Biological Control of Cycad Scale, *Aulacaspis yasumatsui*, Attacking Guam's Endemic Cycad, *Cycas micronesica*

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Despite attempted classical biological control with a predator and two parasitoids, greater than 90% of Guam's endemic *Cycas micronesica* plants have been killed since the island was invaded by the cycad aulacaspis scale (CAS), *Aulacaspis yasumatsui* (Hemiptera: Diaspididae) in 2003 (Marler and Lawrence, 2012). Prior to this invasion, *C. micronesica* was the most numerous plant in Guam's forests with a stem diameter greater than five inches (Donnegan et al. 2004). The CAS infestation was so severe that by 2006 *C. micronesica* was listed as endangered by the International Union for Conservation of Nature (Marler et al., 2006). This ecological disaster is still unfolding. Marler and Lawrence (2012) predict extirpation of wild cycads on Guam by 2019 if current trends persist.

CAS, described by Takagi (1977), is considered a minor pest of *Cycas* within its native Asian range (Anonymous 2006a), presumably as a result of natural biological control organisms. Outside of its native range, where CAS has escaped its natural enemies, it is a very serious pest of *Cycas*. This scale insect infests all parts of the plant including roots and reproductive structures. CAS is small enough to invade minute cracks and crevices where it is undetectable during quarantine inspections (Marler and Moore 2010). In the absence of chemical or biological control, infested plants become totally encrusted with multiple layers of CAS within a few months and die within a year (Anonymous 2006a). Accidental introduction of CAS to Florida in the 1990s (Howard et al. 1999) initiated subsequent invasions of the pest throughout several other states within the United States and other countries (Anonymous 2006b). In the Pacific, CAS was first detected in Hawaii in 1998, Taiwan in 2000, Guam in 2003, Rota in 2007, and Palau in 2008. The presumed pathway for this invasive species is movement of scales attached to cycads in the ornamental plant trade, although accidental, long-range movement of scale crawlers is an alternate invasion pathway.

CAS infestation on Guam progressed very rapidly. Initial detection in December, 2003 was on *Cycas revoluta* and *C. micronesica* growing in floral displays at the entrances to two of Guam's major hotels. Within a year the infestation had spread into a nearby population of wild *C. micronesica* and by 2006, the infestation was island-wide and plants had started dying in large numbers.

We observed no pre-existing natural enemies during frequent surveys of infested plants. A predator, *Rhyzobius lophanthae* (Coleoptera: Coccinellidae) and a parasitoid, *Coccobius fulvus* (Hymenoptera: Aphelinidae) were imported for CAS biocontrol during 2004 and 2005 (Moore et al. 2005). A second parasitoid, *Aphytis lignanensis* (Hymenoptera: Aphelinidae), was imported in 2012. The predator established rapidly. However, both parasitoids failed to establish in captivity and in the field.

About 100 *R. lophanthae*, were field collected on Maui, Hawaii in November 2004, flown to Guam and reared for one month in quarantine. Field releases on CAS-infested, wild *C. micronesica* at Ritidian Point were initiated in February 2005. The beetle established immediately and its initial population explosion peaked in the vicinity of the release site in June 2005, when we counted up to 57 adults per minute in visual inspections of infested wild *C. micronesica*. We also monitored adult beetles, scale crawlers, and male scales at Ritidian using a transect of yellow sticky cards. The

resulting time series data clearly indicate collapse of the CAS population following introduction of the predator followed by establishment of a dynamic equilibrium with scale levels near the trapping detection threshold (Fig. 1). Following establishment at Ritidian, more than 7,450 laboratory reared and field collected *R. lophanthae* adults were introduced at 115 sites throughout Guam by collaborators.

R. lophanthae adults and grubs are voracious predators of CAS. Eggs are laid beneath female scale covers were first instar grubs consume the adult scale. Later instar grubs and adults feed on female and male scales. *R. lophanthae* are currently ubiquitous throughout Guam. They are preventing mortality of mature cycads from scale infestation, but residual scales on these trees are preventing vigorous growth and seed production. More importantly, even though *R. lophanthae* are ubiquitous within their habitat, all *C. micronesica* seedlings become infested with CAS and eventually die (Marler and Lawrence 2012). Thus, with no reproduction occurring, health of the *C. micronesica* population is still in decline. We offer two explanations for the partial failure of *R. lophanthae* as a biocontrol agent for CAS:

1. Marler et al. (2012) provide evidence that the *R. lophanthae* predation rate decreases near the ground. This at least partially explains why seedlings are more vulnerable to mortality from scale infestation than mature plants.
2. *R. lophanthae* is much larger than CAS and it is not able to prey on individuals living in small cracks and crevices on the plant. CAS living in refugia provide a steady stream of crawlers which rapidly repopulate external surfaces of the plant during periods of low predation.

We suggest that there is a urgent need to introduce one or more smaller biocontrol agents which are active near the ground and can follow CAS into its refugia.

Unfortunately, attempts to introduce CAS parasitoids to Guam have failed. A Chinese strain of *Coccobius fulvus* from Florida was imported and released several times starting in 2005. On each occasion, the parasitoids died out both in the field and the laboratory, probably out-competed by *R. lophanthae* (G.V.B. Reddy, personal communication). We are currently attempting to introduce *Aphytis lignanensis* (Hymenoptera: Aphelinidae) which coexists with *R. lophanthae* as a CAS biocontrol agent in Texas (Flores and Carlson 2009) and Hawaii (B. Kumashiro, personal communication). In 2012, we imported about 100 *A. lignanensis* adults from Honolulu, Hawaii. These wasps were reared from CAS infesting *Cycas revoluta* in a home garden. (There are no wild cycads in Hawaii.) We put these wasps in a cage containing CAS-infested *C. micronesica* leaves. We had carefully removed all visible *R. lophanthae* adults and grubs from these leaves, but there were enough beetle eggs and first instar larvae hiding beneath scale covers to consume all scales before any adult wasps emerged. In our next attempt, we will present imported *A. lignanensis* with caged *C. revoluta* infested with CAS but without *R. lophanthae*.

Our immediate objective is to establish a biocontrol agent, in addition to *R. lophanthae*, which will provide adequately protect *C. micronesica* seedlings from CAS-related mortality so that this important endemic plant species can start to recover.

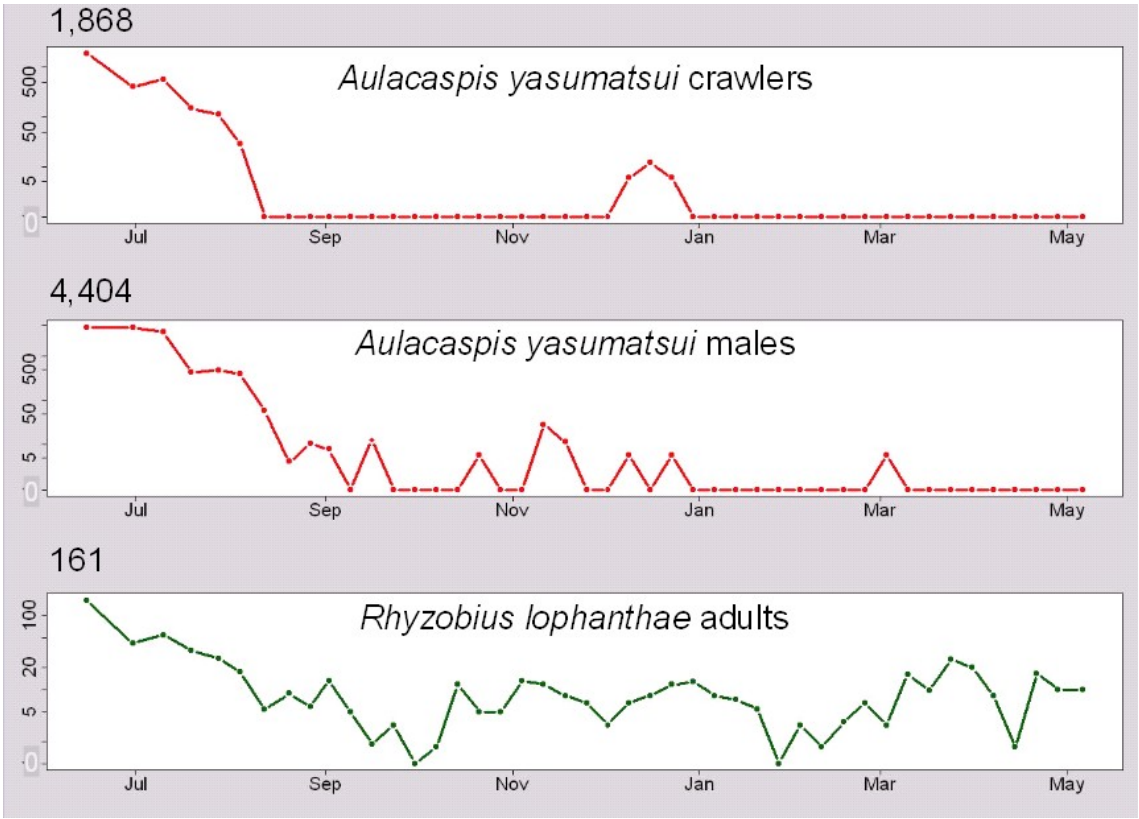

Figure 1: Insects trapped on yellow sticky cards at Ritidian Point, Guam following field release of *Rhyzobius lophanthae* in February, 2005. X axis runs from July 2005 through May 2006; Y-axis, in log scale, is number of insects trapped per square meter per day.

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