2019 Progress Report Hardwood Reduction in Pinelands
Fish and Wildlife Research Institute
Ecosystem Assessment and Restoration Section
Upland Habitat Research and Monitoring

Project:	Hardwood Reduction in Pinelands
Investigation:	**Monitoring Effects of Herbicide on Vegetation at Chassahowitzka WMA, Perry Oldenburg WEA, & Watermelon Pond WEA as Part of a Hardwoods Control Study**
Period covered:	December 2017 – June 2019
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Abstract: The goal of this study is to develop best management practices that will not only result in top kill of invasive woody species in pinelands but will also impact the below ground root systems to prevent re-sprouting. The most common woody plants that are creating re-sprouting issues for agency land managers tasked with pineland restoration are turkey oak (*Q. laevis*), sand live oak (*Q. geminata*), myrtle oak (*Q myrtifolia*), and laurel oak (*Q. laurifolia*). Herbicide is the best option for eliminating the cycle of retreatment every 3-5 years or earlier. Four herbicide prescriptions are being evaluated in this experiment: (1) low rate of Arsenal AC (12 oz/ac imazapyr + 32 oz/ac Methylated Seed Oil (MSO) surfactant); (2) high rate of Arsenal AC (16 oz/ac imazapyr + 1 gal/ac MSO; (3) Krenite S (64 oz/ac) + Trycera (triclopyr, 32 oz/ac) + Milestone (aminopyralid, 7 oz/ac) + MSO (24 oz/ac); and (4) Arsenal AC (16 oz/ac) + Trycera (32 oz/ac) + MSO (24 oz/ac). This report summarizes all project activities to date including site selection, plot establishment, vegetation sampling, herbicide contract work and preliminary results and conclusions.

2019 PROGRESS REPORT:
Hardwood Reduction in Pinelands

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Introduction

The ability to re-sprout is a widespread adaptation of woody plants allowing them to persist in frequently disturbed ecosystems (Bond and Midgley 2001). Re-sprouting plants can respond to many types of disturbances that result in top kill by quickly re-growing aboveground biomass from buds located at or below the soil surface (Bond and Midgley 2003). Thus, the same genotype can continue to occupy a site throughout disturbance cycles, causing long-term stability for many pyrogenic ecosystems (Clarke et al. 2010). In fact, clonal re-sprouts can occupy the same space for hundreds to thousands of years and have minimal changes in population size (Bond and Midgley 2003).

The re-sprouting of woody species after removal of above ground biomass by mechanical means or fire has proven to be one of the most difficult obstacles in the restoration of all types of pinelands. Decades of fire suppression throughout the southeast have resulted in hardwood encroachment at densities that often-become impediments to fire once it is returned to the system. For example, hardwoods can shade out herbaceous ground cover vegetation including native warm season grasses, such as wiregrass (*Aristida stricta*), that provide fine fuels necessary for ignition and the spread of low intensity ground fires. Rather, most of the fuel is retained in the xerophytic leaves of the oak vegetation making fires difficult to ignite, and once ignited, often resulting in poor burn coverage. Thus, the challenge for land managers is to shift the vegetative composition of fire suppressed pinelands back to fire-supporting species that enhance the continuity of fine fuels.

Many studies investigating various treatment methods for control of woody encroachment have been conducted to develop best management practices. When prescribed fire is applied, dormant season burns are usually not effective in controlling woody re-sprouting, and in some cases, have led to vigorous re-sprouting that exceeded the woody biomass prior to the burn. While growing season burns did not eliminate re-sprouting, the practice was found to be more effective in controlling re-sprouting than dormant season burns (Waldrop et al. 1992; Drewa et al. 2002, 2006; Robertson et al. 2014).

Furthermore, fire is not expected to top kill larger oaks (*Quercus* spp.) (Waldrop et al. 1992; Streng et al. 1993) and top killed oaks generally re-sprout at densities that would far exceed pre-burn levels in the absence of frequent fires (Waldrop et al. 1992). Therefore, additional methods coupled with fire are often needed to meet restoration and management goals while preserving the longleaf pine (*Pinus palustris*), and wiregrass components (Provencher et al. 2001).

Intensive mechanical techniques are reported to be effective for preparing sites for longleaf pine establishment (Johnson and Gjerstad, 2006), but are very detrimental to wiregrass (Clewell 1989), and therefore they are not the best options on sites where understory conservation is desired. Soil disturbance resulting from techniques such as roller chopping also typically creates vectors ideal for plant invasion by weedy offsite herbaceous species that may cause a shift in the ground cover composition (Williges et al. 2006). In addition, mechanically clipped plants typically have more stems post treatment than plants top killed by fire (Williges et al. 2014, Hmielowski et al. 2014). Thus, mowing or roller chopping to reduce woody cover appear to be only short-term remedies, and will need frequent reapplication every 3-5 years (Williges et al. 2006). Felling/girdling is also an effective treatment for shrub cover reduction (Provencher et al. 2001), but the application process is very laborious and time intensive at the landscape level, and the same issues with re-sprouting exists.

Herbicides are another commonly applied hardwood control technique utilized throughout the southeast. Triclopyr (Garlon) has been widely used throughout the region since 1980, and basal bark applications are effective in controlling a wide range of woody species (Yeiser 2000). Atwater (2017) describes triclopyr as "the equivalent of a hot summer fire in a bottle" which will attack all broadleaved plants, while shifting groundcover to grasses and sedges. Triclopyr has the advantage of no residual soil activity and is described as the "go to" herbicide for control of wax myrtle (*Morella cerifera*), blackberry (*Rubus* spp.), gallberry (*Ilex glabra*), *Bacchari*s spp., and the various oak species. Long term control varies with the species, size, density, timing of application, and the general vigor of the plants prior to, and at the time of application (Atwater 2017).

Imazapyr (Arsenal) is described as perhaps the most versatile and flexible herbicide tool because selectivity can be affected by rate, timing, and tank mix (Atwater 2017). The drawback is that imazapyr does have residual soil activity, which can not only act as additional preemergent control of hardwoods but can also delay herbaceous groundcover recovery. Generally, applications of Arsenal later in the year (October or November) greatly reduces harmful effects on warm season grasses including wiregrass (Atwater 2017). Low rates of imazapyr (0.21 kg/ha) have been used effectively as a control of understory shrubs (Jose and Freeman 2009; Jose et al. 2010).

Hexazinone (Velpar) is probably the most common herbicide used in the southeast for control of oaks. Optimum time of application is during the growing season from bud break to full leaf expansion, and efficacy is enhanced if there is enough re-sprouting/regrowth following disturbance, and good soil moisture prior to and following application (Atwater 2017). Since hexazinone is taken up primarily by the roots, larger trees are more susceptible than smaller ones due to their larger root systems. This water-soluble herbicide can also move laterally through the soil particularly after heavy rainfall events following the first application (Atwater 2017). Thus, care must be taken when using close to desirable trees. Brockway et al. (1998), Brockway and Outcalt (2000), and Provencher et al. (2001) reported that low rates of hexazinone (0.56 – 2.2 kg/ha) were effective in reducing woody cover of turkey oak (*Quercus laevis*) in north Florida sandhills with minimal impact to herbaceous groundcover vegetation. In addition, other studies have shown that members of the Ericaceae family have been highly hexazinone resistant (Wilkins et al., 1993; Outcalt et al., 1999; Miller et al., 1999). These include dwarf huckleberry (*Gaylussacia dumosa*), Darrow's blueberry (*Vaccinium darowii*), and shiny blueberry (*Vaccinium myrsinites*) which all have very high wildlife value.

Another herbicide prescription that is often used for roadside right-of-way control of hardwoods is a Krenite S (fosamine)/Trycera (triclopyr)/Milestone (aminopyralid) mixture plus a MSO surfactant. This prescription is effective at promoting grass establishment, with minimum impacts to longleaf and slash pine as it has no residual soil activity (Greg Boozer, Helena Chemical Co., per. comm.).

However, most studies to date have reported only reductions in woody cover over a short term. Control methods that result in a reduction of the target woody species(s) until a desired level of stem density is achieved, with minimal impacts to the desired ground cover over a long term have been rarely investigated.

The goal of this study is to develop best management practices that will not only result in top kill of invasive woody species but will also impact the below ground root systems to prevent re-sprouting. This hopefully will eliminate the cycle of endless retreatment every 3-5 years or earlier. We also want to have as minimal an impact to native ground cover vegetation and preserve as much diversity as possible. Based on a review of the literature as indicated above, it appears that herbicide methods offer the best chance for control over a long term. The herbicides selected for this study were chosen after an extensive literature review, in addition to recommendations from industry experts. These chemical methods are not intended to be a substitute for fire. Prescribed fire will be the primary management tool, once a desired level of woody density is achieved. However, it is not the objective of this study to include fire as one of the experimental treatments.

Study Sites.

The most common woody species that are currently creating issues for agency land managers tasked with pineland restoration are turkey oak, sand live oak, myrtle oak, and laurel oak. Sweetgum (*Liquidambar styraciflua*) and gallberry can also be problematic to a lesser degree on mesic sites.

The areas selected for this study are sandhills restoration sites that currently have issues with these species and stand to benefit from some hardwood reduction as the restoration progresses. These sites include Chassahowitzka Wildlife Management Area Perry Oldenburg Mitigation Park & Wildlife and Environmental Area and Watermelon Pond Wildlife and Environmental Area.

Methods.

Experimental design:

A complete randomized block design is established at each study area. There are 3 replicate blocks per site. Blocks did not need to be contiguous, but each block did contain only one soil type to minimize variation between treatment plots within a block. Treatment blocks are assigned such that the tree density and size within each block are as visually similar as possible to reduce any possible landscape differences between treatments. Five treatment plots are delineated within each block, and were 1 ac in size, measuring 63.614 m^2 (Figure 1). Thus, a total of 15 acres (15 plots) are used at each site to conduct this experiment. The experimental treatments are then randomly assigned to the individual test plots (Figure 2-4).

Experimental treatments:

The 5 treatments are: (1) low rate of Arsenal AC (12 oz/ac imazapyr + 32 oz/ac Methylated Seed Oil surfactant) referred to as LRIMAZ throughout the report; (2) high rate of Arsenal AC (16 oz/ac imazapyr + 1 gal/ac Methylated Seed Oil surfactant) (HRIMAZ); (3) Krenite S (64 oz/ac) + Trycera (triclopyr, 32 oz/ac) +Milestone (7 oz/ac aminopyralid) + Methylated Seed Oil surfactant (24 oz/ac) (KTM); (4) Arsenal AC (16 oz/ac) + Trycera (32 oz/ac) + Methylated Seed Oil surfactant (24 oz/ac) (TRYIMAZ), and (5) untreated control (CONTROL). Individual treatment types are to be applied in each test plot per study site on the same day but not all treatments types were completed on the same day.

Polaris AC was substituted in for Arsenal AC at Chassahowitzka WMA and Watermelon Pond WEA. Arsenal AC was used exclusively at Perry Oldenburg and was used for treatments 1 and 2 at Chassahowitzka. Polaris AC was used in Treatment 4 at Chassahowitzka and all imazapyr treatments at Watermelon Pond. No change to treatment results is expected due to both products having the same amounts of active ingredients.

Herbicide application:

The herbicide application work was awarded to Kestrel Ecological Services through an informal ($\leq$ \$35,000) written quote process. Foliar spot treatment as opposed to broadcast application was used to avoid potential harmful effects to non-target species. Target species were sand live oak, myrtle oak, laurel oak, and turkey oak with stems < 8 cm DBH. Turkey oak was avoided at Perry Oldenburg per request of the WEA biologists.

Herbicide treatments took place in 2018 at: Perry Oldenburg on June 5th- June 11th, Chassahowitzka on June 11th - June 18th and Watermelon Pond June 18th– June 27th (Appendix 1 & 2). Herbicide treatments were applied within designated experimental plots to the plot border except in the case of treatment 3 where it was only sprayed to the internal 10 m buffer. The 10 m buffer inside the acre plot, decreased the sampling area to 0.41 acres but provided a more continuous treatment result and reduced the overall land need for this project. This also allowed for treatment 3 to stay within the maximum yearly use rate of aminopyralid which is 7-oz/acre/year.

Lack of water at the study sites required chemical treatments to be applied from low to high rates of imazapyr to reduce the need to fully rinse sprayer tanks between each treatment. Treatments where mixed in the following order: Treatment 1, treatment 2, treatment 4 and finally treatment 3. Sprayer tanks were triple rinsed after treatment 4 and treatment 3 was then mixed. After the final treatment the sprayers were triple rinsed and prepared for the next site.

Vegetation monitoring:

The 4 primary variables of interest in this project are (1) the cover of the target oak species present in the plot, (2) the stem densities of the target oaks present in the plot; (3) ground cover composition and relative abundance; and (4) the amount of litter present in the plot as it relates to fine fuel availability. The null hypothesis is that there is no difference in these variables in the pre-treatment condition or resulting from the 5 treatment types.

Within each test plot boundary, 10 random sample points spaced at least 5 m apart were pre-generated in the lab using ArcGIS allowing for an internal 10 m buffer along the plot perimeter to minimize any potential edge effects. Permanent sampling points are more statistically powerful than temporary ones for detecting change between 2 or more years for many plant species (Elzinga et al. 1998). Therefore, the sample points were permanently marked on the ground within the plot using 18” metal tag stake and fitted with a consecutively numbered metal tag. Sample point coordinates were downloaded onto hand-held data loggers/iPads equipped with GPS for relocation on the ground during the vegetation sampling.

A 2-m radius circular quadrat was centered on each sample point (Figure 1). The presence/absence of all herbaceous plants rooted within this quadrat area was identified to species level. The shrub strata, referred to as woody vegetation, included ericaceous shrubs, pines, oaks, and woody vines. Woody vegetation cover, occurring but not required to be rooted within, was visually estimated in the 2-m radius quadrat with no height restrictions on observations. All visual cover estimates in this study were taken using the Daubenmire cover class system which minimizes inter-observer variability. Stems of woody species rooted within the 2-m radius quadrat with a DBH ≥ 4-cm were also recorded for each species.

The cover of the ground strata including herbaceous vegetation, woody vegetation, litter, and bare ground was visually estimated within the center 0.5-m radius circular quadrat (vegetation does not need to be rooted within). Woody vegetation cover, visually estimated in the 0.5-m radius quadrat, included shrub cover occurring to 3-m in height. The stems of woody plants with a DBH < 4-cm were also recorded per species that were rooted within the 0.5-m quadrat. Stems of *Rubus* species and vines were not counted but their cover was recorded in the 0.5-m quadrat.

Pre-treatment baseline vegetation data was collected in 2018 on: April 16th -April 27th at Watermelon pond WEA; April 30th- May 15th at Perry Oldenburg WEA; and on May 16th-May 30th at Chassahowitzka WMA (Figure 5). Treatment data was then collected a year later in 2019 on: April 15th-25th at Watermelon pond WEA; April 29th-May 14th at Perry Oldenburg WEA; and on May 20th-May 24th at Chassahowitzka WMA. Additional data will be collected 2 and 5 years after treatment, with the intent that fire has been applied at least twice, once before the second-year post-treatment data is collected and then prior to the 5th, at all locations within this time interval.

Data analysis.

QA/QC of the dataset is currently underway. Pre-treatment and post-treatment data were found to not be normally distributed and will require multiple data transformations to be able to perform parametric tests. Site locations had vegetation cover that was highly variable. We attempted to reduce some of this variability using a completely randomized block experimental design, but site variability still appears to have an influence on the data. We analyzed plants by functional groups which included (1) target oaks (sand live oak, turkey oak (with the exception of Perry Oldenburg), myrtle oak, and laurel oak, (2) Ericaceous shrubs (shrubs in the Ericaceae family such as the *Vaccinium*, *Gaylussacia*, and *Lyonia* genera), (3) Other shrubs (4) Bunchgrasses (including wiregrass), and (5) Forbs/Graminoids. Once transformations of the data are complete, data will be analyzed using a t-test to compare means of litter cover, functional group herbaceous ground cover, functional group woody cover, and functional group woody stem regen within each treatment type, and a repeated measures ANOVA to test for treatment effects between plots.

Chassahowitzka Wildlife Management Area

Site Description.

Chassahowitzka Wildlife Management Area (CWMA) is located on the Gulf Coast of Florida just north of the city of Weeki Wachee in Hernando county. It is a 24,423-acre Wildlife Management Area managed by the Florida Fish and Wildlife Conservation Commission (FWC 2014). It largely consists of hydric hammock, sandhill, mesic flatwoods and basin swamps (FWC 2014). Many of the plant communities at CWMA have been modified by human activities such as fire suppression, heavy logging of cedar, cypress and pines in the early 1900's, and the development of pine plantations and grazing pastures (FWC 2019a). Since the acquisition of CWMA in 1985 (FWC 2019a), biologist have been actively restoring the area's native plant communities which facilitated this study to be incorporated into the WMA's restoration plan.

Our 15-acre study site was located at the southeastern corner of CWMA (Figure 2). It occurred on Candler fine sands and consisted of degraded sandhill and rosemary scrub habitat largely fire suppressed due to its proximity to local residences (Figure 2). Sand pine (*Pinus clausa*), sand live oak, myrtle oak, laurel oak, turkey oak and ericaceous shrubs made up much of the hardwood component of the landscape. Wiregrass, gayfeathers (*Liatris spp.)*, chaffheads (*Carphephorus* spp.), and other legume and bunchgrass species represented the herbaceous component present at the study site.

Preliminary site conditions:

Due to the reintroduction of fire to some parts of the management unit, oak density and total vegetation cover was not uniformly spread across the study site. Therefore, some variability in vegetation still occurred despite our attempts to avoid differences. Block A is located on the perimeter of the burn unit and had the most established and dense oak hammock (Figure 2). It had limited ground cover and a well-established canopy.

Pre-treatment total mean vegetation cover (the cover of herbaceous and woody plants combined) in Block A ranged from about 29% to 68% with the LRIMAZ and KTM treatment plots having less total vegetation cover compared to the other treatments within the block. Block C was the most open with large sandy areas of bare ground and islands of oaks more characteristic of a rosemary scrub habitat. Total vegetation cover in Block C ranged from 31% to 53% across treatment plots. Block B had an intermediate appearance when compared to the former 2 blocks, although it contained the highest mean total vegetation cover estimate recorded at CWMA (72% in treatment KTM). In general, however, the oak canopy was not as dense as Block A as oak islands were more apparent, and it had less sandy bare ground than Block C. Mean total vegetation cover in Block B ranged from 48% to 70% across treatment plots.

Preliminary results.

Woody cover and stem counts:

Mean target woody oak vegetative cover for trees >3 meters tall decreased across all treatments especially in HRIMAZ where mean target oak cover decreased from about 50% to only 2% (Figure 6). Likewise, mean stem counts of target oaks with a DBH ≥ 4-cm also show a decrease across all treatments, with HRIMAZ again exhibiting the greatest amount of change from the baseline (Figure 7). There was minimal if any change in the controls.

Mean target oak cover for plants ≤ 3 meters in height also decreased across all treatments and showed the same general trends as for the taller oaks: the greatest decrease was in HRIMAZ, then TRYIMAZ, LRIMAZ, and finally KTM (Figure 8). The same pattern holds true for the stem counts of target oaks with a DBH < 4 cm (Figure 9).

Unfortunately, it appears that some of the non-target oaks including southern red oak (*Quercus falcata*) and bluejack oak (*Quercus incana*) also took a hit. Although found at just a few sample points in the LRIMAZ, HRIMAZ, and TRYIMAZ treatment plots with minimal cover (5% - 20%) during the pre-treatment survey, these species were not found alive in these same plots during 2019.

Ericaceous shrubs at CWMA were not abundant (pre-treatment mean cover < 5%). Where they were present however, there was no substantial change in mean cover with possibly the exception of the KTM treatment (Figure 10). Mean shrub cover exhibited decreases in HRIMAZ, KTM and CONTROL (Figure 11).

Herbaceous cover:

Pre-treatment mean bunchgrass cover including wiregrass was very low (3% - 7%). The greatest reduction occurred in the KTM treatment where mean bunchgrass cover appears to be reduced by 50% (Figure 12). However, all post-treatment means are similar to the control. Mean pre-treatment Legume and Forb/Graminoid cover was also very low (< 5% in the controls) and were reduced even further post-treatment. In fact, Legume species appear to be eliminated in the KTM treatment (Figure 13). Forb and graminoid mean cover also exhibited reductions in mean cover in all treatments excluding the control (Figure 14).

Species richness:

Total species richness decreased in all treatments, including the control at CWMA

(Table 1). CWMA was the only project study site that exhibited a loss of species in the control plots. The cause of this phenomenon is currently unknown. Twelve of the species lost in TRYIMAZ and CONTROL were herbaceous, while HRIMAZ experienced the overall largest loss of woody species (13). LRIMAZ and KTM showed a similar loss of both herbaceous and woody species.

General treatment plot characteristics:

Mean total vegetation cover decreased across all treatments except for the control which showed virtually no change from the baseline data (Appendix 3 & 4). HRIMAZ and TRYIMAZ showed 59% and 61% decrease in vegetative cover, respectively, while LRIMAZ and KTM decreased by less than 50%. Mean bare ground cover decreased by about 50% in the TRYIMAZ treatment but increased slightly in all others including the control (Appendix 5). Mean litter cover and litter depth did not appear to have any substantial differences compared to baseline conditions or between the different treatments (Appendix 5-6).

Preliminary conclusions.

Preliminary results indicate that all herbicides had some success in controlling target oaks at CWMA with KTM appearing to be the least effective. These differences between herbicides will need to be analyzed further to determining any significant difference. No re-sprouts were observed in the field in any of the treatments, and target oaks that were not missed by application error appear to have been killed. Unfortunately, non-target oaks were impacted as well indicating there was some aerial spray drift or underground drift through the soil. Ericaceous shrub and shrub cover did not appear to be heavily impacted by non-target damage but slight decreases in coverage were observed and will need further monitoring to determine if these are long term effects.

Herbaceous species did not appear to be heavily impacted by non-target damage. Bunchgrasses fared well across all treatments. Forb/graminoid and legume species appear to have struggled in LRIMAZ and KTM especially, but further monitoring is needed in order to determine if these are long term effects. Milestone and Trycera are both effective at controlling many herbaceous broadleaf weeds, and both are soil active and water soluble. Milestone requires very small concentrations of active ingredient to cause damage to non-tolerant plants, which could explain the strong impact on legumes and forbs in treatment KTM and TRYIMAZ.

Though species richness did decrease across all treatments, that is to be expected when applying herbicide using the foliar spray application technique due to overspray and potentially chemical drift. Hopefully, the seed bank will be released and replenish these lost species and with the help of other restoration efforts, return this site to a healthy sandhill community in the long term.

Perry Oldenburg Wildlife and Environmental Area

Site description.

Perry Oldenburg Wildlife and Environmental Area (POWEA) is located 8 miles northeast of Brooksville, Florida in Hernando county. It is a 380-acre mitigation park managed by the Florida Fish and Wildlife Conservation Commission. Located on the Brooksville Ridge, POWEA is known to have historically consisted of longleaf pine sandhill, mesic hammocks and basin marsh plant communities (FWC 2019b). Unfortunately, fire suppression prior to state ownership provided favorable conditions for oak and hardwood growth that gradually replaced open sandhill habitats with oak hammocks and thickets (FWC 2019b). Currently, POWEA is actively restoring these sandhill communities to maintain the population of protected Gopher tortoise (*Gopherus polyphemus*) in the area. This need for sandhill restoration facilitated this study to be included in the WEA’s restoration plans.

This study site was located in the northeastern corner of POWEA (Figure 3). It occurs on Arrendondo fine sands sloping 0-8% and consisted of 15 acres of degraded sandhill habitat that, due to fire suppression, had been overgrown by hardwood oak species. The site is characterized by longleaf pine, turkey oak, bluejack oak, sand live oak, wiregrass, gopher apple (*Geobalanus oblongifolius*) and shiny blueberry along with other legume and bunchgrass species.

Preliminary site conditions:

Due to fire having already been reintroduced to the study location, total vegetation cover was not uniform ranging from 28.5% to 70% across the site. Even with blocking, all blocks had some variability with at least one plot exhibiting substantially less cover when comparing mean total vegetative cover (Appendix 7). The western edge of the study site (Block A) had the highest visual density of oaks including primarily sand live oak and laurel oak with sparse amounts of bunchgrass groundcover. Block B was comparable to Block A and was comprised mainly of scattered areas of dense laurel oak and sand live oak with sparse amounts of sand post oak (*Quercus margaretta*), bluejack oak, dwarf live oak, turkey oak and live oak. Block C did not have a large presence of oaks and was the most open. Dwarf shrub and groundcover in Blocks B and C was more widespread and included shiny blueberry and wiregrass occurring throughout.

Preliminary results.

Woody cover and stem counts:

Mean target oak vegetative cover for trees >3 meters, decreased by more than 50% across all treatments except the control (Figure 16). Herbicides ranked by order of effectiveness were TRYIMAZ, KTM, HRIMAZ, and LRIMAZ. Likewise, mean cover for smaller target oaks ≤ 3 meters in height also decreased across all treatments although effectiveness rankings were slightly different: TRYIMAZ, HRIMAZ, KTM, and LRIMAZ (Figure 18). However, these differences were very minimal. Post-treatment cover estimates were all less than 3% excluding the control (Figure 18). There were few stems with a DBH ≥ 4-cm at POWEA, and in fact they were not tallied in the HRIMAZ treatment. However there did appear to be a decline except for the control (Figure 17). However, stems for target oaks with a DBH < 4-cm were reduced to less than 1 stem on average across all treatments (excluding the control) (Figure 19).

Turkey oaks were avoided at POWEA at the request of the managers. Other non-target oaks included southern red oak and sand post oak. Although they were relatively uncommon (pre-treatment means ranged from 9% to 15%), these species seem to have been impacted as well and exhibited declines in mean cover across all treatments (Figure 20). This is particularly true for the smaller trees (Figure 21).

Post-treatment mean shrub cover in the outer circle was reduced by more than 50% except for TRYIMAZ and CONTROL (Figure 22). There was a decline in both controls for both the inner and outer circle which may indicate some drift was involved (Figures 22 - 23). Ericaceous shrubs in general were not common at POWEA (Figures 24 - 25). Mean cover for plants > 3 m tall averaged less than 10% across the site in the pre-treatment condition, while smaller shrubs averaged < 5%. These estimates declined even more post-treatment and might even have been eliminated in HRIMAZ (Figures 24 - 25).

Herbaceous cover:

Bunchgrasses, legumes, forbs, and graminoids were all much more common at POWEA. While mean bunchgrass cover increased slightly in KTM, the trend was a decrease in all other treatments including the control (Figure 26). Mean legume cover exhibited a substantial decrease in cover across all treatments including the control (Figure 27). Forb and graminoid cover showed a decrease in HRIMAZ, KTM and CONTROL, while there was a slight increase and no change in treatments LRIMAZ and TRYIMAZ, respectively (Figure 28).

Species richness:

Total species richness increased across all treatments due to an increase in herbaceous plant species (Table 1). Herbaceous species richness increased across all treatments, but the greatest changes were seen in LRIMAZ, HRIMAZ, and KTM (Table 1). Woody species richness decreased across all plots except the control (Table 1).

General treatment plot characteristics:

A year after herbicide treatments, mean total vegetation cover decreased substantially across all treatments except KTM and the control (Appendix 8). Mean total vegetative cover in HRIMAZ and TRYIMAZ decreased by approximately half, while LRIMAZ and KTM decreased by 28% and 18%, respectively (Appendix 8). Mean litter cover decreased slightly across all treatments except TRYIMAZ and CONTROL (Appendix 9). Mean litter depth and bare ground cover both showed minimal change across all treatments, although mean bare ground cover tended to increase slightly in all treatments excluding the control (Appendix 10 & 11).

Preliminary conclusions.

All herbicide treatments were effective in controlling target oaks. No re-sprouting was observed in the field and this was reflected in the stem count data. All herbicide treatments also negatively impacted the shrub component of the landscape including ericaceous shrubs.

Species richness increased across all treatments at POWEA with the herbaceous component increasing the most. This could be due to the release of the seed bank brought about by the opening of the canopy and could be a sign of early pioneering plant species beginning to recolonize the site. This will be investigated further in order to determine which species are increasing.

HRIMAZ and TRYIMAZ appear to have had the strongest negative impact on the total vegetative cover, which was possibly caused by the loss of bunchgrasses (Figure 26). Bunchgrasses seem to have been more tolerant in KTM, which would explain the relatively minor loss of mean total vegetative cover compared to the other treatments (Appendix 8 and Figure 26). Legumes were impacted in all treatments but even the control showed a loss of cover so there could be other outside factors that caused the decrease.

Forb/Graminoids fared well amongst all the treatments with HRIMAZ and KTM having the most obvious negative impact on cover which could possibly be insignificant (Figure 28). Also, Forb/Graminoids might have been slightly more tolerant of the imazapyr used in LRIMAZ which could explain the small increase in cover in this treatment. However, there is the possibility that this is simply a reflection of applicator accuracy which increased due to the openness of Block C which reduced non-target damage in these locations. It could also be the result of early pioneering species colonizing the site as stated previously which could offset the loss of the original plants. Additional monitoring will need to be done to verify these hypotheses.

Milestone and Trycera are both effective at controlling many herbaceous broadleaf weeds and both are soil active and water soluble. Furthermore, Milestone requires very small concentrations of active ingredient to cause damage to non-tolerant plants. Therefore, any of these issues could explain the strong impact on legumes and forbs in treatment KTM and TRYIMAZ.

Watermelon Pond Wildlife and Environmental Area

Site description.

Watermelon Pond Wildlife and Environmental Area (WPWEA) is located between the cities of Archer and Newberry, 18 miles southwest of Gainesville, Florida in Alachua county and is managed by the Florida Fish and Wildlife Conservation Commission. It lies on the northern edge of the Brooksville Ridge, which is known for its tracts of longleaf pine sandhills (FWC 2019c). The WEA consists of 4,200 acres of historical longleaf pine sandhill habitat along with areas of xeric hammock, sinkholes, depression marshes and basin marshes (FWC 2019c). Prior to The State of Florida acquiring WPWEA, much of the sandhill habitat was disturbed through commercial logging and timber production, agricultural plantings and cattle grazing operations (FWC 2019c). Land that was not converted into agricultural land, pasture or slash pine plantation was left fire suppressed, which allowed oaks to flourish. Gradually, oak trees out competed grasses and pine seedlings and transformed much of the remaining sandhill habitat into oak hammocks. Currently, WPWEA has been actively trying to restore these sandhill habitats for protected species, such as gopher tortoise and Sherman's fox squirrels (*Sciurus niger*). The need for sandhill restoration of oak habitats facilitated this study to be included in the WEA's restoration plans.

Our study site was located on the northwest edge of WPWEA, near the North Trailhead and off State Highway 337 (Figure 4). It occurred on Candler fine sand soils with a slope of 0-5% and consisted of 15 acres of degraded sandhill habitat that, due to fire suppression, had been overgrown hardwood oak species (Figure 4). Laurel oak and sand live oak were the most prominent oak species found at this study location. Southern red oak, bluejack oak, turkey oak, dwarf live oak, water oak (*Quercus nigra*) and live oak were also present at the site but to a lesser extent.

Preliminary site conditions:

The site was blocked to reduce variability since oak density was not uniformly spread across the site due to the reintroduction of fire (Figure 4). Even with blocking however, there was still substantial variability within block A for mean total vegetation cover which ranged from 27% to 75% prior to herbicide treatments (Appendix 12). Block A, which is located in the southwest corner of the burn unit, had the highest density of hardwoods (especially in the control) and closely resembled an early growth oak hammock that was heavily shaded and contained large amounts of leaf litter with little to no groundcover. The central and northern areas of the study site (Blocks B and C) resembled remnant sandhill habitat with few open sandy areas, large islands of dense oaks, and small patches of wiregrass, bunchgrasses, forbs and ericaceous shrubs.

Preliminary results.

Woody cover and stem counts:

Mean target oak cover for trees > 3 meters in height decreased across all treatments (Figure 30). Herbicides ranked in order of effectiveness were TRYIMAZ, LRIMAZ, HRIMAZ, and KTM. Stem counts for target oaks with a DBH ≥ 4-cm also decreased across all treatments except in the control (Figure 31). Mean cover also decreased across all treatments for target oaks ≤ 3 meters in height except for the control which was comparable to the baseline data (Figure 32). Mean stem counts for target oaks, with a DHB < 4-cm, also showed a trend of decrease for all treatments except the control (Figure 33).

Like the other 2 study sites, there was also an impact on non-target oaks including southern red oak, bluejack oak, water oak, and live oak. Mean cover for oaks > 3 m in height decreased in all imazapyr treatments (Figure 34). However, there was also a slight decline in the control which may have been caused by herbicide drift. Likewise, mean cover decreased across all treatments for non-target oaks < 3 m in height (Figure 35).

Also negatively impacted was mean ericaceous shrub and shrub cover for plants > 3 meters in height which also decreased across all treatments except for the control (Figures 36 & 37). This was also true for ericaceous shrubs and shrubs ≤ 3 meters in height (Figures 38 & 39). In fact, small ericaceous shrubs may have been eliminated in the LRIMAZ and TRYIMAZ treatments (Figure 38).

Herbaceous cover:

Mean bunchgrass cover at WPWEA showed no substantial change from the baseline data or the controls (Figure 40). However, mean legume cover decreased across all treatments except the control (Figure 41). Forb/graminoid cover showed an increase in cover for HRIMAZ, KTM, and TRYIMAZ and a decrease for the control and LRIMAZ but these differences were not substantial and further analysis will be needed to determine any statistical significance (Figure 42).

Species richness:

Species richness for both herbaceous and woody species decreased across all treatments except for the control (Table 1). The largest decreases in overall species richness occurred in LRIMAZ and HRIMAZ which lost approximately 18% of their species diversity, while treatments KTM and TRYIMAZ decreased by 11.5% and 7.2%, respectively. The control's species diversity increased by 9.3% and showed a greater increase in herbaceous plant species compared to woody species. HRIMAZ and KTM had a greater loss of herbaceous species than woody, while treatment LRIMAZ showed a larger loss of woody species. TRYIMAZ lost equal amounts of both woody and herbaceous species.

General treatment plot characteristics:

A year after herbicide treatments, mean total vegetation cover at WPWEA decreased across all treatments except the control (Appendix 13). It appears that LRIMAZ, HRIMAZ and TRYIAMZ decreased total vegetative cover by approximately 33% to 50%, while treatment KTM and the control showed little change from the baseline data (Appendix 13). Bare ground cover, litter cover and litter depth showed no substantial changes (Appendix 14-16).

Preliminary conclusions.

All herbicide treatments at WPWEA were at successful in killing target oaks and no re-sprouting was observed in the field or in the stem count data (Figure 36). Non-target oaks, ericaceous shrubs and other shrubs also experienced non-target damage from all herbicide treatments. All differences between treatments will need further analysis to determine significant differences but KTM appears to have had the least impact on woody species including target oaks.

Bunchgrass and forbs/graminoids were not heavily impacted by non-target damage. This could be due to the plants themselves being more tolerant of the chemicals or due to recolonization from the seed bank by weedy pioneering herbaceous species as a result of the canopy opening. It most likely is due to the latter since species richness did not remain constant and decreased for herbaceous species. Therefore, ground cover has been maintained by a few opportunistic species. Legumes appeared to be less tolerant and decreased in cover across all treatments which was similar to trends noted on the other 2 study sites experienced by other broad-leafed plants in this study.

Overall Preliminary Conclusions

All herbicide prescriptions experimented with in this study appear to be effective in killing the target oaks. There was no regrowth or re-sprouting observed to date. The non-target oaks including sand post oak, bluejack oak, southern red oak, live oak, and water oak, although not as common, were affected as well by either aerial spray drift, or underground movement through the soil. This may be a consequence of using imazapyr herbicides in areas heavily encroached and intermixed with different hardwood species. There are some reports that imazapyr might be exuded from the roots of target species. It can also be mobile within roots and transferred between intertwined root systems of some species (Tu et al. 2001). Furthermore, imazapyr does not bind strongly to soil particles, and depending on soil pH, can be neutral or negatively charged. If negatively charged, imazapyr remains available in the environment (Tu et al. 2001).

Based on our data, the Krenite + Trycera + Milestone mix (KTM) currently appears to have the least impact on the functional groups, in general, but is probably the least effective of the mixes at controlling the target oaks.

The herbicide applicators took great care to avoid non-target vegetation. Never-the less, the herbicides also reduced the cover of bunchgrasses (including wiregrass), shrubs, forbs, and graminoids but these plants were not eliminated completely. It is anticipated that these functional groups will recover to at least pre-treatment conditions if not exceeding them. Additional monitoring will detect these changes and is recommended. Legumes on the other hand took the hardest hit and seemed to be negatively impacted equally by all herbicides. There was minimal change to bare ground, litter cover, or litter depth on any of the study sites resulting from any of the herbicide mixes.

The experimental plots are scheduled to be burned by area staff at some point before the next sampling event. Perry Oldenburg burned their study sites on May 21, 2019 shortly after the post-treatment data was collected. The Rx fire should remove the standing dead oak biomass that currently makes the sites aesthetically unpleasing (Figure 15, Figure 29 & Figure 43), and stimulate herbaceous regrowth. The experimental plots will be sampled again during the spring of 2020. This should document any further mortality/recovery of the target oaks, non-target oaks or in the various functional groups.

This is a preliminary report and further data collection and statistical analysis is needed before conclusive recommendations can be made.

Figures and Tables

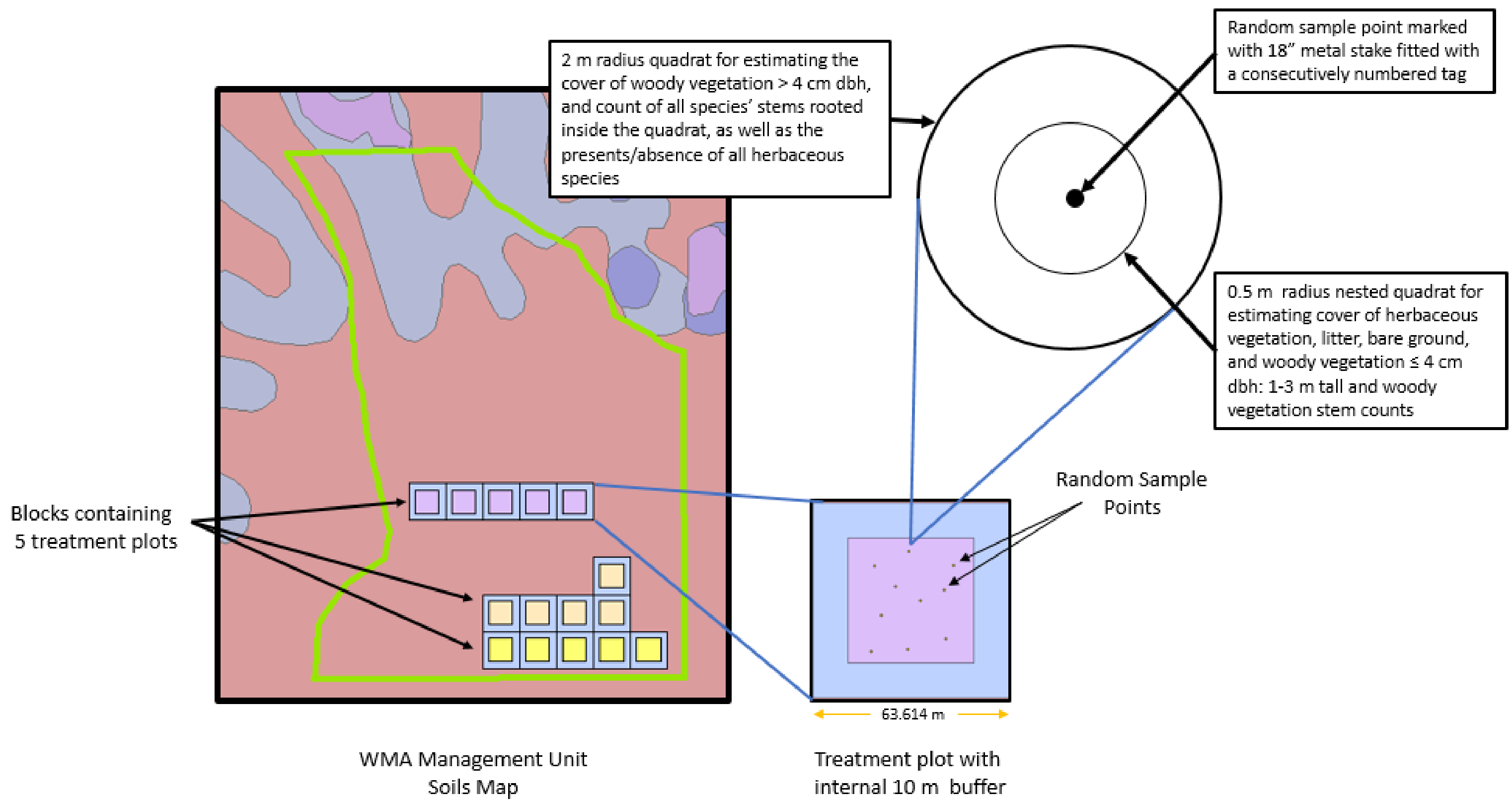

Figure 1. Diagram of the experimental design at Chassahowitzka WMA depicting the arrangement of blocks, plots, and quadrats, including the parameters collected within each quadrat. Not drawn to scale.

FWC Hardwood Reduction in Pinelands Study Location
Chassahowitzka Wildlife Management Area

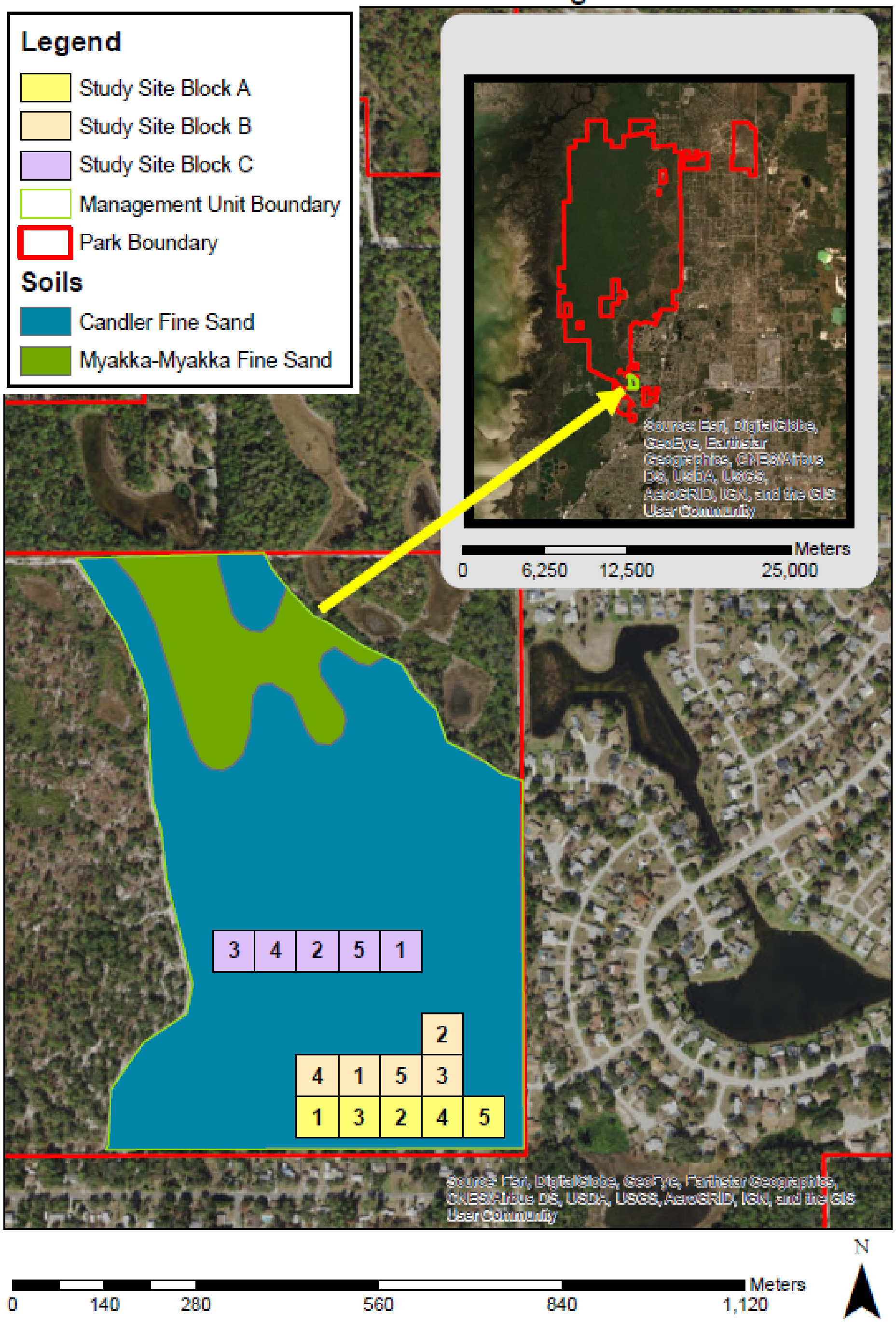

Figure 2. This map identifies the study site, soil types and locations of herbicide treatments at Chassahowitzka Wildlife Management Area in Hernando county Florida. This site is part of the Florida Fish and Wildlife Conservation Commission's study to control encroaching oak species in fire suppressed sandhill plant communities. This is one of 3 study locations. Numbers, 1-5, represent the randomized experimental treatments for a given test plot.

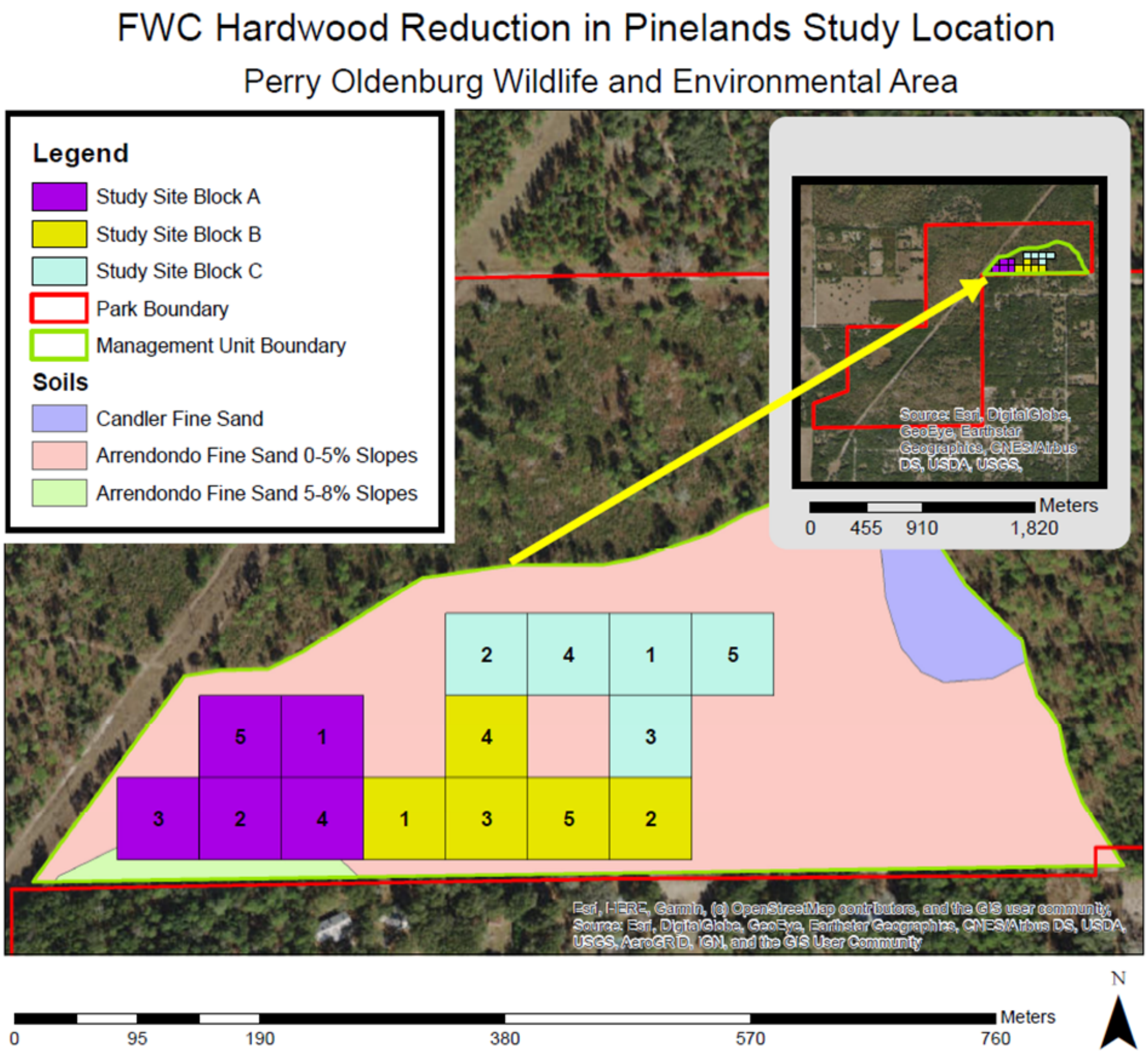

Figure 3. This map identifies the study site, soil types and locations of herbicide treatments at Perry Oldenburg Wildlife and Environmental Area in Hernando county Florida. This site is part of the Florida Fish and Wildlife Conservation Commission's study to control encroaching oak species in fire suppressed sandhill plant communities. This is one of 3 study locations. Numbers, 1-5, represent the randomized experimental treatments for a given test plot.

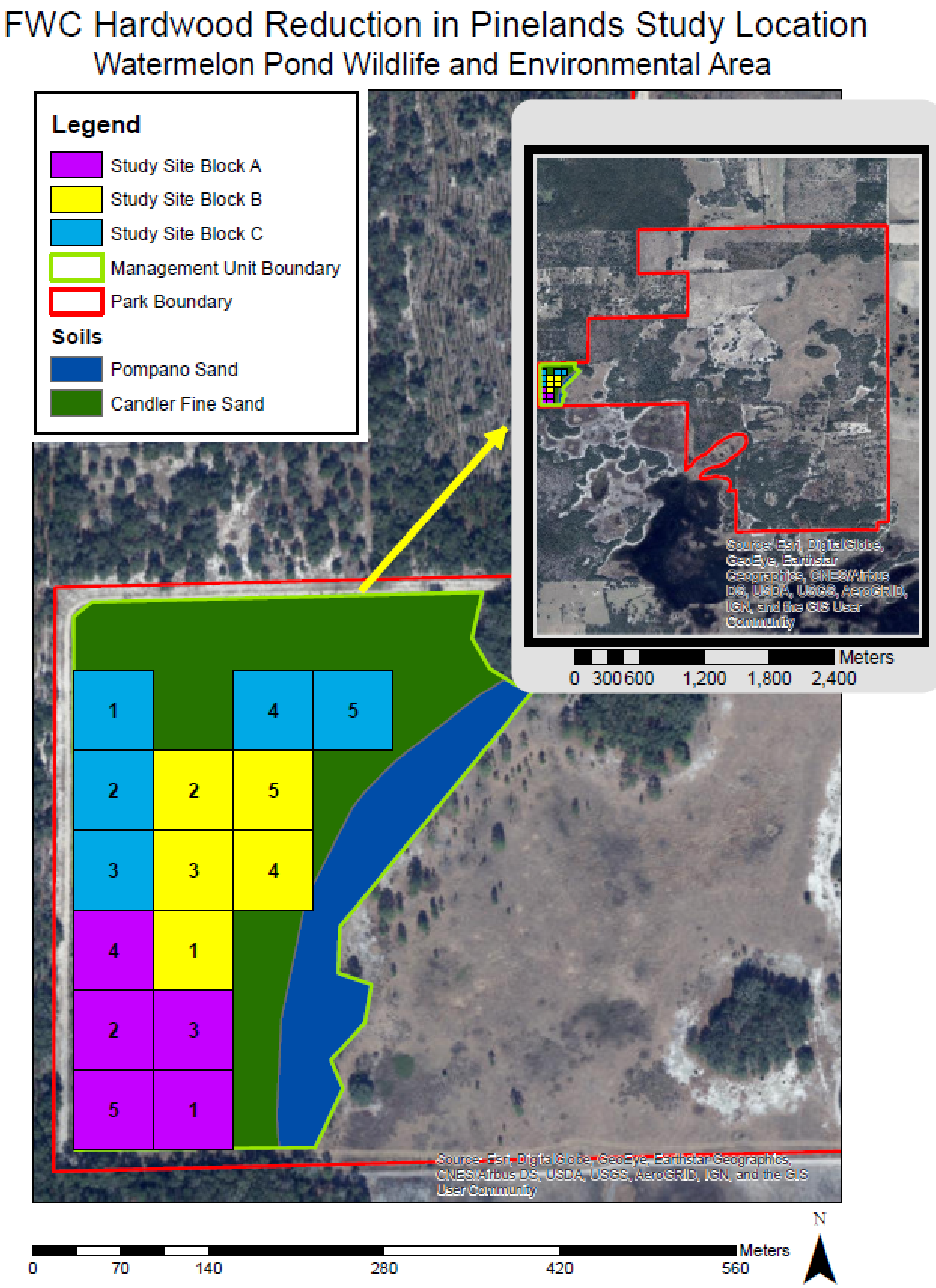

Figure 4. This map identifies the study site, soil types and locations of herbicide treatments at Watermelon Pond Wildlife and Environmental Area in Alachua county Florida. This site is part of the Florida Fish and Wildlife Conservation Commission's study to control encroaching oak species in fire suppressed sandhill plant communities. This is one of 3 study locations. Numbers, 1-5, represent the randomized experimental treatments for a given test plot.

Figure 5. Biologists sampling vegetation at Watermelon Pond Wildlife and Environmental Area for the Florida Fish and Wildlife Conservation Commission's study on hardwood reduction in pinelands.

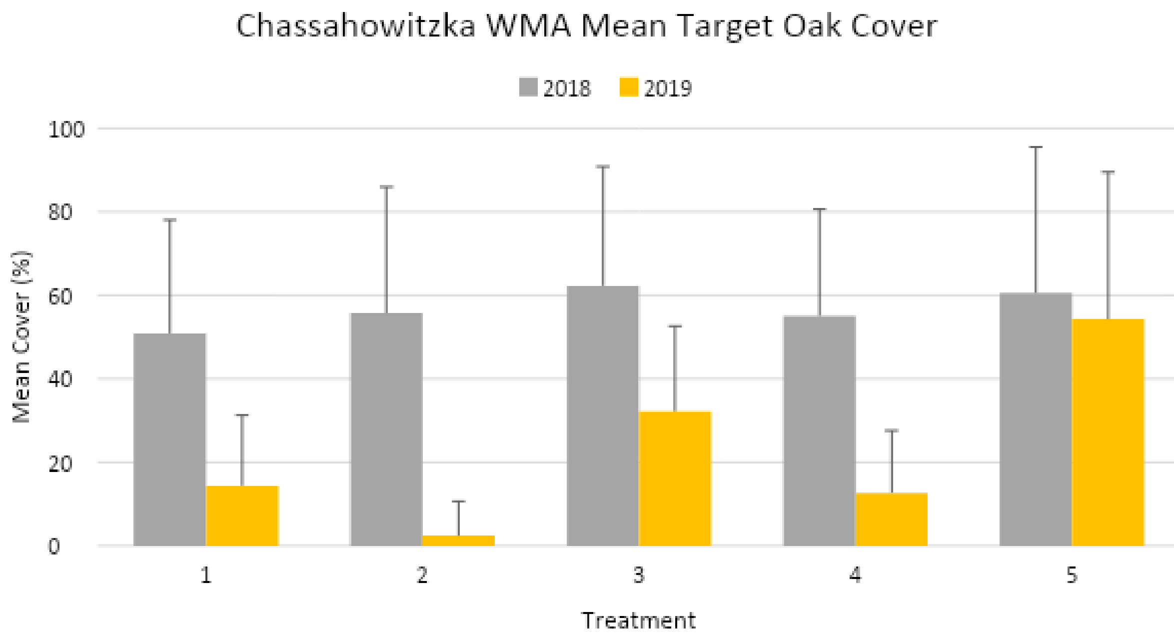

Figure 6. Pre-and post-treatment comparisons of the mean cover of the target oaks > 3-meters in height in the outer circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.

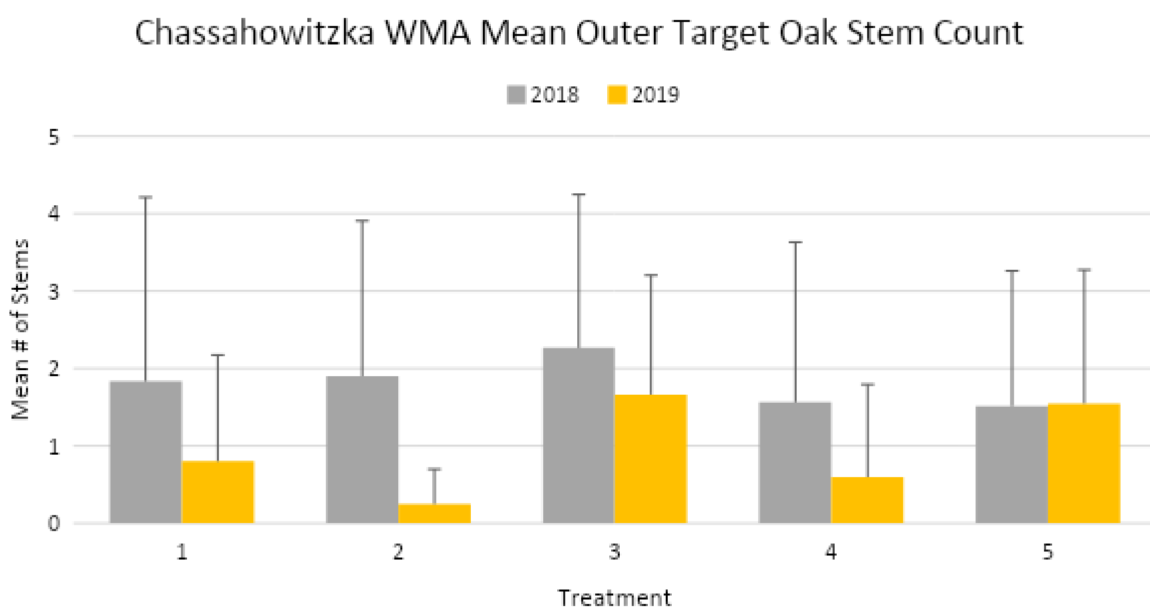

Figure 7. Pre-and post-treatment comparisons of the mean stem counts of the target oaks in the outer circle with a DBH ≥ 4-cm for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.

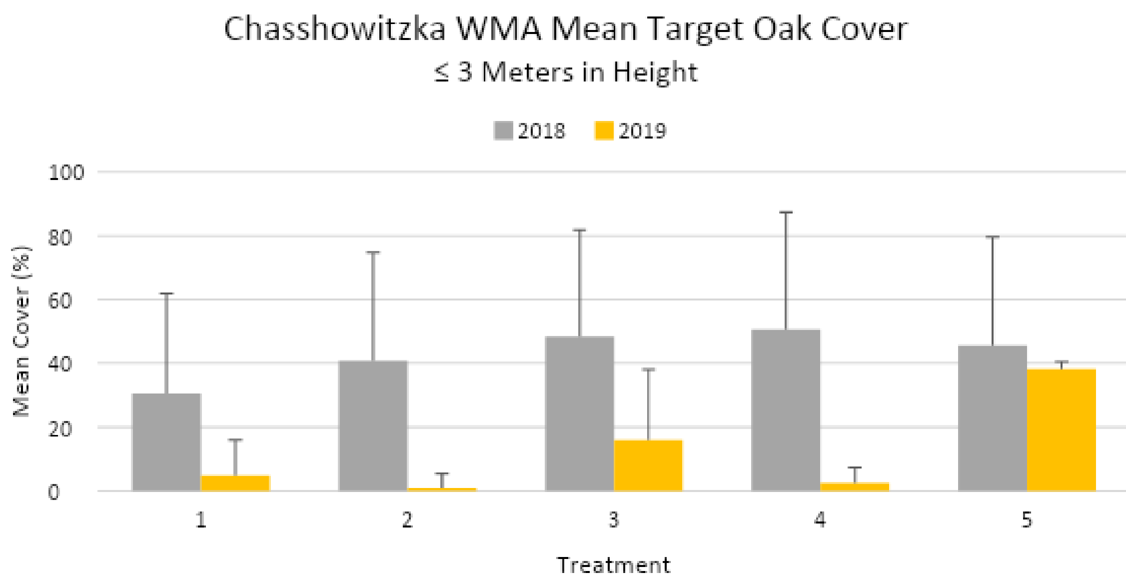

Figure 8. Pre- and post-treatment comparisons of the mean cover of target oaks ≤ 3 m in height in the inner circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.

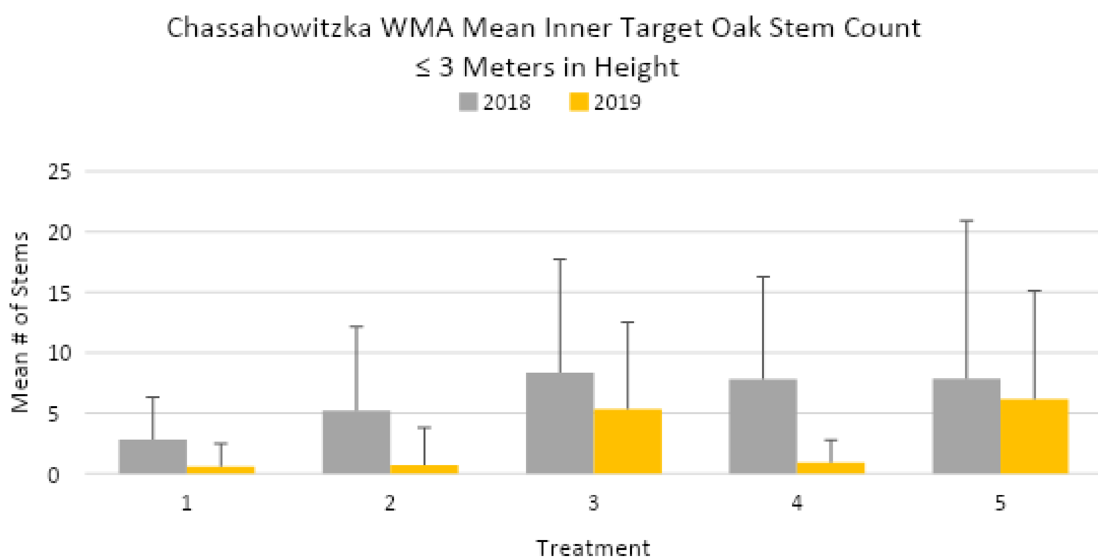

Figure 9. Pre- and post-treatment comparisons of mean target oak stem counts for inner circle trees with a DBH < 4-cm for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.

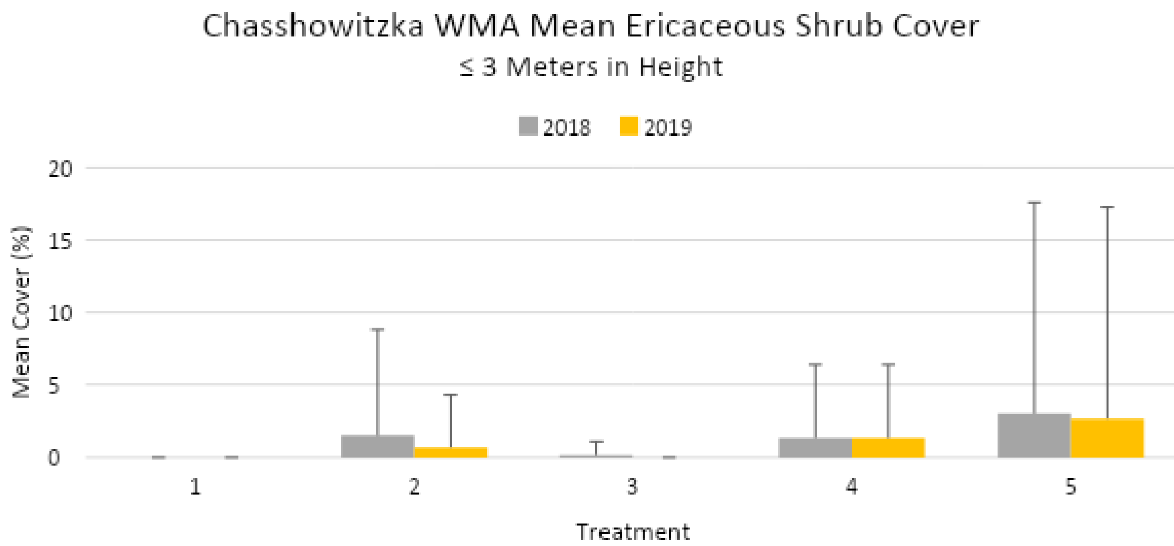

Figure 10. Pre- and post-treatment comparisons of mean cover of shrubs in the Ericaceae family functional group in the inner circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.

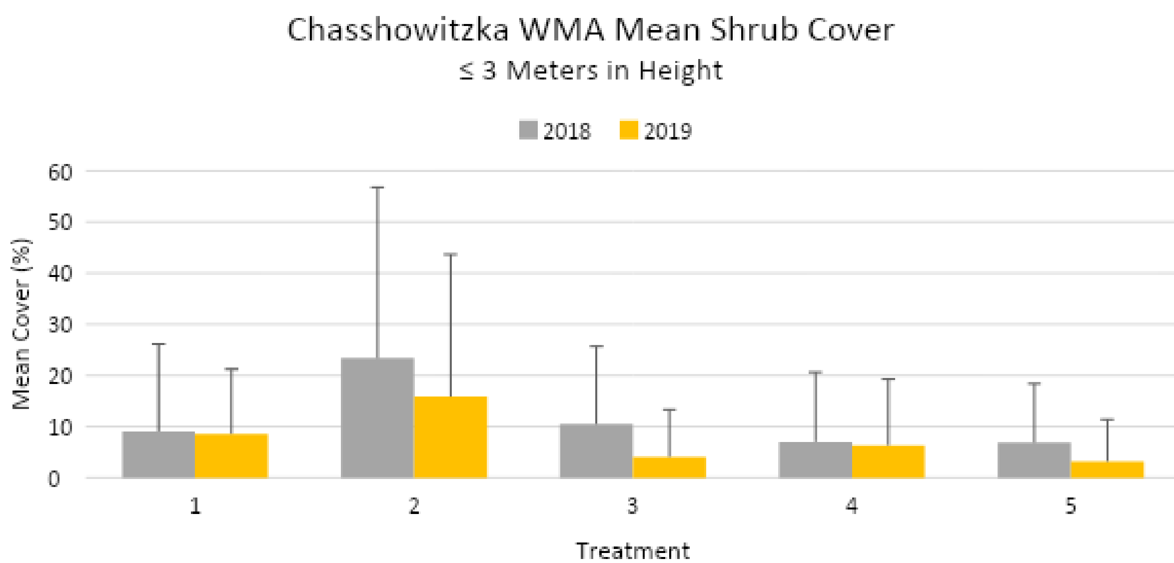

Figure 11. Pre- and post-treatment comparisons of mean cover of shrubs functional group in the inner circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowtizka WMA. This did not include non-target/target oaks and ericaceous shrubs.

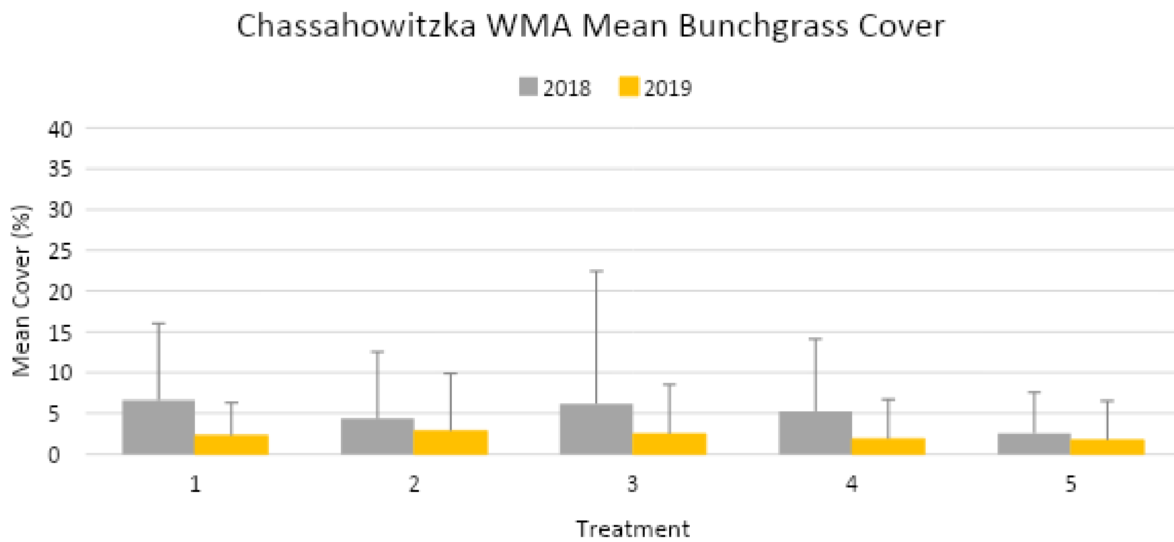

Figure 12. Pre- and post-treatment comparisons of the mean cover of the bunchgrass functional group in the inner circle for each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.

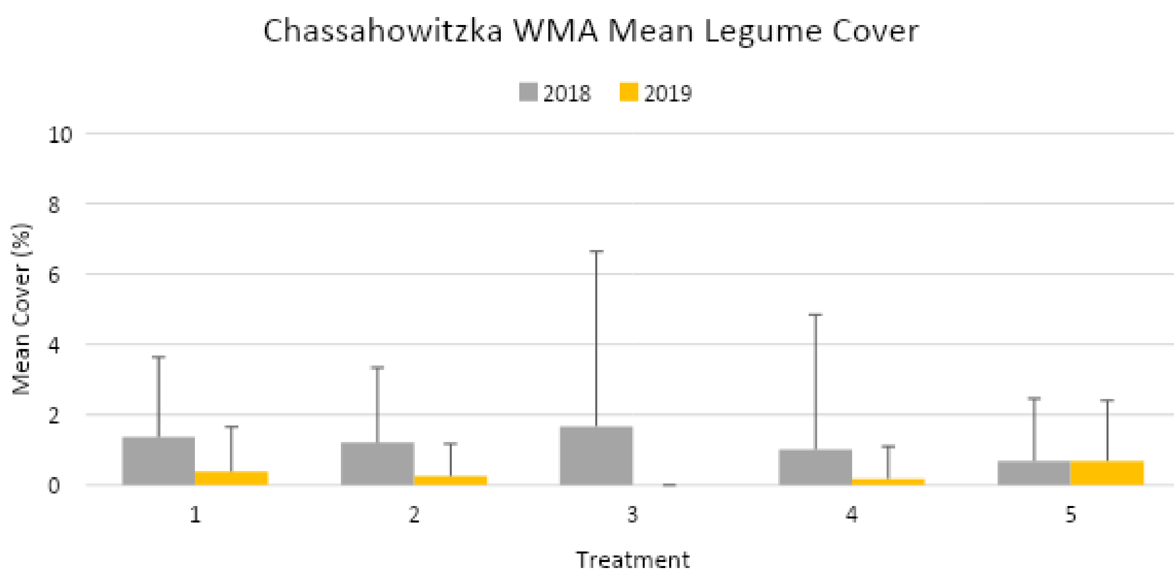

Figure 13. Pre- and post-treatment comparisons of the mean cover of the legume functional group in the inner circle for each of the herbicide treatments: (1) low rate of imazapyr LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.

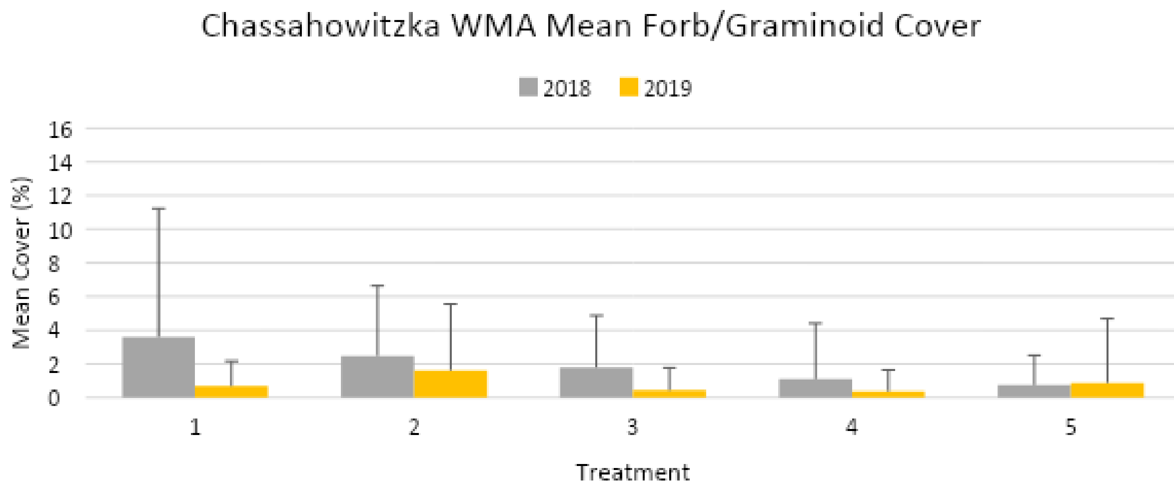

Figure 14. Pre- and post-treatment comparisons of the mean cover of the forb and graminoid functional group in the inner circle for each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.

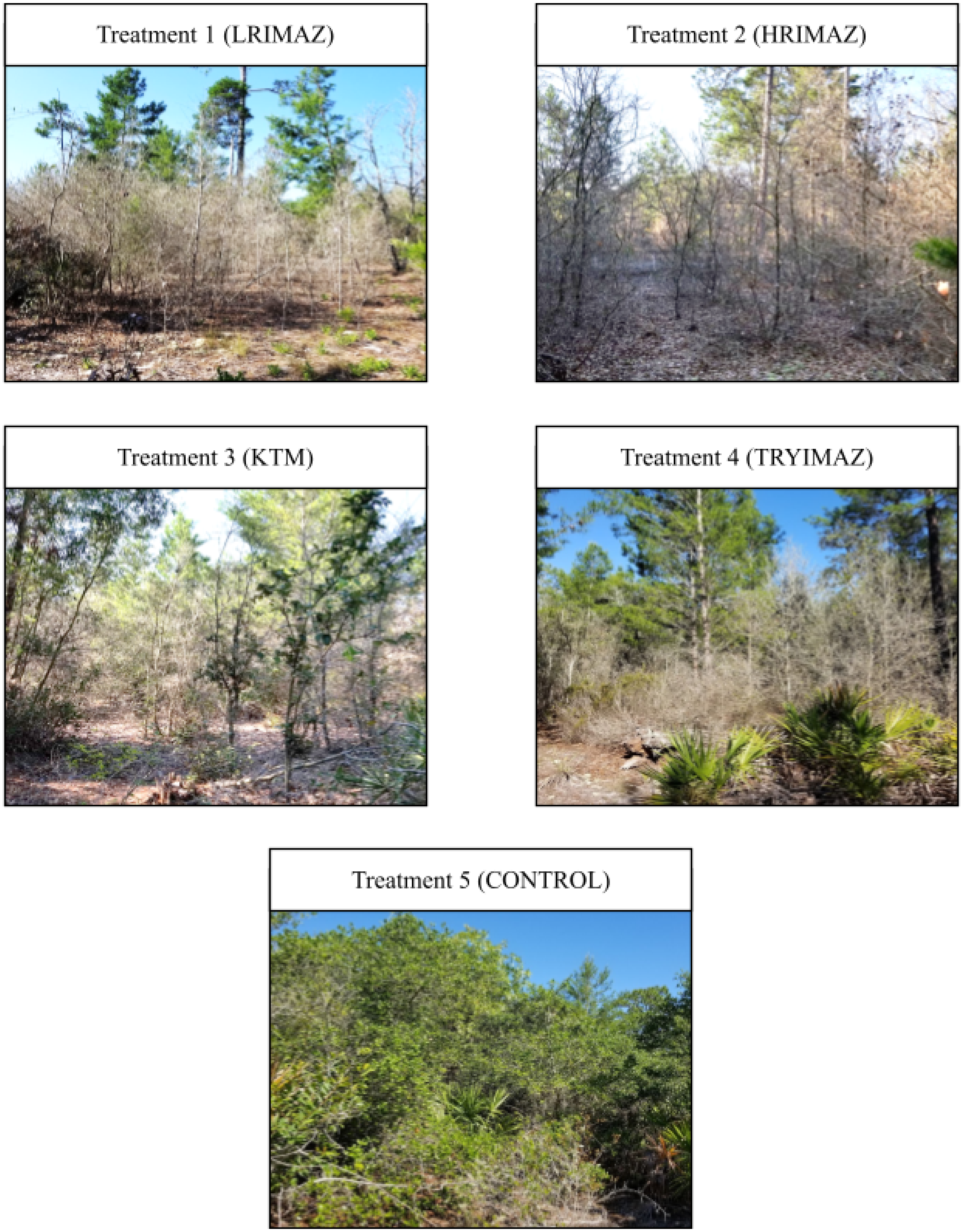

Figure 15. Post-treatment site photos at Chassahowitzka Wildlife Management Area for treatments 1-5 in Block B taken May 2019, 1-year post-treatment.

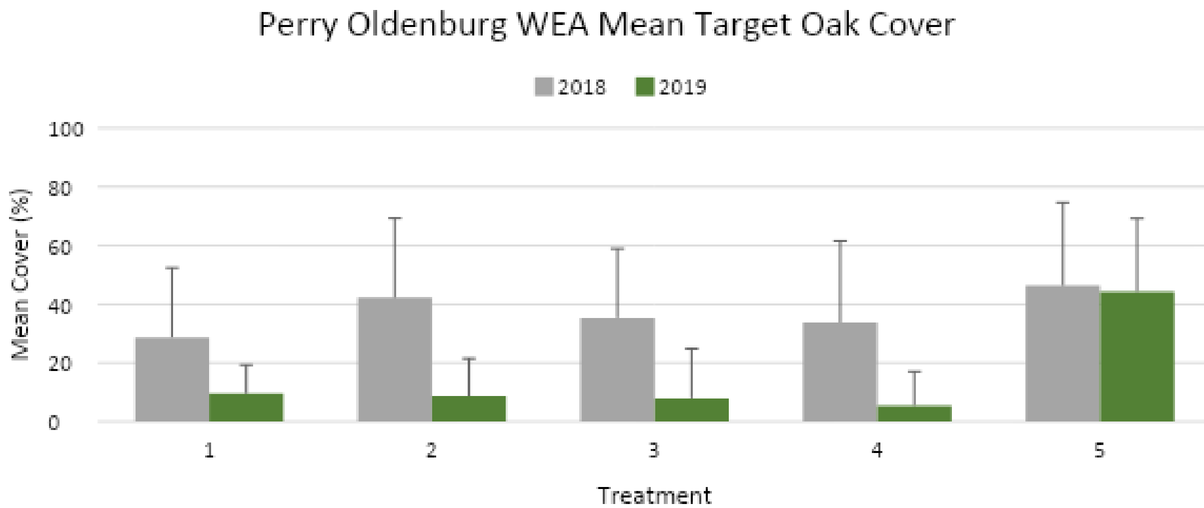

Figure 16. Pre-and post-treatment comparisons of the mean cover of the target oaks > 3-meters in height in the outer circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

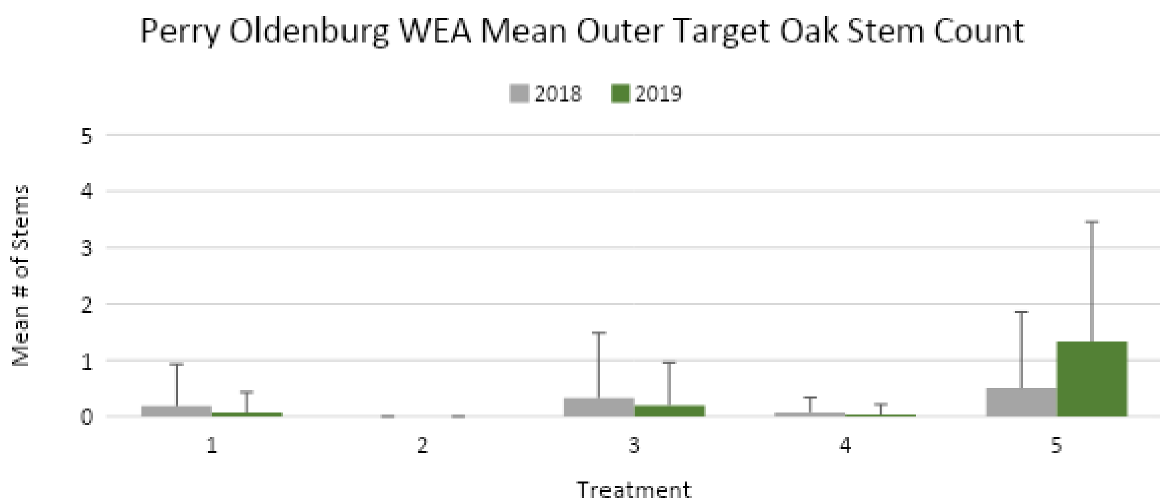

Figure 17. Pre-and post-treatment comparisons of the mean stem counts of the target oaks in the outer circle with a DBH ≥ 4-cm for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

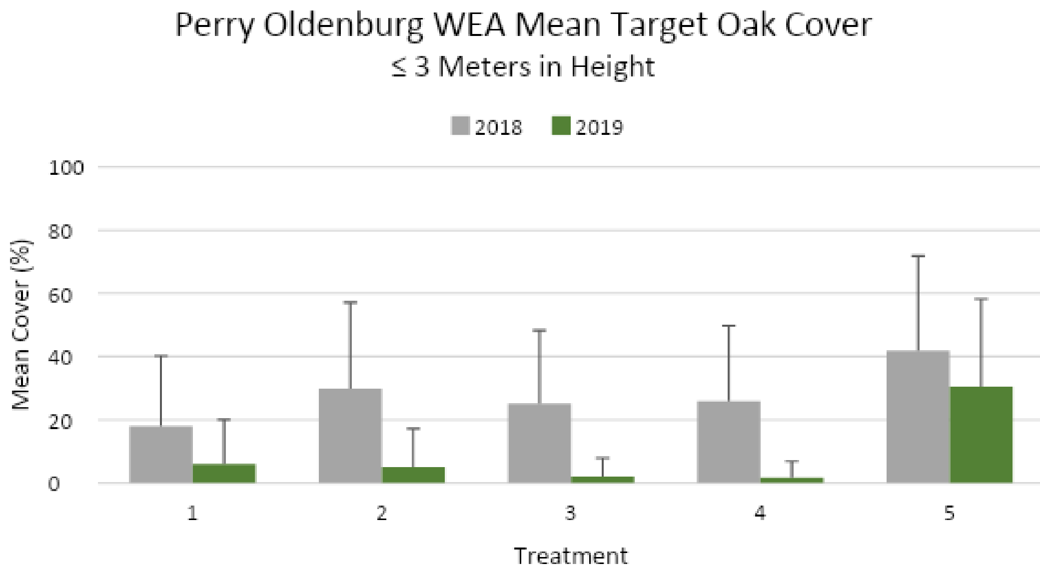

Figure 18. Pre- and post-treatment comparisons of the mean cover of target oaks ≤ 3 m in height in the inner circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

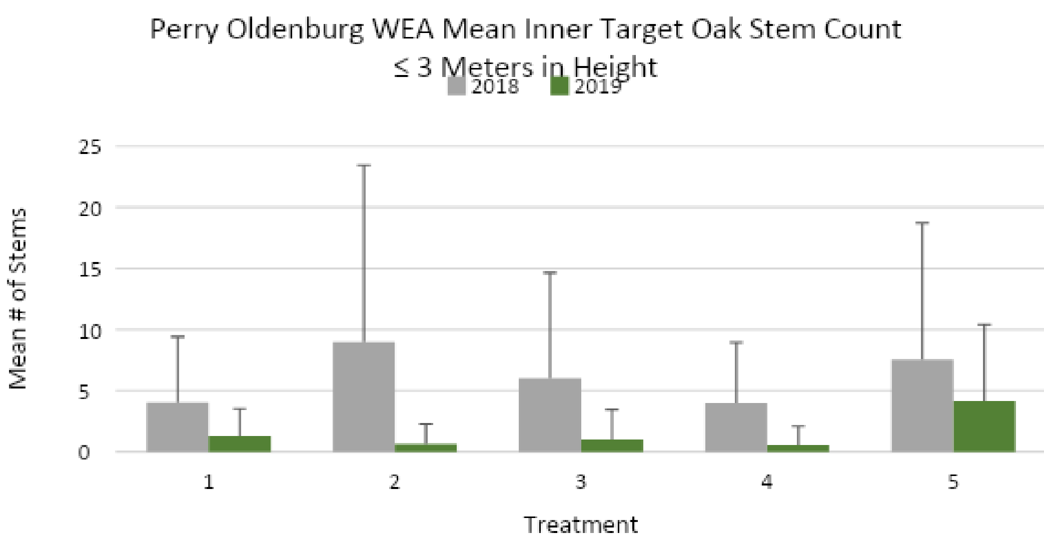

Figure 19. Pre- and post-treatment comparisons of mean target oak stem counts for inner circle trees with a DBH < 4-cm for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

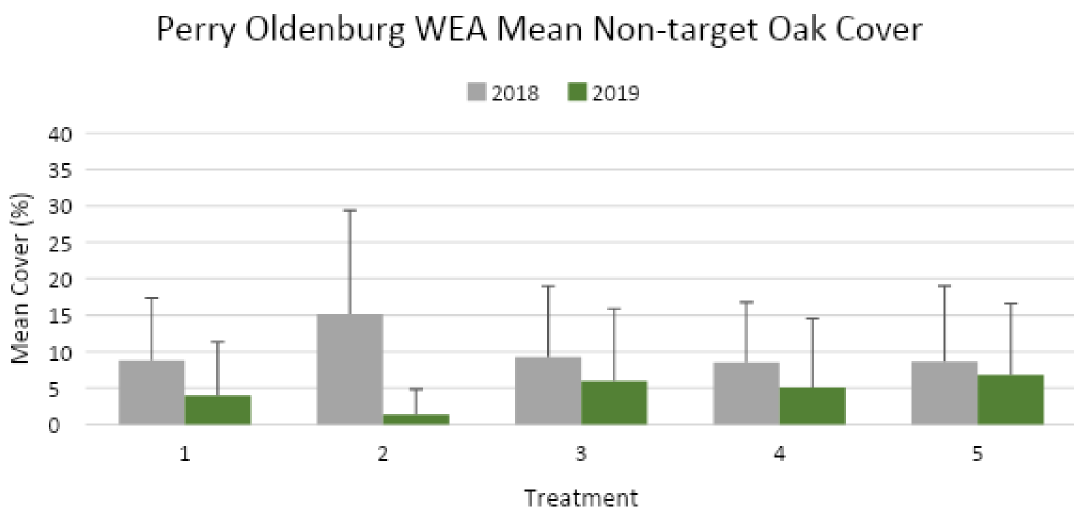

Figure 20. Pre-and post-treatment comparisons of the mean cover of the non- target oaks > 3-meters in height in the outer circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

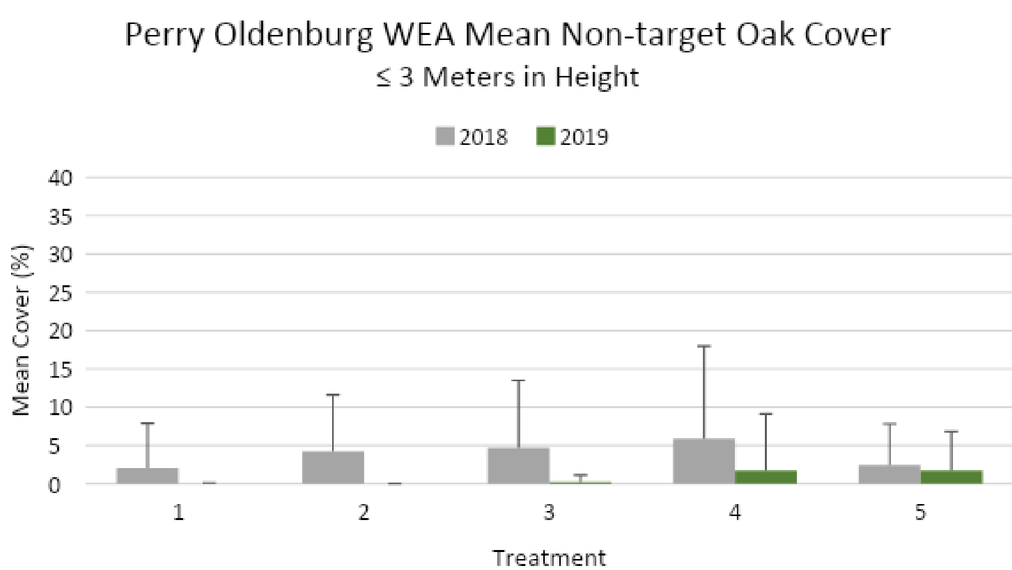

Figure 21. Pre- and post-treatment comparisons of the mean cover of non- target oaks $\leq$ 3 m in height in the inner circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

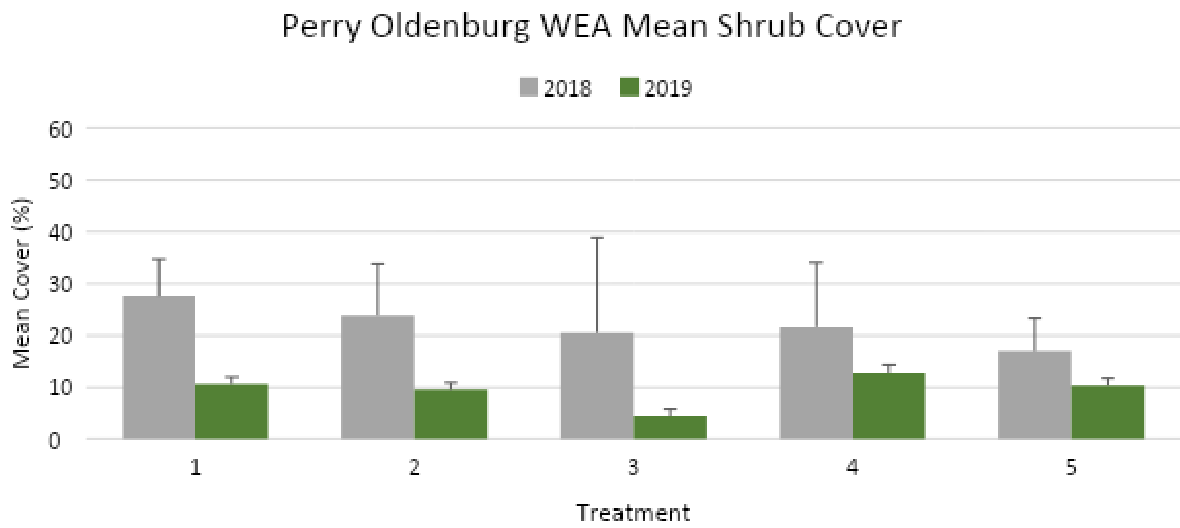

Figure 22. Pre- and post-treatment comparisons of mean cover of shrubs functional group in the outer circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA. This did not include non-target/target oaks and ericaceous shrubs.

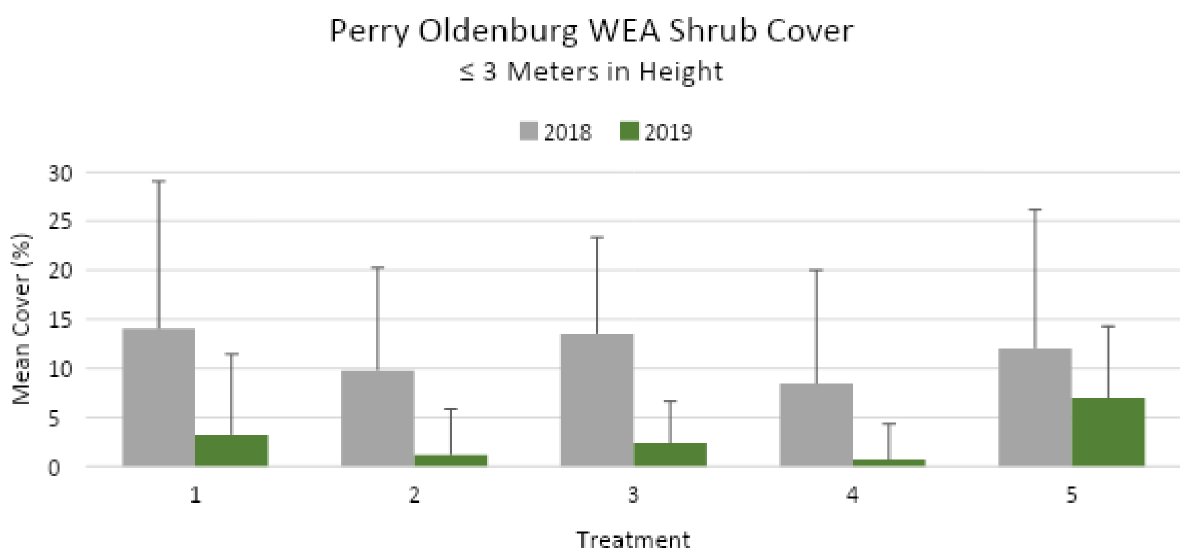

Figure 23. Pre- and post-treatment comparisons of mean cover of shrubs functional group in the inner circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA. This did not include non-target/target oaks and ericaceous shrubs.

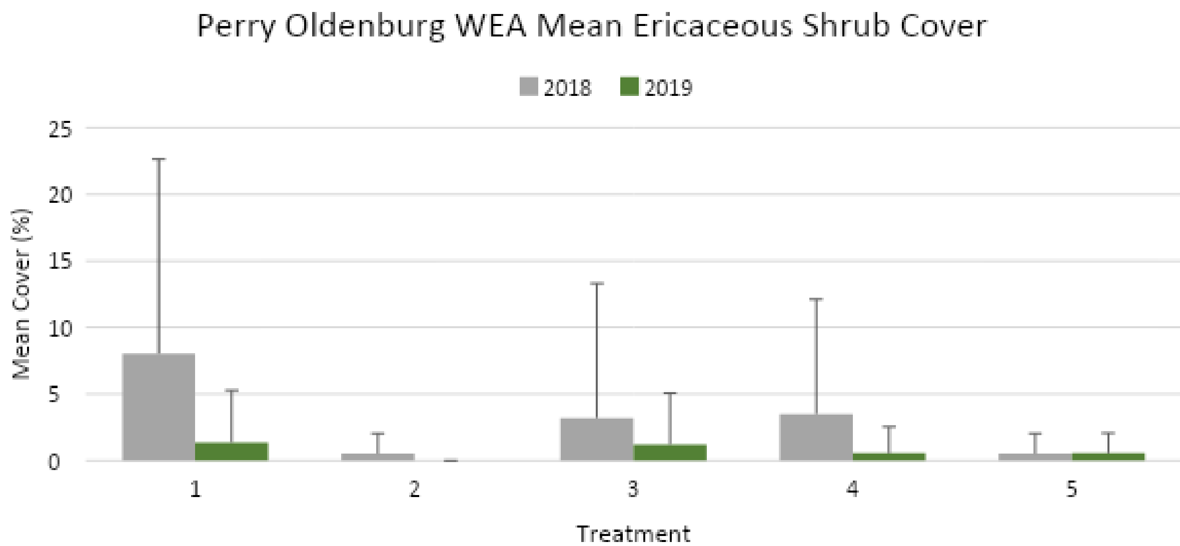

Figure 24. Pre- and post-treatment comparisons of mean cover of shrubs in the Ericaceae family functional group in the outer circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

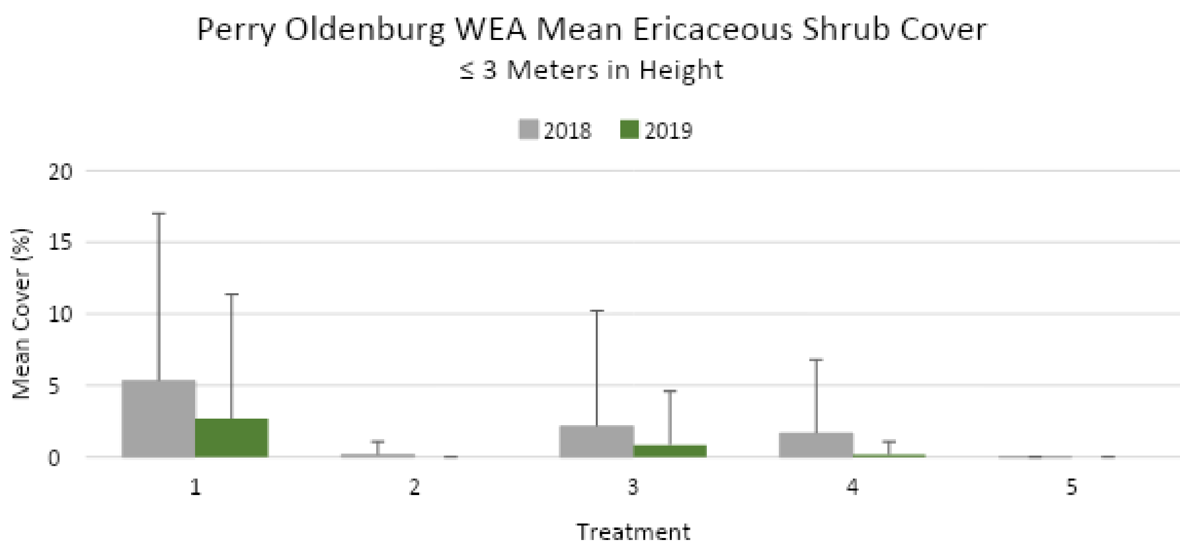

Figure 25. Pre- and post-treatment comparisons of mean cover of shrubs in the Ericaceae family functional group for the inner circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

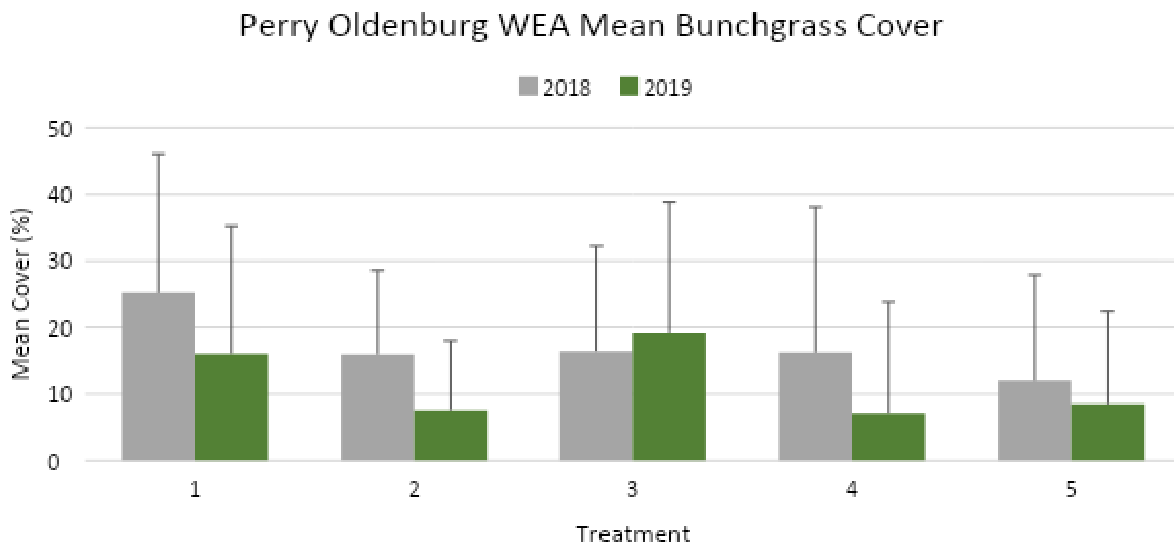

Figure 26. Pre- and post-treatment comparisons of the mean cover of the bunchgrass functional group in the inner circle in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

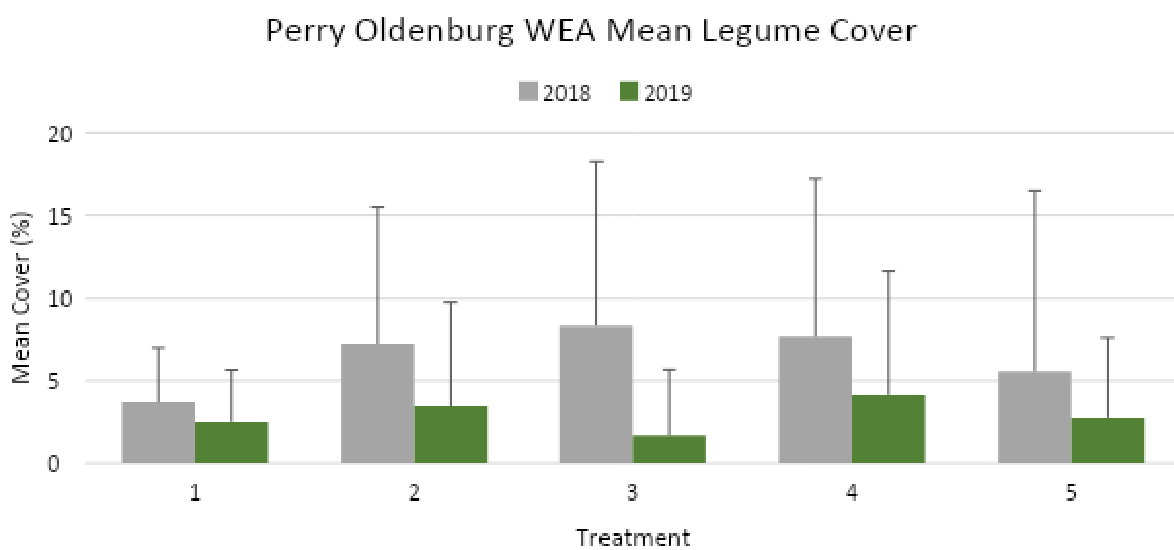

Figure 27. Pre- and post-treatment comparisons of the mean cover of the legume functional group in the inner circle in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

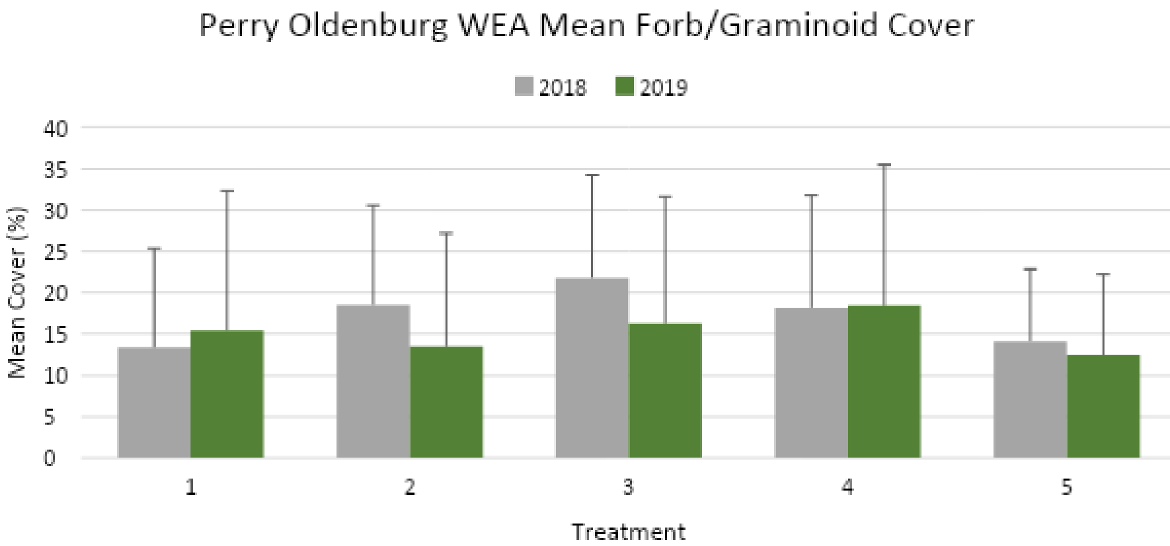

Figure 28. Pre- and post-treatment comparisons of the mean cover of the forbs/graminoid functional group in the inner circle for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.

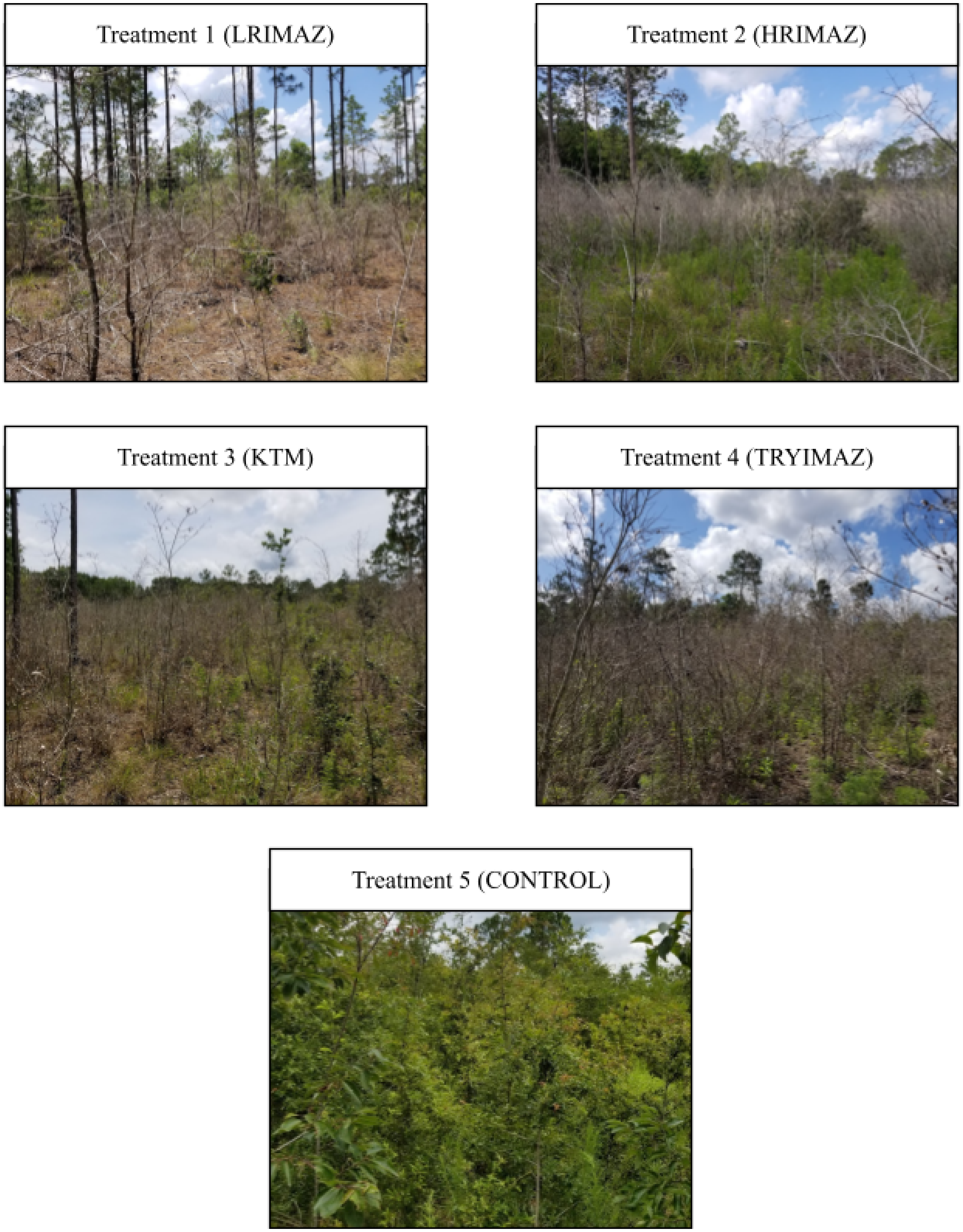

Figure 29. Post-treatment site photos at Perry Oldenburg Wildlife and Environmental Area for treatments 1-5 taken May 2019, 1-year post-treatment.

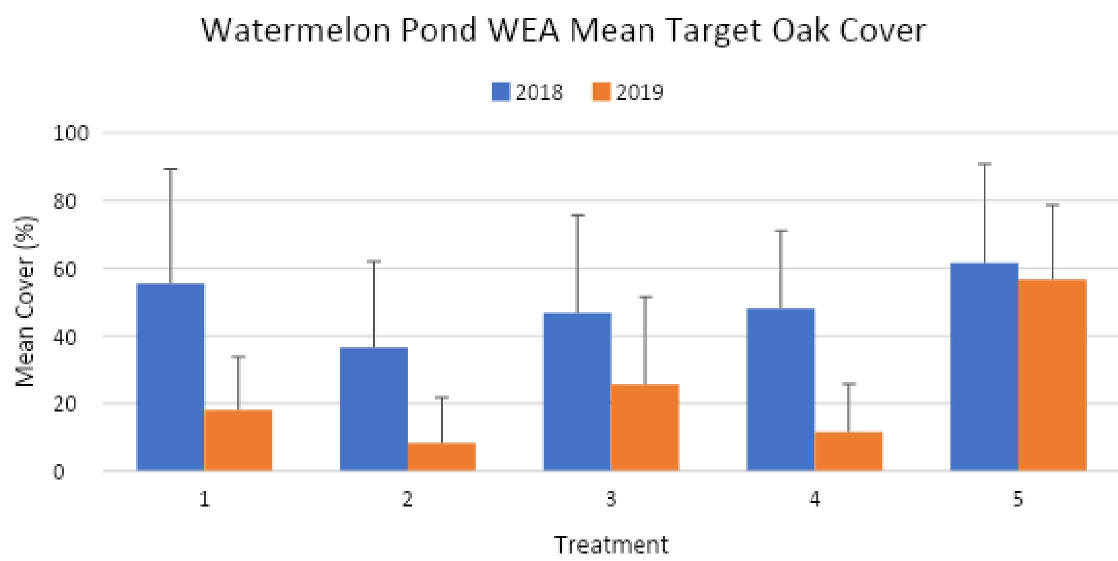

Figure 30. Pre-and post-treatment comparisons of the mean cover of the target oaks, > 3-meters in height in the outer circle, for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

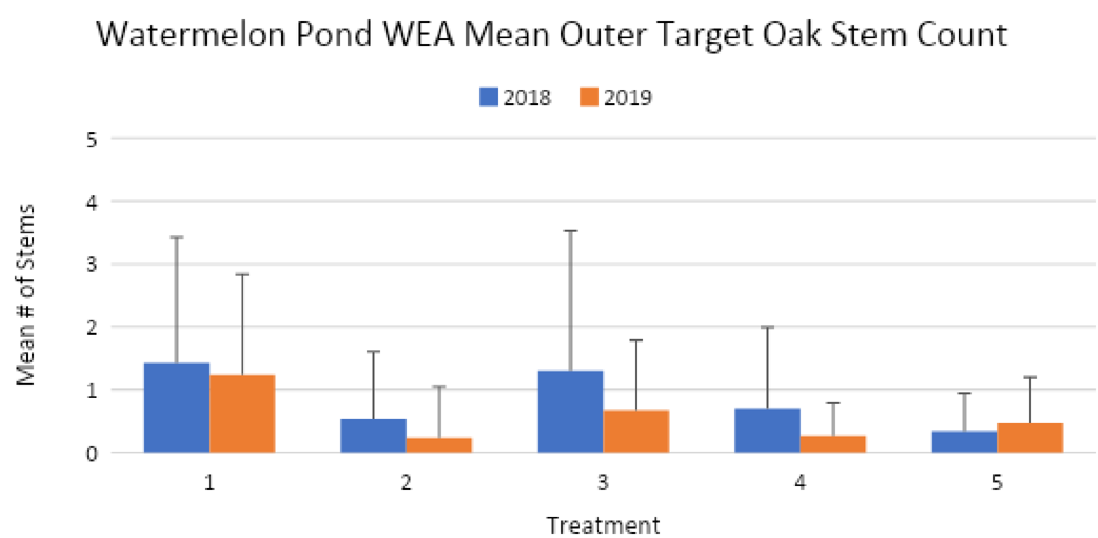

Figure 31. Pre-and post-treatment comparisons of the mean stem counts of the target oaks in the outer circle with a DBH ≥ 4-cm for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

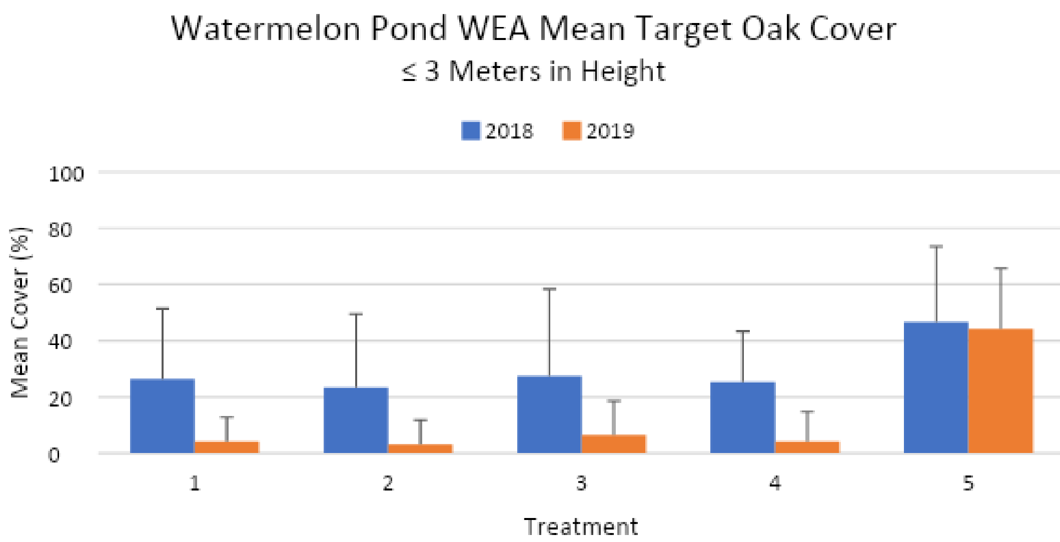

Figure 32. Pre- and post-treatment comparisons of the mean cover of target oaks ≤ 3 m in height, in the inner circle, for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

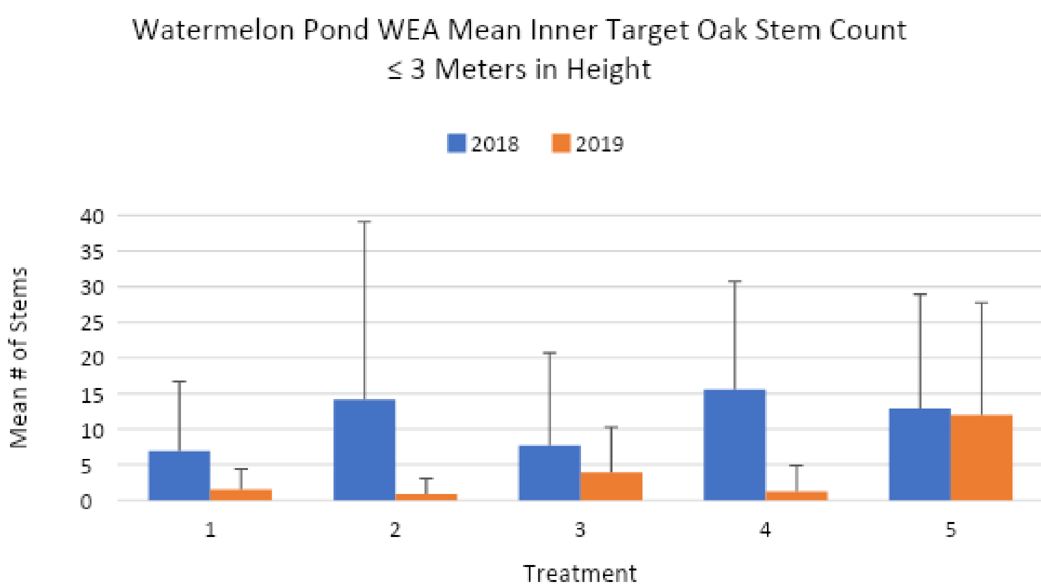

Figure 33. Pre- and post-treatment comparisons of mean target oak stem counts for inner circle trees with a DBH < 4-cm in each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

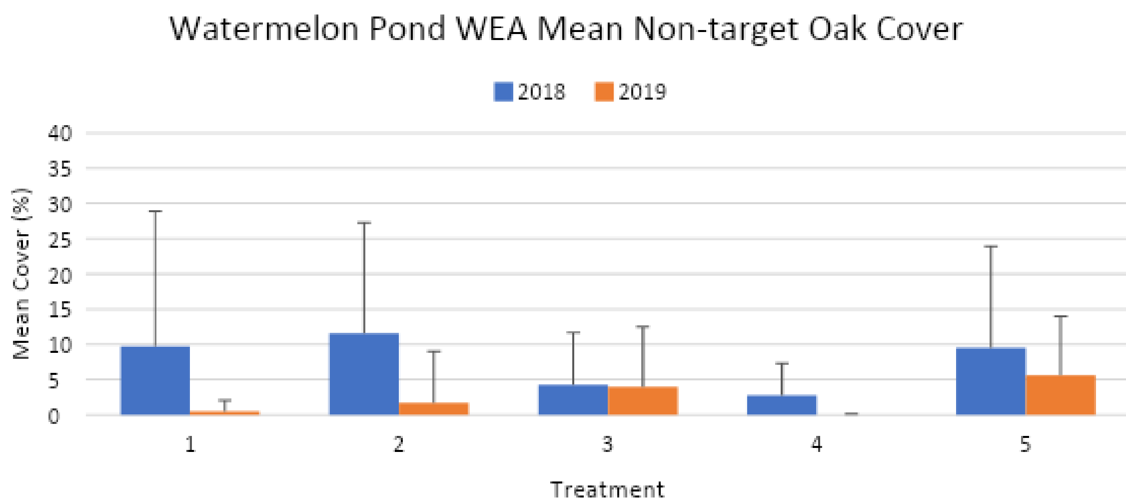

Figure 34. Pre-and post-treatment comparisons of the mean cover of the non- target oaks, > 3-meters in height in the outer circle, for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

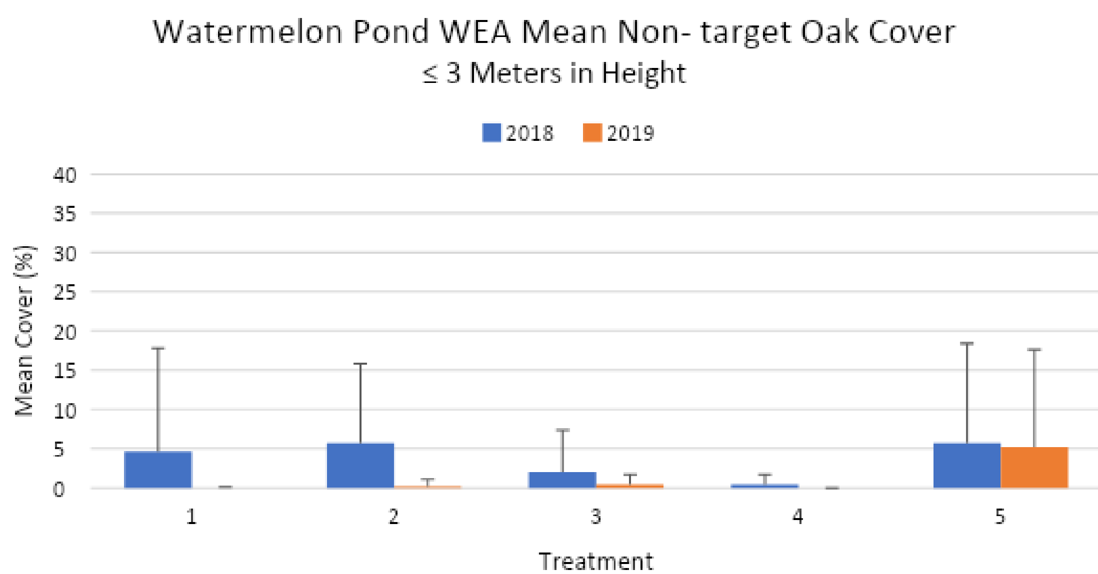

Figure 35. Pre- and post-treatment comparisons of the mean cover of non- target oaks ≤ 3 m in height, in the inner circle, for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

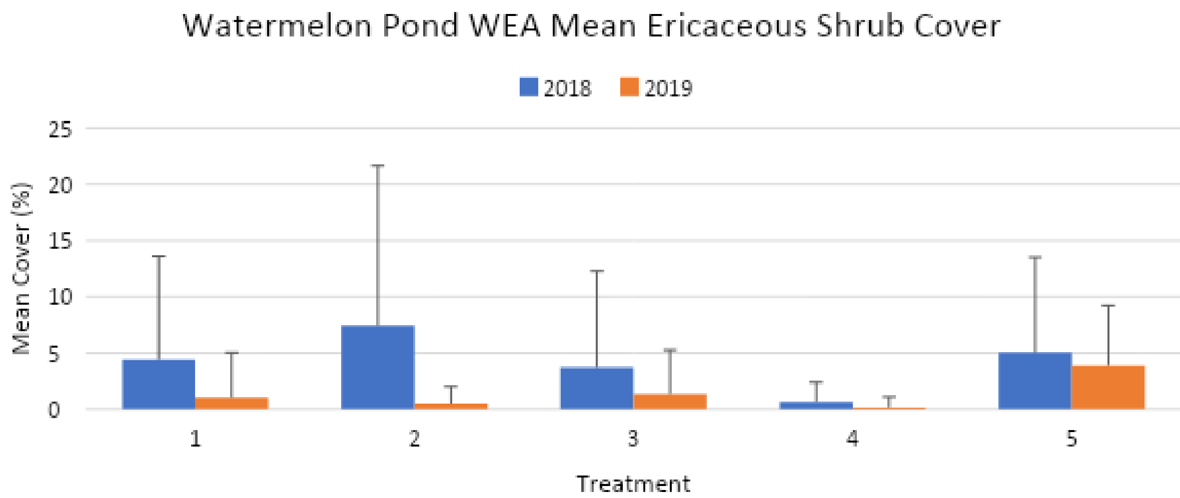

Figure 36. Pre- and post-treatment comparisons of mean cover of shrubs in the Ericaceae family functional group, in the outer circle, for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

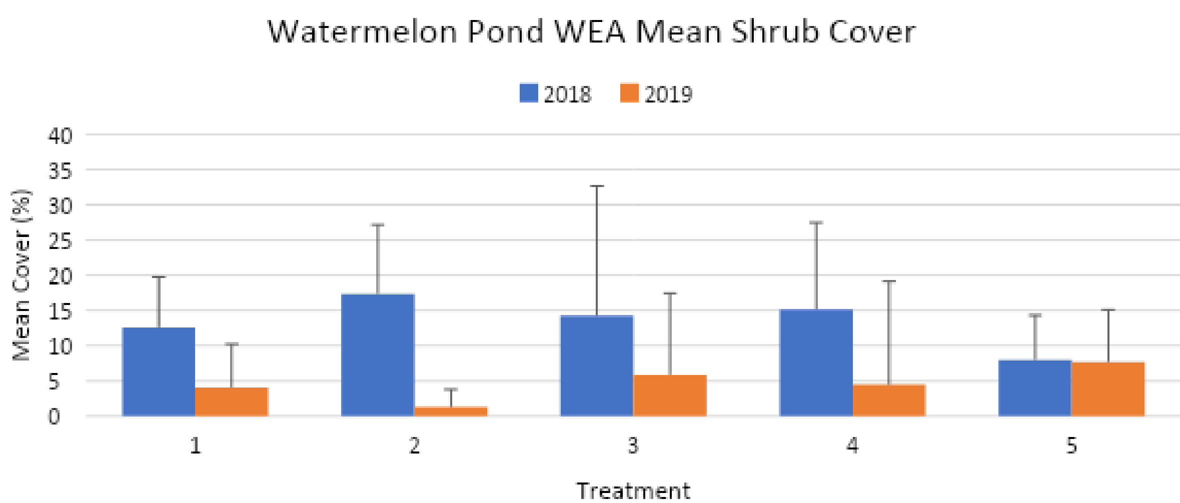

Figure 37. Pre- and post-treatment comparisons of mean cover of the shrub functional group, in the outer circle, for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA. This did not include non-target/target oaks and ericaceous shrubs.

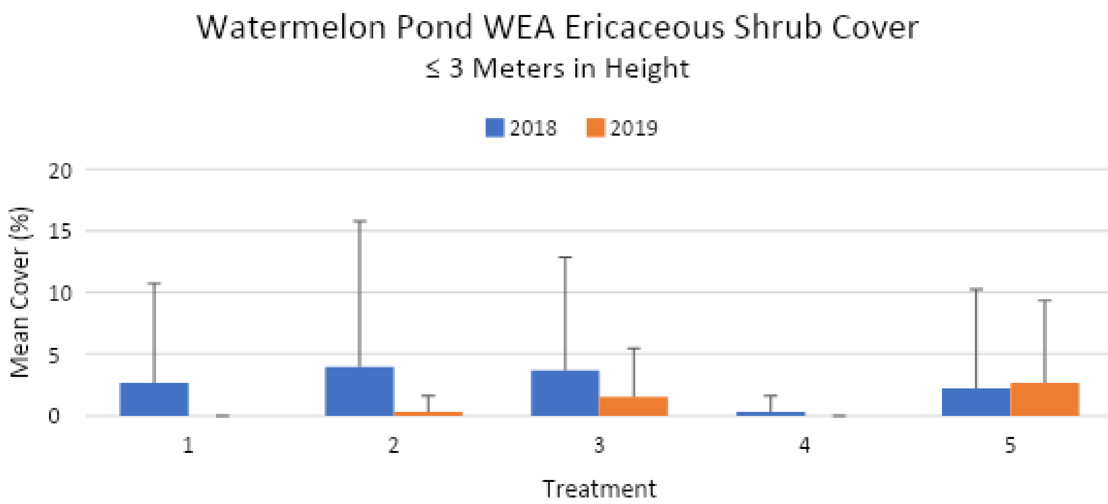

Figure 38. Pre- and post-treatment comparisons of mean cover of shrubs in the Ericaceae family functional group, in the inner circle, for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

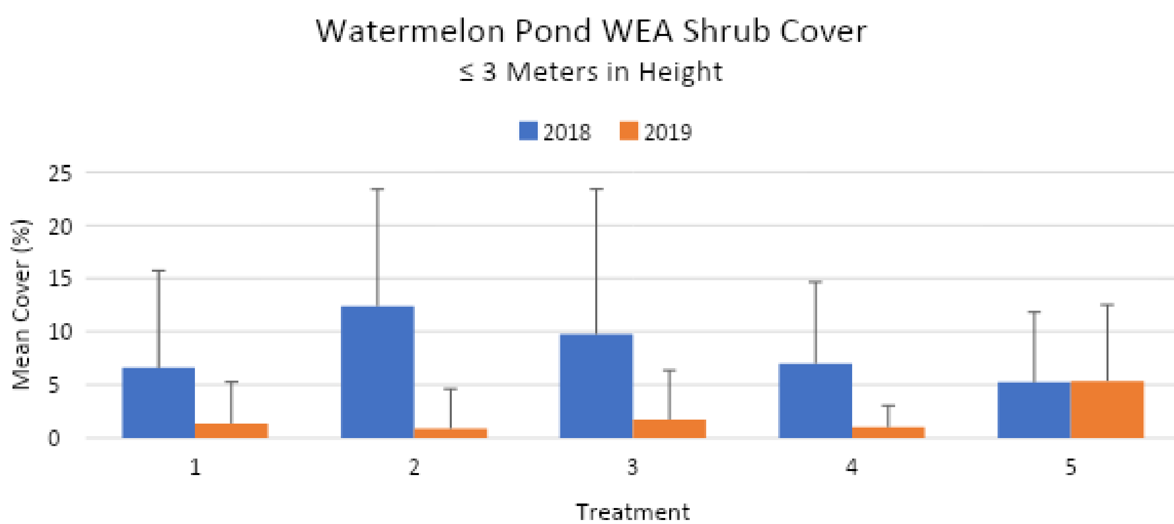

Figure 39. Pre- and post-treatment comparisons of mean cover of the shrub functional group, in the inner circle, for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA. This did not include non-target/target oaks and ericaceous shrubs.

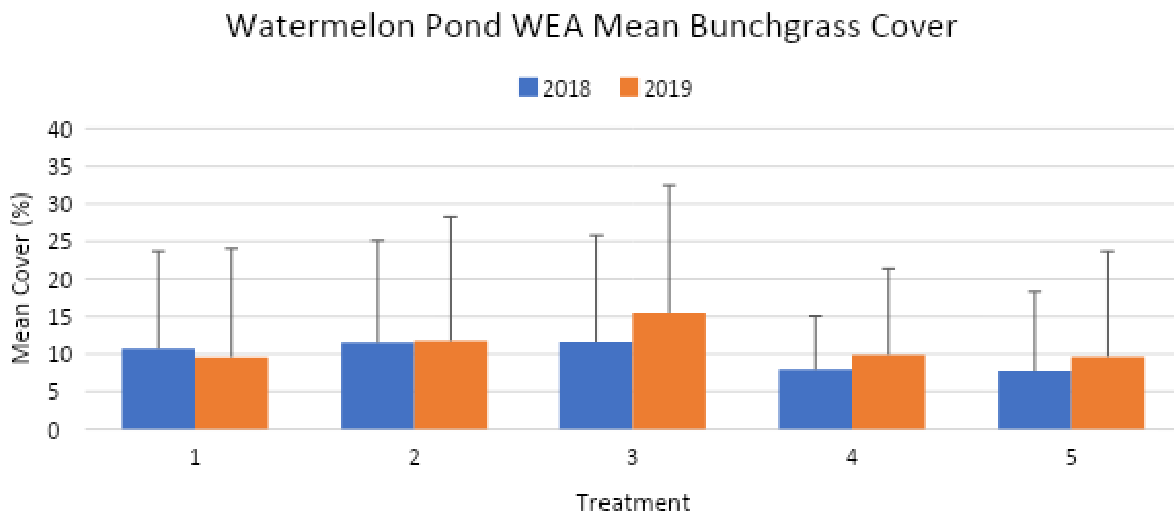

Figure 40. Pre- and post-treatment comparisons of the mean cover of the bunchgrass functional group, in the inner circle, in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

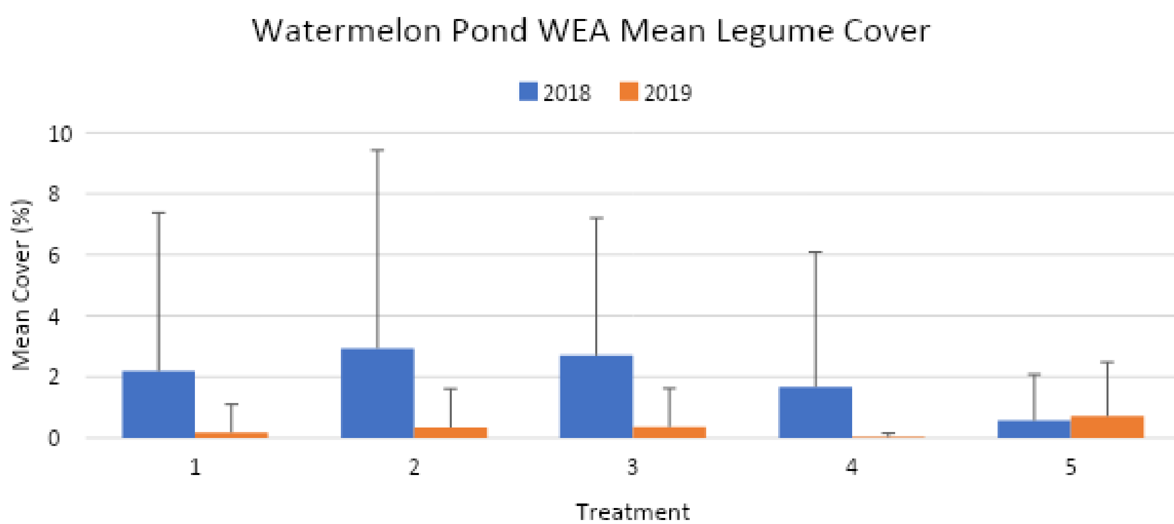

Figure 41. Pre- and post-treatment comparisons of the mean cover of the legume functional group, in the inner circle, in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

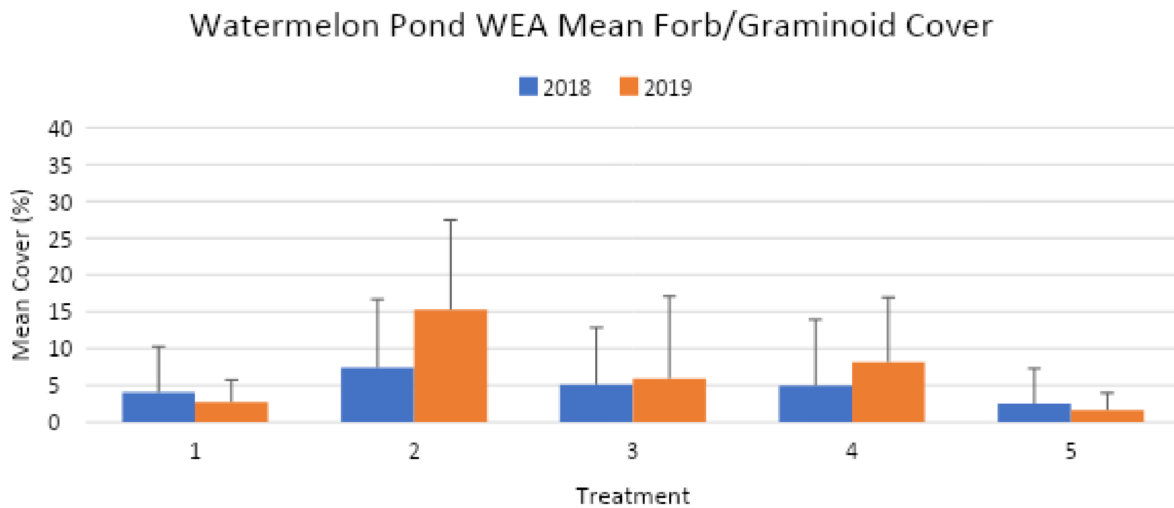

Figure 42. Pre- and post-treatment comparisons of the mean cover of the forb and graminoid functional group, in the inner circle, in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.

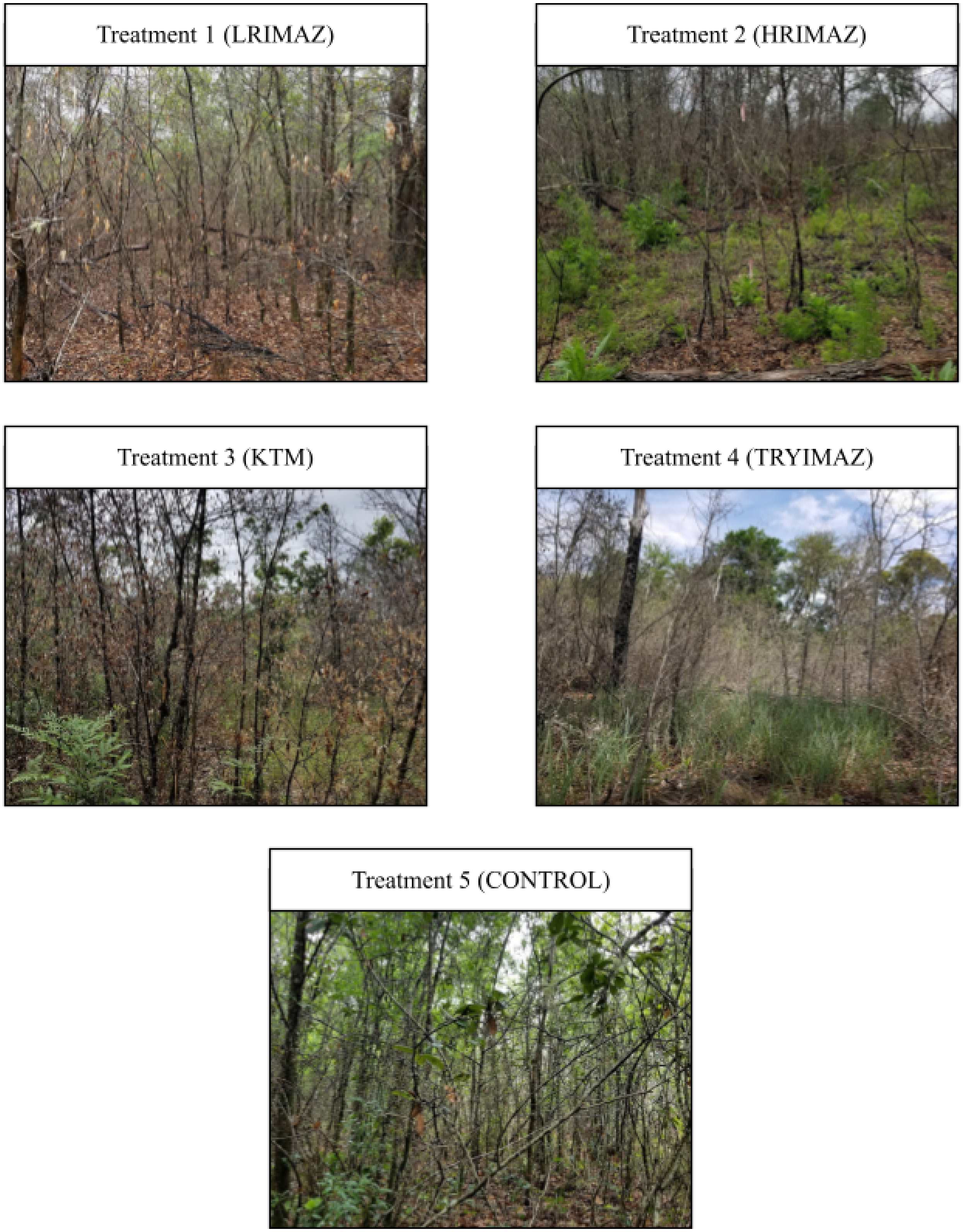

Figure 43. Post-treatment site photos at Watermelon Pond Wildlife and Environmental Area for treatments 1-5 taken May 2019, 1-year post-treatment.

Site	Treatment	# Herbaceous Species 2018	2019	Δ*	# Woody Species 2018	2019	Δ*	# Total Species 2018	2019	Δ*
Chassahowitzka	1	40	35	-5	20	13	-7	60	48	-12
	2	39	36	-3	26	13	-13	65	49	-16
	3	41	34	-7	24	20	-4	65	54	-11
	4	47	35	-12	26	19	-7	73	54	-19
	5	39	27	-12	33	31	-2	72	58	-14
Perry Oldenburg	1	100	122	+22	26	22	-4	126	144	+18
	2	101	126	+25	27	24	-3	128	150	+22
	3	104	126	+22	31	25	-6	135	151	+16
	4	103	114	+11	27	21	-6	130	135	+5
	5	93	95	+2	28	29	+1	121	124	+3
Watermelon Pond	1	60	53	-7	38	27	-11	98	80	-18
	2	83	71	-12	28	20	-8	111	91	-20
	3	77	66	-11	27	26	-1	104	92	-12
	4	61	58	-3	22	19	-3	83	77	-6
	5	59	64	+5	27	30	+3	86	94	+8

**(Δ) Indicates change in species richness from 2018-2019. (+/-) Indicates an increase/decrease in species richness.*

Table 1. Pre- and post-treatment total species richness results for herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ), and (5) untreated control, for the Florida Fish and Wildlife Conservation Commission's study on hardwood reduction in pinelands. Study sites were located at Chassahowitzka Wildlife Management Area and Perry Oldenburg Wildlife and Environmental Area in Hernando County, Florida as well as at Watermelon Pond Wildlife and Environmental Area in Alachua County, Florida.

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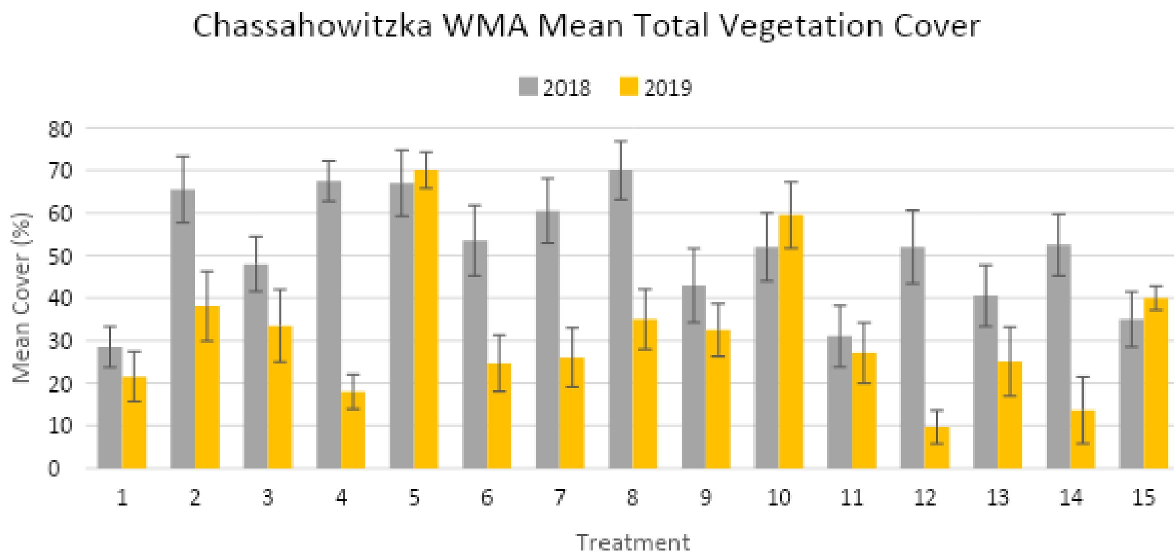
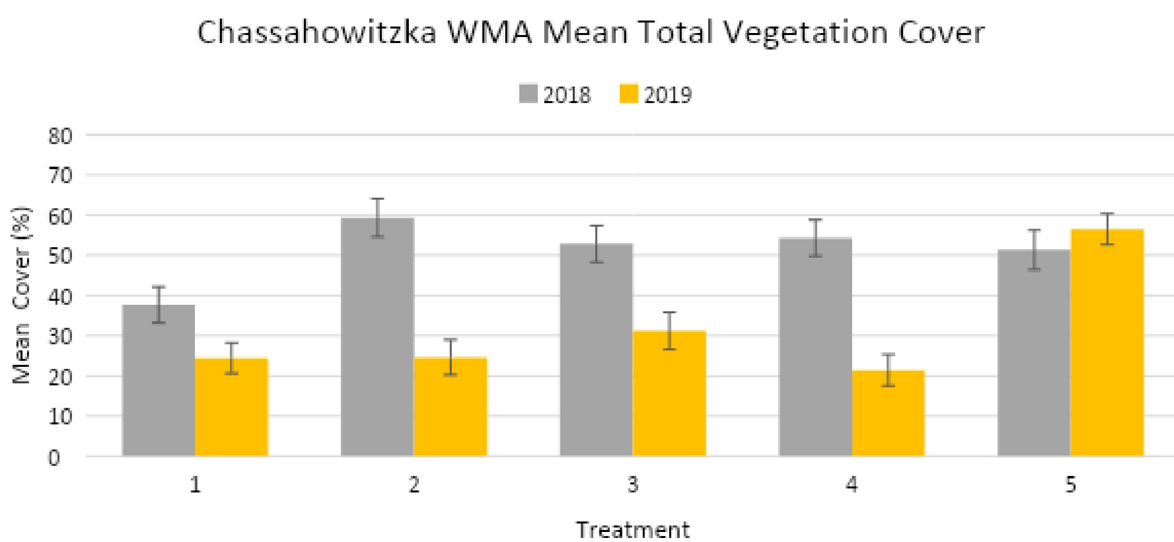
Appendix

Appendix 1. Herbicide application vehicles used in the Florida Fish and Wildlife Conservation Commission’s study on hardwood reduction in pinelands.

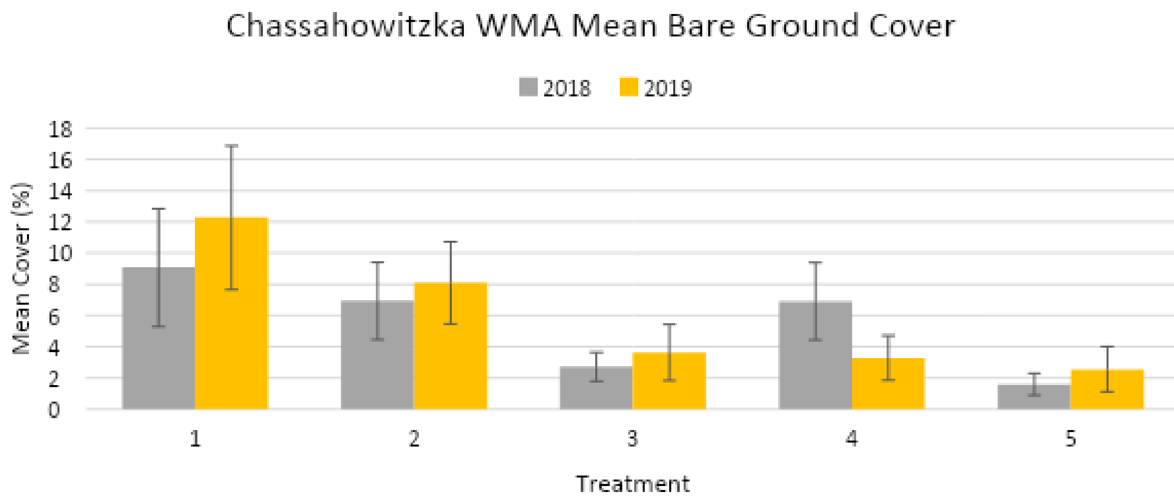
Appendix 2. Herbicide application photo of contractor spraying oaks at Chassahowitzka Wildlife Management area for Florida Fish and Wildlife Conservation Commission's study on hardwood reduction in pinelands.



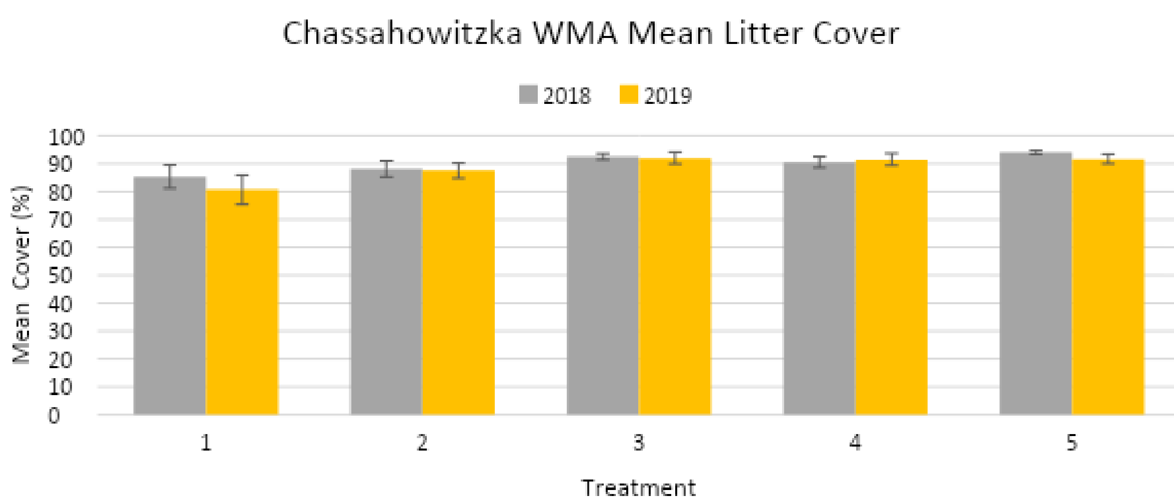
Appendix 3. Pre- and post-treatment comparison of the mean total vegetative cover in each block (A-C) and for each herbicide treatment: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.



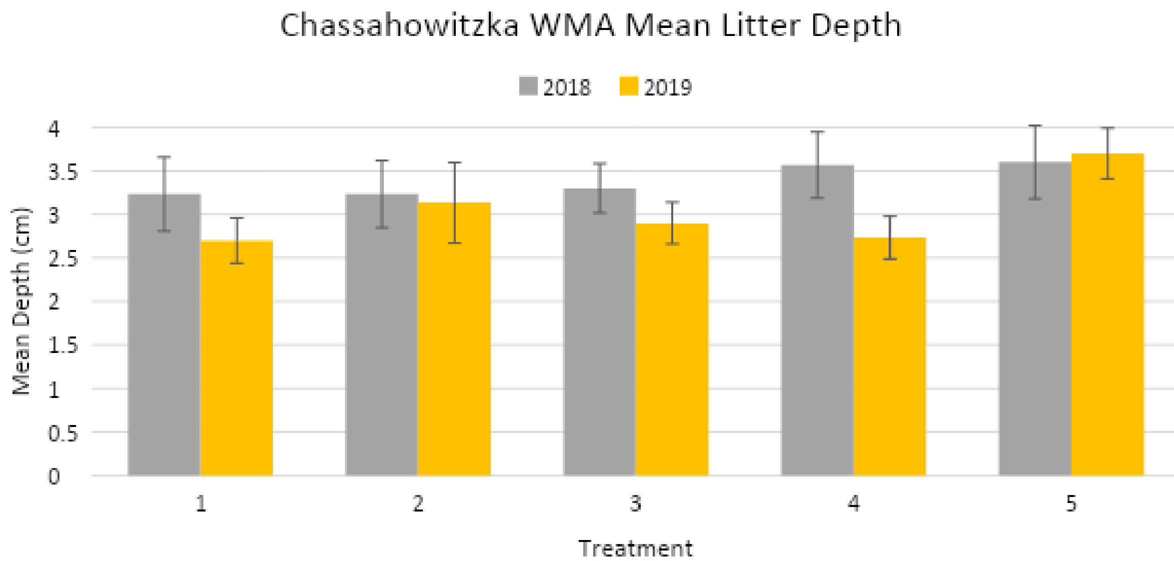
Appendix 4. Pre- and post-treatment comparison of the mean cover of total vegetation in each of herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.



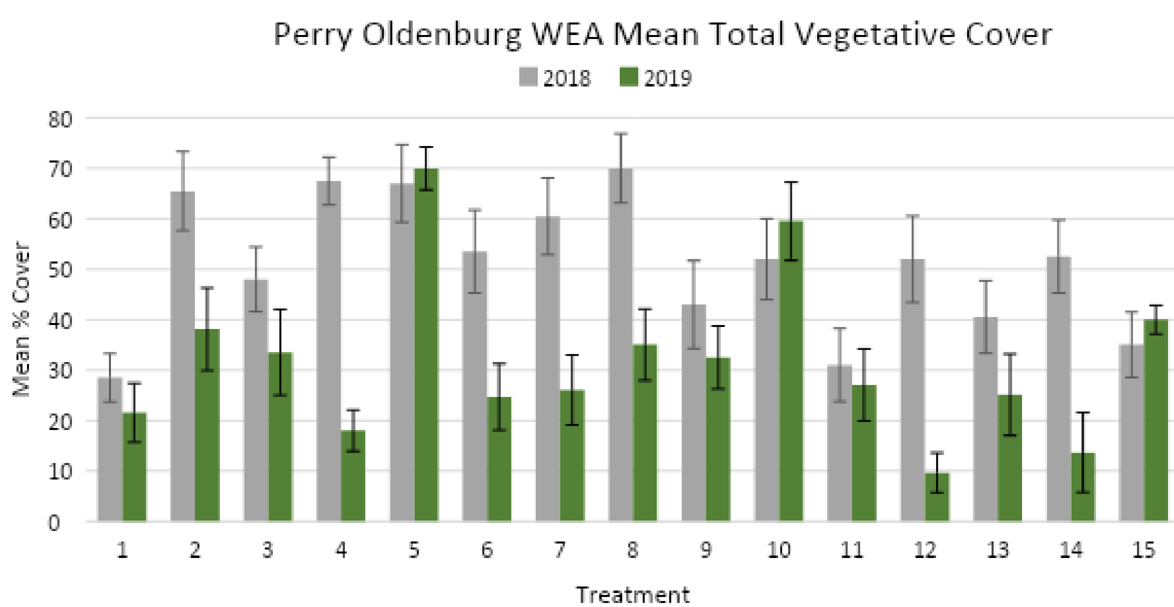
Appendix 5. Pre- and post-treatment comparison of the mean cover of bare ground in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.



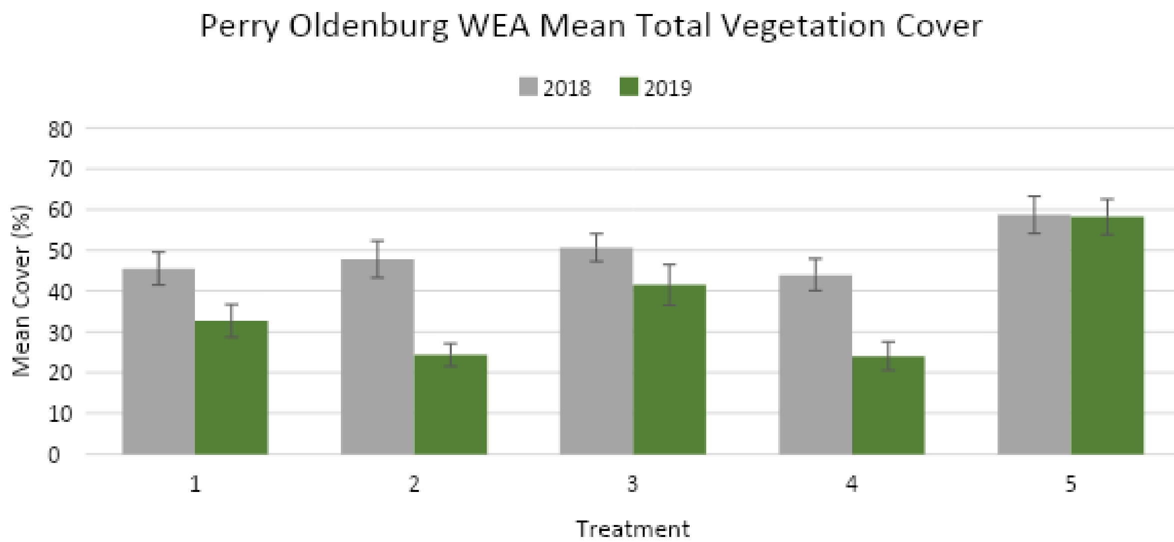
Appendix 5. Pre- and post-treatment comparison of the mean cover of litter in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.



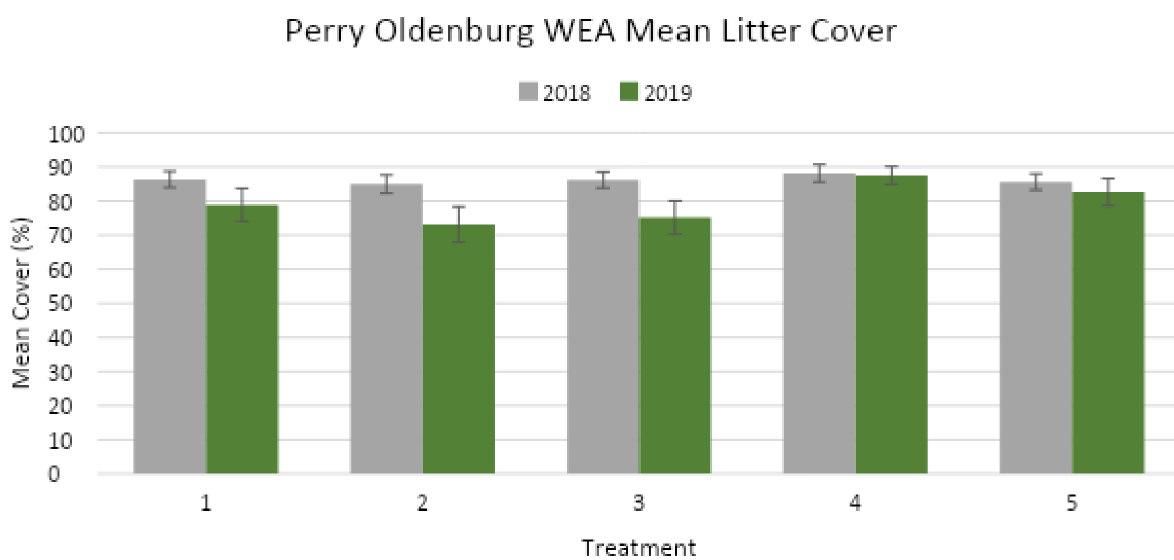
Appendix 6. Pre- and post-treatment comparison of the mean litter depth in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Chassahowitzka WMA.



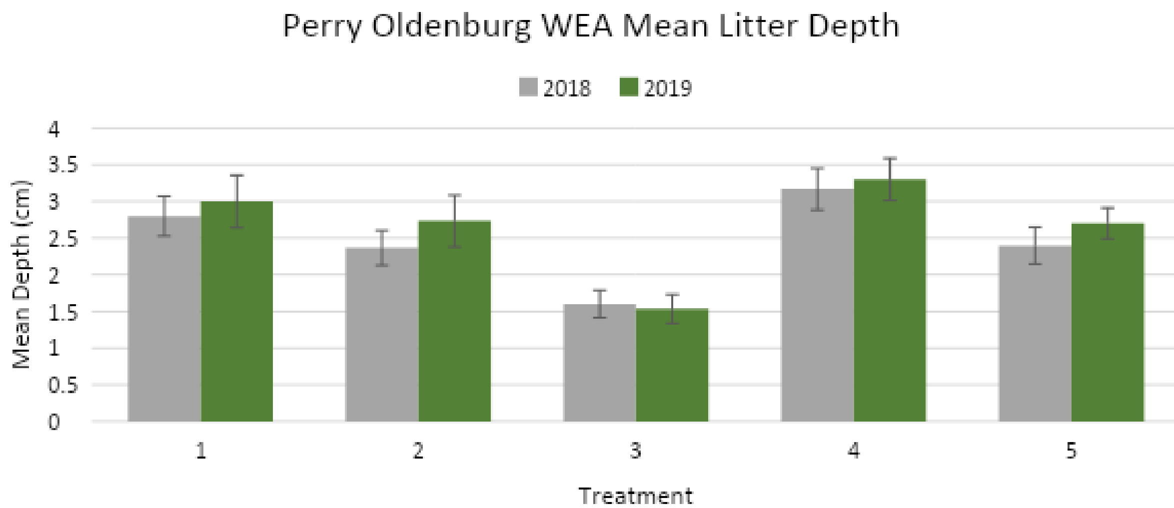
Appendix 7. Pre- and post-treatment comparison of the mean total vegetative cover in each block (A-C) and for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.



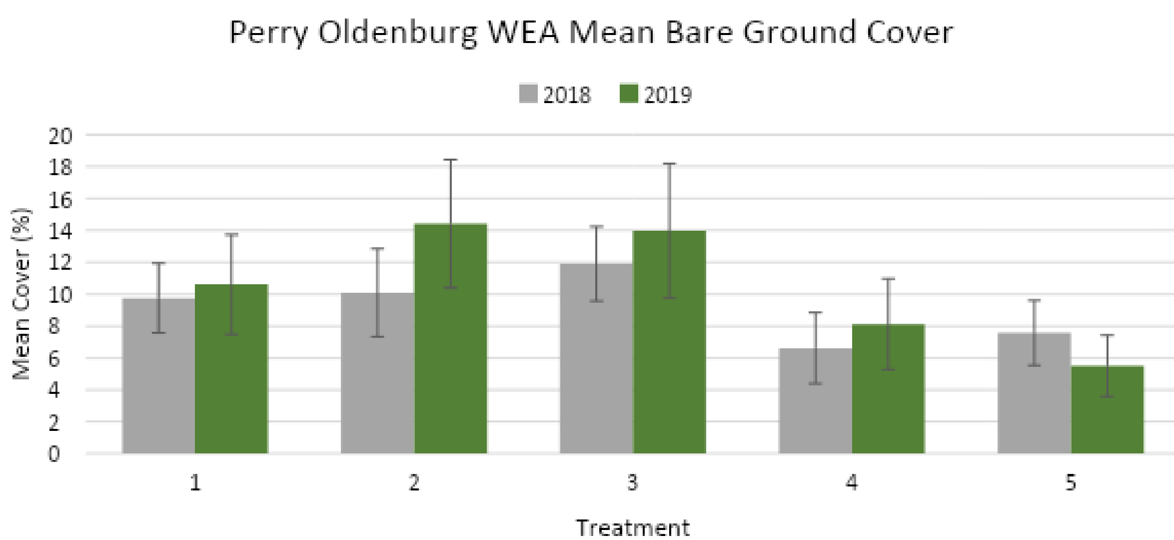
Appendix 8. Pre- and post-treatment comparison of the mean cover of total vegetation in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.



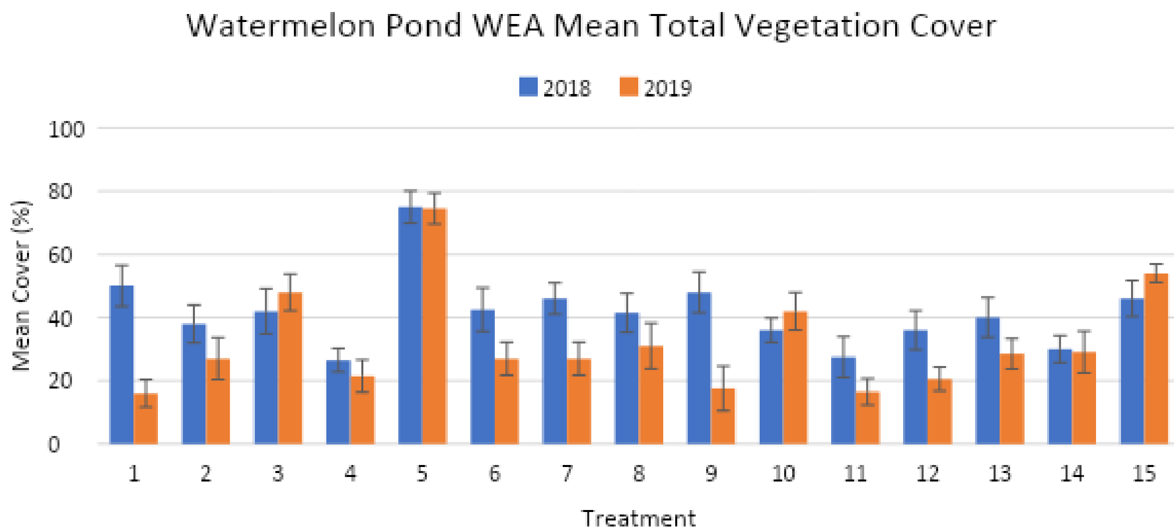
Appendix 9. Pre- and post-treatment comparison of the mean cover of litter in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.



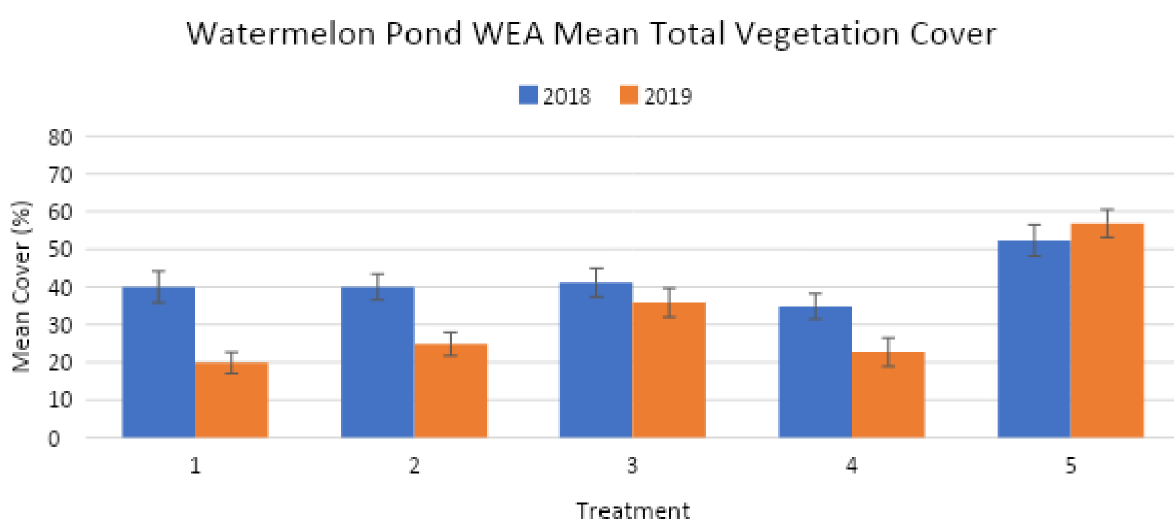
Appendix 10. Pre- and post-treatment comparison of the mean litter depth in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.



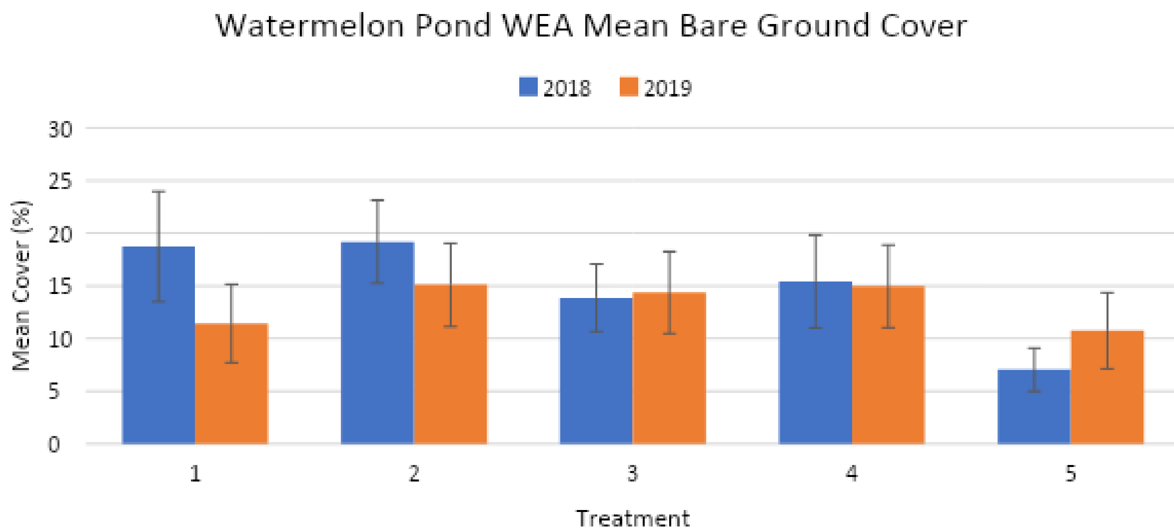
Appendix 11. Pre- and post-treatment comparison of the mean cover of bare ground in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Perry Oldenburg WEA.



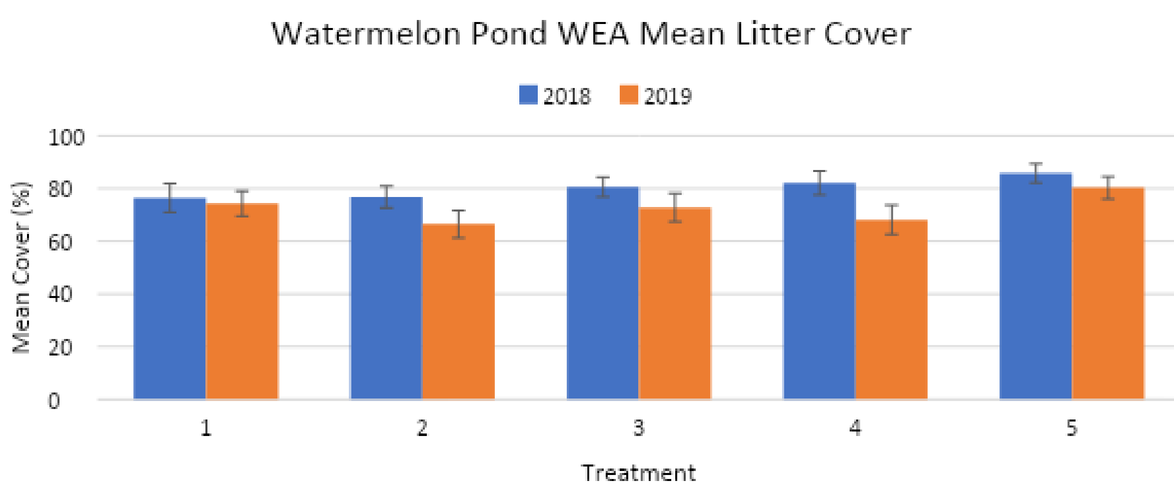
Appendix 12. Pre- and post-treatment comparison of the mean total vegetative cover in each block (A-C) and for each herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.



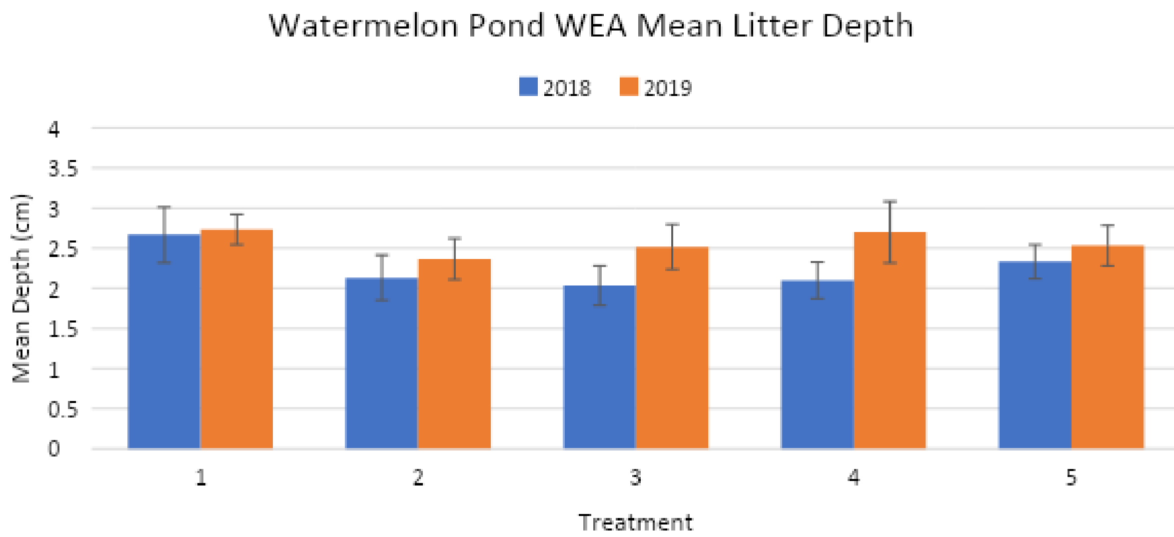
Appendix 13. Pre- and post-treatment comparison of the mean cover of total vegetation in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.



Appendix 14. Pre- and post-treatment comparison of the mean cover of bare ground in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.



Appendix 15. Pre- and post-treatment comparison of the mean cover of litter in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.



Appendix 16. Pre- and post-treatment comparison of the mean litter depth in each of the herbicide treatments: (1) low rate of imazapyr (LRIMAZ); (2) high rate of imazapyr (HRIMAZ); (3) Krenite S, Trycera and Milestone (KTM); (4) Trycera and imazapyr (TRYIMAZ) and (5) control at Watermelon Pond WEA.