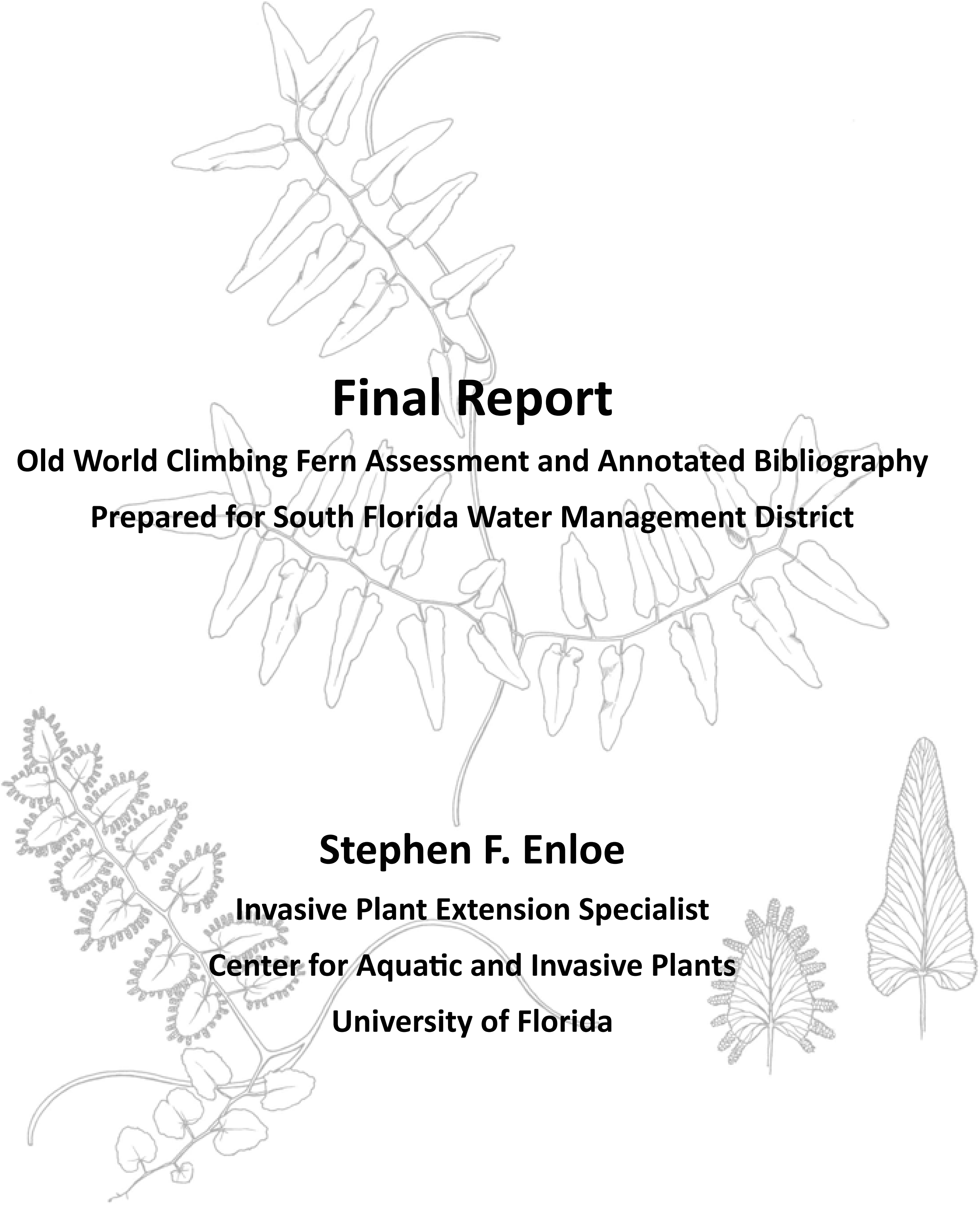

Final Report

Old World Climbing Fern Assessment and Annotated Bibliography

Prepared for South Florida Water Management District

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Introduction

Old World climbing fern is an invasive plant native to the wet tropical and subtropical areas of Australia, Asia, and Africa. It was first detected in Martin County, Florida in 1965. However, expansion in Florida was slow until the 1990's, when it literally exploded across south Florida. Many land managers quickly realized that this invasive species was a true ecosystem transformer, smothering out native plant species under dense rachis mats and altering fire frequency and severity, even in fire tolerant communities. Its aggressive spread by both unseen spores and creeping rhizomes in both disturbed and undisturbed habitats has made it one of the greatest invasive plant problems in south Florida. Infesting a broad range of habitats, Old World climbing fern can be found in cypress, bayhead, and maple swamps, sawgrass marsh, wet prairies, tree islands, mangrove communities, and many disturbed, wet areas.

In 1999, several State Agencies, Universities, and Private Conservation groups came together through the Florida Exotic Pest Plant Council to address the Lygodium problem and formed the Lygodium task force. The first Lygodium management plan for Florida was subsequently produced in 2001. In 2006, the Lygodium task force released the second version of the Lygodium management plan for Florida, which documented the known biology, ecology, spread, available management tools, and land manager experiences in dealing with this invasive plant. Since 2006, Lygodium management efforts have continued throughout south, central, and more recently, north Florida, as Lygodium has continued to spread. The task force initially committed to update the Lygodium management plan every five years. However, following 2006, there was considerable turnover of task force participants. Many moved to new jobs with new responsibilities, retired, or sadly, passed away. Subsequently, there have been no updates since the 2006 document was released.

In 2015, a small contingent of Lygodium managers convened at the Florida Exotic Pest Plant Council Annual Conference to discuss the future of the task force and Lygodium management issues. This project was subsequently conceived as an effort to determine exactly where Florida stands in relation to the problem and how South Florida Water Management District should proceed regarding research over the next five years. Additionally, the project was hopeful to reinvigorate interest in stronger statewide collaborative Lygodium management through rejuvenation of the Florida Lygodium Task Force.

Objective

The overall goal of this project was to determine “the state of the State” of Old World climbing fern in Florida. We sought to understand what has transpired over the last decade, since the Lygodium task force updated the 2006 second Lygodium Management Plan for Florida. We specifically wanted to survey the published literature since 2006 to understand what research questions have been answered from the 2006 plan. We then surveyed numerous land managers, state agencies, and University personnel to find out what was currently being done, what new or innovative tools were being used, where land managers were struggling, and what the research directions should be for the immediate future. Determining quantitative estimates of acres infested, rates of spread, or acres treated were beyond the scope of this project and are not included within.

Methods

Literature review. Searches were conducted using APIRS, Google, and CABI databases for all papers and citations published on Lygodium since 2006. The primary focus of the search was information pertinent to advancing management approaches. PDF documents were captured where possible and all relevant papers were summarized using a bibliographic approach. Additionally, we linked all published research back to the specific research questions that were posed in Appendix 1, p. 98-102 of the 2006 Lygodium Management Plan for Florida.

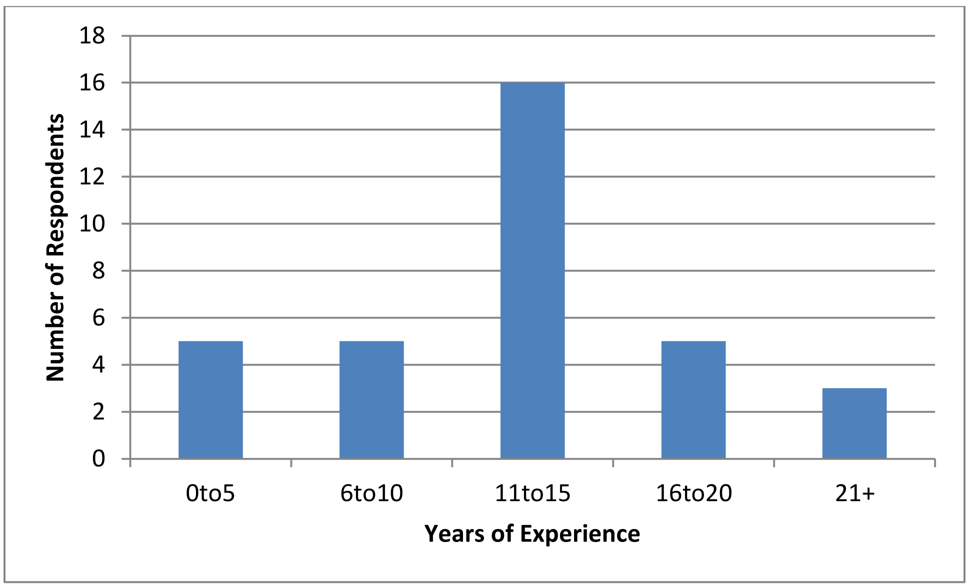
Individual interviews. Thirty-six individuals, consisting of Federal, State, and County Agency, University, and private Contractors were contacted and interviewed. Interviews were conducted by phone or in person, and interviews ranged in length from 30 to 75 minutes (mean interview time = ~45 minutes). Fifteen primary questions were discussed with each individual, with some additional follow-up questions for clarification, or when individual responses opened up a side bar of interest. During the interview process, questions were carefully worded to prevent influencing respondent’s answers. Not all respondents were able to answer all questions, as their role in Lygodium management did not include responsibility for that area. Respondent answers were recorded as accurately as possible and approximately 90 pages of text were transcribed. Interview data were then qualitatively coded and summarized by question across respondents’ answers, to highlight common themes, disagreements and outlier responses. Common themes were built on the discussion that followed each question with each participant.

Part I. Interview Results and Discussion

1) **How long have you been dealing with OWCF in your current and or previous position(s)?**

   Respondents had over 402 years of cumulative experience working with OWCF, with a mean of 11 years per respondent, and a range of 3 to 30 years. Almost 50% of the total respondents had 11 to 15 years of experience (Figure 1), which correlates well to when many State efforts against Lygodium began ramping up.

   Figure 1. Histogram of Respondent Experience with OWCF.



   This demographic indicates that respondents' answers were based upon considerable years of experience in managing OWCF. Gender demographics indicated approximately 2/3 male and 1/3 female. No other demographic data was captured, nor was the intent of this project to ascertain any demographic elements beyond years of experience.

2) **Describe your current OWCF overall strategy, then break it down by the following components (a-d):**

The overall strategies employed by most respondents followed a somewhat typical adaptive management formula for invasive plant management, including survey/detection, prioritization, treatment, monitoring, reassessment, and follow-up. *Lygodium microphyllum* is a top management priority for FWC and the Water Management Districts on Public Lands in South and Central Florida. Numerous efforts have been ongoing over the last decade with a strong emphasis on both protecting uninfested areas by treating new infestations and bringing dense infestations down to more manageable levels.

a. *Survey/Detection/Mapping approaches*

There is not currently a Statewide Survey Plan in Place and numerous independent entities are involved in piecemeal survey and detection efforts. These are largely done under tremendous personnel and budgetary constraints. Digital aerial sketch mapping has resulted in the most comprehensive geographically broad survey across a large swath of south Florida. Additional aerial surveys are highly desirable to many land managers but have not been systematically implemented. Several respondents reported opportunistic aerial mapping when they could hitch a ride on other planned flights (Manatee surveys, etc.) Remote sensing tools have been studied but no comprehensive efforts have been undertaken. Most land managers collect a wide range of OWCF ground based survey data on an opportunistic basis (i.e., when they can and where they can). However, on many State contracts, contractors do not have clear apriori knowledge of infestations at the time of the bid process. Spray crews systematically work thru these properties, treating as they go, but not necessarily collecting survey data.

b. *Treatment timing (Seasonal or all 12 months)*

The concept of an optimal treatment timing for OWCF to maximize control would be ideal, but it is completely unrealistic. Treatments can be and are done all 12 months out of the year in certain situations. Treatment prior to peak spore production is desirable and implemented as often as possible. Outlier infestations are frequently treated when found, to prevent any further growth and spread. In reality, there are several limitations to this. Some contractors try to avoid spraying in winter (January), especially during cold weather, when OWCF treatments seem to be less effective. Hydroperiod also strongly influences treatment timings in many situations. Access to remote sites is severely limited when water is too low and treatment is often impossible when water is too high. For example, seasonally high water in the summer prevents spray coverage of rachis mats that are temporarily inundated. These quickly begin growing as water recedes and control is nil.

c. *Treatment Techniques used*

Three herbicide techniques are used: The first is aerial foliar treatment. This is primarily done for large, dense patches and where access is limited. The second is ground based foliar treatment with backpack or handgun sprayers. This includes treating all matted Lygodium on the ground and all Lygodium climbing over other understory plants. The third is the integrated mechanical/chemical treatment of cutting vines at 4-5 feet (i.e., a "poodle cut"), pulling them off the trees if needed, and treating all foliage below the cut. There has really been no major breakthrough in these treatment techniques over the last ten years.

Hand pulling is also used on a limited basis, where very young infestations are detected. In these cases, an attempt is made to remove the entire rhizome, which is still small for new plants. Mowing, clipping, or other types of cutting are only used to create access trails into densely infested areas. These are not effective as standalone tools.

Fire is of great interest to many land managers and is still somewhat debated regarding its utility for OWCF management. The reality is that fire is widely needed and used as a landscape management tool and will continue to be utilized for many purposes beyond OWCF management. Many reports have provided mixed observations on the response of OWCF to fire. However, these have not provided any real clarification on impacts between individual plant responses and population level responses. It is very clear that OWCF is a fire adapted plant and its use in OWCF management needs to be clarified for both spore management as a standalone tool and when used in an integrated manner with herbicide treatment and biological control.

d. *Follow-up monitoring and retreatment schedule*

Follow-up monitoring and retreatment schedules vary widely and are affected by many issues. Time is the biggest issue for follow-up monitoring. Most respondents reported that they did not have enough time or personnel to do thorough post treatment monitoring. Many reported doing spot checks, to get a feel for overall treatment effectiveness. Short term monitoring occurs on contracted projects, to ensure contract requirements are met. These generally occur within a few months of treatment. However, contractors are often disconnected from monitoring efforts and do not go back to sites unless they receive a contract for subsequent year follow-up treatments. Some respondents reported that they attempted to do follow-up monitoring at six and twelve months after treatment. Others attempted annual follow-up monitoring of treated sites. Again, time and access often limited comprehensive monitoring.

3) What are the specific herbicide strategies you currently employ against OWCF?

Overall, glyphosate is the most widely used herbicide. One hundred percent of respondents indicated that glyphosate was the primary herbicide used for OWCF control. Glyphosate concentration ranged from one to five percent. Forty-seven percent of respondents used a 3% concentration, while 37% provided a range of 2-3%. Higher concentrations above 3% (up to 5%) were primarily used for very small or sparse infestations, under the premise that it was best to increase the rate to get complete kill in these situations. Lower rates (less than 2-3%) were rarely used.

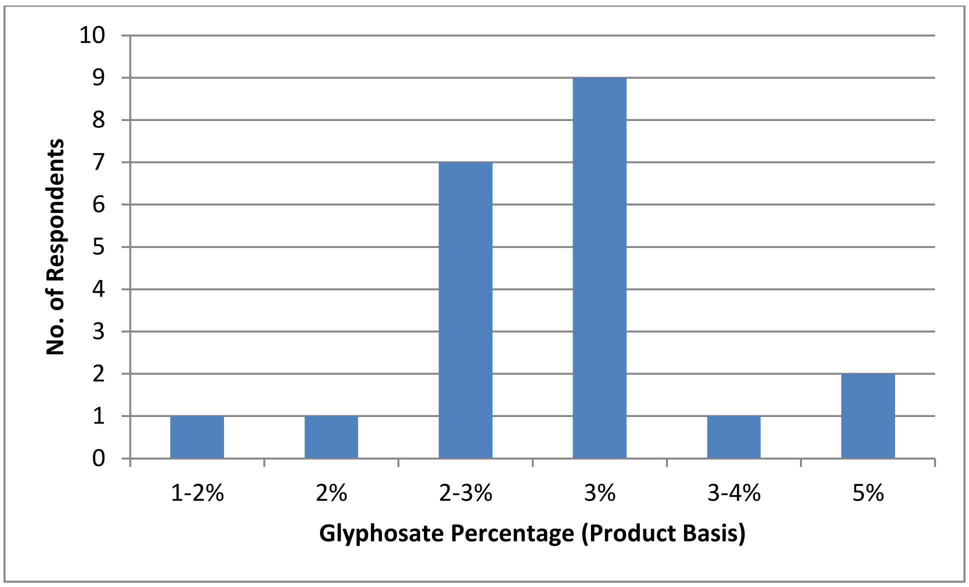
Metsulfuron was primarily used for aerial treatment, in accordance with the 24C label directions. This includes 0.5 to 2 oz/A for broadcast applications. However, some metsulfuron use was also reported for backpack treatments in accordance with the 24C label at a use of 0.5 to 2 oz/100 gallons for spot applications made on a spray to wet basis. In these cases, metsulfuron is primarily used when requested by site managers, either in a rotational fashion with glyphosate or in a tank mix with glyphosate. The key issue here is resistance management, which will be discussed further in question number six. For backpack use, metsulfuron is primarily limited by the 24C label language that specifies 0.5 to 2 oz/100 gallons of diluent. Applicators have observed reduced control at this rate and believe this is too low for effective control, when the total application volume by backpack is only 25-40 gallons per acre.

Side Bar: Regarding the future of the 24C label for metsulfuron. Additional interview questions were provided to Bayer Crop Science Representatives to ascertain the future of this label. The outcome of this discussion included the following: Bayer support s this 24C SLN. However, future renewal of this may require additional studies at a cost of $600,000 to $1,200,000. Bayer is likely to weigh the value of this cost against Escort sales for this use. Bayer is also concerned about the illegal use (swapping) of generic metsulfuron products that are not supported by the 24C label for Escort. At some point a meeting between Bayer Crop Science, EPA, IFAS, and all relevant Florida State Agencies should occur to forge a plan to move forward. Loss of Escort (metsulfuron) would be a severe setback to selective aerial treatment of Lygodium infestations across south Florida.

Triclopyr has not been widely used for OWCF control. Only eight percent of respondents indicated using triclopyr and concentrations ranged from one to three percent. Triclopyr was discussed to be an effective option. However, non-target damage to trees and shrubs is the primary issue, which will be further discussed in Question 10.

No other herbicides were reported to be widely used on OWCF. One applicator reported adding Milestone (0.25% v/v) with the standard Glyphosate treatment in certain situations. However, the utility of this has yet to be determined. It is also likely that there has been some imazapyr used, especially when treating other species. However, as a focused treatment for Lygodium, imazapyr is generally perceived to have too many non-target issues in most Lygodium situations.

Figure 2. Glyphosate concentration used for OWCF foliar treatment.



4) What adjuvants do you use for OWCF control?

Respondents indicated that several adjuvants are used including wetters, spreaders, stickers, and water conditioners. These include nonionic surfactants, nonionic silicone blends, methylated seed oils, and ammonium sulfate. Hard water conditions have resulted in apparent reduced glyphosate efficacy. However, discussion of the hard water issue and AMS use was limited to only a few applicators and most respondents did not mention it. In general, applicators frequently develop a relationship with specific adjuvant suppliers, or use the cheapest adjuvants they can find that suit their needs.

5) **Have you noticed any difference in efficacy among adjuvants?**
   It quickly became apparent that this adjuvant/efficacy question was not relevant in this discussion. Applicators use adjuvants they deem to work and that fit their programs. Rarely had any respondent paid attention to this issue. Only two things prompted applicators to really ask this question. These included: a) a lack of treatment efficacy not attributed to other issues and b) rapid foliar burn issues. One applicator reported experience that products containing limonene burned foliage too quickly, while one other applicator reported a foliar burn issue with a NIS in the hottest part of the summer.

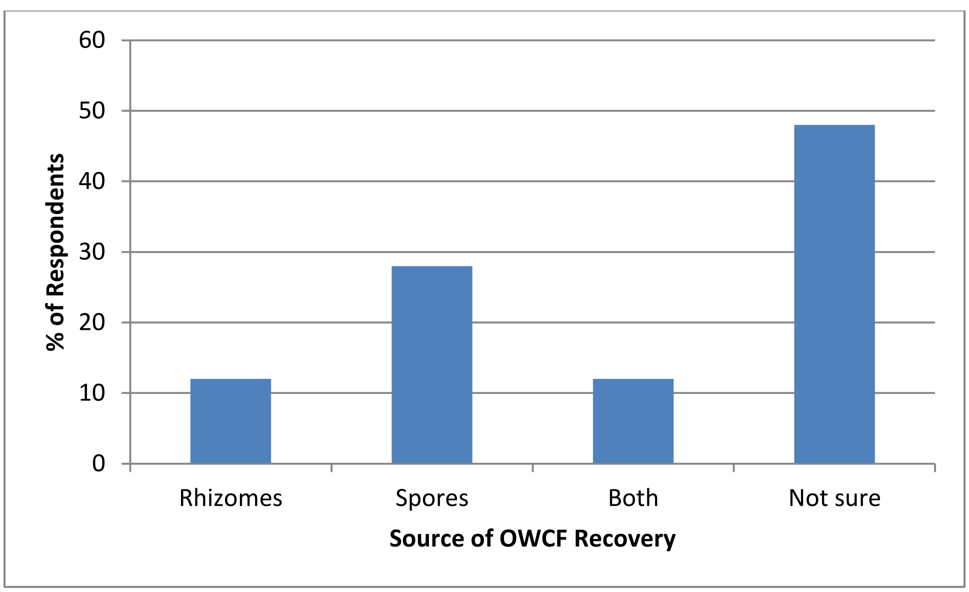
6) Have you experienced any catastrophic treatment failures, when you are confident that you did everything correctly?

All (100%) of the respondents reported to have never observed complete herbicide treatment failure with either glyphosate or metsulfuron. Many respondents indicated that incomplete control was commonly observed during follow-up monitoring. However, it was attributed to incomplete coverage due to thick rachis mats, difficulty in accessing areas to treat, or applicator error in missed swaths or missed patches. Follow-up treatment of these types of missed areas has always resulted in control. One case of metsulfuron reduced efficacy was reported to be due to very old product and another case of reduced glyphosate efficacy was due to hard water. This would suggest that herbicide resistance is still not a problem anywhere in the State for OWCF. A lack of evolving herbicide resistance to glyphosate and metsulfuron does beg the question, "Why not?" Both herbicides have resulted in resistance developing in agriculture and non-crop settings. Possible explanations for this include the following: 1) a lack of selection pressure (we are simply not treating at a high enough frequency); 2) high propagule (spore) numbers both from the spore bank and from new spores moving into treated areas from untreated stands. These could essentially wash out any buildup of resistance in the treated population; 3) a severe fitness cost due to resistance (not likely). Whatever the case, it would be useful to determine exactly what degree of selection pressure is required to drive herbicide resistance in OWCF.

7) Following herbicide treatment, do you primarily observe OWCF recovery from which source?

This question prompted considerable uncertainty among respondents, many of which paused for an extended time before answering. Only 25 out of the total provided a direct answer. Ten of the respondents could not answer due to a lack of responsibility for this area and thus, were excluded from the question. However, the clear result was that 48% of respondents were not sure in exactly where OWCF recovery was originating on sites they managed. The key explanations provided for this uncertainty included two main issues. The first is a lack time and personnel to do any thorough post treatment monitoring. Most respondents reported that they are dealing with extremely large areas and cannot spend time examining this issue. There is also a strong disconnect between contractors and monitoring efforts. Monitoring is usually done by site managers or other State personnel after the contractors work through a site. Only a few contractors interviewed reported that they used their own QC personnel to assess treatment efficacy. However, they were generally only looking for spray skips and missed treatment areas and were not looking at the source of recovery. There is some institutional knowledge among contractor spray crews where a given crew ends up treating a site over several years. However, this knowledge is difficult to access and may only be remembered when spray crews revisit sites.

Figure 3. Respondent views on Post-treatment OWCF Recovery (n=25).

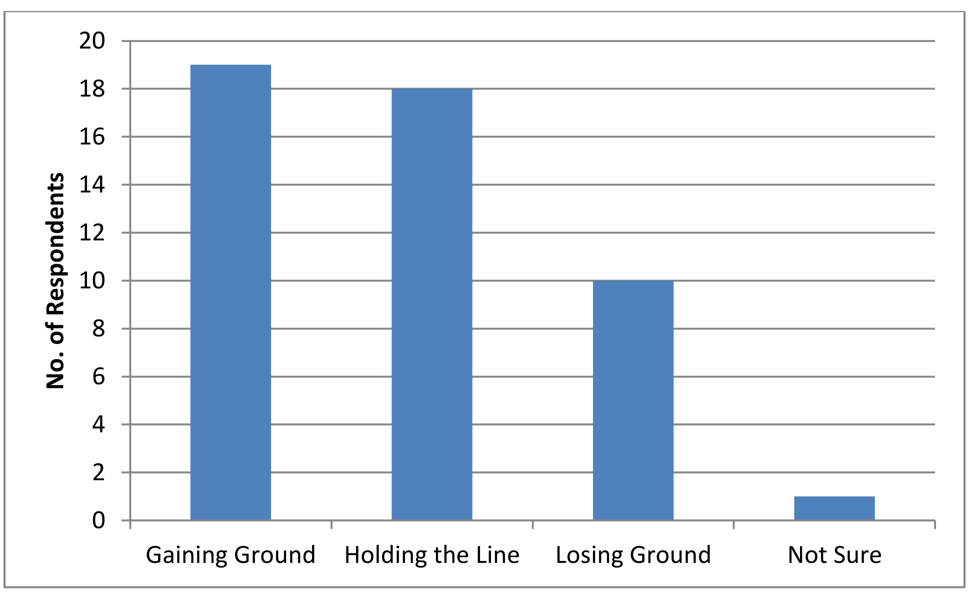


8) In your current OWCF strategy, are you:

a. Gaining ground against Lygodium
b. Losing ground to Lygodium
c. Holding the line against Lygodium
d. Not sure

Respondents were allowed to provide more than one answer for this question. This generated clarification of where they felt they observed situational specific successes and failures. Respondents that were able to do follow-up treatments generally felt they were gaining considerable ground (63%). No one stated or implied eradication, but felt they were able to bring severe infestations under maintenance control. One contractor noted that for most recent Lygodium contracts, infestations were much less severe than those of ten years ago. Sixty percent of respondents felt they were holding the line, but also noted that concept is difficult to judge due to long distance spore dispersal. Respondents involved with the Central Florida Lygodium strategy felt they were holding the line by a thread, but also felt strongly that the monitoring was worth the continued investment. Anthropogenic long distance dispersal beyond the sentinel sites was a great concern to future northward spread. Money was frequently mentioned as the key factor in their assessment. Where money was limited for retreatment, respondents almost always felt they were losing ground (33%). Private lands were widely viewed as losing ground, as were Public lands with very limited exotic plant management resources. Areas characterized by limited access due to geographic remoteness or seasonal hydroperiod were also perceived to be losing ground.

Figure 4. Respondents' perceptions on progress against OWCF (n=30).



9) **What type of tool or tools do you think would most improve your OWCF management strategy?**

This question prompted a tremendous diversity of responses, which included the following. Responses are ranked by 7 categories.

Herbicide related (13 total)
-Herbicide retreatment interval strategy (2)
-Herbicide with residual effects against spores (1)
-Herbicides for better rhizome kill (3)
-More selective herbicides (3)
-Escort 24C label modified for low volume (1)
-Escort label increase to 3 oz/A (1)
-Herbicide treatment sequences for different community types (1)
-Herbicide rotational treatment for reduction in spore production (1)

Detection/Monitoring related (8 total)
-Increased use of helicopters for detection (1)
-improved aerial detection/monitoring (1)
-GPS waypoint for every remote infestation (1)
-Upgrading to use GIS (1)
-Drones for detection (1)
-UAV automated survey (1)
-Decision tool for prioritizing areas to search (1)
-Better reconnaissance in bay swamps (1)

Biocontrol related (8 total)
-more effective biocontrol agents (8)

Money and personnel related (7 total)
-Funding (3)
-more contractors/personnel (3)
-increased public/private partnerships (1)

IPM related (5 total)
-IPM for fire/herbicide/biocontrol (5)

Fire related (3 total)

-Improved fire ecology/fire management strategies (3)

Lygodium biology and ecology (3 total)
-knowledge of spore viability (1)
-cold weather effects (1)
-response to salinity (1)

The diversity of responses to this question is indicative of several important things. First, it is clear that respondents are indeed thinking about the Lygodium issue extensively. Land managers want to win this battle and they clearly need more tools to do so. The second is the diversity in tools suggested. Land managers want more tools in the toolbox. The third is the clear need for an accelerated program of herbicide research, as the toolbox is strikingly limited. The fourth is a greater emphasis on biological control and its integration with herbicides and fire.

10) Are you seeing any positive impacts of the current biocontrols on OWCF?

Respondents overwhelmingly answered NO. Most respondents provided some knowledge of both the brown lygodium moth (*Neomusotima conspurcatalis*) and the Lygodium gall mite (*Floracarus perrepae*). Many reported USDA brown moth releases on their managed site(s). However, moth establishment was often observed to be very limited or it failed completely. When asked to describe the extent of visual damage observed, moth damage was commonly reported as limited, minor, spotty, sporadic brown patches, or totally nonexistent. No landscape scale damage was reported. The strongest impact was reported from Johnathan Dickenson State Park where considerable brownout of localized patches was observed.

Respondents generally had less experience with the gall mite. Several respondents reported observing some mite spread and damage, even when no mites had been released on site. Optimal impacts of mites were reported to be observed on new growth following fire. In one situation, Lygodium height was reportedly reduced by sixty to seventy percent. However, in general, mite damage was reported as extremely limited.

The comment was also made that there have been few releases on NRCS conservation easement properties. Recommendations on biocontrol included:

1) Increased research efforts. Biocontrol efforts have been stymied over the last decade by significant employee turnover at USDA-ARS. The permanent hiring of two new scientists should help the workflow considerably. Specific research topics include:
    a. Interactions of current biocontrol agents with other management strategies. Key interactions include prescribed fire, herbicide treatment, and combinations of all three.
    b. Interactions of current biocontrols with parasitoids that may be limiting moth populations.
    c. Interactions of biocontrols and seasonal hydroperiod.
    d. Exploration for subterranean insects as biocontrols, including rhizome borers.
    e. Stem borers
2) Increased releases of the current insects, especially on private lands, where future management may be limited.

11) **Do you see buy in from surrounding private landowners to treat OWCF? What will it take to get buy in?**

The private landowner issue is of immense concern to many respondents and no one has a clear solution for this issue. Interactions with private landowners are often very limited or non-existent. Many public lands in south Florida border other public lands on most sides. Public lands adjacent to large private landowners provide opportunity for some interaction, while Public lands bordering large scale urban development result in very limited interaction. Absentee land ownership is also a significant issue as is private land planned for future development. In this case there is no incentive to treat Lygodium until mitigation opportunities arise.

Respondents who do interact with large private landowners indicated that many of them are well aware of Lygodium problems on their properties. However, they generally cannot afford to treat natural areas. Many of these are ranchers and do not manage invasive plants in natural areas where they do not impact forage production. The most responsive private lands situations are generally where high value hunting leases generate an economic return that allows for Lygodium treatment.

NRCS programs offer private landowners significant cost sharing opportunities for invasive plant treatment, including Lygodium. This has resulted in treatment on many properties for landowners who are willing to enroll in the program. The long term outcomes on these programs are uncertain.

The Central Florida Lygodium Strategy has likely had the most success in interacting with private land owners on the Lygodium issue. Since 2005, they have surveyed almost twenty thousand acres and treated over 1,300 acres of private land. They report that very few private landowners have declined to participate in the effort. As a “hold the line” strategy for containment of Lygodium and protection of conservation lands, the CFLS annually reassesses the effort to decide if it is worth continuing. To date, there has been tremendous positive response to continue the effort.

12) What are key non-target impacts that need to be lessened when treating OWCF?

The non-target issue is both incredibly complex geographically and somewhat surprisingly simple in reality. The complexity lies in the sheer numbers of ecological communities and species within those communities that could be of concern for non-target damage from herbicide treatment. This is something that applicators are well aware of, but it becomes lessened within some site specific realities.

The foundational issue is the stark reality of a “do-nothing” approach for Lygodium management. Where Lygodium is allowed to grow unchecked, it tends to smother out most or all other herbaceous ground cover species. Where it canopies over trees and shrubs, the smothering effect, combined with the fire ladder effect, result in loss of mid and overstory species. These characteristics strongly indicate its potential role as an “ecosystem transformer” by altering species richness and diversity, and altering habitat structure. Following these basic alterations are likely a host of cascading effects on other ecosystems services and trophic relationships. However, these have not been well studied, especially across different community types. Regardless, respondents were clear on the basic premise that there was nothing left underneath dense OWCF mats to worry about killing because it was already gone. The direct impact of Lygodium far exceeded many concerns of non-target impact. With this in mind, specific herbicides and application techniques require the following discussion.

Non-target damage was reported to not be a significant issue by many respondents. Clarification on this generally pointed to the techniques being used. Non target damage was rarely seen with poodle cutting followed by glyphosate treatment. For sparse infestations, non-target damage was minimized where possible by pulling vines off of other vegetation before treatment or by covering native species before treatment. However, this was not always possible and some collateral damage was expected in those situations, especially with glyphosate. For aerial treatment, metsulfuron was observed to be much less injurious to many trees compared to glyphosate or triclopyr. However, metsulfuron was observed to injure or kill many native ferns, palms, and maples, including royal fern, sable palm, cabbage palm and maple. Overall, the general consensus among applicators was that for broadcast applications, metsulfuron resulted in the least amount of non-target damage. Furthermore, it could be safely applied to sawgrass and bromeliads where glyphosate could not be applied without severe damage. Glyphosate could be utilized over deciduous woody species in the dormant season (cypress) with minimal negative impacts. On a final note, it is quite interesting that respondents provided very few species of importance negatively impacted by herbicide treatment. Reasons for this were not explored, but may be an indication of a general lack of time spent examining non-target injury.

13) Do we need an OWCF task force? If so, what should be its role?

Respondents were largely supportive of the need for a task force. Ninety one percent agreed the task force is needed. The enormity of the problem dictates some centralized coordination of information. However, clarification of the role of the task force was requested. Who exactly is the task force serving? Who exactly is the target audience?

A number of benefits were discussed and included getting people together, updating the management plan, formulating the necessary questions, providing technical updates as they emerge, developing additional tools, disseminating the updates in a timely manner, sharing experiences, assisting detection and reporting, providing leadership on treatment, updating the current and potential range, addressing vectors, coordinating between public and private land owners, reaching out to roadside managers, All of these can help focus efforts.

Some advice was also provided by many participants. Time is precious and frequent, regular meetings are not needed. We need to include contractors to share experiences. We need day to day leadership. No coordinator equals no momentum and a loss of the spotlight on the problem! The Everglades CISMA has taken on the task force role somewhat, but not for the entire State. The task force must be functional. The 2006 Lygodium management plan document was very helpful and needs to be updated. Everyone is currently disconnected and this is not good. Can the task force help overcome this? Meet every two years, somewhere nice, get the big picture, and see what questions have been answered.

The no votes provided two key points. We should instead expand the IFAS Aquatic Weed Control Short Course to include more upland issues and cover Lygodium.
It is too little too late, we should go treat Lygodium instead.

14) Are there any additional comments that you might have?

Most respondents did not have many final comments to end the interview. However, most were very grateful that this project was being conducted. The following is a final list of questions posed in a brief session of brainstorming at the end of each interview.

1. Are we doing all we can?
2. Does aerial treatment do more harm than good?
3. How bad will Lygodium get in semi-flooded habitats?
4. Can anything be done in sand mining tailings areas, where treatment has been futile?
5. It is important to avoid an overwhelming sense of futility. The focus must be on what you are protecting.
6. The herbicides in the truck are what I will use in many cases. This is reflective of the operational realities of treatment.
7. What is the best decontamination protocol?
8. What is the spore fate in brackish/saline waters?
9. Does live Lygodium carry a fire better in cypress than dead Lygodium?
10. What is the best IPM sequence of treatments?
11. Can we develop treatment intervals for optimal control?
12. Can we develop data on success criteria related to State Contract Projects?
13. Is Lygodium hybridization an issue?

15) What other people I should talk to that are Lygodium experts or have considerable experience controlling Lygodium?

This question was used to progressively expand the interview list and ensure thorough coverage of the State. Respondents generally provided three to five names of other Lygodium focused individuals they were aware of. The list was then expanded until respondent recommendations became repetitive. Almost all recommended individuals were subsequently contacted and interviewed.

Part II. Annotated Bibliographic Literature Review

1. **Fujisaki I, Brandt LA, Chen H, and Mazzotti FJ. (2010). Colonization, Spread, and Growth of *Lygodium microphyllum* on Tree Islands in a Wetland in Florida. *Invasive Plant Science and Management* 3: 412-420**

Monitored colonization, spread, and growth on tree islands in Loxahatchee to determine the effect of environmental factors. The number of patches increased over the ten year study period; however the mean patch area and height did not increase. Water depth affected both number of patches and height, with more patches occurring in low water and taller patches occurring in high water. A pattern of growth from the exterior toward the interior of the tree island was observed, however patches of OWCF were less likely to occur in the sawgrass dominated margins than areas inhabited by woody plants.

2. **Hutchinson JT and Langeland KA. (2015). Response of Old World climbing fern and native vegetation to repeated ground herbicide treatments. *Journal for Aquatic Plant Management* 53: 14-21**

Hutchinson and Langeland (2015) examined the effect of four herbicides (glyphosate, metsulfuron, triclopyr, and imazapic) applied alone and in combination every six months for two years (4 total applications) at six sites in south and Central Fl. They found all herbicide treatments reduced OWCF cover to less than 4.4% at 24 MAIT with no differences between them. They observed that OWCF recovery was initially from rhizome sprouts at 6 MAIT. However, at 12, and 24 MAIT, OWCF cover was primarily from spore germination. Native cover declined after initial treatment, but increase in most treatments to near pretreatment levels. However, composition changed from late successional ferns to ruderal species. They concluded that a follow-up treatment at 6 MAIT help control the initial stand and then subsequent follow-up treatments every six months to control new recruitment from spores.

3. **Hutchinson JT and Langeland KA. (2014). Tolerance of *Lygodium microphyllum* and *L. japonicum* Spores and Gametophytes to Freezing Temperature. *Invasive Plant Science and Management* 7: 328-335.**

OWCF and Japanese Climbing fern spores were exposed to different periods of freezing (0, 0.25, 0.5 0.75, 1, 3, 6 or 12h) to determine the effect of freezing on germination rates. Although OWCF spores were highly susceptible to freezing, with 100% necrosis exhibited 24 hours after exposure, 6 months after freezing new growth was observed for exposure times less than or equal to 6 hours. This indicates that OWCF may have the potential to spread further North.

4. **Hutchinson JT and Langeland KA. (2013). Susceptibility of Old World Climbing Fern (*Lygodium microphyllum*) Gametophytes to Metsulfuron Methyl. *Invasive Plant Science and Management* 6:304-309.**

Treatment of gametophytes led to ~1% survival (compared to 36% in the untreated control). Low doses of metsulfuron (<432 mg ai/L) increased survival. No sporophyte development occurred when dosed at or higher than standard field treatment (432 mg ai/L). Sporophyte biomass also decreased with increased concentration. There is the potential for resistance at low concentrations of metsulfuron (<432 mg ai/L), likely through enhanced herbicide metabolism.

5. **Hutchinson JT, Puri A, Royuela M, and Langeland KA. (2012). Biochemical assay on acetolactate synthase activity in *Lygodium microphyllum* exposed to metsulfuron. *Biological Sciences* 75: 105-112.**

ALS was rarely found in the foliage of Old World Climbing fern when taken from samples grown in laboratory conditions. This may indicate that the ALS enzyme is largely present in the rhizomes of OWCF and metsulfuron is effective due to preventing the formation of new rachis. In vitro bioassays indicated OWCF ALS is sensitive to metsulfuron at concentrations as low at 100 ppb. Although overall translocation of metsulfuron is limited, it appears that the low amount that moves to rhizomes is sufficient to inhibit ALS. This paper provides some baseline data for future monitoring for metsulfuron resistance.

6. **Hutchinson JT and Langeland KA. (2012). Repeated Herbicide Application for Control of Old World Climbing Fern (*Lygodium microphyllum*) and the Effects on Nontarget Vegetation on Everglade Tree Islands. *Invasive Plant Science and Management* 5: 477-486.**

Comparative study of the effects of annual aerial and ground herbicide treatments. Initial aerial treatments had a strong effect with metsulfuron treatments decreasing OWCF coverage by >98% and glyphosate treatments reducing coverage by >88%. Follow-up ground treatment maintained low levels of OWCF coverage (1-2% pf pretreatment metsulfuron, 8-10% glyphosate). Survival rate of non-target species was lower for glyphosate (6-20%) than for metsulfuron (65-93%). This study shows aerial treatment can be used for control but follow-up ground treatments are required and should be conducted within 1 year of aerial application. Necessary repeats may be partially due to spores remaining in soil and debris as well as windblown spores.

7. **Hutchinson JT and Langeland KA. (2011). Tolerance of Old World Climbing Fern (*Lygodium microphyllum*) Spores to Herbicides. *Invasive Plant Science and Management* 4: 411-418.**

Studied spore germination rates when exposed to six herbicides (metsulfuron, imazapyr, glyphosate, fluroxypyr, asulam, and triclopyr. Spore germination rates were much lower for spores exposed to metsulfuron (0.4% at 0.1 g ai/L) and 0% at rates greater or equal to 0.2 g ai/L compared to a control (47.9% germination 30 DAT). This indicates that metsulfuron may have translocated through the cell wall. Spore germination rates with the other herbicides ranged from 10.4% with triclopyr to 42.6% with asulam, indicating that spores are more tolerant to these herbicides than metsulfuron. The I95 value for spore germination with metsulfuron was 63 mg ai/L, which was 1000 times lower than any other herbicide. The effect of metsulfuron on native fern spores should be considered and investigated as well.

8. **Hutchinson J and Langeland K 2010. Monitoring of applied management techniques to control Old World Climbing Fern (*Lygodium microphyllum*) in disturbed habitats. Florida Scientist 73(3/4):262-273.**

Hutchinson and Langeland 2010 looked at the response of OWCF to fire and a tank mix of glyphosate + metsulfuron in disturbed habitats. They found that at sites where fire and herbicides were used in an integrated manner, other non-native plants rapidly occupied the niche left open after OWC cover was reduced by the treatments.

9. **Hutchinson JT, Langeland KA, MacDonald GE, and Querns R. (2010). Absorption and Translocation of Glyphosate, Metsulfuron, and Triclopyr in Old World Climbing Fern (*Lygodium microphyllum*). *Weed Science*. 58: 118-125**

In response to reports of repeat applications being necessary in *L. microphyllum* management, this study investigated absorption and translocation patterns for glyphosate, metsulfuron, and triclopyr in different application scenarios, (cut and spray, basal spray, 25% foliar spray, 50% foliar spray, and 100% foliar spray). Radioactively tagged herbicides were used to evaluate absorption and translocation. Triclopyr (1.68 kg ai/ha) had almost double the absorption (60.3%) compared to glyphosate (31.2%) and metsulfuron absorption was substantially less (19.8%). Most of the compound remained in treated leaf are or rachis. All three of the tested compounds showed basipetal and acropetal movement, although this was minimal. Limited translocation into the rhizomes and no observed horizontal translocation corroborated reports of resprouting and required retreatment.

10. **Hutchinson J and Langeland K. 2008a. Control of Old World Climbing Fern with increased rates of glyphosate and metsulfuron under greenhouse conditions. Florida Scientist 71(3):201-207.**

Hutchinson and Langeland (2008) studied 2x max label rates for glyphosate (9.4 kg ae/ha) and metsulfuron (168 g ai/ha). They found complete control with no regrowth under greenhouse conditions. However, neither herbicide inhibited new spore germination nor new sporophytes were observed in as little as five weeks after treatment. No data was presented on whether or not new sporophytes emerging following treatment developed fertile leaflets by the end of the study. They concluded that additional research was not necessary on above label rates of either herbicide since retreatment would be required anyway to address new spore germination.

11. **Hutchinson JT and Langeland KA. (2008b). Response of Selected Nontarget Native Florida Wetland Plant Species to Metsulfuron Methyl. *Journal for Aquatic Plant Management* 46: 72-76**

Five rates of metsulfuron methyl were tested on native wetland species to assess non-target damage. Lizard's tail, golden canna, fire flag, swamp fern, and cinnamon fern were severely affected by metsulfuron treatments (0-46% survival rate in treated replications). Some of the species were more resistant to lower rates or had variable survival rates (soft rush, sand cord grass, and swamp lily). Sand cord grass had 87-100% survival rate, while soft rush had a 100% survival rate across all treatments. Buttonbush had a 60-100% survival and swamp lily was the most variable with a 19-88% survival rate in treated replications. Based on the high rates of necrosis, conservative ground applications should be used over aerial spray in order to reduce non-target damage.

12. **Hutchinson J and Langeland KA. (2007). Final Report: Evaluation of Current and Potential New Herbicides to Control *Lygodium microphyllum*. DEP Contract Number: 078 Task Number: 078 UF Project Number: 63022.**

When performing ground treatments of Old World Climbing Fern glyphosate (2-4%), metsulfuron methyl (2 oz. product/ 100 gal), triclopyr (2%) and imazapic (1.5%) are the most effective while minimizing non-target damage. Tank mixes are also effective but do not eliminate the need for retreatment for control but showed no significant difference in control. Further testing should be done on increased rates of triclopyr, imazamox, penoxsulam and aminopyralid as well as fluroxypyr. Environmental factors can drastically affect the efficacy of treatment.

13. **Hutchinson J and Langeland, K. 2006. Survey of control measures on old World climbing fern (*Lygodium microphyllum*) in Florida. Florida Scientist 69(4):217-223.**

Hutchinson and Langeland (2006) surveyed natural area managers (95% public lands) in 2004 across south Florida regarding OWCF management practices. They summarized data received back from 19 out of 130 surveys sent out (14.6% response rate). They found 68% of respondents characterized OWCF as the most serious threat to natural communities in south Fl. Managers averaged large areas of responsibility (~44,000 ha) and had a low number of trained applicators for the given area. Glyphosate was the dominant herbicide used (100%) while metsulfuron (27%) and triclopyr (18%) were used by far fewer managers. The most successful method was cut and spray, followed by foliar spray. Most managers (72%) treat all year. Managers reported that a single herbicide treatment resulted in 85% mortality, while sequential treatments resulted in ~95% mortality. Fifty percent of respondents retreated in six months or less while 44% retreated in less than 1 year. Fire was a generally uncertain, largely unused tool for OWCF management. Eighty five percent of respondents had an invasive species management plan. 45% of respondents do post treatment monitoring and 95% maintain records of treatment. Only 31% use sanitation to prevent spore dispersal. The limiting factors include time, personnel, funding, site access, and lack of management on adjacent properties.

14. **Langeland, K and Link, M.2006.Evaluation of metsulfuron methyl for selective control of *Lygodium microphyllum* growing in association with *Panicum hemitomon* and *Cladium jamaicense*. Florida Scientist 69(3):149-156.**

Langeland and Link (2006) examined the response of OWCF to metsulfuron at 1 and 2 oz/A applied with a backpack sprayer at ~100 GPA. They found that 2 oz/A applied annually for two years resulted in 94% control 702 days after initial treatment. However, regrowth 14 months after the second treatment. They also examined the response of *Panicum hemitomon* and *Cladium jamaicense* to metsulfuron and found no significant injury to either monocot. Additionally, only transient in jury was noted on *Cephalanthus occidentalis* from metsulfuron treatment.

15. **Hutchinson, J. 2006. Potential spread of *Lygodium microphyllum* spores by herbicide applicators. Wildland Weeds (Spring):13-15.**

Hutchinson sampled OWCF applicators and found a high degree of contamination among boots, clothing and equipment. Guidelines for decontamination are provided, including equipment wash-downs before leaving the site, washing all clothing daily, and limiting vehicle movements through heavily infested areas.

16. **Maldonado AN. (2009).valuation of three-dimensional patterns and ecological impacts of the invasive Old World Climbing Fern (*Lygodium microphyllum*). Master's Thesis, University of Central Florida. 86 pp.**

Abstract. Invasion by non-native species has had significant ecological and economic impacts on a global scale. In the state of Florida, Old World climbing fern (*Lygodium microphyllum*) is an invasive plant listed by FLEPPC as a category one invader with significant ecological impacts that threaten native plant diversity. This species relies on existing vegetative structures for support to climb into the forest canopy and forms dense mats that cover tree crowns. This subsequently affects the resources available to other species present. Quantifying the structural changes due to the presence of this species has proved logistically difficult, especially on a large spatial scale. Airborne LiDAR (Light Detection And Ranging) technology is a form of remote sensing that measures the elevation of surfaces over a site. In this study I utilized LiDAR to calculate various forest structure metrics at Jonathan Dickinson State Park (JDSP) in Hobe Sound, Florida across various management frequencies and densities of Old World climbing fern. These data were used to quantify the degree to which this invasive species alters forest structure across these two gradients. I also recorded species composition in the field to relate how Old World climbing fern impacts native plant diversity. Structural measurements including average canopy height, height of median energy (HOME), rugosity, canopy openness, and vertical structural diversity (LHDI) were calculated for a total of three hundred 0.25ha sites stratified by invasion density and management frequency. Using a combination of univariate and multivariate statistical analyses I found that the presence of Old World Climbing fern altered the physical structure of the forest communities it invades. Higher percent cover of Old World climbing fern decreased structural diversity while increased management effort was found to mitigate those impacts. The management for Old World Climbing fern was also found to impact both species richness and diversity at JDSP. I also demonstrated that there were several species that were not found and others that were more common in the presence of Old World climbing fern and that there was a relationship between management and what species were present. The results show that both Old World climbing fern and the management practices used to control it have had significant ecological impacts on the natural communities in South Florida.

17. **Sebesta, N (2015). The effects of fire on spore viability on *Lygodium microphyllum* (Old World Climbing Fern). Master's Thesis, Florida International University. 44 pp.**

Abstract. *Lygodium microphyllum*, native to the Old World tropics, has invaded central and southern Florida, destroying native habitats, reducing biodiversity and altering fire regimes. Prescribed fire, one of several methods used to manage *L. microphyllum* infestations, reduces fern biomass over large areas, but its effects on spore viability are unknown. To provide tools to evaluate whether fire-dispersed spores are viable, this research determined how heat affects spore viability. Spores were exposed to temperatures of 50°C to 300°C for durations of 5 seconds to 1 hour, then allowed to germinate on agar in petri plates. Percent germination was assayed after two weeks. Temperatures of 50°C had little effect; 300°C killed spores for all durations. Results indicate that while viability of unburnt spores decreases with increasing temperature and duration of heat exposure, spores are killed when exposed to relatively low temperatures compared to those in fires.

18. **Soti PG, Jayachandran K, Purcell M, Volin JC, Kitajima K. (2014). Mycorrhizal symbiosis and *Lygodium microphyllum* Invasion in South Florida - a biogeographic comparison. *Symbiosis* 62: 81-90.**

Field root samples showed high colonization of arbuscular mycorrhizal fungi in drier conditions, such as those in Florida, compared to the wetter native conditions. Growth Chamber experiments also indicate increased rates in plants with mycorrhizal interactions. *L. microphyllum* appear to be dependent on mycorrhizae for nutrient and phosphorus uptake and that mycorrhizae play a fundamental role in vegetative reproduction and enhancing the invasiveness of Old World Climbing Fern.

19. **Stocker R K, R E Miller, D W Black, A P Ferriter, and DD Thayer. 2008. Using fire and herbicide to Control *Lygodium microphyllum* and effects on a pine flatwoods plant community in south Florida. Natural Areas Journal 28(2):144-154.**

Stocker et al. (2008) examined burning integrated with full foliar triclopyr treatment (using undiluted Pathfinder II) at retreatment frequencies of bimonthly and biannually. They found that bimonthly was similar to biannual treatment for OWCF cover and that integrated fire did not improve OWCF control. The triclopyr rate used in this study is indicative that even extraordinarily high rates (5-6x the max label rate) of triclopyr will not eradicate OWCF.

20. **Toth L. 2009. Hydrologic restoration of wetlands on the Kissimmee River flood plain: complementarity of an herbicide treatment of the exotic vine *Lygodium microphyllum*. Florida Scientist 72(2) 103-120.**

In a unique study, Toth (2009) combined restoration of hydrologic regimes with glyphosate treatment in the Kissimmee river floodplain for OWCF management. He found glyphosate nearly eliminated OWCF while hydrologic restoration shifted the plant community toward the desired goal. However, uncontrolled OWCF inhibited the restoration trajectory of the wetland community.

21. **Volin JC, Parent J, and L. Dreiss. (2013). Functional basis for geographical variation in growth among invasive species. *In:* Jose, S., Singh, H.P., Batish, D.R. and Kohli, R.K. (eds.) *Invasive Plant Ecology*, CRC Press, Taylor & Francis Group (ISBN13: 9781439881262).**

Although it is predicted only 10% of nonnative plants become invasive, those that become invasive have the capacity to cause economic and ecosystem damage. One of the most commonly discussed hypotheses for invasive success is the 'enemy release' hypothesis that suggests that decreased/no pressure from predators or disease promote success in novel environments, which is expressed in *Lygodium microphyllum* due to lack of natural soil borne enemies. Another hypothesis states that decreased predation pressure in an novel range will promote growth and reproduction over defense mechanisms in the nonnative plant; however, studies using *L. microphyllum* do not support this hypothesis. *L. microphyllum* is homosporous, giving it the ability to produce bisexual gametophytes and utilize three different reproductive strategies (Intragametophytic selfing, intergametophytic selfing, and outcrossing). Intragametophtic selfing allows for long distance dispersal due to only needing a single gametophyte to establish. The hydrological plasticity that *L. microphyllum* exhibits gives it a distinct advantage over native species as they can outcompete natives in a variety of hydrological conditions. Based on soil studies involving sterilized soil from its native range and three separate populations of OWCF the invasiveness of *L. microphyllum* is in part due to lack of soil borne enemies.

22. **Volin JC. (2010). Invaders. *Current conservation*. 4.1: 29-32.**

Summary article describing same aspects as previously listed paper (Functional basis…Volin et al 2013).

23. **Volin, J.C., M.S. Lott, J.D. Muss and D. Owen. 2004. Predicting rapid invasion of the Florida Everglades by Old World Climbing Fern (*Lygodium microphyllum*). *Diversity and Distributions* 10:439-446.**

Lygodium microphyllum possesses most traits that are considered to increase competitive ability including self and wind pollination, rapid growth, high and continuous spore production, long and short range dispersal methods and sexual reproduction. *L. microphyllum* is also very efficient in its carbon use, which contributed to its exponential expansion in a short period of time, unlike many other invasives.

24. **Gandiaga S, Volin JC, Kruger EL, and Kitajimak K. (2009). Effects of hydrology on the growth and physiology of an invasive exotic, *Lygodium microphyllum* (Old World climbing fern). Weed Research 49:283–290.**

Gandiaga et al. (2009) manipulated hydrology in a glasshouse study to determine the impact on OWCF growth. Flooding reduced growth rates of OWCF. However, it still maintained positive growth rates even after two months of inundation. They found considerable plasticity in response to altered hydrology and concluded that short term hydrologic manipulation would not be an effective management strategy.

25. **Volin JC, Krueger EL, Volin VC, Tobin, MF, Kitajima K. 2010. Does release from natural belowground enemies help explain the invasiveness of Lygodium microphyllum? A cross-continental explanation. Plant Ecology 208:223-234.**

Volin et al. (2010) tested the natural enemies release hypothesis (belowground focus) and the EICA (Evolution of increased competitive ability) hypothesis for OWCF from Florida and its native range. They found evidence for increased growth due to release from soil borne natural enemies. This may suggest biological control efforts should increase focus on belowground efforts.

26. **Soti, PG, K Jayachandran, S Koptur, JC Volin. 2015. Effect of soil pH on growth, nutrient uptake, and mycorrhizal colonization in exotic invasive Lygodium microphyllum. Plant Ecology 216:989-998.**

Soti et al. (2015) examined the influence of soil pH on OWCF growth. They found it grew well at a wide pH range (4.5-8) with greatest growth rates at 5.5-6.5. Root colonization by mycorrhizal fungi was greatest at a pH range of 5.5-6.5 and lower at 4.5 and 8. Nutrient uptake correlated well with changing soil pH. In general OWCF is well suited for a very wide range of soil pH, and is not likely to be limited by this in south Florida.