.956050	(0.1695)

Table A-4. Dunn posthoc test results for $FCI_{HYDROLOGY}$.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	2.127663	(0.0167)*
Burned–Mowed	1.343546	(0.0895)
Burned_Mowed–Mowed	−0.331859	(0.3700)
Burned–Unmanaged	3.017692	(0.0013)*
Burned_Mowed–Unmanaged	1.822753	(0.0342)
Mowed–Unmanaged	1.952157	(0.0255)

Table A-5. Dunn posthoc test results for V_{HERB}.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	−2.080455	(0.0187)*
Burned–Mowed	0.194419	(0.4229)
Burned_Mowed–Mowed	1.559205	(0.0595)
Burned–Unmanaged	2.727748	(0.0032)*
Burned_Mowed–Unmanaged	3.456961	(0.0003)*
Mowed–Unmanaged	2.299776	(0.0107)*

Table A-6. Dunn posthoc test results for F_{NBG}.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	−1.870613	(0.0307)
Burned–Mowed	2.100162	(0.0179)*
Burned_Mowed–Mowed	2.978200	(0.0014)*
Burned–Unmanaged	2.830230	(0.0023)*
Burned_Mowed–Unmanaged	3.456684	(0.0003)*
Mowed–Unmanaged	1.390121	(0.0822)

Table A-7. Dunn posthoc test results for FCI_{PLANTS}.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	−2.669820	(0.0038)*
Burned–Mowed	0.410039	(0.3409)
Burned_Mowed–Mowed	2.132342	(0.0165)*
Burned–Unmanaged	2.811375	(0.0025)*
Burned_Mowed–Unmanaged	3.800465	(0.0001)*
Mowed–Unmanaged	2.260281	(0.0119)*

Table A-8. Dunn posthoc test results for $V_{LANDSCP}$.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	−0.732166	(0.2320)
Burned–Mowed	7.393580	(0.0000)*
Burned_Mowed–Mowed	6.545741	(0.0000)*
Burned–Unmanaged	4.405683	(0.0000)*
Burned_Mowed–Unmanaged	4.395797	(0.0000)*
Mowed–Unmanaged	0.000000	(0.5000)

Table A-9. Dunn posthoc test results for $FCI_{ANIMALS}$.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	−2.853572	(0.0022)*
Burned–Mowed	4.360353	(0.0000)*
Burned_Mowed–Mowed	5.490069	(0.0000)*
Burned–Unmanaged	2.967639	(0.0015)*
Burned_Mowed–Unmanaged	4.027683	(0.0000)*
Mowed–Unmanaged	0.325251	(0.3725)

Table A-10. Dunn posthoc test results for $FCI_{BIOGEOCHEM}$.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	−1.870434	(0.0307)
Burned–Mowed	0.615188	(0.2692)
Burned_Mowed–Mowed	1.762350	(0.0390)
Burned–Unmanaged	2.811138	(0.0025)*
Burned_Mowed–Unmanaged	3.438988	(0.0003)*
Mowed–Unmanaged	2.152435	(0.0157)*

Table A-11. Dunn posthoc test results for FCI_{Avg}.

Management Comparison	*Z* statistic	α
Burned–Burned_Mowed	−2.249546	(0.0122)*
Burned–Mowed	2.748289	(0.0030)*
Burned_Mowed–Mowed	3.763815	(0.0001)*
Burned–Unmanaged	2.897224	(0.0019)*
Burned_Mowed–Unmanaged	3.689744	(0.0001)*
Mowed–Unmanaged	1.109056	(0.1337)

Table A-12. Dunn posthoc test results for FCI_{Avg}.

Site Comparison	*Z* statistic	α
1–10	−1.116759	(0.1320)
1–2	−0.021339	(0.4915)
10–2	1.341610	(0.0899)
1–3	0.893220	(0.1859)
10–3	2.148161	(0.0159)*
2–3	1.052741	(0.1462)
1–4	−1.149493	(0.1252)
10–4	0.192069	(0.4238)
2–4	−1.511776	(0.0653)
3–4	−2.343109	(0.0096)*
1–5	−1.713546	(0.0433)
10–5	−0.948661	(0.1714)

Note: 1—South Forest Heights ILF; 2—Middle School West ILF; 3—Old Fort Bayou unmanaged; 4—Old Fort Bayou; 5—Old Fort Bayou Phase III; 6—Devil's Swamp; 7—Oaklawn; 8—Mossy Hill; 9—Abita Creek; 10—Lake Ramsay.

Table A-12. (cont.). Dunn posthoc test results for FCI_{Avg}.

Site Comparison	*Z* statistic	α
2–5	−1.897323	(0.0289)
3–5	−2.512467	(0.0060)*
4–5	−1.172890	(0.1204)
1–6	−2.605540	(0.0046)*
10–6	−1.764919	(0.0388)
2–6	−3.468766	(0.0003)*
3–6	−3.799155	(0.0001)*
4–6	−3.145420	(0.0008)*
5–6	−0.037782	(0.4849)
1–7	−1.212786	(0.1126)
10–7	−0.117608	(0.4532)
2–7	−1.459218	(0.0723)
3–7	−2.244188	(0.0124)*
4–7	−0.341433	(0.3664)
5–7	0.865499	(0.1934)
6–7	1.615556	(0.0531)
1–8	−1.927313	(0.0270)
10–8	−0.858200	(0.1954)
2–8	−2.547887	(0.0054)*
3–8	−3.115407	(0.0009)*
4–8	−1.663847	(0.0481)
5–8	0.517039	(0.3026)
6–8	1.415346	(0.0785)
7–8	−0.710078	(0.2388)
1–9	−1.144705	(0.1262)
10–9	0.145124	(0.4423)
2–9	−1.472917	(0.0704)
3–9	−2.303901	(0.0106)*
4–9	−0.055732	(0.4778)

Note: 1—South Forest Heights ILF; 2—Middle School West ILF; 3—Old Fort Bayou unmanaged; 4—Old Fort Bayou; 5—Old Fort Bayou Phase III; 6—Devil's Swamp; 7—Oaklawn; 8—Mossy Hill; 9—Abita Creek; 10—Lake Ramsay.

Table A-12. (cont.). Dunn posthoc test results for FCI_{Avg}.

Site Comparison	*Z* statistic	α
5–9	1.125402	(0.1302)
6–9	2.723096	(0.0032)*
7–9	0.286966	(0.3871)
8–9	1.421888	(0.0775)

Note: 1—South Forest Heights ILF; 2—Middle School West ILF; 3—Old Fort Bayou unmanaged; 4—Old Fort Bayou; 5—Old Fort Bayou Phase III; 6—Devil's Swamp; 7—Oaklawn; 8—Mossy Hill; 9—Abita Creek; 10—Lake Ramsay.

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14. ABSTRACT
This report assesses the functional capacity of wet pine flatwood wetland habitats in the Gulf Coastal region of the United States, with a specific focus on compensatory mitigation sites maintained using mowing or prescribed fire, or both, as understory management strategies. The use of mowing in lieu of prescribed fire treatments has been proposed for a variety of reasons, including when mitigation sites are located near residential areas or where fires pose a risk to private property and public safety. This study evaluates the effects of mechanized mowing on ecosystem functions by using the hydrogeomorphic (HGM) wetland functional-assessment method to compare mitigation sites managed by mowing to sites managed by prescribed-fire regimes. Assessing mowing as a vegetation-control strategy in lieu of prescribed-fire regimes provides valuable information that can improve the design and management of wet pine flatwoods mitigation sites throughout portions of the southeastern United States, where this wetland class occurs.

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