Biological Control of the Cycad Aulacaspis Scale, *Aulacaspis yasumatsui*

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Ecological impact of CAS invasions varies greatly with location, largely due to differences in characteristics of host plant populations, climate, and presence of natural enemies. When CAS arrived in Florida (1995) and Hawaii (1998), it became a pest of ornamental cycads which could be protected using a combination of pesticide applications and biological control. However, when CAS arrived in Guam (2003), it rapidly spread from *Cycas revoluta* and *Cycas micronesica* planted as ornamentals to the wild *Cycas micronesica* population, causing an uncontrolled island-wide outbreak.

C. micronesica taxonomy *Cycas micronesica* K. D. Hill 1994 is endemic to Micronesia currently growing on Guam, the Northern Mariana Islands, the Yap Islands, and the Palau Islands. Prior to its description of a new species (Hill 1994), it was identified as *C. rumphii* or *C. circinalis*.

Pre-invasion status of _C. micronesica_ Based on an island-wide census of Guam's trees performed by the U. S. Forest Service in in 2002, a year before arrival of CAS, *C. micronesica* was identified as the most abundant tree in Guam's forests Donnegon et al. 2004.

First detection and invasive pathway for arrival of _A. yasumatsui_ on Guam Arrival of CAS on Guam was predicted: on February 13 2000 T. E. Marler published an article in the Gardening section of the Pacific Daily News entitled *Looking out for scale insects* (Haynes and Thomas E. Marler 2005). Alarmed by establishment of CAS in Hawaii, Marler warned of pending arrival on Guam and pleaded for a ban cycad imports to the island.

CAS was first detected in the Tumon Beach hotel area of Guam near the end of 2003 on *C. micronesica* and *C. revoluta* growing as ornamental plants at two hotels. In those days, almost every hotel on Guam had cycad displays near their entrances.

The invasion pathway along which CAS travelled to Guam is unknown. It is likely that this pest arrived via importation of infested cycads from Hawaii, Florida or elsewhere. However, there are is no evidence of this: there are no records of legal cycad importation to Guam in the two years prior to detection of CAS on the island (R. Campbell, Guam Plant Inspection Facility, personal communication to AM).

An intriguing alternative is that CAS arrived on Guam as crawlers. For several years prior to arrival, there was an active infestation of CAS on *C. revoluta* growing in an outdoor garden at the Honolulu International Airport located within a few hundred meters of where passengers boarded a daily 7.5 hour flight to Guam. Possibly, crawlers were carried on clothing of passengers visiting this garden or airborne scale crawlers may have been blown into cargo holds, wheel wells, or other spaces on Guam-bound aircraft. The location of initial CAS detection sites in Tumon Bay are only about 1 km downwind of the Guam International Airport.

Trajectory of the Guam CAS infestation and impact on the *C. micronesica* population The Guam CAS outbreak, which was severe and spread rapidly throughout the island (Table 1), was well documented by Marler and others. Within 12 years, *C. micronesica* went from being the most abundant tree in Guam's forests to being listed as a under the U.S. Endangered Species Act. There is a consensus among biologists working on this problem that CAS was the major driver of this ecological catastrophe, although other recently arrived invasive species and even some native species are also involved (Moore, R. H. Miller, T. E. Marler, et al. 2013).

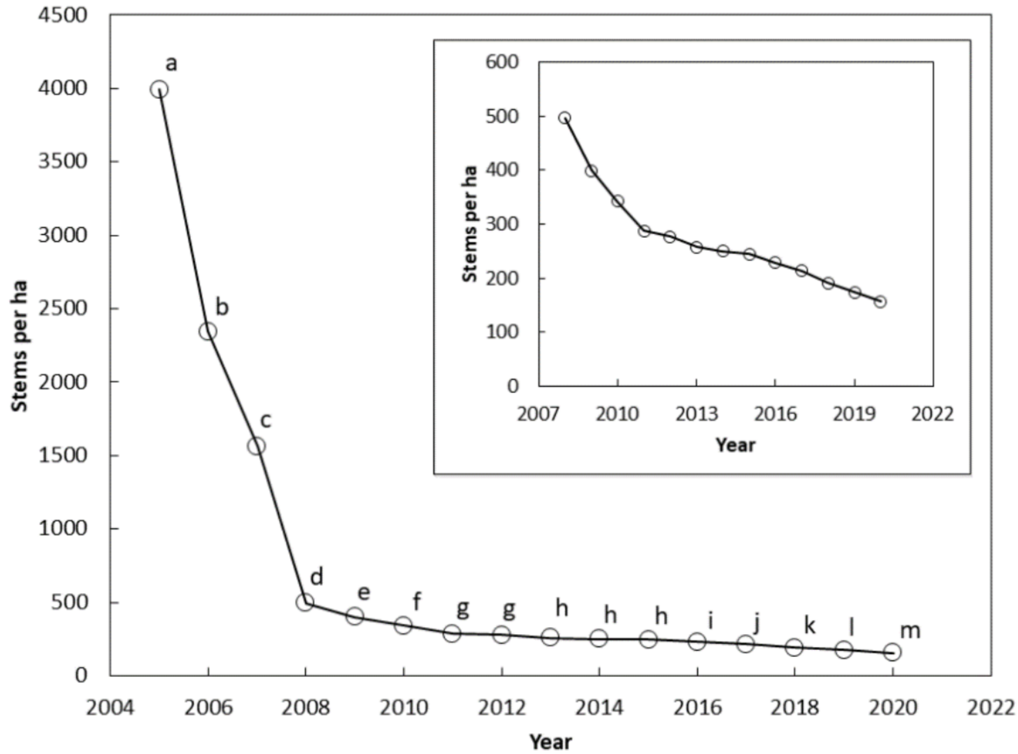

Figure 1: [From Thomas E. Marler and Krishnapillai 2020] The number of Cycas micronesica stems per ha (all size categories) among 12 Guam habitats from 2005 until 2020. The inset shows results from 2008 until 2020 with smaller vertical axis range. Ordinates of markers with the same letter are not significantly different.

Rapid decline of the Guam *C. micronesica* population was documented by Thomas E. Marler and Krishnapillai 2020 (Figure 1). Data are annual cycad stem counts in 120 permanent plots established after infestation of Guam's wild cycads, but prior to any mortality. It can be seen in the figure that cycad stem count declined to only 12.5% of the original within the first 3 years of the survey (2005-2008) and continued to decline to only 4% of the original count in succeeding years (2009-2020). In addition to high plant mortality surviving cycads stopped reproducing. Thomas E. Marler and Krishnapillai 2020 reported that last seedling (0-10 cm tall) was seen in their plots in 2006 and the last juvenile (10-100 cm tall) was seen in 2014.

Pending exterpation of Guam's native cycads is not the first or last ecological disaster caused by invasive species in Guam's forests. The brown tree snake killed virtually all of Guam's forest birds and the cocounut rhinoceros beetle is killing large numbers of coconut palms, formerly the second most abundant trees in Guam's forests (Donnegon et al. 2004).

Prior to introduction of *Rhyzobius lophanthae* as a biological control agent in 2005, untreated, CAS-infested *C. micronesica* typically died within a year. Several overlapping generations of CAS totally encrusted all leaves within a few months of infestation. Plant mortality was caused by a combination of nutrient removal by CAS sap feeding plus blockage of photosynthesis. Muniappan et al. 2012 suggest that toxic effects of CAS saliva may also be involved in cycad mortality.

Table 1: Timeline for the Guam CAS infestation.

2000	T. E. Marler predicts of arrival of CAS on Guam in a Pacific Daily News article (Haynes and Thomas E. Marler 2005) in response to detection of this pest in Florida during 1996 (Howard et al. 1999) and Hawaii during 1998 (Heu, Chun, and Nagamine 2003)
2002	An initial US Forest Service survey indicates that *C. micronesica* is Guam's most abundant tree (with stem diameter greater than 5 inches) and estimates a population size of 1,571,556 (Donnegon et al. 2004)
2003	CAS first detected on ornamental *Cycas revoluta* and *C. micronesica* at hotels in Tumon Bay
2006	*C. micronesica* added to the IUCN Red List of Endangered and Threatened Species
2013	A second US Forest Service survey ranks *C. micronesica*, misidentified in the report as *C. circinalis*, is Guam's xxrd most abundant tree (with stem diameter greater than 5 inches) and estimates a population size of n,nnn,nnn (Lazaro et al. 2020)
2015	*C. micronesica* listed as a threatened species under the US Endangered Species Act (United States Government 2015)

Current status of the Guam *C. micronesica* population 96% mortality (Thomas E. Marler and Krishnapillai 2020)

Impact of CAS on the Guam *C. micronesica* population

Impact of CAS on *C. micronesica* individuals Increased threat of island endemic tree?s extirpation via invasion-induced decline of intrinsic resistance to recurring tropical cyclones

Impacts to plants infested with CAS linger after the scale insects have been killed by insecticides or biocontrol agents. Scale covers block photosysnthesis (Tang et al. 2005).

Plants which have recovered from CAS infestation are structurally weakend and are susceptible to typhoon damage (T. Marler 2013).

Plants which have recovered from CAS infestation are less able to reproduce (T. Marler and Terry 2021), (T. Marler and Terry 2021),

Saliva toxicity (Muniappan et al. 2012).

Seeds from infested plants are deficient in nonstructural carbohydrates (Thomas E. Marler and Cruz 2019) and germination rates are much lower 43% to 7%.

Cascading impacts of CAS Effects on soil Thomas E. Marler and Calonje 2020

Haynes and Thomas E. Marler 2005

5 Natural enemies of CAS - Cave

6 Classical biological control

6.1 Florida - Cave

6.2 Hawaii - Wright

6.3 Guam - Moore

6.3.1 *Rhyzobius lophanthae*

About 100 adults of *Rhyzobius lophanthae* were field collected on Maui and imported to Guam during November 2004. This coccinelid was originally introduced to California from Australia in 1892 and to Hawaii from California in 1894. It was observed feeding voraciously on CAS shortly after arrival of this new pest in Hawaii.

R. lophanthae was previously introduced to Guam on two separate occasions under various synonyms: *R. satelles* Blackburn, *Lindorus lophanthae* (Blaisdell), and *R. pulchellus* Montrouzier (Nafus and Schreiner 1989). In 1925 and 1926 *Rhyzobius satelles* was imported to Guam from California to control the coconut scale, *Aspidiotus destructor* Signoret. However, attempts at field establishment failed.

Nafus and Schreiner 1989 also reported:

> In 1971, *Rhyzobius satelles* Blackburn (as *R. pulchellus* Montrouzier) was introduced to Guam from New Caledonia to aid in the control of coconut scales and citrus scales. A single specimen of *R. satelles* was recovered in 1978, indicating establishment. The beetle, however, is very uncommon; an intensive survey of coconut insects in 1984 yielded no specimens.

The beetles from Maui were reared on scale-infested *C. micronesica* cuttings placed in a large screened camping tent set up in a laboratory. Adult offspring were collected for field release by aspirating them from the walls of the tent into plastic vials. Field releases were initiated on February 16 2005 at the Guam National Wildlife Refuge at Ritidian Point. The beetles established readily. By July 7 2005 high densities on adults were observed on cycads anywhere within a 1 km radius of the release site. Establishment and dispersion of the beetles were monitored using yellow sticky traps deployed between June 2005 and May 2006. Unexpectedly, we were also able to monitor CAS crawlers and adult males using these traps (Fig. 2) (Moore 2017). Following establishment of *R. lophanthae* at Ritidian Point, laboratory-reared and field-collected beetles were released at about 30 other sites throughout Guam.

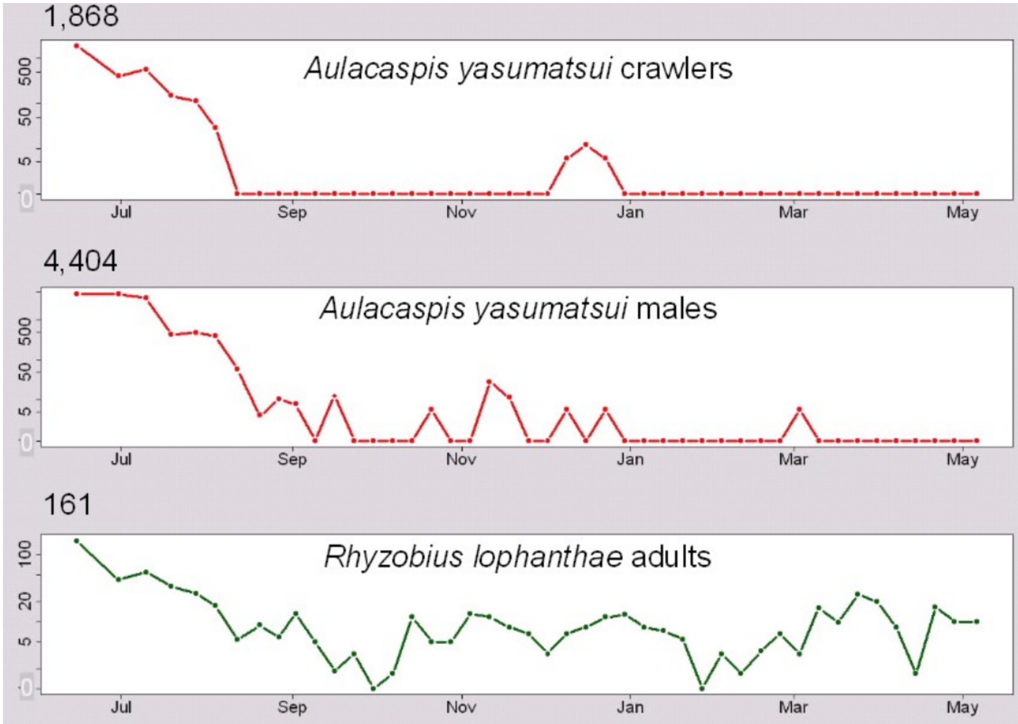

Figure 2: Insects trapped on yellow sticky cards at Ritidian Point, Guam following field release of Rhyzobius lophanthae in February, 2005. X axis runs from July 2005 through May 2006; Y-axis, in log scale, is number of insects trapped per square meter per day. [Figure from Moore, R. H. Miller, and Thomas E. Marler 2013]

By about 2010, *R. lophanthae* larvae or adults could be found on almost every CAS-infested cycad on Guam, preventing CAS from killing mature cycads. By 2010, about 90% of wild cycads had been killed on Guam (REF). Unfortunately, the *C. micronesica* population is not recovering because almost all seeds and seedlings are being killed by CAS and other causes (REF). T. Marler, R. Miller, and Moore 2013 showed that *R. lophanthae* predation of CAS is significantly reduced close to the ground and suggest that this may partially account for failure of the beetle to protect CAS seedlings. They also suggested:

The causes of reduced scale predation by *R. lophanthae* near the ground are unknown, but a parasitoid biological control agent may not exhibit these same limitations. Furthermore, because a parasitoid would be much smaller than *R. lophanthae*, it would likely be better able to access scale infestations within cracks and crevices on *C. micronesica* and *C. revoluta* trees.

6.3.2 *Coccobius fulvus*

6.3.3 *Aphytis lignanensis*

6.3.4 *Arrhenophagus*

Ask Mark, Janis about Bernarr's report on fortuitous introduction of CAS parasitoids.

Ask Reddy about his report.

Ask Arnold Harra.

6.4 Elsewhere - Cave

7 Prospects for future action - Cave, Wright, and Moore

References

Donnegon, Joseph A., Sarah L. Buttler, Walter Grabowiecki, Bruce A. Hiserote, and David Limtiaco (2004). *Guam's Forest Resources, 2002*. PNW-RB-243. URL: http://www.fs.fed.us/pnw/pubs/pnw_rb243.pdf (visited on 07/30/2016).

Haynes, Jody and Thomas E. Marler (2005). *Exotic Invasive Pest Insect Critically Threatening Guam's Flora , Fauna and Island Ecosystem*. URL: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwibg5n2-vj0AhX5SGwGHbFJCL8QFnoECAUQAQ&url=http%3A%2F%2Fwww.montgomerybotanical.org%2Fmedia%2FCAS%2FHaynes-Marler-Guam-CAS-Overview.pdf&usg=AOvVaw1mtuqo4K8qYL0_hiJII35J.

Heu, RA, M Chun, and WT Nagamine (2003). "Sago Palm Scale, Aulacaspis Yasumatsui Takagi (Homoptera: Diaspididae)". In: *State of Hawaii Department of Agriculture New Pest Advisory* 99-01. URL: https://hdoa.hawaii.gov/pi/files/2013/01/npa99-01-spalmscale2.pdf.

Hill, K. D. (1994). "The Cycas Rumphii Complex (Cycadaceae) in New Guinea and the Western Pacific". In: *Australian Systematic Botany* 7.6, pp. 543–567. ISSN: 1446-5701. DOI: 10.1071/sb9940543. URL: https://www.publish.csiro.au/sb/sb9940543 (visited on 01/08/2022).

Howard, Forrest W., Avas Hamon, Michael Mclaughlin, Thomas Weissling, and Si-lin Yang (Mar. 1, 1999). "Aulacaspis Yasumatsui (Hemiptera: Sternorrhyncha: Diaspididae), a Scale Insect Pest of Cycads Recently Introduced into Florida." In: *Florida Entomologist*, pp. 14–14. ISSN: 1938-5102. URL: https://journals.flvc.org/flaent/article/view/74858 (visited on 01/17/2022).

Lazaro, Michelle, Olaf Kuegler, Sharon Stanton, Ashley Lehman, Joseph Mafnas, and Mikhail Yatskov (2020). “Guam’s Forest Resources: Forest Inventory and Analysis, 2013”. In: *Resour. Bull. PNW-RB-270. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 43 p.* 270. DOI: 10.2737/PNW-RB-270. URL: http://www.fs.usda.gov/treesearch/pubs/59433 (visited on 01/11/2022).

Marler, Thomas (June 26, 2013). “Increased Threat of Island Endemic Tree’s Extirpation via Invasion-Induced Decline of Intrinsic Resistance to Recurring Tropical Cyclones”. In: *Communicative & integrative biology*, e223611–223616. DOI: 10.4161/cib.22361.

Marler, Thomas, Ross Miller, and Aubrey Moore (Jan. 1, 2013). “Vertical Stratification of Predation on Aulacaspis Yasumatsui Infesting Cycas Micronesica Seedlings”. In: *HortScience: a publication of the American Society for Horticultural Science*, pp. 60–62. DOI: 10.21273/HORTSCI.48.1.60.

Marler, Thomas and Irene Terry (Nov. 13, 2021). “Aulacaspis Yasumatsui Invasion Reduced Cycas Micronesica Microstrobilus Size and Pollinator Brood Site Competence”. In: *Insects* 12, p. 1023. DOI: 10.3390/insects12111023.

Marler, Thomas E. and Michael Calonje (June 2020). “Two Cycad Species Affect the Carbon, Nitrogen, and Phosphorus Content of Soils”. In: *Horticulturae* 6.2 (2), p. 24. DOI: 10.3390/horticulturae6020024. URL: https://www.mdpi.com/2311-7524/6/2/24 (visited on 12/23/2021).

Marler, Thomas E. and Gil N. Cruz (2019). “Source and Sink Relations Mediate Depletion of Intrinsic Cycad Seed Carbohydrates by Aulacaspis Yasumatsui Infestation”. In: *HortScience* 54.10, pp. 1712–1717.

Marler, Thomas E. and Murukesan V. Krishnapillai (May 2020). "Longitude, Forest Fragmentation, and Plant Size Influence Cycas Micronesica Mortality Following Island Insect Invasions". In: *Diversity* 12.5 (5), p. 194. DOI: 10.3390/d12050194. URL: https://www.mdpi.com/1424-2818/12/5/194 (visited on 05/21/2020).

Moore, Aubrey (Apr. 4, 2017). "Biological Control of Cycad Scale, *Aulacaspis Yasumatsui*, Attacking Guam's Endemic Cycad, *Cycas Micronesica*". 2017 Pacific Island Forestry Professionals Workshop (Tumon Bay, Guam). URL: https://github.com/aubreymoore/Guam-Forestry-Workshop-Resources/raw/master/CycadScaleBiocontrolChile.pdf (visited on 04/03/2017).

Moore, Aubrey, Ross H. Miller, T. E. Marler, and Lee S. Yudin (2013). "A Coalition of Invasive Species Attacks Guam's Endemic Cycad, Cycas Micronesica". In:

Moore, Aubrey, Ross H. Miller, and Thomas E. Marler (2013). "Biological Control of Cycad Scale, *Aulacaspis Yasumatsui*, Attacking Guam's Endemic Cycad, *Cycas Micronesica*". In: *Entomological Society of America Annual Meeting*. Austin, Texas. URL: https://github.com/aubreymoore/presentations/raw/master/CycadScaleBiocontrol/CycadScaleBiocontrolSource.pdf.

Muniappan, RANGASWAMY, GILLIAN W. Watson, GREGORY ALLYN Evans, AUNU Rauf, and NATALIA Von ellenrieder (Sept. 1, 2012). "Cycad Aulacaspis Scale, a Newly Introduced Insect Pest in Indonesia". In: *HAYATI Journal of Biosciences* 19.3, pp. 110–114. ISSN: 1978-3019. DOI: 10.4308/hjb.19.3.110. URL: https://www.sciencedirect.com/science/article/pii/S1978301916301425 (visited on 12/23/2021).

Nafus, Donald M. and Ilse H. Schreiner (1989). "Biological Control Actiivities in the Mariana Islands from 1911 to 1988". In: *Micronesica* 22.1, p. 1. URL: https://micronesica.org/file/727/download?token=6WuIPk1B.

Tang, William, J Donaldson, Jody Haynes, and Irene Terry (Sept. 18, 2005). *Report and Recommendations on Cycad Aulacaspis Scale. Aulacaspis Yasumatsui Takagi (Hemipter: Diaspididae)*. IUCN/SSC Cycad Specialist Group - Subgroup on Invasive Pests, p. 13. URL: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwj3pOrlrrL1AhXczDgGHZoCB1AQFnoECCMQAQ&url=https%3A%2F%2Fwww.fs.usda.gov%2FInternet%2FFSE_DOCUMENTS%2Fstelprdb5437896.pdf&usg=AOvVaw3xiWPvjue71JwK8Gz_M5Ne.

United States Government (Oct. 1, 2015). *Endangered and Threatened Wildlife and Plants; Endangered Status for 16 Species and Threatened Status for 7 Species in Micronesia*. Federal Register. URL: https://www.federalregister.gov/documents/2015/10/01/2015-24443/endangered-and-threatened-wildlife-and-plants-endangered-status-for-16-species-and-threatened-status (visited on 01/19/2022).