IUCN/SSC Cycad Specialist Group – Subgroup on Invasive Pests

Report and Recommendations on Cycad Aulacaspis Scale, *Aulacaspis yasumatsui* Takagi (Hemiptera: Diaspididae)

18 September 2005

Subgroup Members (Affiliated Institution & Location)

- William Tang, Subgroup Leader (USDA-APHIS-PPQ, Miami, FL, USA)
- Dr. John Donaldson, CSG Chair (South African National Biodiversity Institute & Kirstenbosch National Botanical Garden, Cape Town, South Africa)
- Jody Haynes (Montgomery Botanical Center, Miami, FL, USA)[1]
- Dr. Irene Terry (Department of Biology, University of Utah, Salt Lake City, UT, USA)

Consultants

- Dr. Anne Brooke (Guam National Wildlife Refuge, Dededo, Guam)
- Michael Davenport (Fairchild Tropical Botanic Garden, Miami, FL, USA)
- Dr. Thomas Marler (College of Natural & Applied Sciences - AES, University of Guam, Mangilao, Guam)
- Christine Wiese (Montgomery Botanical Center, Miami, FL, USA)

Introduction

The IUCN/SSC Cycad Specialist Group – Subgroup on Invasive Pests was formed in June 2005 to address the emerging threat to wild cycad populations from the artificial spread of insect pests and pathogens of cycads. Recently, an aggressive pest on cycads, the cycad aulacaspis scale (CAS)—*Aulacaspis yasumatsui* Takagi (Hemiptera: Diaspididae)—has spread through human activity and commerce to the point where two species of cycads face imminent extinction in the wild.

Given its mission of cycad conservation, we believe the CSG should clearly focus its attention on mitigating the impact of CAS on wild cycad populations and cultivated cycad collections of conservation importance (*e.g.*, Montgomery Botanical Center). The control of CAS in home gardens, commercial nurseries, and city landscapes is outside the scope of this report and is a topic covered in various online resources (see www.montgomerybotanical.org/Pages/CASlinks.htm). It will be discussed only if it contributes to the understanding of CAS control in wild settings or *ex-situ* conservation collections.

Objective & Tasks

The current objective of this subgroup, as outlined by John Donaldson, Chair of the Cycad Specialist Group (CSG), is to gather facts and make recommendations to the CSG concerning CAS. This report will be organized around specific tasks, which are as follows:

1. Determine how to control the current CAS outbreaks;
2. Determine how to anticipate and, more importantly, stop the spread of CAS;
3. Determine how to preserve the gene pool of species that are already affected by CAS or may become affected; and
4. Undertake an analysis of the current distribution of CAS and identify high risk areas/species.

---

[1] Official contact for CSG Subgroup on Invasive Pests (jhay@montgomerybotanical.org)

Findings & Recommendations

1) CAS control measures

Control measures can be divided into four categories: 1) insecticides, 2) biological control, 3) mechanical/cultural methods, and 4) integrated control (the combined use of 1, 2 & 3). Currently there are no measures for eradicating CAS in cultivated or wild settings short of destroying all cycads in the vicinity of an outbreak. Measures for managing CAS to acceptable levels[2] have been achieved in *ex-situ* conservation collections, but only at high costs in chemicals and labor.

INSECTICIDES

Ex-situ Conservation Collections

All chemicals require repeated applications for effective and continuous control. Therefore, it is desirable to identify those insecticides that have the longest lasting effect and, thus, require fewer repeated doses. Systemic insecticides suppress CAS populations the longest (usually for around one month after application). Systemics are usually applied to the soil, and sometimes on leaves, and are taken up into leaf tissues, where they persist and remain effective deterrents to the target pest.

A number of insecticides have been tested on CAS in cultivation (see Emshousen & Mannion [2004] for a summary). The most widely used systemic for CAS has been dimethoate (trade name Cygon). It has the advantage of being relatively cheap, but it is highly toxic to humans and other mammals. A more expensive systemic noted for its low toxicity to humans is imidacloprid (trade names Merit, Marathon, and Premise). Unfortunately, it has not been effective on CAS in container or field trials based on application rates prescribed by the manufacturers (C. Mannion & C. Wiese, pers. comm.) and, thus, it cannot be recommended here. Another systemic that may be useful is aldicarb (trade name Temik). Although it has not been tested on CAS, it is highly effective on a wide range of invertebrates and may remain effective in soil and plant tissues longer than other systemics. Aldicarb has been shown to be a carcinogen, however, and its use is highly restricted in the U.S.

Many contact (non-systemic) insecticides, such as Diazinon, are effective on CAS, but infestations return much more quickly than using systemics; therefore their use is not recommended over systemics like Cygon. Horticultural oils (*e.g.*, Ultrafine, fish oil) have been widely used with some success, often in tandem or in conjunction with contact and/or systemic insecticides.

Montgomery Botanical Center (MBC) has been a leader in testing various chemical control measures in a cultivated conservation collection. Currently, MBC is rotating two products—the growth regulator, pyriproxyfen (trade name Distance), and the contact/systemic insecticide, dinotefuran (trade name Safari)—to effectively control and suppress reproduction of CAS. Although these various chemical approaches are effective in keeping CAS at acceptable levels, as mentioned above they carry a high cost in chemicals and labor. For example, MBC recently spent USD$2,800.00 to purchase enough dinotefuran for a single application on its *Cycas* collection, which currently comprises 1,043 plants spread over 0.8 ha of land area—resulting in unit costs of USD$2.68 per plant or USD$3,500.00 per ha. In addition to the cost of the chemicals, it took two horticulturists three full days to apply this single treatment (C. Wiese, pers. comm.). The costs in chemicals and labor make insecticides an unattractive option for long-term control. For conservation collections in Third World countries, where labor is relatively inexpensive, the cost of chemicals alone may be prohibitive.

[2] The term “acceptable” is defined here as plants maintaining healthy foliage and being able to produce cones and seeds.

Wild cycad populations

For various reasons, CAS chemical control measures in wild cycad populations require radically different approaches than in cultivation. For example, in the two wild populations where CAS has recently invaded—*Cycas micronesica* in Guam and *C. taitungensis* in Taiwan—terrain obstacles, such as tangled foliage and cliffs, often make hand application of insecticides impossible. Also, the sheer numbers of plants (there are reportedly 1.5 million widely dispersed *C. micronesica* on Guam) impose severe limits on how many plants can be treated. An alternative to treatment on a plant-by-plant basis is broad-scale insecticide application. Aerosols (fine mists) of insecticides can be applied from generators mounted on ground-based vehicles or aircraft to cover wide areas; these are effective for flying insects, such as mosquitoes, but aerosol insecticides are not deposited in effective concentrations on leaf surfaces. Scale insects such as CAS are covered by a protective waxy coat and are often tucked into crevices in their hosts and are usually not affected by aerosols.

Broad-scale applications of insecticides by aircraft can be effective on scale insects if they are rained down as small droplets; these are usually liquids or liquid suspensions of fine solids, and they may be mixed with foliar sticking agents or surfactants that increase their effectiveness. Aerial applications are usually reserved for use on dense monoculture crops. In wild situations when target plants are widely scattered and/or obscured by trees, most pesticides will be wasted and non-target organisms—which may include predators or parasitoids deliberately released for CAS control—will be adversely impacted.

In native habitats, repeated large-scale pesticide applications have additional risks not associated with cultivated settings: they run the risk of driving crucial symbiotic insects (*e.g.*, pollinators) locally extinct, thus jeopardizing the reproductive future of a population. In addition, repeated large-scale applications may result in a build-up of resistance in pests over time, creating resistant strains of CAS that may reinvade habitats and/or cultivated areas where less-resistant strains are being effectively controlled.

Overall, the distribution, morphology, and behavior of CAS in large wild cycad populations do not allow for effective targeting with pesticides. For these reasons, application of pesticides cannot be recommended as a protective measure in wild populations, except those that are small and easily accessible or when the objective is to preserve only a small subsample of a larger population.

The latter may be a crucial and perhaps only available alternative on Guam given current knowledge, and this option should not be disregarded. Recently, Dr. Aubrey Moore (University of Guam) proposed a study where a subsample of the Guam cycad population is to be preserved with the use of either pyriproxyfen (insect growth regulator) or imicide (which contains the active ingredient imidacloprid and is applied as a trunk injection using a closed microinjection system).

BIOLOGICAL CONTROL

In practice, the introduction of predators or parasitoids is the most cost- and labor-effective method of controlling scale insect infestations. It is also the standard approach for long-term control of introduced exotic scale pests (Meyerdirk, 2002). The existence of effective natural biocontrol agents for CAS can be assumed, since the scale is usually in low or moderate densities in wild populations of *Cycas* in Thailand, where CAS is native, where it does not cover foliage like it does in cultivated plants (Tang *et al*., 1997). At least three such predators or parasitoids have been identified and tested in the field as biocontrol agents for CAS.

In 1996, Dr. Richard Baranowski of the University of Florida-Homestead (retired), working with Banpot Naponpeth, director of the Natural Biological Control Research Center at Kawetsart University in Bangkok, Thailand, identified two potential biocontrol organisms. This research was conducted in part on the grounds of Nong Nooch Tropical Garden. Both insects were evaluated and then widely released in Florida as biocontrol agents of CAS.

> *Coccobius fulvus* (Compere & Annecke) (Hymenoptera: Aphelinidae) is a parasitoid[3] wasp no larger than its host, ca. 1 mm long (see Fig. 1). Observations of this organism in south Florida suggest that this wasp, by itself, is not aggressive enough to control CAS on *Cycas* plants, such as *C. revoluta*, that are highly susceptible to CAS (Caldwell, 2005), but it can be effective in large, heavily infested plants of other *Cycas* species and/or plants with dense foliage in which pesticide application is inhibited (Wiese *et al.*, in press). *Coccobius fulvus* has also been released as a biocontrol agent of other diaspid scale insects in the U.S. (Meyerdirk, 2002).

> *Cybocephalus binotatus* Grouvelle (Coleoptera: Nitidulidae) is a predatory beetle not much longer than CAS (see Fig. 2). The adult punctures the scale cover and chews on the living scale underneath; it will also deposit eggs under the scale cover, where its larvae then feed on CAS eggs. A study of the effects of this predator on a similar species of *Aulacaspis* on mangos suggests that, because it requires a substantial scale population to maintain effective numbers, it must be re-released periodically into infested areas to maintain effective control (Lagadec, 2004). Thus, an active, ongoing release program may be necessary for effective control using this biocontrol agent. Recently the beetle released in Florida has been re-identified as *Cybocephalus nipponicus* (Endrody-Younga) (R. Cave, pers. comm.).

The ladybird beetle, *Rhyzobius lophanthae* (Blaisdell) (Coleoptera: Coccinellidae), a native of Australia that is often called the "scale destroyer," has been successfully used as a control agent for CAS on cultivated *Cycas* plants in Hawaii by the University of Hawaii and the Hawaii Department of Agriculture (Hara *et al*., undated). It has also been reared and released on Guam since February 2005 to combat the CAS infestation in wild *Cycas micronesica* populations. This beetle seems to be taking hold and spreading on Guam, but effective control of CAS has not yet been achieved to date (A. Brooke & I. Terry, pers. comm.). Although this beetle was established in Florida as a predator of other scale insects prior to the outbreak of CAS, it has not been observed to have any significant impact on CAS infestations (R. Cave, pers. comm.). To be effective, this predator must be reared and released in significant numbers in infested areas and re-released as outbreaks reoccur.

Other potential biocontrol agents have been identified or suggested, but these require more surveys in the wild, in addition to subsequent lab and field evaluations, before their effectiveness will be known. They include insects, mites, and fungi.

<u>Insects</u>

The twice stabbed lady beetle, *Chilocorus stigma* (Say), a species native to the U.S., has been observed feeding on CAS on cultivated *Cycas* in Florida (Cave & Duetting, 2004; Tang & Skarlinsky, unpubl.). Again, observations suggest that, to be effective, such coccinellid beetles require repeated mass release in infected areas. This species is a generalist that attacks a variety of diaspids.

The following parasitoids of the wasp families Aphelinidae and Encyrtidae have been identified in southern China and Vietnam and may have potential as biocontrol agents of CAS (Cave, unpubl.; Meyerdirk, 2002):

- *Aprostocetus* sp. (possibly *A. purpuratus* Girault)
- *Arrhenophagus* sp. (possibly *A. chionaspidis* Aurivillius)
- *Aphytis lepidosaphes* Compere
- *Encarsia* sp.
- *Pteroptrix chinensis* (Howard)
- *Thomsonisca sankarani* Subba Rao

[3] A parasitoid is an organism whose larval stage lives and grows in its host. The winged adult emerges to find more hosts to lay eggs and thus continue the control cycle.

Mites

The mite, *Hemiarcoptes* sp. (prob. *H. coccophagus*), has been found to control a related species of *Aulacaspis* in a lab setting (Meyerdirk, 2002).

Fungi

An unidentified fungus is known to grow on masses of the scale, *Aulacaspis tegalensis* (Zehntner) (Meyerdirk, 2002). Another unidentified fungus has been observed growing on CAS in Florida (Caldwell, 2005).

MECHANICAL & CULTURAL CONTROL

Heavily infested leaves are usually removed from *Cycas* plants as part of most control programs, especially prior to other types of treatments. As part of good cultural practices, infested leaves and other plant parts should be bagged, buried, burned, or otherwise disposed of to eliminate them as potential sources of further infestations. This is especially true if an eradication program is being attempted.

Even when they have been killed by chemical application, the scale covers of dead CAS adhere to foliage, blocking photosynthesis and interfering with the pest controller's ability to determine if another CAS outbreak is occurring. CAS can also be removed from intact cycad foliage with high pressure water sprays.[4] This approach is labor-intensive and is not recommended for extensive plantings or in wild populations, but it avoids the toxicity to the applicator and biological control agents posed by pesticides.

INTEGRATED CONTROL

Integrated control, or integrated pest management (IPM), is the combined use of a variety of control measures (chemical, biological, mechanical) together with exploitation of seasonality, pest behavior, and other factors to achieve a more effective control than any given method can effectively yield alone. IPM programs are usually flexible and can be adhered to for long-term management. Below are some observations and tentative recommendations on IPM control of CAS.

Ex-situ Conservation Collections

Locus of infection: In cultivated collections, CAS multiplies most readily on highly susceptible species, such as *Cycas revoluta*, and such plants serve as infective agents to other areas of a collection. More manageable control can be achieved if such specimens are removed from core plantings. If such specimens must be retained, they should be placed in areas where they receive extra attention for pest control to prevent them from becoming a repeated source of outbreaks.

Climate/seasonality: CAS is a tropical species, and in a subtropical climate such as south Florida it enters a period of lower reproductive activity in the cooler, drier, winter months (late Nov. through early May). In the springtime (late May), it shows a surge of reproduction from adults that survive on roots and stem crevices—probably responding to an increase in translocated nutrients in the hosts themselves. Temporal targeting of pesticides just prior to this spring flush of activity (*e.g.*, applying granular chlorpyrifos [trade name Dursban] to the crown of the stem) is effective in delaying or preventing outbreaks of CAS at the beginning of the hot, wet, summer months (W. Tang, pers. obs.). Pesticides and/or mechanical methods must, then, be periodically maintained throughout the summer to keep CAS at acceptable levels.

[4] Addition of insecticidal soap to the water helps in the removal of old, dead scale, and may even provide an additional level of control.

At MBC, one application of dinotefuran (Safari) in late May, just as the insects began to emerge, proved successful in controlling and preventing a full-scale outbreak. No additional action was required until late July, when a treatment of pyriproxifen (Distance) was applied.

Balancing biological, mechanical & chemical control: Insecticides can adversely impact biological control agents. Scheduling the use of insecticides to allow for the continued growth of parasitoid/predator populations is difficult. To get around this difficulty, certain plants within a collection may be excluded from pesticide regimes and set aside as breeding sites for biological control agents. Preferentially, these “sentinel” plants should be large *Cycas* specimens on which parasitoids/predators can build large, stable populations.

While biocontrol agents are establishing themselves, CAS can be kept below lethal densities on sentinel plants by mechanical removal with periodic high pressure water sprays. Effective biological control has been achieved on semi-isolated cultivated plants in south Florida using this method (Tang & Skarlinsky, unpubl.). In such cases, agents besides insect parasitoids/predators, such as fungi pathogenic to CAS (Caldwell, 2005), may also be involved. The use of growth regulators or target-specific insecticides that do not adversely affect the predators/parasitoids is another option (Wiese & Mannion, in press).

If acceptable levels of CAS can be achieved with biocontrol in sentinel plants, other specimens in a collection may be added to the program, so that effective biological control is achieved step by step while an ongoing chemical control program continues. While such a gradual introduction program is progressing, it provides an opportunity to conduct in-depth studies of how the biological control organisms function (see Wiese *et al.*, in press). Such data may provide crucial insight into accelerating the introduction and establishment of effective biological control organisms to an area suffering from an incipient CAS outbreak.

Wild cycad populations

To date, populations of two wild cycad taxa located in areas where CAS is not native have been infected by CAS. These are *Cycas micronesica* in Guam and *C. taitungensis* in Taiwan. Other wild species in China may also be newly infected, but further surveys are needed to confirm this.

Currently, CAS is spread from one land area to another via plants (most often *Cycas revoluta*) transported for cultivation. Consequently, new outbreaks in countries or territories previously un-infested with CAS begin in gardens, nurseries, and urban settings. Young CAS crawlers are then blown or transferred via tools or other means from these cultivated plants to others nearby until they reach the wild populations. If such initial infestations are highly isolated, eradication may be a possibility. Eradication is most effective when all infected plants are removed and destroyed. Plants should not be left in place to see if infestations can be controlled by insecticides; this will only allow for further spread.

When eradication is not an option, the outbreak needs to be immediately isolated and suppressed. Insecticides are most appropriate for immediate suppression. This will buy time to prepare for other conservation measures, including gathering funds and other resources for a control program, introduction and establishment of biological control agents, and collection of germplasm for deposition into *ex-situ* conservation collections. CAS will kill an infected *Cycas* host plant within a year if no control measures are taken. Isolating and suppressing the initial outbreak keeps the window of opportunity open longer for the possibility of implementing more permanent solutions.

No IPM program can, at this time, be recommended for control of CAS once it has spread widely into a wild population. Various approaches, including those discussed above for cultivated collections, may be tried, but effectiveness can only be determined by actual trials in the field—and then each field situation may vary. It is imperative that the experience now being gained on the two infested wild taxa mentioned above be intensively documented and studied.

2) Preventing the spread of CAS

Preventing the spread of plant pests is an issue appreciated by governments in most countries, in which entire departments are dedicated to this role. In the U.S., this role belongs in large part to the Plant Protection and Quarantine component of the Department of Agriculture's Animal and Plant Health Inspection Service (USDA-APHIS-PPQ). There are also international organizations/treaties devoted to this objective, such as the European and Mediterranean Plant Protection Organization (EPPO) and the International Plant Protection Convention (IPPC), the latter of which is hosted by the United Nations Food and Agriculture Organization (FAO). Signatories to these treaties/organizations abide by certain regulations and standards for pest exclusion, much as signatory countries of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) abide by regulations of that treaty to control the international trade in endangered plants and animals.

Preventing the spread of pests is actually a multi-stage process. It first involves recognizing the pathways of a pest species' spread—such as its host materials and the routes by which the hosts are transported (how, when, and where). Once they are determined, these pathways are manipulated by establishing programs 1) at the point of origin to minimize export, 2) at the border to exclude entry of the hosts/pests into a country, and 3) inside a country to eradicate or control spread if the pest enters.

International plant protection organizations and those of individual countries focus on known pests of agricultural importance. CAS was unrecognized as a pest of concern when it first made its startling appearance in south Florida in 1995. Government agencies typically act slowly, and by the time the USDA considered control measures, CAS had already spread widely and, regrettably, it was considered impractical to implement quarantines within the U.S. and its territories (W. Tang, pers. obs.). Similarly, the need to exclude CAS has not caught the attention of the plant protection organizations of most countries, which have many other pests of greater concern to deal with. As a result, few funds, training, or regulatory programs are currently geared toward this pest. One exception is EPPO, which lists CAS on its website as a pest of concern[5]. Obviously, free trade is a significant international issue, and in today's political climate it is becoming more difficult to establish and enforce quarantine barriers if they impinge on economically significant products.

Currently in many plant protection organizations (such as USDA-APHIS-PPQ and the FAO) and trade treaties (such as the General Agreement on Tariffs & Trade [GATT]), the movement of pests is ultimately governed by risk assessments. Risk assessments are made using the behavior of pests, the quantities and qualities of host materials that carry them, the frequency of transport pathways, and the probability of establishment in areas of destination. For example, commercial shipments of harvested products, such as cycads, may have consistent levels of CAS infestations associated with them: they may arrive during months when the chance of establishment is high; the climate of the nurseries where the plants are being re-established prior to sale to the public may be favorable to CAS establishment; suitable host material for the establishment of the pest may be widely prevalent in the landscape; etc. Multiply all of these factors together and you will have a probability of successful introduction of a pest. Quarantine decisions are then made based on such risk assessments. If the product is determined to be a high risk, its import may either be prohibited or mandatory fumigation may be required as a condition of entry. Currently in the U.S., the pest risk of cycad imports is considered moderate and commercial shipments may enter after inspection reveals that they are free of dangerous pests. The problem, of course, is that CAS can be very difficult to

[5] The link to EPPO's CAS alert page is as follows: http://www.eppo.org/QUARANTINE/Alert_List/insects/aylsya.htm

detect on imported plants. The CSG may want to consider developing its own pest risk analysis and make it available on a website for plant protection organizations to use.

There are currently three main pathways of spread for CAS: 1) botanic gardens, 2) the commercial nursery industry, and 3) private collectors (see discussion below). The importance of each pathway will vary from country to country. In countries that do not import commercial quantities of *Cycas revoluta*, private collectors may be the most important pathway. In others where collectors and commercial shipments are absent, botanic gardens may be the primary pathway. Most of the people involved in these pathways are unwitting participants in the spread of CAS. These participants need to be alerted to this pest and encouraged to develop their own barriers for introduction. This can be accomplished with repeated alerts in trade magazines and on websites viewed by people most likely to spread CAS by their activities. It should be made clear that such alerts and preventative measures are a benefit to all; many people, however, have no experience with the destructiveness of pests such as CAS, and may merely view such measures as unnecessary hindrances. The need for a continuous and proactive information campaign cannot be overstressed.

How do these factors and models apply to the CSG? It should be the job of this subgroup of the CSG to conduct a risk and pathway analysis on CAS. We need to determine which countries are sources of infestation and which are vulnerable to CAS and then establish or assist other agencies in establishing measures for preventing the spread of CAS. The CSG can easily and effectively contribute in the following ways:

1. Raising concern among the many national and international plant protection agencies via an awareness campaign using general as well as targeted media outlets (see above and below for further discussion);
2. Providing readily accessible posters and alerts (in the languages of countries at highest risk) that can be used for the education of plant protection officials and the public; and
3. Providing accurate information on exclusion methods, including the following:
    a. Where to target exclusion attempts (*e.g.*, exclusion efforts may be aimed at commercial *Cycas revoluta* imports or passenger baggage; pathways of highest risk may vary from country to country);
    b. How to inspect for and recognize CAS; and
    c. How to treat plants and cargo to prevent the entry of the pest into high risk countries (*e.g.*, potentially infested plants encountered at border stations may be fumigated as a condition of entry or prohibited entry outright).

If the CSG can use the IUCN name and its media outlets, this would be a highly effective means to promote the exclusion of this pest on an international level.[6] The plight of *Cycas micronesica* and *C. taitungensis* could be used as a tool of great shock value in demonstrating the danger of this pest. Although the initial reaction of local officials and scientists to an outbreak of CAS may be to hide it, on the contrary, every effort should be made to publicize it. Only then will assistance and funding be forthcoming and only then will CAS be recognized as an organism of great extinction power.

[6] To be successful, this media campaign ***must*** effectively alert customs authorities and phytosanitary inspection officers to the problem. This will undoubtedly be difficult because CITES authorities are seldom set up to deal with these sorts of problems, and in most countries CITES and phytosanitary permits are dealt with by different departments.

3) Preserving the gene pool of wild cycads infested by CAS

There are two basic ways to preserve any gene pool: *in-situ* and *ex-situ*. In this sense, the answer to preserving cycad species suffering from CAS infestations is no different from that posed by habitat destruction or commercial collecting. *In-situ* preservation requires that a significant portion of the wild species—representing different populations, varieties, and habitats—be preserved. The chemical, biological, and mechanical control methods stated above, as inadequate as they may be, are currently the best available techniques for achieving this goal. For small populations, a chemical- and labor-intensive program may be feasible. For a large population, only subsamples can be preserved using this approach.

For *ex-situ* conservation, a genetically representative sample is removed from habitat and introduced into cultivation (see Walters [2003] for appropriate methods), where CAS control measures can be more effectively applied. Such *ex-situ* collections should, in theory, be located as close to the natural habitat as possible so that symbiotic organisms (*e.g.*, cyanobacteria, mycorrhizal fungi, pollinating insects, etc.) may also be preserved with the host plants. If this is not feasible, then any *ex-situ* site where the plants can be grown is appropriate. Dr. Anne Brooke currently has a funding proposal to collect such a representative sample of *Cycas micronesica* for establishment on the island of Tinian for *ex-situ* preservation. However, there is no guarantee that CAS will not spread to that nearby island. Therefore, MBC is also intent on developing a population-based *ex-situ* conservation collection of both *C. micronesica* and *C. taitungensis* in its research garden in Miami, FL. The movement of symbiotic organisms to *ex-situ* sites is not recommended, as many countries have barriers to the introduction of exotic insects, soil, and soil-borne organisms like bacteria and fungi because they present a potential ecological risk, just as CAS itself does.

4) Current distribution of CAS and identification of high risk areas/species

CASE STUDIES OF CAS OUTBREAKS

The first known outbreak of CAS outside of its natural range occurred at the Bogor Botanic Garden in Java in the late 1980's, where it wiped out that garden's *Cycas* collection (A. Lindstrom, pers. comm.). It is unknown whether CAS persists on other cultivated or wild plants in Java. Unfortunately, this outbreak was not publicized, so no warning was given to avoid future outbreaks.

The second known outbreak occurred in south Florida in 1995, as two botanical institutions (Fairchild Tropical Garden and the Montgomery Foundation [now MBC]) struggled to recover from damage caused by Hurricane Andrew in 1992. Expeditions funded by a National Science Foundation grant to reconstitute these institutions' collections were instrumental in CAS introduction. The outbreak may have originated from plants collected in Vietnam, which were observed to be infested with CAS in late 1994 in an MBC greenhouse (W. Tang, pers. obs.). South Florida is a major center of the commercial plant industry in the U.S.—where *Cycas revoluta* and other cycads are grown in wholesale quantities for national and international distribution. As a result, CAS spread quickly from there to other parts of the U.S., especially through chain stores that were supplied by south Florida nurseries. In general, commercial dealers do not impose their own quarantines unless it is in their own financial interest, and in this case pest alerts and restrictions were too slow in appearing to prevent the spread. In at least one case a wholesale dealer, who ironically was also a local agricultural official, deliberately sold infested plants to the Cayman Islands and apparently initiated the infestation there.

A third path of infestation occurred in China. Although the scientific description of CAS was originally based in part on a specimen from south China (Takagi, 1977), it does not appear to have been widespread there. In the mid 1990's wholesale quantities of *Cycas inermis* were imported from southern Vietnam to two botanic gardens in China—Fairy Lake Botanic Garden in Shenzhen and Qing Xiu Mountain Botanic Garden in Nanning. This trade in large, wild-collected *Cycas* plants between Vietnam and China continues today in contravention of CITES, and these plants continue to be planted for display in public grounds, hotels, etc. Due to this trade, CAS has become widespread in botanic gardens and nurseries throughout southern China. As in the case of south Florida, south China is a center for a nursery industry that grows and exports *C. revoluta*. The increase of affluence in China in the 1990's led to exploding demands for *C. revoluta* as an ornamental for business buildings and city landscapes. When domestic markets began to saturate in the early 2000's, Chinese cycad nurseries petitioned and received their government's permission to export. This may have led to the introduction of CAS to Taiwan, another center of *C. revoluta* production and export. Today, China and Taiwan are among the world's largest exporters of *C. revoluta* and, with it, presumably CAS. Every month, 20- and 40-foot containers packed with thousands of *C. revoluta* arrive in Miami from these countries (W. Tang, pers. obs.), destined for re-establishment and ultimately retail distribution. Undoubtedly, similar shipments are being sent to other equally or more vulnerable parts of the world.

The three outbreaks mentioned above put into perspective two of the three potential pathways for the spread of CAS—namely botanical gardens seeking to expand their living collections and the commercial nursery industry. The third potential pathway consists of private collectors who trade plants among themselves. The volume of plant movement in the collector pathway is much smaller than that of botanical gardens and the nursery industry; however, the risk of spreading CAS may be just as high, depending on where plants are sent and whether or not there are any safeguards in place at the destination to prevent establishment. Collectors often circumvent plant quarantine inspections (*i.e.*, smuggle) to avoid CITES requirements. In this sense, CITES regulations ironically increase the risk of spread of CAS.

CURRENT DISTRIBUTION OF CAS

The native distribution of CAS extends from wild populations of *Cycas* in India and the Andaman Islands across to Vietnam and includes Thailand and probably Cambodia, Laos, peninsular Malaysia, Myanmar, and southernmost China. In the U.S. and its territories, CAS is reported to have been introduced into Alabama, Florida, California, Georgia, Guam, Hawaii, Louisiana, South Carolina, Puerto Rico, Texas, the U.S. Virgin Islands, and Vieques (Ben-Dov *et al*., 2005; Broome, 2000; J. Haynes, pers. obs.). In the Caribbean, it is also established in the Cayman Islands and on St. Kitts (Ben-Dov *et al*., 2005; W. Tang, pers. obs.). CAS is also now widespread in southern China and it has been introduced to Hong Kong, Singapore, and Taiwan (Ben-Dov *et al*., 2005; Hodges *et al*., 2004; W. Tang, pers. obs.). A report of CAS in Madagascar (Hubbuch, undated) needs confirmation.

AREAS & SPECIES AT RISK

Wild populations of *Cycas micronesica* on Guam and *C. taitungensis* on Taiwan are currently facing the possibility of extinction as a result of CAS infestations. Virtually all other *Cycas* outside of the natural range of CAS are at risk of being infested and extirpated. *Cycas revoluta* is highly vulnerable to attack in cultivation, and wild populations in Japan must be considered vulnerable. All Australian *Cycas* that have been tested in cultivation have proven themselves highly vulnerable to attack (there are 27 species in Australia). *Cycas* plants in northern and northeastern Australia number in the millions and sometimes form dense, continuous stands for tens of miles and comprise significant components of the native flora. An outbreak of CAS there may lead to a cycad holocaust that would far exceed any damage done by habitat destruction and commercial collecting. Many species of the *C. rumphii* complex—which ranges from New Caledonia and Micronesia across to the Philippines, Celebes, Indonesia, and Madagascar—are also vulnerable. The movement of infected plants—either through commercial or scientific shipments or through mail or baggage of collectors—to any of these regions could result in the catastrophic demise of wild *Cycas* populations or even entire species.

In cultivation, with heavily infested *Cycas* in proximity, various species of *Bowenia*, *Ceratozamia*, *Dioon*, *Encephalartos*, *Microcycas*, *Macrozamia*, and *Stangeria* have been observed to be infected by CAS on leaves or cones (Howard *et al*., 1999; J. Haynes, pers. obs.; W. Tang, pers. obs.). Experience with *Cycas* would suggest that vulnerability to CAS in cultivation translates to susceptibility in the wild. Of the other genera, several taxa are at particular risk. The monotypic *Stangeria eriopus* seems particularly susceptible, as does *Macrozamia lucida*. The cones of *Encephalartos manikensis* and its allies, as well as *Ceratozamia robusta* (Belize), become covered with CAS to the point where seed production is aborted. In the event that CAS is introduced to wild populations of these species, reproduction would likely fail, possibly leading to their eventual extinction—though in a less dramatic time frame than infestations on *Cycas*. Undoubtedly, there are other species outside of *Cycas* which may prove to be equally vulnerable.

As with any insect species, *Aulacaspis yasumatsui* populations have natural variation and continue to evolve. The possibility of CAS evolving and shifting to new, previously immune or little-affected species is a distinct possibility. Cycad species that are now little affected may become prone in the future. Many scale insects are known to be polyphagous and to evolve to infect a wide range of plant species. This was one reason why Baranowski moved quickly to find predators/parasitoids of CAS after the initial outbreak in Florida; however, little work has been done since.

Recently, a question has arisen as to the identity of the cycad scale in Guam and whether it is, indeed, the same as the species in Florida. Dr. Greg Hodges (pers. comm.), scale specialist with the Florida Department of Agriculture, reported that a key character of *Aulacaspis yasumatsui*—the number of macroducts on the 6^{th} abdominal segment—may vary with host taxon. On *Encephalartos barteri* these macroducts number 3; on *E. lebomboensis* (?) they number 2; on *Cycas revoluta* they range from 2-3, and on *C. rumphii* they range from 1-2. He also stated that, upon examination of additional samples, the Guam and Florida specimens matched closely. Dr. Gillian Watson, Associate Insect Biosystematist with the Plant Pest Diagnostic Center of the California Department of Food and Agriculture, stated the following in a recent e-mail to Dr. Aubrey Moore:

> I agree with Greg Evans [scale specialist with the USDA-APHIS-PPQ] about the variation on abdominal segment VI, which I too noticed in both samples [from Florida and Guam]. However, since both samples also contain a few specimens that conform with Takagi's original description, illustration and material from the type sample (which Takagi supplied to me while I was at the Natural History Museum, London) in most other respects, I feel this is probably [environmentally-induced] variation within the species.

Thus, further study on both phenotypic plasticity and genetic variation of CAS appears necessary to clarify questions of its exact identity and distribution.

<u>Primary Recommendations to the CSG</u>

To reiterate, the activities of major urgency that the CSG should pursue are the following:

1. A ***major priority*** must be to promote research on identifying new biocontrol agents for CAS and determining how to improve the effectiveness and accelerate the establishment of biocontrol organisms in newly infested areas.
2. Work together with the IUCN/SSC Invasive Species Specialist Group and the Global Invasive Species Programme to alert plant protection organizations of countries throughout the tropics and subtropics—especially those that possess wild species of *Cycas*—about the threat of CAS. Provide them with information and techniques for effective exclusion of CAS. This will require tapping into the IUCN and/or other high profile media outlets.
3. Assist with locating funding for current control efforts in Guam and Taiwan. Aid in collating and documenting such efforts, so as to identify the most effective techniques and avoid repeated duplication of ineffective control measures.

Literature Cited

Ben-Dov, Y., D.R. Miller & G.A.P. Gibson (2005) Scalenet, distribution query. Website: http://198.77.169.79/scalenet/scalenet.htm

Broome, T. (2000) The Asian cycad scale. *Cycad Newsletter* 24(4):6-7.

Caldwell, D. (2005) Some beneficial insects and a fungus that attacks the cycad aulacaspis scale. Website: http://collier.ifas.ufl.edu/Horticulture/CAS_index.htm

Cave, R. (unpubl.) Biological control of *Aulacaspis yasumatsui*, a serious pest of cycads in Florida, Hawaii and Gaum: exploration for and screening of natural enemies.

Cave, R. & P. Duetting (2004) Predatory Coleoptera on king sago (Cycadaceae) in south Florida. Website: http://esa.confex.com/esa/2004/techprogram/paper_15445.htm

Emshousen, C. & C. Mannion (2004) Taming Asian cycad scale (*Aulacaspis yasumatsui*). *Cycad Newsletter* 21(1):8-10.

Hara, A., R. Niino-Duponte, C. Jacobson, S. Chun, W. Nagamine, R. Heu & N. Nagata (n.d.) *What's Killing my Sago Palm*. Pamphlet of the University of Hawaii and Hawaii Dept. of Agriculture.

Howard, F.W., A. Hamon, M. MacLaughlin, T. Weissling & S.-L. Yang (1999) *Aulacaspis yasumatsui* (Hemiptera: Sternorrhyncha: Diaspididae): A scale insect pest of cycads recently introduced into Florida. *Florida Entomologist* 82(1):14-27.

Hodges, G., F. Howard & E. Buss (n.d.) Update on management methods for cycad aulacaspis scale. Website: http://www.doacs.state.fl.us/pi/enpp/ento/aulacaspis.html

Hubbuch, C. (n.d.) Are the king and queen dead in Florida? Palm & Cycad Societies of Florida website: http://www.plantapalm.com/uce/misc/dioon.htm

Lagadec, M. (2004) The control of mango scale in commercial orchards through the use of the predatory beetle, *Cycbocephalus binotatus*. Website: http://www.actahort.org/books/645/645_67.htm

Meyerdirk, D. (2002) *Control of Cycad Scale,* Aulacaspis yasumatsui *(Homoptera: Diaspididae)*. USDA Environmental Assessment.

Takagi S. 1977. A new species of *Aulacaspis* associated with a cycad in Thailand (Homoptera: Cocoidea). *Insecta Matsumurana New Series* 11:63-72.

Tang, W. & T. Skarlinsky (unpubl.) IPM control of the cycas scale, *Aulacaspis yasumatsui* (Diaspididae): A case study in Miami, Florida.

Tang, W., S.L. Yang & P. Vatcharakorn (1997) *Cycads of Thailand*. Nong Nooch Tropical Garden & Cycad Conservation Co., Bangkok.

Walters, T. (2003) Off-site collections. *In*: J. Donaldson (ed.), *Cycads: Status Survey and Conservation Action Plan*. IUCN, Gland, Switzerland and Cambridge,UK.

Wiese, C., D. Amalin, R. Coe & C. Mannion (In press) Effects of the parasitic wasp, *Coccobius fulvus*, on cycad aulacaspis scale, *Aulacaspis yasumatsui*, at Montgomery Botanical Center, Miami, Florida. *Proceedings of the Florida State Horticultural Society*.

Wiese, C. & C. Mannion (In press) Managing cycad aulacaspis scale (*Aulacaspis yasumatsui* Takagi) at Montgomery Botanical Center, USA. *Proceedings of the 7th International Conference on Cycad Biology, Xalapa, Mexico*.

Figure 1. The parasitoid wasp, *Coccobius fulvus*, on a female CAS host. Photo: D. Caldwell, 2005.

Figure 2. The predatory beetle, *Cybocephalus binotatus*, larva (left, with adult female CAS) and adult (right, with penny for scale). Photos: D. Caldwell, 2005.