Running title: Potential distribution of invasive fern

Potential distribution of the invasive Old World climbing fern, *Lygodium microphyllum* in North and South America

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2100 words

Abstract: The climate matching program CLIMEX is used to predict the potential distribution of the fern, *Lygodium microphyllum* in North and South America, with particular reference to Florida, USA where it is invasive. A predictive model was fitted to express the known distribution of the fern. Several new collection locations were incorporated into the model based on surveys for the plant near its ecoclimatic limits in China and Australia. The model predicts that the climate is suitable for further expansion of *L. microphyllum* north into central Florida. Large parts of the Caribbean, Central and South America are also at risk.

Index terms: Invasive species, weeds, Florida Everglades, predictive modeling, CLIMEX.

INTRODUCTION

Lygodium microphyllum (Cav.) R. Br. (Lygodiaceae, Pteridophyta), the Old World climbing fern, is native to the Old World wet tropics and subtropics of Africa, Asia, Australia, and Oceania (Pemberton 1998). It is an aggressive invasive weed in southern Florida, USA (Pemberton and Ferriter 1998) and is classified as a Category I invasive species by the Florida Exotic Plant Pest Council (Langeland and Craddock Burks 1998). It was first found to be naturalized in Florida 1965; however, its rapid spread is now a serious concern because of its dominance over native vegetation. In 1999, over 43,000 ha were infested in South Florida, a 150% increase from 1997 (Pemberton et al., 2002). Pemberton and Ferriter (1998) predict the plant could spread further north in Florida into areas with low winter temperatures (USDA Plant Hardiness Zone 9b) (Cathey 1990).

Because *L. microphyllum* has become so invasive in South Florida, with a strong potential to spread, a biological control program was initiated in 1997.

As part of the world wide surveys for biological control agents of *L. microphyllum* (1998-2003) 321 locations were visited in Australia, China, Fiji, India, Indonesia, Malaysia, New Caledonia, Singapore, Sri Lanka, Taiwan, Thailand, and Vietnam (Goolsby et. al. 2003). *Lygodium microphyllum* was found in a variety of subtropical and tropical habitats throughout its range--from 30°S in New South Wales, Australia, through Southeast Asia, to 24°N in the Guandong Province of China. The northern and southern limits of *L. microphyllum* distribution were surveyed because these areas are climatically similar to Florida, USA and the best adapted biological control agents may come from these areas. Intensive exploration in eastern Australia, combined with a well developed system of weather stations, enabled us to further define the ecoclimatic boundaries of *L. microphyllum*. The ecoclimatic limits estimated from these surveys were used in the software package CLIMEX (Sutherst et al. 1999) to predict the potential distribution of *L. microphyllum* in North and South America.

METHODS

Prior to exploratory surveys, herbaria were contacted to estimate approximate distributions of *L. microphyllum*. In China, several herbaria in Hong Kong and Guangzhou were visited to obtain additional records of distribution. In Australia, state

herbaria in Queensland, New South Wales and the Northern Territory were queried. Site visits were made to as many known locations as possible with particular emphasis on locations near the northern and southern limits of the fern. Specimens of *L. microphyllum* were identified by the Queensland Herbarium. Voucher specimens were lodged in the Queensland Herbarium, Toowong (Brisbane), Australia.

A CLIMEX model using the 'Compare Locations' function, was fitted to express the distribution defined from our surveys. The parameters used in the model are listed in Table 1. The model was validated using the worldwide distribution of *L. microphyllum* and used to predict its potential distribution in North and South America. Locations suitable for *L. microphyllum* have an Ecoclimatic Index of greater than zero. The higher the number the more suitable the location is for *L. microphyllum*. The Ecoclimatic Index (EI) is based on rainfall, degree-days, growth, temperature, moisture, cold stress, heat stress, drought stress, and water stress indices for each location.

RESULTS

The estimated distribution of *L. microphyllum* in Africa, Asia, Australia, and Oceania is similar to published distributions of *L. microphyllum* used by Pemberton and Ferriter (1998). The northern limits of *L. microphyllum* in China are near 24ºN (Goolsby et al. 2003). The EI's for Guangzhou and Wushi, Guandong are below 10 indicating these climates are marginal for *L. microphyllum*. At this latitude, the plant is diminutive, rarely

growing over 1m tall. In comparison, stands in Hong Kong reach 8m, and in Florida up to 30m. At the southern limits of its distribution in Australia, *L. microphyllum* is found as far south as 30ºS.

The CLIMEX model for *L. microphyllum* was projected to North and South America (Figs 1.). The model confirms the suitability of southern Florida were the plant has become invasive. Parts of central Florida may also be at risk. The ecoclimatic index (EI) for West Palm Beach is 80 where *L. microphyllum* is known to be extremely invasive. This index declines for locations in central Florida, with Daytona Beach, Orlando, Tampa and Gainesville having EI's of 54, 67, 64 and 13 respectively. Many locations in Cuba, including Havana, have EI's greater than 80. The climatic suitability of parts of Cuba and its close proximity to Florida underlines the threat to this area by *L. microphyllum*. Additionally large parts of the Caribbean, Central and South America also appear to be vulnerable to invasion.

DISCUSSION

Based on analysis of climate data from our studies, *L. microphyllum* appears to be intolerant of freezing temperatures, but tolerant of average minimum temperatures near 0ºC if daytime maximums are warm. In January, Wushi average minimum and maximum temperatures are 1.0 and 25.8ºC respectively. At the northern limits of the fern's distribution near Wushi, degree accumulation are adequate for growth of *L.*

microphyllum, but stress from lethal minimum temperatures during winter must have a severe impact. Plants may occasionally die back from cold weather and be forced to regrow. *Lygodium microphyllum* can also tolerate subtropical climates with long, cool winters, such as along the east coast of Australia, as long as average minimum temperatures are moderate. In June, Yamba average minimum and maximum temperatures at are 10.8 and 19.5ºC respectively. Near the southern limit of its main distribution near the Clarence River in New South Wales, *L. microphyllum* appears to be limited by lack of sufficient degree-days. Although the plant does not experience defoliation or dieback from cold temperatures, its reduced ability to grow during the prolonged period of cool, winter weather must limit its competitiveness with other plants in its habitat.

In North America, most of southern Florida appears to be suitable for *L. microphyllum*. Expansion of *L. microphyllum* north of its current limit will likely follow the coastline where climates are the most suitable. Although Gainesville, Florida and Brownsville, Texas have positive EI's, the climate data used in CLIMEX is based on monthly averages and does not take into account strong seasonal deviations that are characteristic of North America. Therefore, *L. microphyllum* will likely fail to establish in these locations over the long term due to lethal minimum temperatures that occur during some years. Most of the Gulf Coast of the USA, north of Tampa, Florida, does not appear to be suitable for *L. microphyllum*.

Large parts of the Caribbean, Central and South America are climatically suitable for *L. microphyllum* (Fig 1). Pemberton (1998) reports that the plant is naturalized in Jamaica and Guyana, which provides source populations for further spread. If the New World populations of the plant cannot be eradicated, biological control may be the best solution for management of *L. microphyllum*. Agents being tested for release in Florida are being evaluated for their ability to feed and reproduce on New World *Lygodium* spp. Thus far, none of the native Neotropical *Lygodium* spp. have been demonstrated to be at risk from the proposed biological control agents (Pemberton et al. 2002, Goolsby et al. 2003). Therefore, these same agents may be useful in other parts of Central and South America should biological control program be necessary to manage this invasive fern.

CLIMEX appears to be a useful tool for predicting distributions of organisms in new environments including this primitive climbing fern. Large parts of the New World appear to be climatically suitable for *L. microphyllum*. Many factors, in addition to climate, influence biological invasions. However, based on the rapid spread of this fern in Florida in the 1990's, biologists, land managers, and regulatory officials in Central and South America should make every attempt to prevent movement of this fern into their respective countries. Quick action to manage this fern should be taken if it does become established.

ACKNOWLEDGEMENTS

I would like to thank, Bob Sutherst, Gunther Maywald, and Ric Bottomley (CSIRO Entomology, Indooroopilly, Australia) for help with CLIMEX; Hongyin Chen (USDA-ARS, Sino-American Biological Control Laboratory, Beijing, China) for assistance in southern China; Peter Bostock (Queensland Herbarium, Brisbane, Australia) for identification of *L. microphyllum* specimens; Jeff Makinson (CSIRO Entomology, Indooroopilly, Australia), Marc Poole (Western Australia Agriculture, Perth, Australia), and Robert Pemberton (USDA-ARS, Ft. Lauderdale, USA) for reviewing the manuscript.

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Table 1. CLIMEX model parameters for *Lygodium microphyllum* using the 'Compare Locations' function.

Temperature Index	
Limiting low temperature	12.0
Lower optimal temperature	26.0
Upper Optimal temperature	33.0
Limiting high temperature	39.0
Moisture Index	
Limiting low moisture	0.3
Lower optimal temperature	0.5
Upper optimal temperature	1.75
Limiting high moisture	2.0
Cold Stress	
Cold stress temperature threshold	8.0
Cold stress temperature rate	-0.00075
Cold stress degree-day threshold	26.0
Cold stress degree-day rate	-0.002
Heat Stress	
Heat stress temperature threshold	39.0
Heat stress temperature rate	0.001
Heat stress degree-day threshold	0
Heat stress degree-day rate	0
Dry Stress	
Dry stress threshold	0.3
Dry stress rate	-0.006
Wet Stress	
Wet stress threshold	2.0
Wet stress rate	0.002

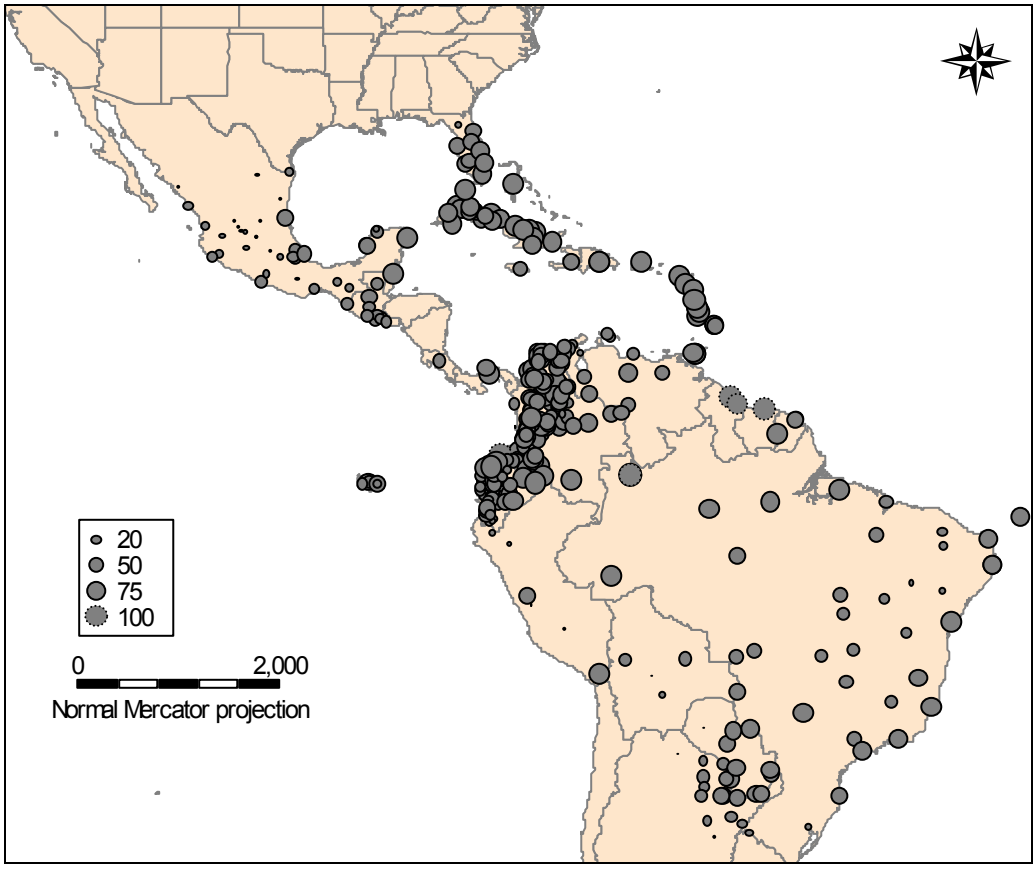
20
50
75
100
0
2,000
Normal Mercator projection

Fig 1. Predicted distribution of *Lygodium microphyllum* in North and South America using the compare locations function of CLIMEX. Circles represent suitable locations for *L. microphyllum* and their ecoclimatic index. Larger circles indicate a higher level of suitability for the invasive fern.