AULACASPIS YASUMATSUI (HEMIPTERA: STERNORRHYNCHA: DIASPIDIDAE), A SCALE INSECT PEST OF CYCADS RECENTLY INTRODUCED INTO FLORIDA.

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ABSTRACT

Observations were conducted in southern Florida on *Aulacaspis yasumatsui* Takagi (Hemiptera: Sternorrhyncha: Diaspididae), a recently introduced armored scale insect native to Southeast Asia. The insect's host plants, exclusively cycads, were identified in the following genera: *Cycas* (Cycadaceae*); Dioon, Encephalartos, Microcycas,* (Zamiaceae), and *Stangeria* (Stangeriaceae). *Cycas* spp. seemed to be preferred over other cycad genera by this insect. *Aulacaspis yasumatsui* infested pinnae, rachides, strobili, stems, and roots of various species of cycads. It generally infested

all above-ground plant parts of *Cycas* spp. and sometimes the primary and secondary roots to a soil depth of 60 cm. No morphological differences in the frond- and root-infesting forms were noted. At an ambient temperature of about 24.5°C, eggs hatched in 8-12 days. In the field, some individuals developed to second instars in 16 days and third instars in 28 days. Third instars (mature females) laid >100 eggs. Most of the females of a generation did not live longer than 75 days. No natural enemies were observed. The scale insect populations became extremely dense and killed 100% of 15 *Cycas revoluta* Thunburg within a year of infestation. Between 1996 and June 1998 the insect spread from a limited area in southern Miami to various sites as far as 120 km north, probably by movement of plants.

Key Words: Cycad, Hemiptera, Homoptera, Sternorrhyncha, Coccoidea, Diaspididae, scale insect, *Aulacaspis,* imidacloprid

RESUMEN

Se llevaron a cabo observaciones en el sur de Florida sobre *Aulacaspis yasumatsui* Takagi (Hemíptera: Sternorrhyncha: Diaspididae), una cochinilla de armadura que ha sido recientemente introducida desde el sudeste de Asia. Las plantas hospederas fueron exclusivamente cicas identificadas en los géneros siguientes: *Cycas* (Cycadaceae*); Dioon, Encephalartos, Microcycas* (Zamiaceae); y *Stangeria* (Stangeriaceae). *Cycas* spp. fueron preferidas en comparación con las cicas de otros géneros. *Aulacaspis yasumatsui* infestó hojas, ráquises, estróbilos, tallos, y raíces de varias especies de cicas. Generalmente infestaron todas las partes de arriba de la tierra de *Cycas* spp. y a veces las raíces primarias y secundarias hasta una profundidad de 60 cm en el suelo. No se observaron diferencias entre las formas que infestaron raíces y las que infestaron partes de arriba de la tierra. Debajo de una temperatura ambiental de aproximadamente 24.5°C los huevos nacieron en 8-12 días. En el campo, unos individuos se desarrollaron al segundo instar en 16 días y al tercer instar en 28 días. Los terceros instares (hembras maduras) ovipositaron >100 huevos. La mayoría de las hembras de una generación no vivieron más que 75 días. No se observaron enemigos naturales. Las poblaciones de la cochinilla se hicieron extremadamente densas y mataron al 100% de las 15 *Cycas revoluta* Thunburg después de un año de infestación. Entre 1996 y junio de 1998, el insecto se extendió desde un área limitada en el sur de Miami a varios sitios hasta 120 km al norte, probablemente a causa del transporte de las plantas.

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*Aulacaspis yasumatsu*i Takagi (Hemiptera: Sternorrhyncha: Diaspididae) was originally described from specimens collected from a cycad, *Cycas* sp., in Bangkok, Thailand, in 1972 (Takagi 1977). Cycads *sensu lato* are plants in the gymnosperm order Cycadales, which consists of three families: Cycadaceae (one genus, *Cycas*), Stangeriaceae (one genus, *Stangeria*) and Zamiaceae (eight genera). Cycads are an ancient group that predate most extant plant taxa; there are 185 species of cycads in the world (Jones 1993).

Aulacaspis yasumatsui is considered a pest of cycads in Thailand, but is usually maintained in low densities in that country by parasitoids (Tang et al. 1997). It was found in Miami, Florida, on cycads grown as ornamental plants in 1996. King-sagos, *Cycas revoluta* Thumberg, the most popular cycad planted in this area, were found to be highly infested with *A. yasumatsui*. Fairchild Tropical Garden (FTG) and Montgomery Botanical Center (MBC), both which have important world collections of cycads, were within the initially infested area. The rampant increase and spread of this scale insect in these collections threatened the survival of several rare and en-

dangered species conserved in these collections. An additional concern was the threat posed to a large concentration of nurseries in southern Florida that grow and ship cycads throughout the U. S. and abroad. We thus initiated a research project with the long-range objectives of elucidating the bionomics of this insect and developing pest management methods for it.

This paper reports results on the bionomics and host relationships of *A. yasumatsui*.

MATERIALS AND METHODS

Observations were conducted in FTG, MBC and other sites within the infested area in southern Miami. Most observations or counts were of the scale insect itself, necessitating that the scale (i. e., the 'testa' or 'scale covering' of some authors) be removed with a fine probe.

A general survey of the extent of the infestation on cycads in southern Miami was conducted in October 1996.

On 19 November 1996, 10 pinnae from a heavily infested *C. rumphii* Miguel about 3 m tall growing in FTG were removed at random and examined under a microscope and the number of males and mature females of *A. yasumatsui* per 5 cm^2 counted on the abaxial and adaxial surfaces.

To determine host range data of *A. yasumatsui*, all species of cycads in FTG and plants of other families adjacent to them were examined at least weekly between October 1996 and June 1998. Cycads at MBC were also examined several times during this period. Because species were not replicated and specimens were not uniform with respect to environmental factors such as age, size, shading, closeness to sprinkler heads, etc., a valid ranking of host plant species preference could not be made. However, infested cycads tended to be either (1) coated with a dense population of scales so as to appear to have been snowed on; such infestations were conspicuous from a distance of 20 m or more (highly infested), or (2) infested with only a sparse population that was not evident without close examination of the plant (lightly infested), or (3) non-infested.

During the first few months of observations, significant populations of this scale insect infested several genera of cycads additional to *Cycas*. At FTG, cycads in the genus *Cycas* were treated with insecticides. In March 1998, observations were conducted to compare the infestation levels on fronds of 14 species of cycads of other genera represented in FTG and MBC. Only species infested with *A. yasumatsui* were included. Ten of the most infested pinnae from the most infested fronds were selected and the number of mature female scales per 5 cm^2 of the abaxial surface of each pinna determined. Cycads with infestations of stems or strobili but not fronds were noted.

An experiment was conducted to determine the developmental rate of *A. yasumatsui* under field conditions. Five *C. revoluta* plants about 20 cm tall with about eight fronds growing in plastic 16 ×17 cm containers were obtained from a nursery outside of the infested area. These were examined and determined to be free of scale insects. On April 2, 1997, these cycads were placed on the ground in FTG. Exposure of the plants to crawlers was maximized by (1) placing them beneath a large cycad that was highly infested with *A. yasumatsui,* and (2) scattering upon them pinnae infested with first instar crawlers of *A. yasumatsui*. Observations were conducted 16, 28, 35, 41, and 75 days after initial exposure of the plants to the scale insects. On each observation date, one pinna was removed from each plant and examined under the microscope. Numbers of crawlers and second and third instar females were counted.

A second series of five cycads with characteristics similar to those above was placed in FTG on August 13, 1997, and infested with *A. yasumatsui* as described. Ob-

servations were conducted 8, 15, 21, and 35 days later with a slightly modified method: on each observation date, two pinnae were removed from each plant and the stages and numbers of *A. yasumatsui* determined.

To determine the duration of the egg stage, the egg nearest the vulva of a female (i. e., presumed to be newly laid) was placed on filter paper in a Petri dish. Five eggs were observed twice daily in a laboratory at a constant temperature of about 25°C until each had hatched.

Barbara Judd, a horticulturist employed at the MBC nursery, informed us that she had often found *A. yasumatsui* on roots of containerized cycads. To verify that scale insects were consistently associated with roots, containerized *C. revoluta* were lifted, and the soil washed from the roots and examined under a stereoscopic microscope. Ten cycads were examined in December 1997 and 10 in June 1998. In addition, in March 1998 five mature *C. rumphii* and one *C. wadei* Merrill were selected at random in the field. The soil was removed from roots to a depth of 60 cm and the roots examined for scale insects.

Microscope slide mounts were made of mature female specimens of *A. yasumatsui* from the roots, fronds, stems and strobili. Fifteen specimens from fronds and 25 from roots were examined to determine whether different morphological forms were associated with the different plant parts.

The impact of high infestations of *A. yasumatsui* on cycad survival was determined. Five *C. revoluta* plants about 0.35 m tall with about 16 fronds growing in 28 × 30 cm plastic containers and 10 plants about 20 cm tall with about 8 fronds growing in 16 × 17 cm plastic containers were treated by soil drenches with a systemic insecticide to prevent establishment of the scale insects. On 12 December 1996, the larger cycads were drenched with five g of Merit 75%WP (® Bayer AG) (3.75 g AI of imidacloprid) in 500 ml of water. On 2 April 1997, the smaller cycads were drenched with two g of this product (1.5 g AI imidacloprid) in 200 ml of water. The plants were placed intermixed with an equal number of cycads and exposed to the scale insects as described above. The fronds of both treated and untreated plants were observed weekly for scale insect infestation and damage.

Distribution and host records of *A. yasumatsui* are from microscope slide mounted specimens collected by personnel of the Florida Department of Agriculture and Consumer Services, Division of Plant Industry (DPI), during routine plant inspections and by the authors.

Results And Discussion

The scales of mature females of *A. yasumatsui* are white, 1.2 -1.6 mm long and highly variable in form. They tend to have a pyriform shape with the exuviae at one end, which is typical of the tribe Diaspidini (Ben-Dov 1990), but are often irregularly circular, conforming with leaf veins, adjacent scales, and other objects. The orange body of the female can sometimes be seen vaguely through the thin scale. The ventral scale is extremely thin to incomplete. The scale of the male is similar to those of many other species of Diaspididae, being 0.5-0.6 mm long, white, and tricarinate, with the exuviae at the cephalic end.

Macroscopically in the field, the scale of the female of *A. yasumatsui* resembles that of *Pseudaulacaspis cockerelli* (Comstock), which is also common on cycads in Florida. However, two characteristics visible with the scale removed under a 10X hand lens distinguish the two species: (1) The color of the body of all stages and of the eggs of A. yasumatsui is orange, except recently molted (callow) individuals, which are yellow. The eggs and all stages of *P. cockerelli* are yellow. (2) *Aulacaspis yasumat-*

sui has an expanded prosoma, an unusual characteristic of the genus (Fig. 2). Finally, scales of *A. yasumatsui* are usually more numerous on the abaxial surface of pinnae, while those of *P. cockerelli* are more numerous on the adaxial surface. The scale of the female of *Pinnaspis strachani* (Cooley) also resembles that of *A. yasumatsui*, but *P. strachani* is far less common on cycads than the other two scale insect species in southern Florida.

Hundreds of cycads examined in southern Miami from October 1996-June 1998 were infested with *A. yasumatsui*. The scale insects were consistently more numerous on the abaxial than on the adaxial surfaces of pinnae, and in light infestations they occupied the abaxial surfaces exclusively. Highly infested cycads were almost completely coated with a white crust that included scales of live and dead insects (Fig. 1). Scales of males, which are less than half the length of scales of females, were nearly always more numerous than those of females. Crusts composed of several layers of scales of males were especially common on rachides, where we observed a maximum of 500 scales per cm^2.

Mean numbers of live scale insects per 5 cm^2 of foliar surface of a heavily infested *C. rumphii* on 19 November 1996, were 43.5 (SD = 34.2) males and 10.8(SD = 12.6) mature females on the adaxial surface, and 128.0 (SD = 87.3) males and 66.8 (SD = 26.3) females on the abaxial surface of pinnae. Examination of microscope-mounted specimens collected from October 1996-February 1998 confirmed the presence of *A. yasumatsui* on 22 species (Table 1).

In October 1996, 65 *Cycas* plants in FTG representing 20 species were highly infested with *A. yasumatsui*. Light populations were observed on some species of *Dioon*, *Encephalartos* (both Zamiaceae), and *Stangeria* (Stangeriaceae). Although *Cycas* spp. were treated by FTG plant protection personnel several times with systemic insecticides between October 1996 and January 1998, the scale insects re-infested these hosts rapidly, and *Cycas* spp. continued to be more highly infested than cycads of other genera. In early 1997, the non-*Cycas* genera that were hosts of *A. yasumatsui* were those listed above. By March 1998, *Microcyas colocoma* (Zamiacae), representing an additional genus, was infested. At this time, *Encephalartos ferox* appeared to be the most highly infested species of non-*Cycas* genera. Pinnae sampled from the most infested fronds of *E. ferox* had 23.2 (SD = 9.4) scales per 5 cm^2 on the abaxial surface. Of the additional non-*Cycas* species that were infested, *Encephalartos manikensis*, *Dioon rzedowski*, and *D. merolae* had more than 11 females and the other non-*Cycas* species listed had less than three females per 5 cm^2 of abaxial surface on the most infested fronds, or infestations were confined to strobili. For comparison, a mean of 66.8 females per 5 cm^2 were observed on the abaxial surface of the highly infested *C. rumphii* on 19 November 1996.

Stangeria eripus (Kunze) Baillon was only lightly infested in FTG and MGC in October 1996, but several plants of this species in the MBC collection were heavily infested by March 1998. One specimen of this species in FTG was highly infested in early 1997 but after several months the population on this plant diminished to a light infestation without any discernible cause.

Although cycads of some other genera native to the Eastern and Western Hemispheres were hosts, *Cycas* spp. were consistently more highly infested. *Cycas* is native to Asia (Jones 1993) where *A. yasumatsui* was first collected, suggesting that it may be the original host genus of *A. yasumatsui*.

Sixteen days after containerized *C. revoluta* were exposed to infestations of *A. yasumatsui* on 2 April 1997, settled first instar crawlers were observed on the plants (Fig. 3a). There was a mean of 69.6 (SD = 14.7) scale insects on the abaxial surface per pinna. A mean of 84.8% (SD = 11.6) were first instars, and the remaining 15.2%

Fig. 1. Frond of *Cycas rumphii* infested with *Aulacaspis yasumatsui*.

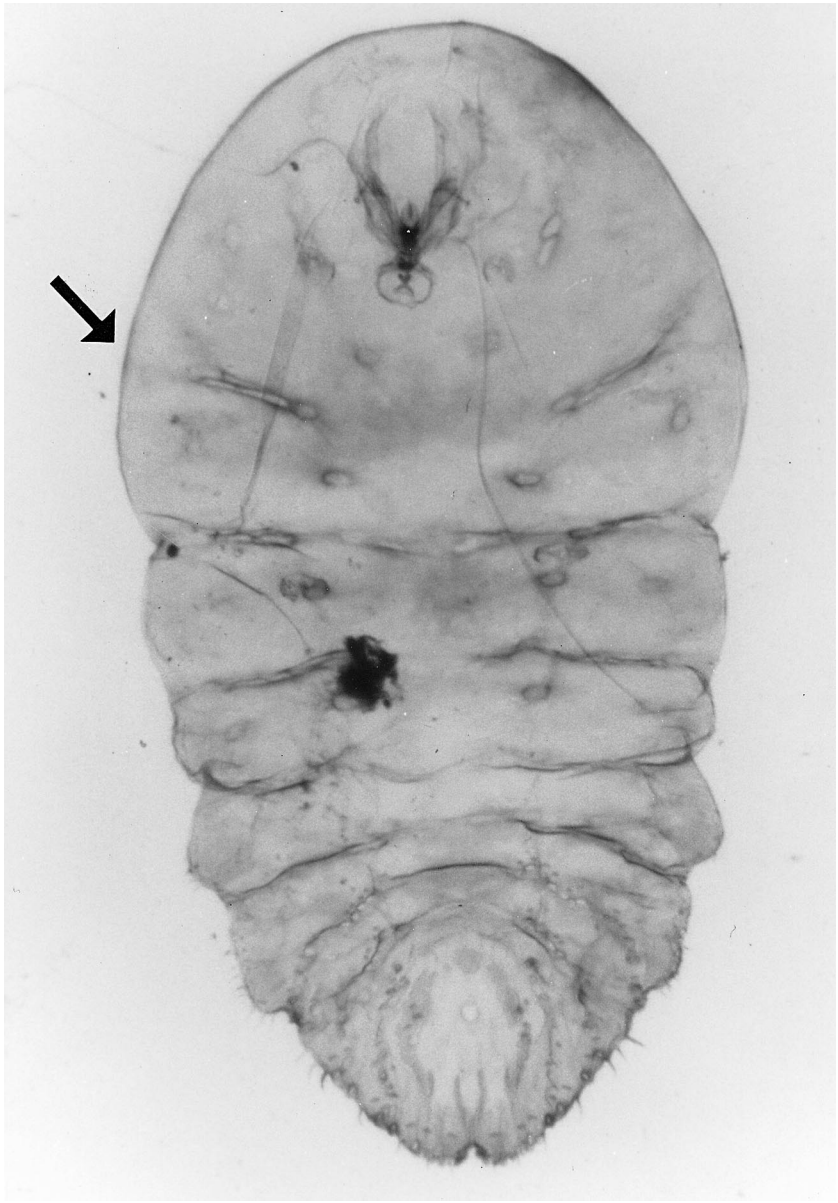

Fig. 2. Slide-mounted mature female of *Aulacaspis yasumatsui*, expanded prosoma indicated.

TABLE 1. CYCADS INFESTED WITH *AULACASPIS YASUMATSUI* IN FAIRCHILD TROPICAL GARDEN, MIAMI, OCTOBER 1996-FEBRUARY 1998.

Family	Genus	Species	Geographic origin
Cycadaceae	Cycas	media R. Brown	Australia & Papua New Guinea
		panzhihuaensis L. Shou & S. Y. Yang	China
		revoluta Thunberg	Japan to Ryukyu Islands
		rumphii Miguel	India, Southeast Asia, Oceania
		seemannii A. Braun	Oceania
		szechuanensis W. C. Cheng & L. K. Fu	China
		thouarsii R. Brown ex Gaudich	Africa
		wadei Merrill	Phillippines
Zamiaceae	Dioon	califanoi De Luca & Sabatori	Mexico
		edule Lindley	Mexico
		merolae De Luca	Mexico
		rzedowskii De Luca, Moreti, Sabatori & Vasquez	Mexico
		spinulosum Dyer (strobili only)	Mexico
		tomasellii De Luca var. sonorense	Mexico

TABLE 1. (CONTINUED) CYCADS INFESTED WITH *AULACASPIS YASUMATSUI* IN FAIRCHILD TROPICAL GARDEN, MIAMI, OCTOBER 1996-FEBRUARY 1998.

Family	Genus	Species	Geographic origin
	Encephalartos	barteri Miguel (strobili only)	Africa
		ferox Bertoloni	Africa
		hildebrandtii nr. Lembombensis A. Braun & Bouché	Africa
		manikensis (Gilliland)	Africa
		pterogonus R. A. Dyer & I. Verd	Africa
		whitelockii P. J. H. Hurter	Africa
	Microcycas	colocoma (Miguel) de Candolle (strobili only)	Cuba
Stangeriaceae	Stangeria	eriopus (Kunze) Baillon	Africa

were in the second instar. Thus, this species was capable of developing to second instar in 16 days, or possibly earlier. Presumably, the individuals in second instar were those that had settled earliest on the plants as first instars.

Twenty-eight days after initial exposure to the scale insects, a mean of 18.1% (SD = 11.4) of the females examined had reached third instar. Again, these were probably individuals that had invaded and settled earliest. The remainder were first instars (44.6%, SD = 10.2), which presumably had invaded and settled relatively recently, and second instars (37.3%, SD = 5.58).

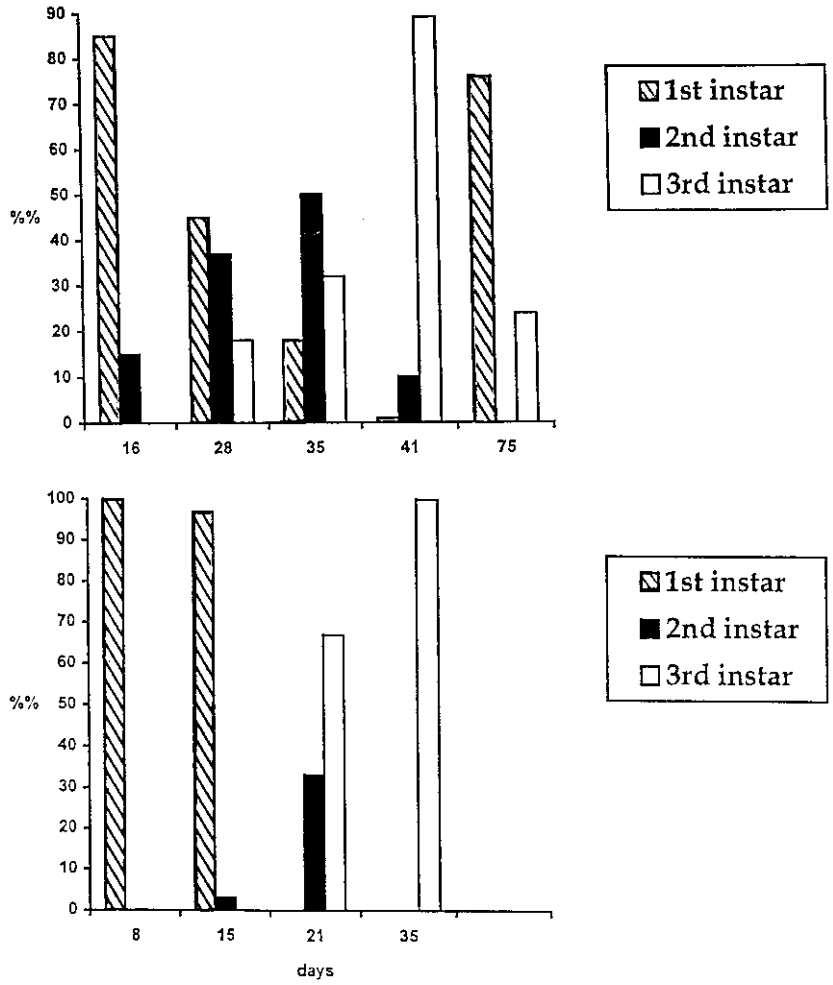

Fig. 3. Percentages of different instars of *Aulacaspis yasumatsui* on cycad host plants at successive intervals after infestation by the scale insects. Top: April-June 1997 bottom: August-September 1997.

After 35 days about half of the population was in second instar and about 1/3 had reached third instar. A mean of 24.7% (SD = 10.8) of the latter had laid eggs.

After 41 days a mean of 89.1% (SD = 8.5) of the scale insects examined were third instars. A mean of 68.2% (SD = 13.9) of these had laid eggs.

After 75 days the portion of the female population consisting of mature individuals had fallen to 24%. Presumably, many of the females of the first generation had expended their eggs and died. A mean of 76.0% of the population were first instars, presumably of the second generation.

Later in the summer, the development of the scale insect was similar to that observed in spring. Eight days after initial exposure to *A. yasumatsui* on August 12, the scale insects on the cycads were all first instars. At 15 days, a small portion of them had attained second instar; at 21 days, about 3/4 of those examined were mature females, and at 35 days all were mature females (Fig. 3b). In summary, during the warm season, females of *A. yasumatsui* developed from egg to adult within the period of one month, and as mature females lived for about one month.

The largest egg masses observed with females beneath scales consisted of about 90-110 eggs. Usually there were in addition several empty egg shells and several crawlers. It should be noted that this does not constitute the total number of eggs produced per female, since wedid not count the eggs developing in ovaries, or crawlers that had already left the mother scale insect. In the laboratory at about 25°C. eggs hatched in about 8-12 days (n = 5).

Roots were infested with *A. yasumatsui* males and females in six of 10 *C. revoluta* in containers examined in December 1997 and four of 10 examined in May 1998. The scale insects usually were aggregated on primary roots (about 10 mm in dia) and singly or in groups of a few on secondary roots (about 2 mm in dia) near the container sides, i. e., near the soil-air interface. Some roots that protruded from drain holes in the containers were also infested. However, several scale insects were found on roots at 15 cm depth and several cm inward from the container sides.

Aulacaspis yasumatsui males and females were also found on roots of four of five *C. rumphii* and on one *C. wadei* growing in the field. They were distributed at different depths on primary (3 cm in diam) and secondary roots in groups of a few to several individuals from near the soil surface to a maximum depth of 60 cm (Fig. 4). Comparisons of 20 specimens of adult females from fronds and 25 from roots of cycads revealed no morphological differences distinguishing the mature females infesting the two different plant parts. However, the scales of females on roots often appear to be more convex than those on fronds.

The few species of Diaspididae known to infest roots of their host plants include *Chortinaspis subterraneus* Lindinger and *C. iridis* Balachowsky. These were found below ground on the root collar of their respective hosts, *Agropyrum* (Graminae) and *Iris* sp. (Iridaceae) (Balachowsky 1941).

Aulacaspis yasumatsui has been tentatively identified (based on field characters) on cycads at many sites in Southeast Asia, but only in areas with a monsoon climate, i. e. with a pronounced wet season alternating with a severe annual dry season of usually five months. It is seldom if ever on cycads in rain forest areas. Their ability to infest roots is apparently not an adaptation to living on deciduous plants, for the fronds of cycads are evergreen and scale insects commonly live on the stems. This may be an important adaptation to surviving brush fires, which are a perennial occurrence in these monsoon areas.

The containerized cycads that were initially exposed to *A. yasumatsui* on 12 December 1996 and on 2 April 1997 in each case were highly infested with *A. yasumatsui* within 2 weeks. Most of the fronds of the first pp.roup, which were larger, were chlo-

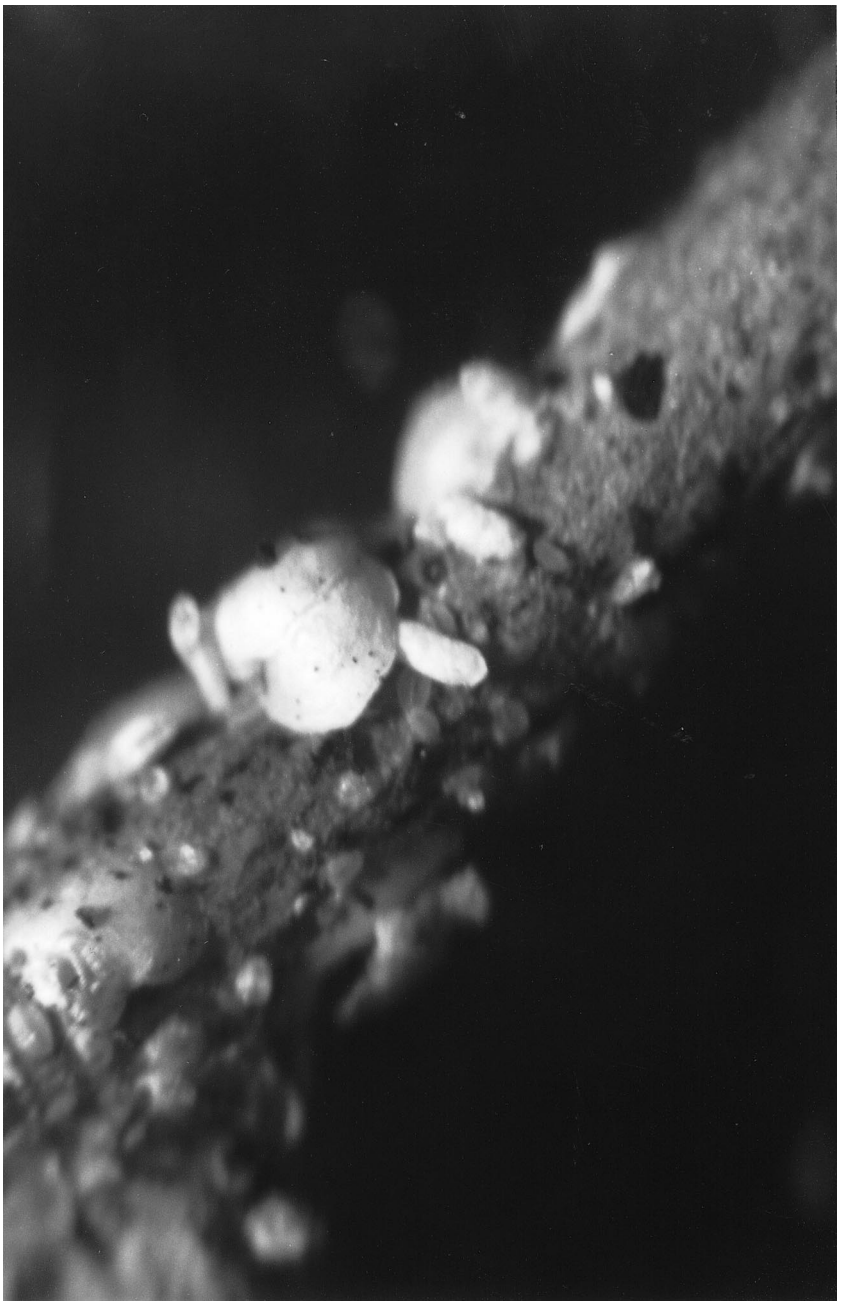

Fig. 4. *Aulacaspis yasumatsui* scales on root of *Cycas rumphii*.

rotic by summer and were brown and desiccated within 270 days. Most of the fronds of the second group, which were smaller, were necrotic within 112 days after being exposed. These plants never recovered and died within one year of initial infestation. In contrast, the 15 plants treated with imidacloprid remained virtually free of scale insects and their fronds were green and healthy during the entire year.

The scales of *A. yasumatsui* males and females are remarkably persistent. Their presence detracts from the appearance of ornamental plants. Cycads continued to appear to be highly infested after most of the scale insects had been killed by insecticides, because the scales did not readily drop off. We were unable to remove old scales easily by mechanical means, e. g., with brushes or high pressure water sprays. Old scales became loosened by soaking excised fronds in soapy water overnight, but similar solutions sprayed on cycad plants did not loosen the scales. A practical treatment that loosens old scales of armored scale insects would be a welcome development in horticulture and plant protection.

No organized survey was conducted, but based on accumulative observations by the Division of Plant Industry and other plant protection and horticultural personnel, the infestation was localized in the Old Cutler Road area of Miami in 1996. We assume it had been introduced into this area a few years previously. By spring of 1997, cycads throughout southern Miami as far north as the downtown area were infested. During the summer of 1997 we found the scale insect at several sites more than 20 km north (North Miami, Hialeah) and east (Miami Beach) of where it is assumed to have been introduced. By February 1998, it was found in Broward County and Palm Beach counties at sites about 55 and 120 km north, respectively, from its assumed introduction site. Although scale insects may be spread short distances by wind dispersal of crawlers, we surmise that the long distance spread of this scale insect was by transport of infested plants.

The unusually dense populations and rapid spread of this scale insect suggests that they were imported without their natural enemies. Indeed, we have examined thousands of scales of this species under the microscope without observing parasitoid exit holes. Occasionally we observed adults of ladybird beetle species (Coccinellidae)long established in Florida crawling on cycads infested with *A. yasumatsui*. However, we have not observed coccinellid eggs or larvae on these plants or obtained other evidence that they feed on the scale insects. *Eumaeus atala* (Lycaenidae), a butterfly whose larvae feed on cycads, sequesters cyasin, a compound contained in cycads, which acts as a defense against predators (Bowers & Larin 1989). Possibly, *A. yasumatsui* similarly sequesters defensive chemicals from its cycad hosts, which could be a deterrent to generalist predators.

Aulacaspis yasumatsui is an unusually severe armored scale insect pest. When not controlled by natural enemies, which is the present situation in Florida, they are highly damaging and often lethal to their host plants. They have a high potential to spread to new areas *via* plant movement, because one to a few fecund females hidden on the fibrous stem or on roots can easily escape detection. Once established, they are an unusually difficult scale insect to control. The experimental treatments mentioned above involved higher rates of imidacloprid than might be practical in the horticultural industries. Furthermore, while these treatments controlled the insect on containerized cycads, we have thus far had inconsistent results with imidacloprid as well as some other chemicals for control of this scale insect on field-grown cycads. Scale insects that survive in the roots may be the source of the rapid re-infestations that we have seen consistently when the scale insect was controlled on the above-ground portions of the plant. This may also make it difficult to control the insect with natural enemies.

Given the value of cycads as ornamentals and the endangered status of some species of these plants, control measures for this pest are urgently needed. The results of studies of chemical control will be reported in another publication. Biological control and other methods are being investigated for control of this pest.

In Florida, an area where the scale insect fauna is well known, in addition to *A. yasumatsui*, 19 species of armored scale insects (Dekle 1976) and 7 species of soft scale insects (Coccidae) (Hamon and Williams 1984) attack cycads. *Aulacaspis yasumatsui* is the only member of its genus known on cycads, thus we have coined the vernacular name 'cycad aulacaspis scale' for this species.

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