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CONTINENTAL COMPARISONS OF THE INTERACTION BETWEEN CLIMATE AND THE HERBIVOROUS MITE, *FLORACARUS PERREPAE* (ACARI: ERIOPHYIDAE)

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Abstract

The Old World climbing fern, *Lygodium microphyllum*, is an invasive weed in the Florida Everglades and the leaf roll galling mite, *Floracarus perrepae*, is a proposed biological control agent. Field studies were conducted for one to two years at sites in its native range in Australia, New Caledonia, and India to evaluate the effect of climate on *F. perrepae*. Monthly counts of the proportion of *L. microphyllum* subpinnae (leaflets) with leaf roll galls were used to measure the incidence of damage caused by *F. perrepae*. Between sites the most significant weather variable was rainfall 14 to 28 days prior to sampling, with higher levels having a depressive effect on the incidence of leaf rolls. Within sites the mean maximum temperature was the only significant weather variable, showing a decrease in the incidence of leaf rolls above 27°C, and it was predicted that no leaf rolls would form above 35°C. The weather parameters in Homestead, Florida for 2002 were within the range of those evaluated in the eight native range field sites. Thus, we do not predict that climate will prevent the establishment of this biological control agent for *L. microphyllum* in southern Florida.

Key Words: climate, biological control of weeds, ferns, Florida Everglades, New Caledonia, India

Resumen

El helecho trepador del viejo mundo, *Lygodium microphyllum*, es una maleza invasora en los Everglades de Florida y el ácaro que causa la agalla de enrollamiento de las hojas, *Floracarus perrepae*, es el agente de control biológico propuesto. Estudios de campo fueron llevados a cabo de uno a dos años en sitios localizados en su área nativa en Australia, Nuevo Caledonia, y India para evaluar el efecto del clima sobre *F. perrepae*. Se usaron los conteos mensuales de la proporción de subpinnae (hojuelas) de *L. microphyllum* con agallas de hojas enrolladas para medir la incidencia del daño causado por *F. perrepae*. Entre los sitios, la variable mas significativa del clima fue la lluvia 14 a 28 dias antes del muestreo, con los niveles mas altos causando un efecto negativo sobre la incidencia de las hojas enrolladas. En el mismo sitio el promedio de la temperatura maxima fue la unica variable del clima significativa, demostrando una baja de la incidencia del enrollamiento de las hojas a las temperaturas mayor de 27°C, y se predijo que ninguna hoja enrollada se formará a temperaturas mayores de 35°C. Los parametros del clima en Homestead, Florida para el año 2002 estaban en el rango de los parametros evaluados en el campo de los ocho sitios estudiados en el área nativo del ácaro. Por eso, nosotros no estimamos que el clima pueda prevenir el establecimiento de este agente de control biológico para *L. microphyllum* en el sur de Florida.

Lygodium microphyllum (Cav.) R. Br. (Lygodiaceae, Pteridophyta), Old World climbing fern, is native to the wet tropics and subtropics of Africa, Australasia, Asia, and Oceania (Pemberton 1998), and is an aggressive invasive weed of moist habitats in southern Florida with the potential to spread into Central and South America (Pemberton & Ferriter 1998; Goolsby 2004). A biological control program was initiated in 1997 and surveys for potential agents were conducted in Australia and South Asia (Goolsby et al. 2003). The eriophyid mite, *Floracarus perrepae* Knihinicki and Boczek, was the most widely distributed with several geographically specific genotypes identified (Goolsby et al. 2003; Goolsby et al. 2004a). Throughout its native distribution in Australia and Asia, *F. perrepae* causes significant damage to *L. microphyllum.* Feeding by the adults and immatures causes formation of leaf roll galls, leading to necrosis and premature defoliation of *L. microphyllum* pinnae, and the gradual debilitation of the plant (Goolsby et al. 2003; Freeman et al. 2005; Ozman & Goolsby 2005). Based on its narrow host-range (Goolsby et al. in press), and significant impact on *L. microphyllum* (Goolsby et al. 2004b), *F. perrepae* was prioritized for evaluation as a biological control agent (Goolsby & Pemberton 2005).

Ozman & Goolsby (2005) documented the biology and seasonal phenology of *F. perrepae* in Southeast Queensland, Australia, and found that it was active year round, with populations peaking when temperatures were cool and soil moisture levels were highest. In these studies, the proportion of mite infested, or incidence of rolled subpinnae, was measured monthly at four locations over a two-year period. The incidence of leaf rolls was used as an indicator of the mite's impact on the fern. Because the effect of weather was the most significant factor in the phenology of the mite in Australia, we replicated this study in India and New Caledonia to determine if the genotypes from these locations were affected in the same manner. The Indian and New Caledonian *F. perrepae* genotypes were known to have unique biological differences, in that they were co-adapted to the local genotype of the fern (Goolsby et al. unpublished data), but little was known about their possible adaptations to climate. Therefore, we used the incidence of the proportion of mite induced leaf rolls (or plant damage) to evaluate the seasonal phenology of *F. perrepae* in other parts of its native range that were climatically different to Southeast Queensland.

Materials and Methods

Study Sites

The initial baseline studies were conducted in Southeast Queensland (QLD) from February 2001 to March 2003 on Bribie Island; at Gallagher's Point (27°01.17'S, 153°06.53'E) and McMahon Rd. (27°04.33'S, 153°10.55'E) and at Logan; Carbrook Creek (27°41.30'S, 153°16.23'E) and Lagoon Rd. (27°40.01'S, 153°16.03'E). Samples were collected monthly from February 2001 to February 2003. These sites are seasonally inundated with fresh water and *L. microphyllum* grows as a climbing vine on paper bark trees, *Melaleuca quinquenervia* (Cav.) St. Blake. The site at Carbrook Creek is different in that *L. microphyllum* grows under a closed canopy of *M. quinquenervia* in deep shade as compared to the other sites with open canopies. The climate in southeast Queensland is subtropical. Rain falls mainly in the summer months, which are hot and humid. Winters are cool and dry with an average yearly temperature of 20.6°C and average rainfall of 1393 and 1256 mm at Bribie Island and Logan, respectively.

Sites in India were located in southern Tamil Nadu at Thomaiyarpuram, Nagercoil (8°19.00'N, 77°25.70' E) and in Kerala near Ithikkara River, Quilon (8°51.95'N, 76°41.79'E). Samples were collected monthly from July 2002 to August 2003. At the Nagercoil site *L. microphyllum* was growing under a canopy of coconut palms in deep shade. The Quilon site was exposed to full sun, with the fern growing in a ditch up a roadside embankment. The climate in southern India is monsoonal with heavy rainfall from April to August and hot, humid summers. The average yearly temperature and rainfall for Nagercoil and Quilon are 30.0 and 27.5°C, and 905 and 2932 mm, respectively. Sites in New Caledonia were located in Province Sud near Noumea at la Coulee (22°14.09'S, 166°34.75'E) and Yaté (22°06.36'S, 166°56.08'E). Samples were collected monthly from May 2002 to November 2003. At both sites *L. microphyllum* grows in partial shade with *M. quinquenervia*. The climate in New Caledonia is subtropical with rain evenly spaced throughout the year with an average yearly rainfall of 1106 mm. The average yearly temperature is 23.4°C.

We obtained the weather data from the closest available weather station for each location, daily maximum and minimum temperature, RH at 9 a.m. and 3 p.m. and rainfall. From these the daily soil moisture index (between 0 and 1 at soil saturation) was calculated based on a simple model developed by Fitzpatrick and Nix (1969). Yearly rainfall averages for India and New Caledonia were obtained from CLIMEX 2 (Sutherst et al. 2004) and the Queensland Department of Natural Resources for sites in Australia (Queensland 2004). For comparison of the native range to the proposed area of introduction for *F. perrepae*, we used weather data from 2002 for the Florida Automated Weather Network (Florida 2004), for Homestead, Florida, USA, which is located near Everglades National Park.

Sampling Methods

Lygodium microphyllum grows as a twining vine, and each shoot or rachis is a true leaf, consisting of pinnae (leaflets) and subpinnae (subleaflets). Vines were typically found climbing up the trunks of trees, reaching up to 10 m with many yellowish-green, fertile or sterile pinnae branching off the main stem. Each pinna consists of 6-12 paired subpinnae, which are the smallest leaf unit. Fertile subpinnae are fringed with lobes of sporangia, with sterile subpinnae having a smooth outer margin. *Floracarus perrepae* feed on and cause leaf roll galls on the fertile subpinnae, but they did not prefer this leaf form. Therefore, the field phenological studies were based on counts of sterile subpinnae. Each month 50 newly expanded sterile pinnae were collected at each site along a transect and returned to the laboratory for counting. At each site the numbers of infested and uninfested subpinnae were counted for each pinna. This count provided a measure of the incidence of infested subpinnae (leaf rolls), or total mite damage, at each location.

Statistical Analyses

Based on previous field research, it was determined that leaf rolls were the result of *F. perrepae* feeding activity from between 28 and 14 days before field collection (Goolsby et al. 2004; Ozman & Goolsby, in press). Therefore mean values of weather variables for this two-week period were used for the analyses. An analysis of variance was performed on the proportional incidence of leaf rolls to determine which of the weather variables accounted for the most variation between and within sites. Sites were assigned a value of 1 if the *L. microphyllum* grew under a canopy of full shade, with a value of 0 for sites with partial shade or full sun.

Results

The incidence of leaf rolls was observed monthly for periods between one and two years at eight sites, two in India, two in New Caledonia, and four in Australia. The mean value of the proportional incidence of leaf rolls at each site is shown in the Table 1, together with mean weather variables daily maximum and minimum temperature, rainfall, soil moisture, and shade.

An analysis of variance was performed on the proportion of leaf rolls to determine which of the abiotic variables accounted for the most variation between and within sites. The rainfall of the previous two-week period, averaged over each site, fitted as a quadratic equation explained 90% of the variation between the 8 sites ($P < 0.001$, linear regression coefficient (b1) = -0.00323, SE 0.00031 and quadratic regression coefficient (b2) = 0.0000485, SE = 0.000009, $F_{2,4} = 22.71$) (Fig. 1). Shade explained a further 5% of the between site variation but only at ($P < 0.07$) with leaf rolls from shaded locations (0.048 SE 0.019, $F_{1,4} = 3.22$) higher than unshaded. The shape of the quadratic for rainfall indicated that rainfall decreased the incidence of leaf rolls steadily as it increased. However, after 72 mm of rainfall for a two-week period, the predicted proportional incidence of leaf rolls remained fairly constant as rainfall increased. Temperature, relative humidity, and soil moisture were not significant in the analysis between sites.

Within sites (after adjusting for mean site differences) the mean maximum temperature fitted as a quadratic explained the most variation in the incidence of leaf rolls ($P < 0.001$, b1 = 0.1598, SE 0.0532, b2 = -0.00319 SE = 0.00099, $F_{2,138} = 7.95$) (Fig. 2). From the shape of the fitted curve, maximum temperature appeared to decrease the incidence of leaf rolls as the temperature rose above 27°C, but below the prediction was fairly constant. At mean maximum of above 35°C no curls were predicted. There was no interaction between the variables and sites; hence, all sites had the same response to the weather variables. Relative humidity, rainfall, and soil moisture were not significant within sites.

Table 1. Mean proportion of *Floracarus perrepae* induced leaf roll galls on *Lygodium microphyllum* with selected weather variables for each field site.

Site	No. obs.	Mean[a] proportion leaf rolls ± SE	Mean[b] max. temp. °C	Mean[b] min. temp. °C	Mean[c] rain mm.	Soil[d] moisture	Shade[e]
Quilon, India	12	0.222 ± 0.051 ab	32.4	23.5	60.1	0.63	0
Nagercoil, India	13	0.346 ± 0.065 bcd	32.7	23.8	37.1	0.59	1
La Coulee, New Caledonia	20	0.157 ± 0.036 a	28.1	17.3	70.0	0.74	0
Yate, New Caledonia	20	0.170 ± 0.028 a	26.9	19.6	117.0	0.85	0
Carbrook Creek, Australia	24	0.358 ± 0.022 cd	26.0	15.4	34.0	0.61	1
Lagoon Rd., Australia	24	0.289 ± 0.035 bc	26.0	15.4	33.5	0.66	0
Gallagher's Pt., Australia	24	0.329 ± 0.029 bcd	25.7	16.3	30.0	0.65	0
McMahon Rd., Australia	12	0.432 ± 0.053 d	25.5	16.0	18.5	0.65	0
Homestead, Florida	12	n/a	29.1	18.4	89.6	0.80	n/a

[a]Means in the column followed by the same letter are not significantly different ($P < 0.05$) from transformed data analysis.
[b]Mean of the means for daily maximum/minimum temperatures 28-14 days prior to each sampling date.
[c]Mean of the sum of rainfall for 28-14 days prior to each sampling date.
[d]A value of 1 indicates soil saturation.
[e]Zero indicates full sun, with 1 being partial or full shade at the site.

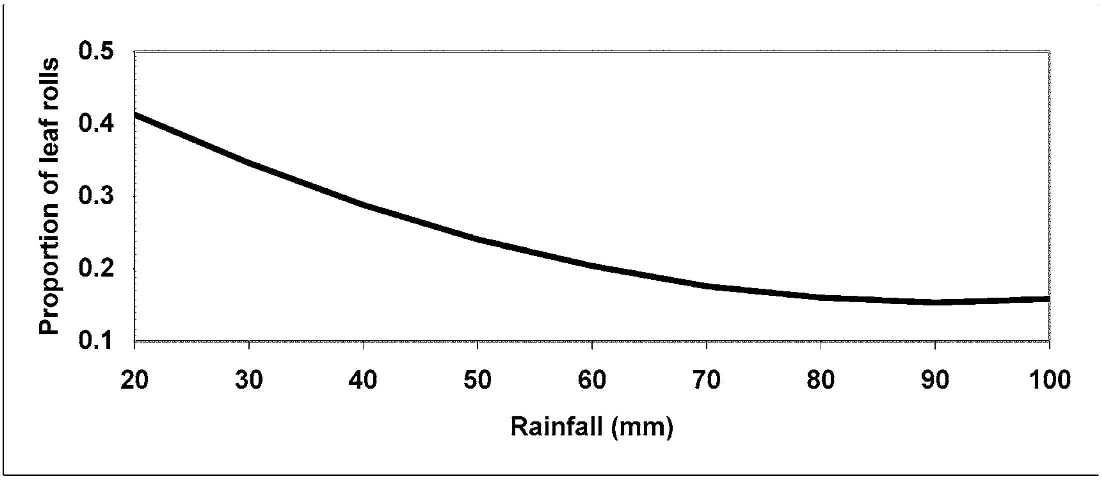

Fig. 1. Estimated effect of rainfall on annual proportion of uninfested subpinnae and mite induced leaf rolls (between sites). A higher proportion indicates a higher level of plant damage.

The weather data from Homestead, FL was calculated for 12 hypothetical monthly sample dates in 2002. The mean rainfall of the 12 two-week totals was 90 mm with the mean maximum temperatures of the two-week sampling periods in a range between 23.1 and 32.4°C (Table 1).

Discussion

Floracarus perrepae is widely distributed in Australia and Asia across a range of tropical and subtropical climates (Goolsby et al. 2003). Within this distribution are several location specific genotypes that are adapted to their corresponding genotypes of their host, *L. microphyllum* (Goolsby et al. 2004a; Goolsby et al., unpublished data). From these studies, it appears that the specific genotypes represented in southern Australia, New Caledonia, and India responded similarly to the weather variables in their environments, since there was no interaction with sites in the within site analysis.

The most significant weather variable between sites was rainfall. Jeppson et al. (1975) reported similar effects from high rainfall during the rainy season of Asiatic monsoon climates, which caused major reductions in mite populations such as the tea spider mite, *Oligonychus coffeae* (Nietner). In our studies, high amounts of rainfall 28-14 days months prior to the sampling date had a negative impact on the incidence of leaf rolls, which is an indicator of the local population density. Persis-

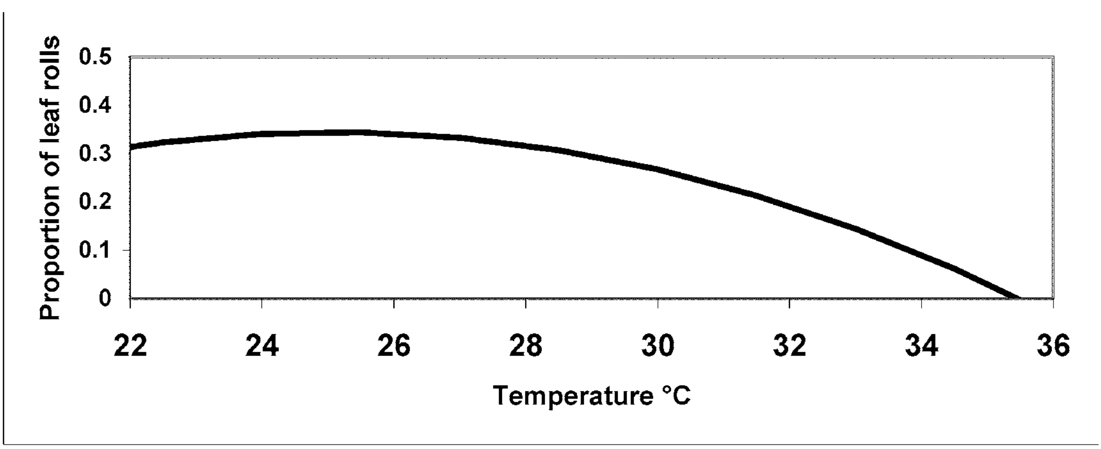

Fig. 2. Estimated effect of mean maximum temperature on proportion uninfested subpinnae and mite induced leaf rolls (within sites). A higher proportion indicates a higher level of plant damage.

tent and heavy rainfall during this time period most likely dislodged the dispersing *F. perrepae* as they attempted to settle and induce leaf rolls. This may explain why the sites in Quilon, India and New Caledonia had the lowest mean proportional incidence of leaf rolls. Quilon receives a double rainy period during the monsoon, and heavy persistent rain is common. In addition, the Quilon site has high rainfall, is in the open, and exposed to the direct effect of rain. In contrast, the site in Nagercoil received less rain, the *L. microphyllum* stand was under a sheltering canopy of palms, and the incidence of leaf rolls galls was higher, within the range of values for the Australian sites. In New Caledonia, high rainfall during 2002-03, including that associated with cyclone Erica, (March 2003) appears to have been responsible for the lower incidence of leaf rolls. Additionally, both sites in New Caledonia are partially exposed with *L. microphyllum* growing under a broken canopy of *M. quinquenervia*, thus allowing for the full impact of rainfall.

The higher average proportional incidence of leaf rolls at the Australian field sites also may be due to the drought conditions, which have affected eastern Australia since 2001 (Queensland 2004). *Floracarus perrepae* at these field sites have been exposed to fewer episodes of high rainfall, and mortality of dispersing females may have been lower. Thus, the higher proportional incidence of leaf rolls. The coconut mite, *Aceria guerreronis* Keifer (Acari: Eriophyidae), appears to be affected similarly across its known distribution where it reaches higher densities in areas with drier climates (Moore & Howard 1996). The study by Ozman & Goolsby (2005) found populations of *F. perrepae* peaked when temperatures were cool and soil moisture levels were highest, which appears to contradict the findings of this study. However, the results from the continental comparisons of climatic effects further clarify the differences between the effects of soil moisture and rainfall on *F. perrepae* populations. Our results suggest that *F. perrepae* performs best when soil moisture is near saturation (promoting growth of *L. microphyllum*) and there are few periods of high intensity rainfall, which interfere with dispersal.

The mean rainfall for Homestead, Florida in 2002 was higher than that for any station measured in Australia. One could predict that populations of *F. perrepae* in the latter localities, would be similar to those in New Caledonia, where the mite caused considerable damage to *L. microphyllum*. The rainfall effect appears to have a limit as shown in Figure 1, in which the model predicts that effect will remain constant above 72 mm for a two-week period. This prediction is corroborated by the data from New Caledonia and India, which showed that high rainfall reduced the incidence of leaf rolls but the populations remained stable.

High temperatures also had a significant negative impact on *F. perrepae* populations within sites. The model predicts that the proportional incidence of leaf rolls will decrease as the mean maximum temperature rises above 27°C with no leaf roll formation above 35°C. None of the sites in the native range experienced mean maximum temperatures for a two-week period above 35°C. Similarly, in Homestead, Florida during 2002 the highest means for the summer months ranged between 31 and 32°C, respectively. High temperatures are important to consider for rearing and release of *F. perrepae*. Summer greenhouse temperatures can often reach mean maximum temperatures above 35°C. Optimum rearing environments should be maintained at a mean maximum temperature of 27°C. Field colonization of *F. perrepae* in Florida would be the most difficult in the summer months when temperatures and rainfall are the highest.

In conclusion, the genotypes of *F. perrepae* evaluated in this study from its native range in Australia, New Caledonia, and India were all negatively impacted by high rainfall and temperatures during leaf roll formation. Conversely, populations of *F. perrepae* reach their highest levels when temperatures are cool and episodes of high intensity rainfall are few. The climate of southern Florida falls within the parameters experienced in the native range of *F. perrepae*. Therefore, we do not predict that climate will prevent the establishment of this biological control agent for *L. microphyllum*.

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References Cited

Florida. 2004. Florida Automated Weather Network. University of Florida, IFAS. http://fawn.ifas.ufl.edu/scripts/reportrequest.asp.

Fitzpatrick, E. A., and H. A. Nix. 1969. A model for simulating soil water regime in alternating fallow-crop systems. Agri. Meteorol. 6: 303-319.

Freeman, T. P., J. A.,Goolsby, S. K. Ozman, and D. R. Nelson. 2005. An ultrastructural study of the relationship between the mite *Floracarus perrepae* Knihinicki & Boczek (Acariformes: Eriophyidae) and the fern *Lygodium microphyllum* (Cav.) R. Br. (Lygodiaceae). Aust. J. Entomol. 44: 57-61.

Goolsby, J. A., A. D. Wright, and R. W. Pemberton. 2003. Exploratory Surveys in Australia and Asia for

Natural Enemies of Old World Climbing Fern, *Lygodium microphyllum*: Lygodiaceae. Biol. Control 28: 33-46.

GOOLSBY, J. A., J. R. MAKINSON, D. M. HARTLEY, R. ZONNEVELD, AND A. D. WRIGHT. 2004a. Pre-release evaluation and host range testing of *Floracarus perrepae* (Eriophyidae) genotypes for biological control of Old World climbing fern, pp. 113-116 *In* J. M. Cullen, D. T. Briese, D. J. Kriticos, W. M. Lonsdale, L. Morin, and J. K. Scott [eds.], Proceedings of the XI International Symposium on Biological Control of Weeds CSIRO Entomology, Canberra, Australia.

GOOLSBY, J. A., AND R. W. PEMBERTON. 2004. Proposed field release of the Australia *Floracarus perrepae* Knihinicki & Boczek (Acariformes: Eriophyidae), a leaf roll galler of the Old World climbing fern, *Lygodium microphyllum* (Cav.) R. Br. (Pteridophyta: Lygodiaceae) in Florida. On file at the U.S. Department of Agriculture, Agricultural Research Service, Biological Control Documentation Center, National Agricultural Library, Beltsville, Maryland, USA (petition to release a biological control agent).

GOOLSBY, J. A., R. ZONNEVELD, AND A. BOURNE. 2004b. Pre-release assessment of impact on biomass production of an invasive weed, *Lygodium microphyllum* (Lygodiaceae: Pteridophyta), by a potential biological control agent, *Floracarus perrepae* (Acari: Eriophyidae). Environ. Entomol. 33: 997-1002

GOOLSBY, J. A. 2004. Potential distribution of the invasive Old World climbing fern, *Lygodium microphyllum* in North and South America. Nat. Areas J. 24: 351-353.

GOOLSBY, J. A., R. ZONNEVELD, J. R MAKINSON, AND R. W. PEMBERTON. Host-range and cold temperature tolerance of *Floracarus perrepae* (Acariformes: Eriophyidae) a potential biological control agent of *Lygodium microphyllum* (Pteridophyta: Lygodiaceae). Aust. J. Entomol. (In Press).

JEPPSON, L. E., H. H. KEIFER, AND E. W. BAKER. 1975. Population ecology; mite responses to weather variations, pp. 28-29 *In* Mites Injurious to Economic Plants. University of California Press, Berkeley.

MOORE, D., AND F. W. HOWARD. 1996. Ecology of coconut mites, pp. 561-570 *In* E. E. Lindquist, M. W. Sabelis, and J. Bruin [eds.], Eriophyoid Mites—Their Biology, Natural Enemies and Control, Elsevier Science, Amsterdam.

OZMAN S. K., AND J. A. GOOLSBY. 2005. Biology and phenology of *Floracarus perrepae*, on its native host in Australia, Old World climbing fern, *Lygodium microphyllum*. Exp. Appl. Acarol. 35: 197-213.

PEMBERTON, R. W. 1998. The potential of biological control to manage Old World climbing fern (*Lygodium microphyllum*), an invasive weed in Florida. Am. Fern J. 88: 176-182.

PEMBERTON, R. W. 2003. Northward extension of the invasive weed *Lygodium microphyllum* in Florida. Sida 20: 1759-1761.

PEMBERTON, R. W., AND A. P. FERRITER. 1998. Old World climbing fern (*Lygodium microphyllum*), a dangerous invasive weed in Florida. Am. Fern J. 88: 165-175.

QUEENSLAND. 2004. Bureau of Meteorology, Queensland rainfall maps. http://www.bom.gov.au/climate/drought/drought.shtml.

SUTHERST, R. W., G. F. MAYWALD, W. BOTTOMLEY, AND A. BOURNE. 2004. CLIMEX v2. Hearne Scientific Software Pty. Ltd., Melbourne, Australia.