Short title: Treatment of invasive species

The effects of treatment and management history on the control of Old World Climbing Fern (*Lygodium microphyllum), Brazilian Pepper (Schinus terebinthifolia*) and Punktree (*Melaleuca quinquenervia*).

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Abstract

To successfully reduce overall invasive plant cover over time, an effective treatment plan must be established such that mortality exceeds new colonization and re-spouting growth rates. However, few evaluations of the effects of long-term, consistent treatment at different intervals exist. We report the effects of treatment intensity on Old World climbing fern (*Lygodium microphyllum* (Cav.) R. Br.), Brazilian pepper (*Schinus terebinthifolia* Raddi) and punktree (*Melaleuca quinquenervia* (Cav.) S. T. Blake), as part of a large restoration project that has been underway for six years in Telegraph Swamp at Babcock Ranch Preserve, a 68,000 acre conservation area in Florida, U.S.A. We found that at the end of the six-year period, for all three species, average live cover did not exceed 5% across all transects. In addition, dead foliar cover was higher than live cover for all three invasive plants, indicating progress towards restoration goals. We also found that percent live cover of Old World climbing fern were significantly reduced only after four or more treatments were applied during the six-year period, as opposed to when three or fewer treatments were applied. Reductions in percent cover of live foliage were apparent only when the treatments were applied more often than biennially, as opposed to less often than biennially. Additionally, we found higher Old World climbing fern cover in clear-cut and replanted cypress stands than in natural stands. Based on these findings, we conclude that treatments applied four or more times, or more often than biennially, were more effective at significantly reducing advanced invasions of Old World climbing fern, Brazilian pepper, and punktree, especially where previous management activities or their effects may have increased the cover of invasive plants.

Key Words: treatment effectiveness, invasive plant management, Florida, monitoring, management recommendations, exotic plant control

Management Implications

　　Our study demonstrates that to significantly reduce Old World climbing fern (Cav.) R. Br.) cover, treatments must be applied consistently until managers transition from reducing the overall cover of a plant to a management phase where the target species is maintained at low levels, typically < 5% cover of the management area. In addition, our results suggest that conducting only one to three treatments over six years does little to bring the coverage of Old World climbing fern (OWCF) to maintenance levels (i.e. < 5% cover of the target species). We recommend that managers with limited resources develop a plan to work systematically through infestations of rapidly growing vines, only progressing from one unit to the next when the maintenance phase of treatment is reached and can be sustained. Based on these results, practitioners should be prepared and able to conduct a minimum of biennial retreatments for multiple years at infestation locations, regardless of the infestation size or severity, before committing resources to a treatment program. Our results support a using a "hold-the-line strategy" when attempting to reduce OWCF cover, where managers do not progress the treatment "line" and treat additional areas until the prior unit has been reduced to management levels of invasive cover. Though we determined an effective treatment regimen to be four or more treatments applied over a six-year period for OWCF, these results may be less applicable to other invasive species with different life histories. However, these results do offer a rare evaluation of various treatment plans against three of the world's worst weeds in an environment where treatment is often challenging due to prolific reproduction and year-round growth in a sub-tropical environment. The results of this study can aid managers planning treatment projects by informing decision-making on treatment intervals, number of treatments, and how to prioritize management units when the overall treatment area is large.

Introduction

Though monitoring and treating invasive plant species is an essential task for resource and land managers worldwide (Mack et al. 2000), empirical data on the effectiveness of long-term treatment regimens is lacking from most invasive plant control projects (Kettenring and Adams 2011). When attempting to control invasive plants, understanding the treatment regimen required to achieve mortality and prevent regrowth is key to achieving overall reductions in invasive plant cover. Having this information is especially critical in Florida, as this region has one of the most acute invasive species problems both in the United States and around the world (United States Congress 1993; Corn et al. 2002).

Three invasive species are of great concern in Florida: *Lygodium microphyllum* (Cav.) R. Br. (Old World climbing fern, hereafter: OWCF), *Schinus terebinthifolia* Raddi (Brazilian pepper) and *Melaleuca quinquenervia* (Cav.) S. T. Blake (punktree). OWCF is an invasive twining fern found throughout the Old World tropics, including Africa, India, Sri Lanka, China, Australia, and many countries of the South Pacific (Pemberton 1998; Singh and Panigrahi 1984). This species is classified as a noxious weed by the United States Department of Agriculture (USDA et al. 2012) and is a category 1 invasive plant in Florida (FISC 2019). Category 1 invasive exotic plants are defined as those that alter native plant communities by changing community structure and function or by displacing native species. OWCF is a high priority species for management as it shades canopy trees, envelops herbaceous marshes, entangles wildlife, and alters disturbance regimes by carrying fire into non-pyrogenic communities (Roberts 1996; Wu et al. 2006). Brazilian Pepper is an invasive, evergreen, shrub-like tree native to South America that was introduced to Florida in the mid-1800s as an ornamental plant. This

species is considered a category 1 invasive plant in the state of Florida (FISC 2019).

Management of this species is critical as Brazilian pepper forms monocultures with dense

canopies that shade out nearly all other plant species and alter fire regimes in pyrogenic

communities by retaining moisture in leaf litter and reducing fine fuels in the understory (Gordon

1998; Wade 1980). Punktree is an invasive tree species native to the South Pacific considered a

noxious weed by the United States Department of Agriculture (USDA et al. 2012) and is a

category 1 invasive plant in Florida (FISC 2019). This species is of management concern as it

shades out other species, reducing both plant and animal diversity (Serbesoff-King 2007).

Despite the ecological and economic impacts of these three invasive species, and the frequency

of management actions to reduce them (Serbesoff-King 2003; FEPPC 2006; Stevens and

Beckage 2009), few, if any, empirical assessments of the effects of large scale, long-term, high

intensity treatments exist.

Our study investigated the effectiveness of various treatment regimens on the control of

OWCF, punktree, and Brazilian pepper, with the goal of providing recommendations to

managers that can improve current treatment programs for these and other species. Due to small

sample sizes, we were unable to conduct multivariate analyses for punktree and Brazilian pepper

and therefore only assess whether significant reductions of live cover were made with treatment.

However, we were able to assess the number and timing of treatment applications required to

significantly reduce OWCF cover. Further, we assessed how previous management actions and

habitat might contribute to the effectiveness of different treatment regimen for OWCF.

Methods

Study Site

Babcock Ranch Preserve (BRP) encompasses approximately 68,000 acres of conservation land located in Charlotte County, in southwest Florida (26.854625°N, 81.659186°W). BRP was privately owned up until 2006, when it was purchased by the State of Florida as conservation land. While under private ownership the property was primarily used for timber production and cattle ranching. Currently, the property is managed by the Florida Forest Service in cooperation with the Florida Fish and Wildlife Commission. One of the primary goals of current management at the site is to restore and maintain healthy native ecosystems (FFS 2016). The restoration of BRP likely represents one of the most concerted efforts to restore cypress swamps within Florida (FFS 2016).

Due to the potential negative impacts of invasive species spread, the Florida Fish and Wildlife Conservation Commission and the Florida Forest Service have been intensively treating all invasive plant species in BRP since 2012 (FFS 2016, Linda King pers. comm.). One area of emphasis is Telegraph Swamp, an approximately 8,000-acre swamp in the western half of BRP. Two natural communities comprise Telegraph Swamp: Strand Swamp and Dome Swamp (FFS 2016; FNAI 2010). Strand Swamp is generally shallow, elongated, and found along depressions or troughs within a limestone plain. Strand swamps are dominated by stands of bald cypress (*Taxodium distichum*) with an understory of tropical and temperate woody species. Dome swamps are typically small, round, and located in acidic sands or marl, which in turn cover a limestone or clay lens. Peat is the typical soil covering in dome swamps and is often thicker at the center of the swamp than at the edges. Pond cypress (*Taxodium ascendens*) is the dominant species. Both swamp communities have a mounded profile, as younger, smaller trees are more common along the edges and taller trees are found in the deeper, centers of the swamps (FNAI 2010). Telegraph Swamp plays an important role in the hydrology of the landscape and much of

the surface runoff in the area flows through the swamp, ultimately discharging into the Caloosahatchee River (FFS 2016). Water levels in Telegraph Swamp begin to rise in June in as a result of rain, and are at their lowest in the winter and spring (FSS 2016). Telegraph Swamp contains dense infestations of OWCF with Brazilian pepper and punktree present along the transitional area to uplands.

Field methods

To assess the effectiveness of treatment on invasive species at BRP, we estimated the extent of living and dead fern across Telegraph Swamp. Surveys were conducted in late January and late March of 2020. We employed a space-for-time experimental design to retroactively examine the effects treatment on invasive cover because a monitoring program was not initiated at the start of the project. We stratified transects across treatment groups (i.e. 1, 2, 3, 4, or 5 treatments) and then randomly selected 20 transects from each group to survey. We abandoned transects which were inaccessible due to deep water, impassible roads, or were otherwise deemed unsafe. In total, 83 (40-meter) transects were surveyed throughout 11 of the 13 management units that comprise Telegraph Swamp (Figure 1).

Of these transects, 24 received one treatment, 25 received two treatments, 11 received three treatments, 18 received four treatments, and five transects received five treatments. Treatments of invasive species at BRP consist of ground crews systematically traversing the site while applying herbicide mix via foliar application by backpack sprayers. Crews aim traverse the affected area in its entirety and kill 95% of the plants present. For OWCF, a foliar application of 4% v/v glyphosate and 1% v/v non-ionic surfactant via backpack sprayer was used, with a poodle cut where required. Adult punktree was treated using a girdle/spray method with 15% v/v

imazapyr with hand spray bottles. For adult Brazilian pepper, a basal bark application of 20% v/v triclopyr 4 in 80% v/v basal oil was applied via backpack sprayer. When adult Brazilian pepper occurred in areas with standing water, a cut stump treatment of 20% v/v triclopyr 3A was used instead. However, most treatments for adult Brazilian pepper were conducted via basal bark application. When Brazilian pepper and punktree seedlings and saplings were treated, a foliar application of 3% v/v glyphosate, 0.5% or 1% v/v imazapyr, and a 1% v/v non-ionic surfactant mix was used. All glyphosate, imazapyr, triclopyr 3A, and surfactants used for treatments were aquatic labeled, due to the hydric nature of the Telegraph Swamp.

Along each transect, one 2.5-meter radius plot was placed every 10 meters (5 plots per transect, 415 plots total). The minimum distance between random transects was 100 meters. We confined transects to strand swamp and dome swamp plant communities. Within each plot on a transect, observers made ocular estimates of the percent cover of live plants and the percent cover of plants killed by herbicide (hereafter: dead cover) by considering how much of the 2.5-meter radius plot ($19.6m^2$) would have been covered with living vegetation had the dead cover been living and in leaf. Thus, the estimated dead cover of each target invasive species is an estimate of how much cover has been reduced. Live cover included plants that were untreated, treated inadequately with herbicide, or were new growth. Ocular estimates of the percent cover of live and dead plants for each of the target invasive species were made separately using the following cover classes: <1%, 1-5%, 6-25%, 26-50%, 51-75%, 76-95%, and >95% (Linda King, pers. comm). Handheld Trimble GPS units (model: Nomad) were used to navigate to transects and record data. For each transect we recorded the corresponding management unit, the number of years since that unit had received treatment, and the first year it received treatment.

The dead foliage, rachis, boles, or stems of treated plants are believed to remain in place for several years but the decomposition rate, and the factors that would accelerate or slow decay is not known. Therefore, though we assumed that dead rachis in our study was an accurate estimation of formerly living cover, it is possible that some cover decayed in the time between initial treatment and the data collection. For the purposes of this study, we assume that estimating the prior cover of each target invasive species using dead foliage is a sufficient estimation of previous infestations. To ensure the results of the most recent treatment had time to take effect, we only included management units that were not treated for a minimum of three months prior to the survey.

BRP was used primarily for timber production prior to the State of Florida's acquisition of the property, but records detailing these harvests and other previous management activities are not available. Since 1914, it is very likely that all the cypress in Telegraph Swamp were harvested and replanted (FFS 2016). However, more recently, some areas have had significant alterations to their habitats by large swaths of clearcutting and replanting (FFS2016). Based on our field observations, areas that were recently logged using current commercial silvicultural techniques were differentiated from areas that were not recently logged (Figure 2). Management history does not correspond to management unit boundaries, such that a unit could be only partially clear-cut and replanted (Figure 1). We determined management history post-hoc by grouping transects into those that fell in clear-cut and replanted areas and those that were in natural stands (i.e. not recently logged). Areas with apparent prior clear-cutting included 14 transects that received one treatment, nine transects that received two treatments, one transect that received three treatments, and 11 transects that received four treatments. Natural areas contained 10 transects that received one treatment, 16 transects that received two treatments, 10

transects that received three treatments, seven transects that received four treatments, and six transects that received five treatments. To explore the effects of management history we compared areas that were clear-cut and replanted to natural stands.

Analysis

We averaged the percent live and dead cover of all three target species across each transect to obtain one estimate of live cover and one estimate of dead cover per species, per transect. Using PAST, (Hammer et al. 2001; version 4.0) we conducted K-means clustering to group the total number of treatments with the goal of delineating important treatment thresholds. The total number of treatments a management unit received was binned into two clusters: management units that received 1-3 treatments and those that received 4-5 treatments over the six-year period.

In our analysis, all comparisons were conducted in a Bayesian framework using R (R Core Team 2019, version 3.6.1, Kruschke and Liddell 2018). We compared both the live and dead cover of OWCF between treatment clusters and management history using 89% high density intervals (HDI), which encompass the range of values in the distribution that are the 89% most probable, given the data. The HDI is also a measure of uncertainty surrounding a parameter, where narrower HDIs can be interpreted with greater certainty than wider HDIs. We use a Bayesian index of effect existence, the probability of direction (pd), to assess our certainty of the observed differences between groups. The pd value reflects the certainty associated with the most probable direction of the effect given the data, either positive or negative (Kruschke and Liddell 2018, Makowski et al. 2019a). Pd values were calculated using the *bayestestR* package (Makowski et al. 2019b).

We compared sixteen candidate linear models to test hypotheses about which factors were most important in explaining the live cover of OWCF. We made too few observations of Brazilian pepper and punktree to test multivariate relationships between those species and factors that could have influenced treatment effectiveness. For this reason, we compare live and dead cover of Brazilian pepper and punktree on transects, as opposed to using models to assess overall treatment progress. Models were run with a zero inflated beta distribution using the *brms* package (Bürkner 2017). Model assumptions and performance were assessed using the *Performance* package (Lüdecke et al. 2020). We used the *yarrr* package to visualize the data (Phillips 2017).

To understand whether treating an infestation for a long time was the best explanation of treatment progress, we included a model with only the year a transect was first treated as a single predictor. We also included a model containing the year a transect was last treated as a single predictor to understand if recent treatments were more effective at reducing live cover of OWCF. Another model contained both years since first treatment and years since last treatment to determine if a combination of these effects predicted OWCF cover. To determine if the number of treatments an area received best predicted OWCF cover, we included a fourth model containing only treatment cluster. We included another model that contained treatment cluster, years since an area was first treated, and years since an area was last treated to understand if there was an effect of a combination of these factors. To understand whether factors relating to history or swamp type were important in predicting OWCF cover, we also included a model with the three aforementioned parameters and history, and an additional model with the three parameters and swamp type. To test whether prior land management history was an important predictor of OWCF cover, we included a model containing the interaction of the treatment

cluster and history. Two additional models were included where history and swamp types were single predictors to assess each variable's relative strength as a single predictor. To understand whether areas that were more heavily invaded had a higher cover of OWCF, we included a model that contained the total cover of invasive species (excluding OWCF), the treatment cluster, years since first treatment, and years since last treatment. Finally, to test whether treatment cluster represented an important threshold for controlling OWCF, we also included a model containing the interaction between the total number of treatments (1, 2, 3, 4, or 5) and history, and a model containing total number of treatments as a single predictor.

Models were compared using the Bayes factor (BF), which was calculated using the *bayestestR* package. The Bayes factor is a relative index of support for one model over another that is determined by comparing the marginal likelihoods of the models. We first compared all our candidate models to the null model using the BF to determine which model had the most support over the null model. To check our assertion that the model with the most support over the null model was the top model, we made a second comparison of all the candidate models relative to the top model. A BF of greater than three indicates evidence for the alternative hypothesis (Makowski et al. 2019).

Results and Discussion

Assessment of Current Invasive Cover

Across all transects, 81% had a live or dead invasive plant (OWCF, Brazilian pepper, or punktree). Live cover of at least one invasive plant was found in 63% of transects. Live cover of OWCF was found on 68% of transects, live Brazilian pepper was found on 19% of transects, and live punktree was found on 6% of transects. Despite the frequent occurrence of live plants on

transects, we found the average live percent cover of each of the three focal species along a transect was less than 35% (Figure 3). Dead cover of OWCF was found on 74% of transects, dead Brazilian pepper cover was found on 31% of transects, and dead punktree was found on 19% of transects.

Effects of Management Actions on OWCF

Treatment cluster was related to the average live and dead cover of OWCF along a transect. On transects that were treated 1-3 times, average live cover of OWCF was 3.4% (1.9-4.5%), and on transects treated 4-5 times average live cover was 0.4% (0.1-0.6%). Based on the pd, there was a 92% chance of a negative effect of more treatments on live OWCF cover. Along transects that were treated 1-3 times, dead OWCF cover was 13.3% (9.3-16.7%) and on transects treated 4-5 times average dead cover was 4.2% (2.0-5.8%). Based on the pd, there was a 95.4% chance that transects treated 4-5 times had less dead cover than transects treated 1-3 times. Across transects, those that received 4-5 treatments were likely to have less total cover (live cover and less dead cover) than those transects treated 1-3 times.

Management history (i.e. clear-cut vs. natural) was correlated with average live OWCF cover along a transect (Figure 4). Transects in clear-cut and replanted areas had an average live OWCF cover of 3.7% (0.7-2.4%) and those in natural stands had an average live OWCF cover of 1.7% (0.7-2.4%). Based on the pd, there was a 92% chance that clear-cutting and replanting resulted in higher cover of OWCF. Dead OWCF cover was 14.8% (2.0, 5.8%) along transects in clear-cut areas and 7.8% (4.1, 10.6%) in natural stands. Based on the pd, there was a 91% chance that dead OWCF cover was lower in clear-cut and replanted areas than in natural stands.

The best model to explain the cover of live OWCF along transects was an interaction between treatment cluster and history (Table 1; Figure 4). The top model received more support than the null model (BF: 7.46; Table 1). To affirm that this model was the top model, we compared it to the other models in our data set and found that all had a BF < 1, indicating that no model received more support than the top model (Table 1). For this reason, we rejected models that included time since first treatment, time since last treatment, swamp type, cover of other invasives, and total number of treatments. Models containing the treatment cluster performed better than those that contained the number of treatments (Table 1). This indicates that the difference between treatment clusters was a meaningful threshold for making significant reductions OWCF, as compared to a reduction in cover from each additional treatment.

Recommendations for Managers

This brief case study offers a rare look at the results of consistent, repeated efforts undertaken for many years in a natural area that can be considered a near-worst case scenario for invasive species infestation. While this study would have ideally been initiated before any treatments took place, we were still able to detect meaningful patterns using a space-for-time experimental design. We found that significant gains can be made, even with dense and long-established OWCF colonies, with consistent treatment over long periods. As one might expect, we observed declines in OWCF cover when more treatments were applied. However, the relationship between treatment number and OWCF cover was not linear. Instead, significant reductions in OWCF cover only seemed occur after 4 treatments were applied.

A major assumption of our study was that dead rachis mat represented live OWCF cover prior to any treatments. Using this method, it is more likely that the observer would

underestimate dead cover than overestimate it, resulting in a smaller reduction in overall cover than likely occurred. In addition, we have observed OWCF rachis persisting in the field for long durations, though the exact decay rate and conditions that affect decay are not known. It is likely that at BRP these plant materials are protected from intense wind, rain, and ultraviolet light beneath the cypress dome canopy for a longer period relative to other exposed areas. If OWCF rachis does decay at a faster rate than we assume, our estimations of prior cover would be lower than the true cover of dead rachis. Therefore, the reductions in cover we documented would likely be larger than we described. For these reasons, we believe using dead OWCF rachis as a proxy for prior live cover is an appropriate assumption. However, it is possible that dead rachis does not accurately reflect the live cover at the start of the experiment and the results should be interpreted with caution.

We observed lower dead rachis cover on transects treated 4-5 times than on transects treated 1-3 times. One potential explanation for this pattern is that rachis treated earlier in the study (i.e. at the beginning of the six-year period) had more time to decay than rachis treated at the end of the study. A second potential explanation is that transects treated more times likely had less opportunity for new growth in between treatments, therefore reducing the potential for high covers of dead rachis. Determining the decay rates of this and other invasive species after treatment could help improve our comparisons of different treatment regimens and comparisons made by future studies.

Because our study took place over a finite duration, units that received more treatments were inherently treated more often than units treated fewer times. In this case, units in the 1-3 treatment group were treated less than biennially, and units in the 4-5 treatment cluster were treated more frequently than biennially. Therefore, we conclude that treatments applied less often

than every other year were not effective at significantly reducing OWCF cover. We were able to identify that biennial treatment is a critical threshold for outpacing growth and new colonization of OWCF. A study by Hutchinson and Langeland (2012) determined that treating annually for three years was effective at significantly reducing live cover. Our results suggest that treating at a slightly longer interval (less than biennially) is still effective at controlling OWCF if four or more treatments are applied. This threshold may be beneficial to managers who lack the resources to treat on an annual schedule.

Though low samples sizes prevented us from drawing conclusions about a minimum number of necessary treatments to reduce Brazilian pepper and punktree cover, we still observed declines in live cover as the result of treatment. This suggests that consistent treatments of Brazilian pepper and punktree over multiple years will reduce live cover and help control invasions. Based on the treatment threshold required to reduce live OWCF cover, we suggest that managers treating Brazilian pepper or punktree invasions make frequent treatments, less than two years apart, for at least four consecutive treatments. However, as these recommendations are based on our findings of OWCF, we suggest managers regularly reevaluate their progress using this treatment regimen. Once invasive plants are reduced to less than 5% live cover (maintenance levels) managers should reevaluate the necessary treatment intervals to maintain progress.

Some research suggests that spending time, money, and resources on treating smaller, younger, or more rapidly growing infestations is cost-effective at reducing infested acres, money spent per acre, and protecting biodiversity (Moody and Mack 1988; Higgins et al. 2000). All three of the focal species in this study are believed to have detrimental effects on biodiversity (Turner et al. 1998; Gordon 1998). Though we did not assess the overall effects of treatment on biodiversity in our study, biodiversity may increase if the live and dead covers of the target invasive species were significantly reduced. Hutchinson and Langeland (2010) found that while richness and diversity did increase after significant reductions in OWCF cover were made, many

of those gains resulted from increases in non-native graminoids and forbs. However, this study was conducted in areas that were already disturbed from weather events such as hurricanes and heavily invaded by exotics other than OWCF. It is possible that in other areas that are less disturbed and have fewer invasive species biodiversity gains after OWCF treatment would be due to native species recruitment. The lack of information about how both native and non-native species respond after large-scale and long-term OWCF treatments indicate managers must continue to monitor communities even after large invasions have been treated. Additional research in these areas to understand how communities respond after treatment of OWCF is necessary to improve post-treatment management plans.

In addition to considering the resources available to conduct treatments, previous history of disturbance, management activities, and habitat type at potential treatment sites should be considered when creating a treatment plan for OWCF. We found evidence that swamps recently logged using commercial silviculture techniques may be more vulnerable to invasion by OWCF than those that were naturally regenerated. It is well known that disturbed areas have a higher probability of being invaded by exotic species, which may result from physical disruption of soils and increased resource levels (D'Antonio and Meyerson 2002). However, the reasons for increased OWCF cover in commercially harvested areas over naturally regenerated areas at BRP remain unknown and require further investigation. Our finding that invasive cover was high in more disturbed areas of the site may also help conservation agencies estimate the management needs of potential acquisitions when management history is known.

References

Bürkner P (2017) brms: An R Package for Bayesian Multilevel Models Using Stan. J. Stat. Softw 80:1–28 doi: 10.18637/jss.v080.i01

Corn ML, Buck EH, Rawson J, Segarra A, Fischer E (2002) Invasive Non-Native Species: Background and Issues for Congress. Washington, DC: Congressional Research Service and The Library of Congress

D'Antonio C, Meyerson LA (2002) Exotic Plant Species as Problems and Solutions in Ecological Restoration: A Synthesis. Restor Ecol 10:703-713

[FEPPC] Florida Exotic Pest Plant Council Lygodium Task Force (2006) Old World climbing fern (*Lygodium microphyllum*) management plan for Florida.

[FISC] Florida Invasive Species Council (2019) List of Invasive Plant Species. https://www.fleppc.org/list/list.htm

[FFS] Florida Forest Service (2016) Ten-year management plan for the Babcock Ranch Preserve. Florida Forest Service, Florida Department of Agriculture and Consumer Services, Tallahassee, FL, USA

[FNAI] Florida Natural Areas Inventory (2010) Guide to the natural communities of Florida: 2010 edition. Florida Natural Areas Inventory, Tallahassee, Florida

Gordon DR (1998) Effects of invasive, non-indigenous plant species on ecosystem processes: lessons from Florida. Ecol Appl 8:975-989

Hammer Ø, Harper DAT, and Ryan PD (2001) PAST: Paleontological statistics software package for education and data analysis. Palaeontol Electronica 4:9 http://palaeo-electronica.org/2001_1/past/issue1_01.htm

Higgins SI, Richardson DM, and Cowling RM (2000) Using a dynamic landscape model for planning the management of alien plant invasions. Ecol Appl 10:1833-1848

Hutchinson JT, and Langeland KA (2010) Monitoring of applied management techniques to control old world climbing fern (*Lygodium microphyllum*) in disturbed habitat. Fla Sci 73:262-273

Kettenring KM, and Adams CR (2011) Lessons learned from invasive plant control experiments: a systematic review and meta-analysis. J Appl Ecol 48:970-979

Kruschke JK, and Liddell TM (2018) The Bayesian new statistics: hypothesis testing, estimation, meta-analysis, and power analysis from a Bayesian perspective. Psychon Bull Rev 25:178-206

Lüdecke D, Makowski D, Waggoner P, and Patil I (2020) performance: Assessment of Regression Models Performance. CRAN. doi: 10.5281/zenodo.3952174, R package, https://easystats.github.io/performance.

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, and Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecol Appl 10:689-710

Makowski D, Ben-Shachar MS, Chen SHA, and Lüdecke, D (2019a) Indices of Effect Existence and Significance in the Bayesian Framework. Front Psychol 10:2767 https://doi.org/10.3389/fpsyg.2019.02767

Makowski D, Ben-Shachar M, and Lüdecke D (2019b) bayestestR: Describing Effects and their Uncertainty, Existence and Significance within the Bayesian Framework. J. Open Source Softw 4:1541 doi:10.21105/joss.01541

Moody ME and Mack RN (1988) Controlling the spread of plant invasions: the importance of nascent foci. J Appl Ecol 25:1009-1021

Pemberton RW and Ferriter AP (1998) Old World climbing fern (*Lygodium microphyllum*), a dangerous invasive weed in Florida. Am Fern J 88:165-175

Phillips N (2017) yarrr: A Companion to the e-Book "YaRrr!: The Pirate's Guide to R". R package version 0.1.5. https://CRAN.R-project.org/package=yarrr

R Core Team (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria URL https://www.R-project.org/

Roberts RE (1996) Climbing Fern Wreaks Wetland Havoc. Tech. Rep. Florida Department of Environmental Protection Resource Management Notes 8:13

Serbesoff-King K (2003) Melaleuca in Florida: a literature review on the taxonomy, distribution, biology, ecology, and economic importance of control measures. J Aquat Plant Manage 41:98-112

Singh S, and Panigrahi G (1984) Systematics of genus Lygodium Sw. (*Lygodiaceae*) in India. Proc Indian Acad Sci 93:119–13

Stevens JT, and Beckage B (2009) Fire feedbacks facilitate invasion of pine savannas by Brazilian pepper (*Schinus terebinthifolius*). New Phytol 184:365-375

Turner CE, Center TD, Burrows DW, and Buckingham GR (1998) Ecology and management of *Melaleuca quinquenervia*, an invader of wetlands in Florida, USA. Wetlands Ecol Manage 5:165-178

United States Congress Office of Technology Assessment (1993) Harmful Non-Indigenous Species in the United States. *OTA-F-565* Washington, DC: U.S. Government Printing Office.

[USDA] United States Department of Agriculture, [APHIS] Animal and Plant Health Inspection Service, and [PPQ] Plant Protection and Quarantine (2012) Federal Noxious Weed List. https://plants.usda.gov/java/noxious. Accessed: June 9, 2020.

Venables WN and Ripley BD (2002) Modern Applied Statistics with S. 4th ed. Springer: NY.

Wade D, Ewel J, and Hofstetter R (1980) Fire in South Florida ecosystems. U.S. Department of Agriculture: Forest Service General Technical Report SE-17

Wu Y, Rutchey K, Wang N, and Godin J (2006) The spatial pattern and dispersion of *Lygodium microphyllum* in the Everglades wetland ecosystem. Biol Invasions 8:1483-1493

Table 1: The sixteen candidate models that explained live Old World climbing fern (*Lygodium microphyllum*) cover. Model parameters shown are treatment cluster (trt clust), management history (history), swamp type (swamp), number of years since first treatment (yr first trt), number of years since last treatment (yr last trt), the number of treatments an area received (num of trt), and sum of all invasive cover except OWCF (inv cov). Models were compared using the Bayes factor, where values > 3 indicate separation of that model from the comparison. The top model was separated from the null model and contained an interaction of treatment cluster and history (bolded). To confirm that no other models were better predictors of live OWCF cover we also compared the top model to the other candidate hypotheses. No other models better explained live OWCF cover than the top model. Asterisks are used as placeholders to denote the model against which all other models are being compared.

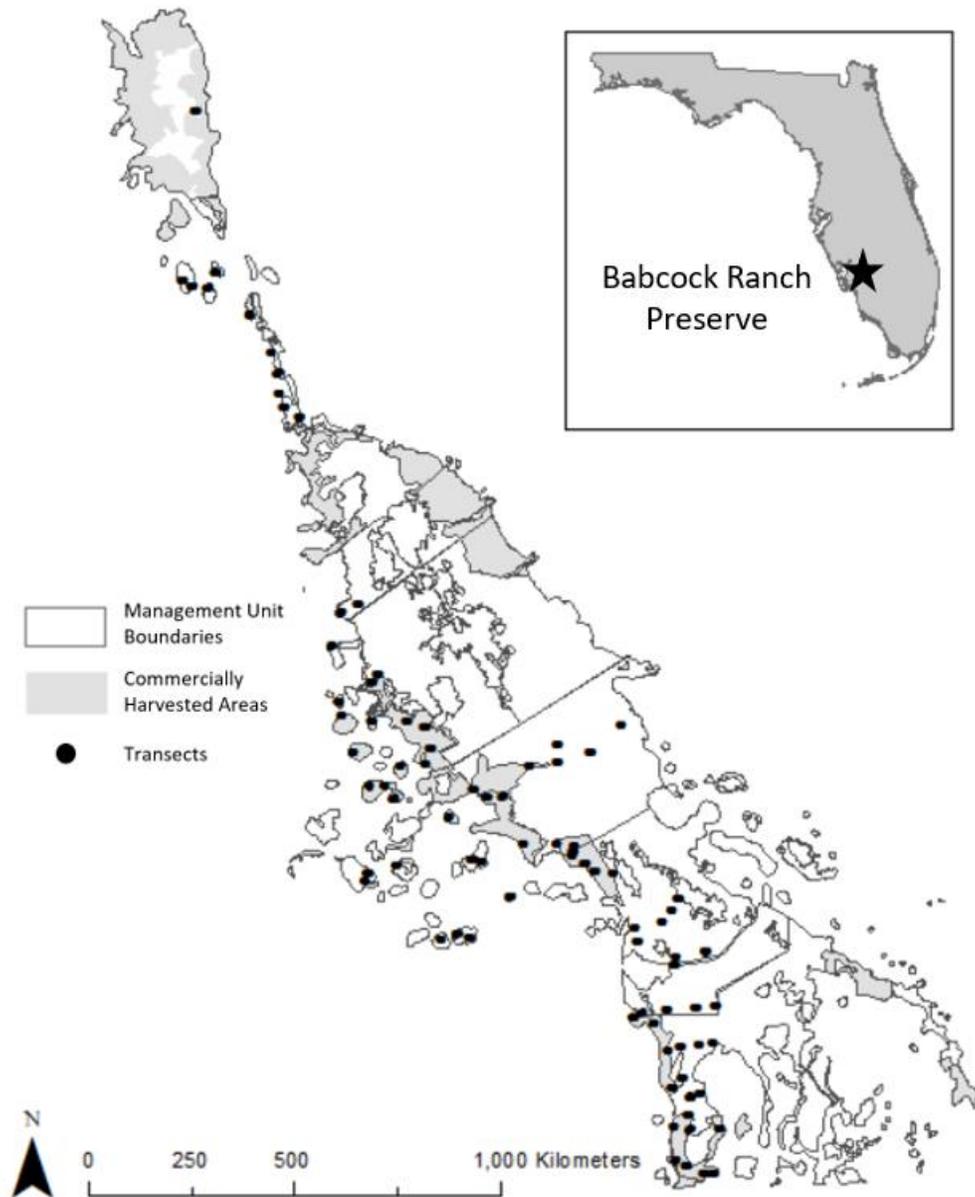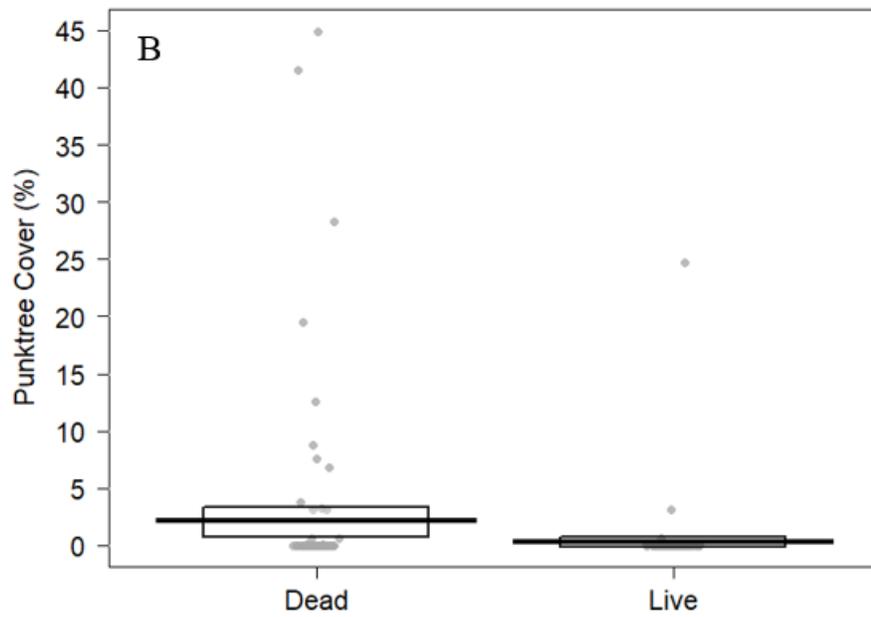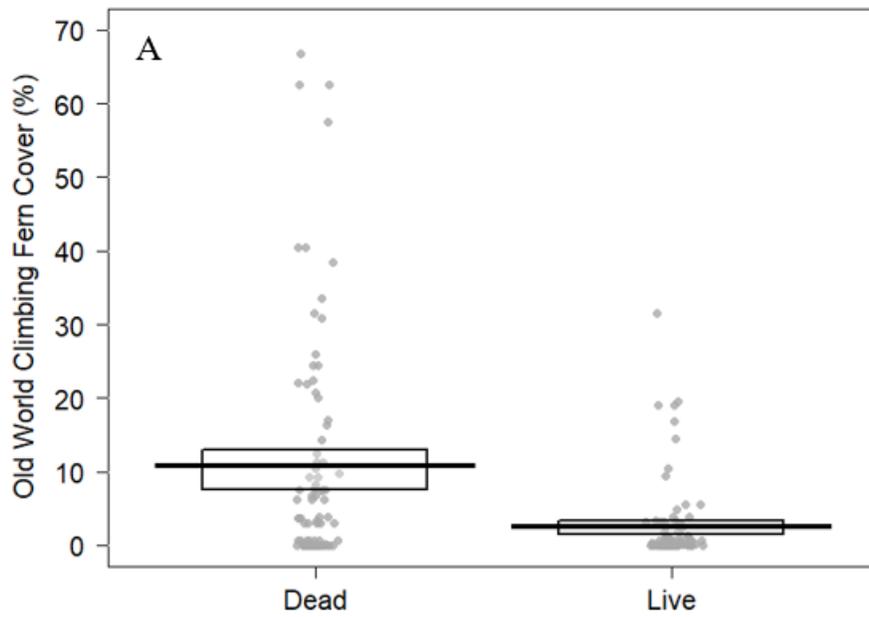|	Bayes Factor	
	Compared to the Null Model	Compared to the Top Model
Intercept Only Model	*	0.13
Trt Clust	1.94	0.26
Yr First Trt	0.17	0.02
Yr Last Trt	0.74	0.10
Yr Last Trt + Yr First Trt	0.32	0.04
Yr Last Trt + Yr First Trt + Trt Clust	0.52	0.07
Yr Last Trt + Yr First Trt + Trt Clust + History	0.82	0.11
Yr Last Trt + Yr First Trt + Trt Clust + Swamp	0.78	0.11
Trt Clust + History	2.60	0.35
Trt Clust * History	**7.46**	*
History	1.65	0.22
Swamp	0.87	0.12
Num of Trt * History	0.35	0.05
Num of Trt	0.27	0.04
Yr Last Trt + Yr First Trt + Trt Clust + Inv Cov	0.01	0.002
Inv Cov	0.02	0.003

Figure 1. Babcock Ranch Preserve management unit boundaries. Areas that were clear-cut and replanted. All other areas were classified as natural stands. Transects are shown as black dots. The inset image shows the preserve's location in Florida, USA.

Figure 2. Aerial photo of cypress swamp at Babcock Ranch Preserve. Arrow A indicates swamp classified as a natural stand. Arrow B indicates areas of swamp that were classified as clear-cut and replanted based on the striated signature seen in the photo.
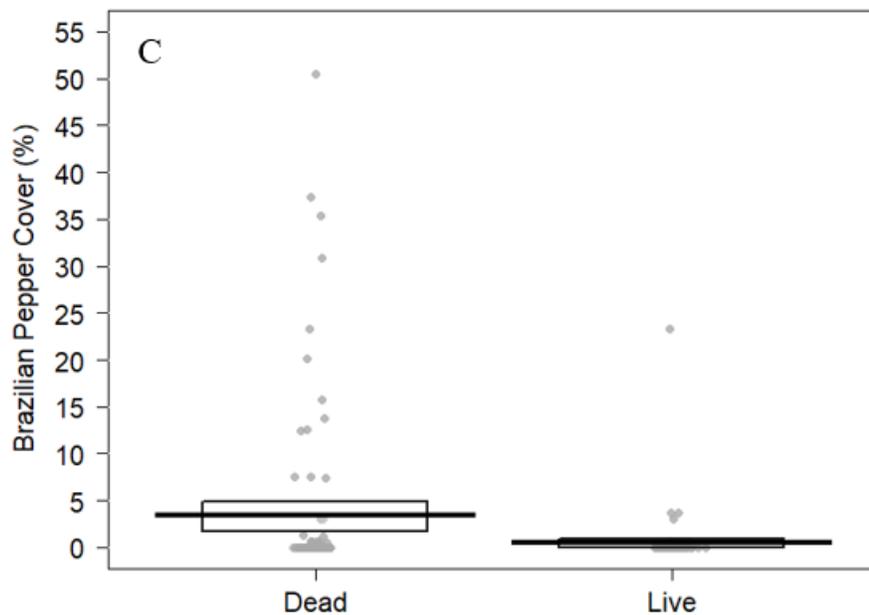
Figure 3. Comparisons of live and dead percent cover of each of the three target invasive species across all transects at Babcock Ranch Preserve. A) Live and dead cover of Old World climbing fern (*Lygodium microphyllum*). B) Live and dead cover of punktree (*Melaleuca quinquenervia*). C) Live and dead cover of Brazilian pepper (*Schinus terebinthifolia*). The black line represents the mean cover, and the boxes represent the 89% high density interval around the mean. Raw percent cover values for each transect are shown as grey dots.
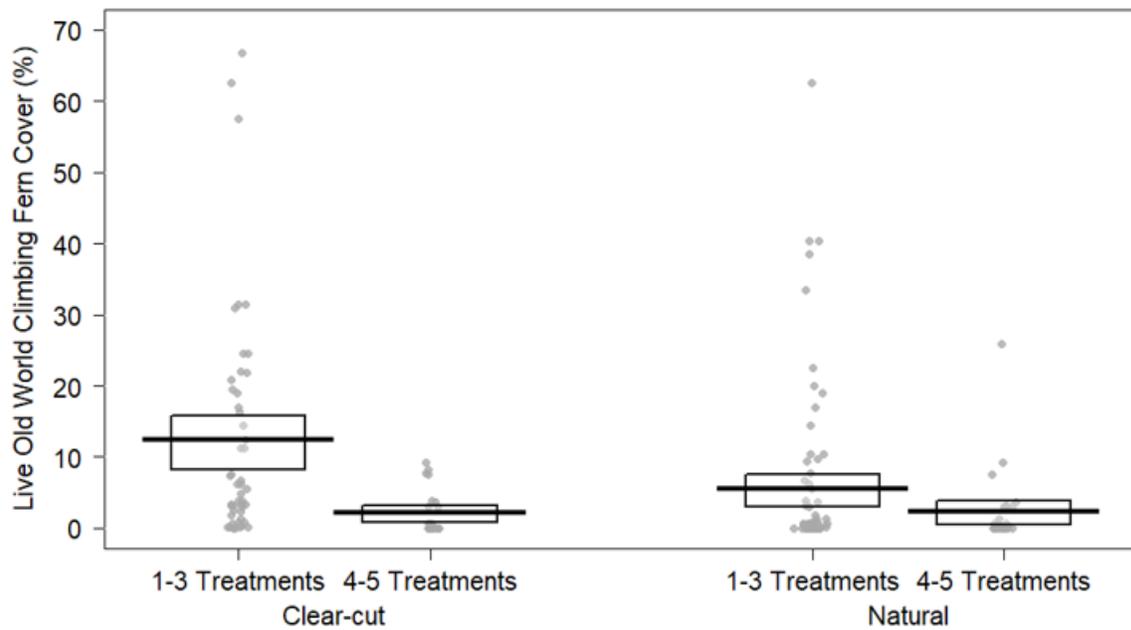
Figure 4. Comparisons of live cover of Old World climbing fern (*Lygodium microphyllum*) along transects in clear-cut and replanted areas (Clear-cut) and natural stands (Natural). Each management history group is further delineated into transects that were treated 1-3 times and those treated 4-5 times. The black line represents the mean percent cover, and the boxes represent the 89% high density interval around the mean. Mean percent cover values for each transect are shown as grey dots.