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An Overview of a Fortuitous and Efficient Biological Control of the Colombian Fluted Scale, *Crypticerya multicicatrices* Kondo & Unruh (Hemiptera: Monophlebidae: Iceryini), on San Andres island, Colombia

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Abstract: The Colombian fluted scale, *Crypticerya multicicatrices* Kondo and Unruh, is a polyphagous iceryine scale insect native to mainland (continental) Colombia and not known from other Central and South American countries. It has become a serious invasive pest on the islands of San Andres and Old Providence in the southwestern Caribbean State of Colombia, where probably it was introduced unintentionally with plants from mainland Colombia. Here we document the efforts that have been made to implement a classical biological control program on San Andres in the period 2010–2013 and explain how control has been achieved by the coccinellid *Anovia* sp., without any deliberate introduction. This predator of the eggs of *C. multicicatrices* is native to mainland Colombia and probably was fortuitously introduced to San Andres in the same manner as *C. multicicatrices*.

Keywords: *Anovia* sp., Chrysopidae, Coccinellidae, *Delphastus quinculus*, *Diomus seminulus*, *Isaria* sp., Phoridae, *Syneura*

Introduction

In the last decade, iceryine scale insects (Hemiptera: Coccoidea: Monophlebidae) have been frequently reported as invasive pests in many parts of the world. Some examples include *Crypticerya genistae* (Hempel) in the State of Espírito Santo, Brazil (Culik *et al*. 2007), on the island of Guadeloupe (Etienne, Matile-Ferrero 2008) and in the State of Florida, USA (Hodges 2008, Hodges *et al*. 2008); *Icerya imperatae* Rao in Australia, Brunei, Fiji, Malaysia and the Republic of Palau (Williams *et al*. 2006; Hodgson, Lagowska 2011); *Icerya aegyptiaca* (Douglas) on the Ryukyu Archipelago, Japan (Uesato *et al*. 2011); *Icerya purchasi* Maskell on the Galapagos Islands (Causton 2004); and *Crypticerya multicicatrices* Kondo & Unruh, 2009, on San Andres island, Colombia (Fig. 1) (Ica 2010, Kondo *et al*. 2012a, Silva-Gómez *et al*. 2012).

San Andres island is the main island of the Archipelago of San Andres, Old Providence and Santa Catalina in a southwestern Caribbean State of Colombia, and is composed of an extensive area of islands, banks and cays in the western Caribbean, located about 700 km northwest of mainland Colombia, and 250 km East of Nicaragua (Geister, Diaz 1997, Hartnoll *et al*. 2006). Thus San Andres island is closer to Nicaragua (and other Central American countries) than to Colombia. However, despite the geographical proximity of this archipelago to Central

America, *C. multicicatrices* was probably introduced to the islands of San Andres and Old Providence on infested ornamental plants brought from continental Colombia, since this is the only place from which it had been reported previously (Kondo 2001 (as *Icerya brasiliensis* Hempel); Kondo 2008 (as *Crypticerya* sp.); Kondo 2009; Kondo, Unruh 2009), and there is intensive trade between the islands and mainland Colombia (Kondo *et al*. 2012a).

The Colombian fluted scale (CFS), *C. multicicatrices*, also known as the multicicatrices fluted scale (Kondo *et al*. 2012a, Silva-Gómez *et al*. 2012), is native to mainland (continental) Colombia. Its external morphology is diagnosed as follows: "Adult female elliptical; antennae, legs and eyes brownish-black; body orange-red, covered dorsally by white wax, with one long caudal tuft (up to 20.5 mm long, usually less than 15 mm long, but always longer than cephalic tuft), one shorter cephalic tuft protruding anteriorly, a marginal row of nine waxy tufts on each side, mealy wax abundant around dorsal submargin just above row of lateral waxy processes and forming a thick elevated submarginal ridge, with a median longitudinal waxy ridge composed of about five short tufts; waxy processes on each side of the caudal and cephalic tufts longer than other marginal processes. Ovisac elongate, white, distal end narrow, often curved upwards, appearing fluted, with 14 or 15 longitudinal furrows. Caudal and cephalic tufts with about four longitudinal furrows. Ovisac with about 120 eggs, each egg elliptical, about 0.8 mm long; ovisac slit on dorsomedial line, where crawlers escape" (Kondo, Unruh 2009: 95) (Fig. 1).

Slide-mounted specimens of the adult hermaphrodite of the CFS are distinctive in having 9–13 cicatrices on the ventral abdomen (Kondo *et al*. 2012a); all other iceryine species in South America usually have between 3 and 7 cicatrices, with the exception of *Echinicerya anomala* Morrison which has more than 30 cicatrices forming 1 or 2 semicircles on the venter of the abdomen (Kondo *et al*. 2012a, Kondo, Unruh 2009).

The CFS is widely distributed on the island of San Andres where it is found on many hosts, including all species of palms, many crops used for food by the islanders and ornamental plants that are part of the tropical landscape of the islands (Kondo *et al*. 2012a). The CFS was originally described based on specimens collected in the States of Antioquia, Tolima and Valle del Cauca, in continental Colombia (Kondo, Unruh 2009), where it was recorded on 11 host plants (Kondo, Unruh 2009). A closely related species, *C. montserratensis* has been reported as a pest of *Citrus* spp. in mainland Colombia but, according to Kondo *et al*. (2012b), this may be a misidentification of *C. multicicatrices*. In 2010, the CFS was reported on 13 plant species (ICA 2010). Recently, Kondo *et al*. (2012a) reported infestations on a further 82 host plants and Silva-Gómez *et al*. (2012), in a study on the incidence of the CFS and *M. hirsutus* on the archipelago of San Andres, Old Providence and Santa Catalina, reported 52 new host plant records, increasing the total host plant species to 147 species.

From about 2010 until early 2013, damage caused by the CFS resulted in the loss of competitiveness and profitability of the agricultural sector of

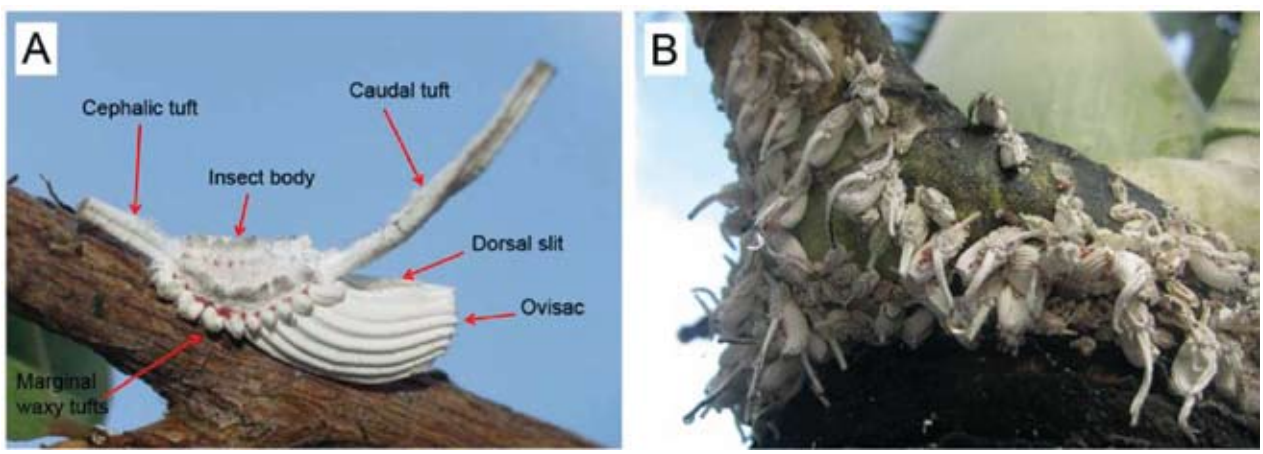

Fig. 1. *Crypticerya multicicatrices* Kondo & Unruh. **A.** Adult hermaphrodite, external morphology. **B.** An infestation of CFS on a palm tree. Photos by T. Kondo

San Andres island, diminishing the quality of life for native families, causing loss of auto-sustainability in the local food security, and decreased satisfaction of tourists visiting the islands due to the visual decay caused by high infestations of this invasive pest. The Colombian Agricultural Institute (ICA) reported that, in 2010, there were 180 hectares affected with *C. multicicatrices* and the pink hibiscus mealybug *Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae) on San Andres island, increasing to 1740 hectares in 2011 (Alterio, Ramos 2011).

Very little is known about the biology of the CFS. It is commonly found on the branches and leaves of the host plant, but can occur on the trunk and fruit when populations are high and it is often tended by ants (Kondo *et al*. 2012a). On San Andres, CFS has been found tended by seven genera of ants (Hymenoptera: Formicidae) distributed in 4 subfamilies, i.e., *Crematogaster*, *Monomorium* (Myrmicinae), *Paratrechina*, *Camponotus* (Formicinae), *Dorymyrmex*, *Dolichoderus* (Dolichoderinae), and *Ectatomma* (Ectatomminae) (Silva-Gómez *et al*. 2012). The CFS has four stages of development, i.e., three nymphal stages and the adult stage. Usually all stages can be found in a single population and the species is considered to be hermaphroditic (Kondo *et al*. 2012a), similar to the closely related species *C. zeteki* (Hughes-Schrader, Monahan 1966). Males of the CFS were unknown (Kondo, Unruh 2009, Kondo *et al*. 2012a) until the study of Silva-Gómez *et al*. (2012) in which they reported rearing two adult males in the laboratory. *Crypticerya multicicatrices* can be found throughout the year, although infestations are usually more severe in times of drought, and seedlings are especially susceptible and may dry out when populations are high (Kondo *et al*. 2012a). On soursop, *C. multicicatrices* (as *Crypticerya* sp.) has been reported associated with stunted growth (Kondo 2008) and can cause defoliation and death of the host in severe attacks (Kondo *et al*. 2012a). The species produces honeydew, a sugary liquid that promotes the growth of fungi that cause sooty mold and this results in cosmetic damage to the commercial parts of the plant, reducing the quality of the product. When it affects the leaves, it can decrease the host's photosynthetic rate (Kondo *et al*. 2012a). Interestingly, in continental Colombia, the species has not been reported associated with sooty mold symptoms (Kondo, Unruh 2009) but is commonly associated with sooty molds on San Andres (Kondo *et al*. 2012a). Kondo *et al*. (2012a) indicated that it is likely that the honeydew produced by the CFS is low in sugars, because sooty molds are usually not observed when populations are low. When sooty molds are present, no or very few ants are found tending the CFS (Silva-Gómez *et al*. 2012).

In the three years since the CFS was first reported as an invasive pest on San Andres in 2010, various institutions have conducted research to develop control strategies for this pest. Here we summarize the brief history of the control efforts for the CFS on San Andres Island based on the literature, unpublished reports and personal observations produced since 2010 until the most recent two visits by the first author to the island of San Andres in October and November 2013.

Results and Discussion

By 2010, the CFS was well established on San Andres, and was also present on Old Providence island (Alterio, Ramos 2011, ICA 2010). The life cycle of the CFS lasts about 3 months (T.K., personal observations), and so, in order for the CFS to spread to the whole island, it had to arrive on the island in the late 2000's, probably sometime in 2007 or 2008. Management strategies for the CFS were originally based on chemical control. The Colombian Agricultural Institute recommended the use of systemic pesticides that had been approved for use on the island, preferably imidacloprid, although, because of the limited availability of approved pesticides on the island, other pesticides such as systemin were also recommended (ICA 2010).

Many organizations were involved with the management of the CFS, including the Ministry of Agriculture, the Colombian Agricultural Institute (ICA), the Colombian Corporation for Agricultural Research (Corpoica), the Colombian National University (UNAL), the Corporation for Sustainable Development Archipelago of San Andres, Old Providence and Santa Catalina (Coralina), the Ministry of Tourism of San Andres, the Governor's Office, the Ministry of the Environment, and the Association of Farmers and Fishermen of San Andres. Between 2010 and 2013, numerous meetings were held with members of the above organizations, the Governor of San Andres, the House of Representatives of San Andres and other public and

private entities. The Colombian Agricultural Institute (ICA) took the lead in raising the awareness of the problem and putting together meetings on how to control the CFS.

The first attempts by an institution to control the CFS was undertaken by the Colombian National University (UNAL), by mass producing a fungus which was found infesting specimens of CFS collected on a mango plant on San Andres. The fungus was reported initially as *Paecilomyces* sp. (Quiroga *et al*. (2011) but was later identified as *Isaria* sp. (Eurotiales: Trichocomaceae) (Kondo *et al*. 2012a, Silva-Gómez *et al*. 2012). Quiroga *et al*. (2011) conducted pathogenicity experiments involving spraying solutions of fungal conidia onto infestations of CFS and obtained mortality rates of 30–88% under artificially high moisture conditions. Until recently, UNAL continued spraying the *Isaria* sp. on San Andres, probably with some positive results, although no report of the effectiveness of *Isaria* sp. in the field has been published by the time of writing of this article. No other natural enemy of CFS was reported on the islands in 2010 and 2011 (Alterio, Ramos 2011, Ica 2010). Kondo *et al*. (2012a) discussed the need to implement a classical biological control program and recommended the use of specialist natural enemies in order to minimize the ecological impact that generalist natural enemies could cause to non-target insects. In an effort to implement such a program on San Andres, the Colombian Corporation for Agricultural Research (Corpoica), financed by the Colombian Ministry of Agriculture and Rural Development (MADR), conducted research on mainland Colombia, resulting in the discovery of several more natural enemies.

The first were two small-sized ladybird beetles, *Delphastus quinculus* Gordon and *Diomus seminulus* (Mulsant) (Coleoptera: Coccinellidae) which were found for the first time feeding on eggs and first-instar nymphs of the CFS (González *et al*. 2012). The adults of *D. quinculus* and *D. seminulus* eat through the ovisac of the adult female of the CFS in order to reach the eggs and newly hatched first-instar nymphs and occasionally several beetles have been found within one ovisac (González *et al*. 2012).

In another study, Gaimari *et al*. (2012) reported the fly *Syneura cocciphila* (Coquillet) (Diptera: Phoridae) as a predator of the CFS in the city of Cali, in the State of Valle del Cauca, continental Colombia. The predatory larvae of *S. cocciphila* feed on the body contents of the adult and also on the eggs within the ovisac. Pupation occurs inside the damaged insect body, within the ovisac or just outside it (Gaimari *et al*. 2012). The phorid flies usually leave a circular emergence whole at the posterior end of the ovisac or (less frequently) directly on the scale insect body. The fly larvae cause the eggs inside each ovisac to become dried, leaving visible only the egg chorions (Gaimari *et al*. 2012). *Syneura cocciphila* has been previously reared from *C. genistae*, an invasive species in Puerto Rico (Ciomperlik 2010). On the island of Montserrat, *S. cocciphila* was reported attacking *C. montserratensis* (Bartlett (1978), which is closely related to CFS (Kondo, Unruh 2009). *Syneura cocciphila* appears to specialize on scale insects of the tribe Iceryini (Gaimari *et al*. 2012).

Besides the two species of coccinellids and the phorid fly, other natural enemies of CFS have been found in mainland Colombia, including at least two hymenopteran parasitoids (Encyrtidae) extracted from the adults of CFS, and larvae of a species of Chrysopidae feeding on eggs and nymphs of the CFS in Palmira, State of Valle del Cauca (Kondo *et al*. 2012a).

Of the two main parasitoids mentioned by Kondo *et al*. (2012a), one species appears to be the true parasitoid of *C. multicicatrices* (not identified yet) and the other species seems to be a hyperparasitoid, identified as *Cheiloneurus* sp. by Dr. James Woolley (Texas A & M). Some chrysopids found feeding on *C. multicicatrices* collected in Cali, a city just about 18 km from Palmira, have been identified as *Chrysoperla* sp. and *Ceraeochrysa* sp. by Dr. Catherine Tauber (Cornell University).

In February 2013, TK visited San Andres and collected adults and nymphs of a coccinellid beetle in a single location at the Northeast of the island, feeding on the eggs inside the ovisacs of the CFS. The coccinellid was later identified as an undescribed species of the genus *Anovia* Casey (Coleoptera: Coccinellidae: Noviini) by GG (Fig. 2).

Outbreaks of the CFS were observed from 2010 until February 2013 (Fig. 3A). However, when TK visited again in October 2013, only 8 months after *Anovia* sp. was first sighted, the coccinellid beetle had spread to the entire island and populations of the CFS had been decimated to the point that it was very difficult to find any specimens (Fig. 3B).

Fig. 2. Left. Adult *Anovia* sp. preying on eggs of *C. multicicatrices* on a twig of *Pithecelobium dulce* (Fabaceae). **Inset.** Close-up of *Anovia* sp. half way inside ovisac of *C. multicicatrices*. **Center.** Adult *Anovia* sp. Notice bright red venter and legs. **Right.** Two larvae (left side) and several pupae (right side) of *Anovia* sp. Notice the resemblance of the larvae and pupae of *Anovia* sp. to the nymphs of *C. multicicatrices*. San Andres island. Photos by T. Kondo

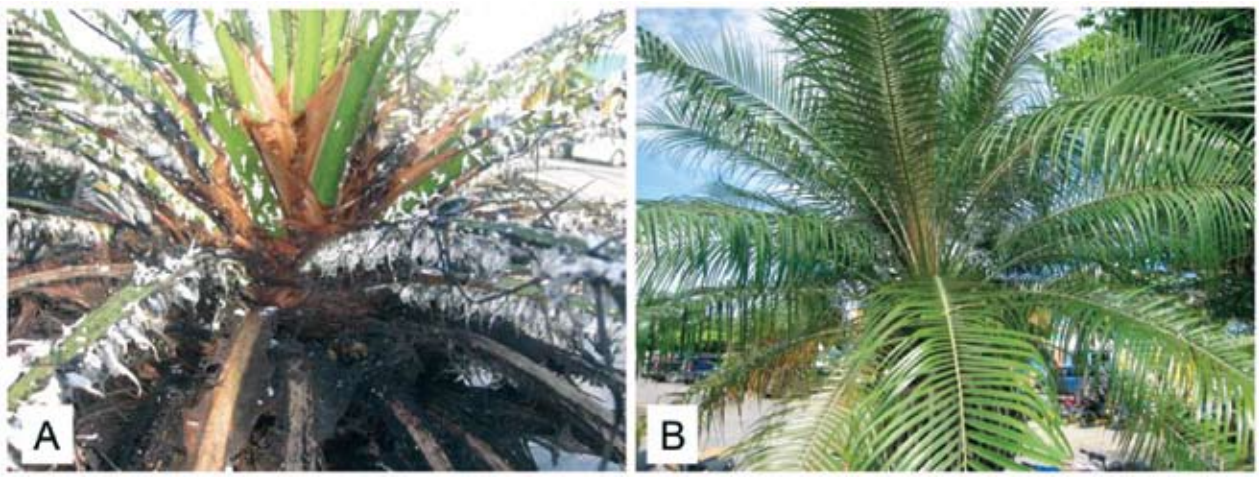

Fig. 3. A. An ornamental palm, *Phoenix roebelenii*, heavily infested with *Crypticerya multicicatrices* on April 8, 2012. **B.** Same palm on October 26, 2013, eight months after the discovery of *Anovia* sp. (Coleoptera: Coccinellidae) on the island of San Andres. San Andres airport. Photos by T. Kondo

This is similar to what happened in 2002 on the Galapagos Islands when the first biological control program was implemented there through the release of *Rodolia cardinalis* Mulsant (Coleoptera: Coccinellidae) to control the cottony cushion scale *Icerya purchasi* (Calderon-Alvarez *et al*. 2012). On Santa Cruz island, in a release experiment of *R. cardinalis* on white mangrove *Laguncularia racemosa* (Combretaceae) infested with *I. purchasi*, there was a 99-100% decrease in the populations three months after their release, suggesting that *R. cardinalis* played an important role in this decline, possibly coupled with the effect of high rainfall over the study period (Calderon-Alvarez *et al*. 2012). Also it has been reported that significant reductions of the invasive *C. genistae* in Barbados and Florida were probably due to the predatory fly *S. cocciphila* and the coccinellid beetle *Anovia circumclusa* (Gorham) (Ciomperlik 2010).

In addition to effective predation by *Anovia* sp., heavy rain on San Andres may have helped to reduce the populations of the CFS. The rainy season on San Andres is composed of a period of moderate rainfall (May-July) and a period of maximum rainfall (October-December) in which 80% of annual rainfall is recorded (Ideam, 1995). However, CFS populations crashed between February and October, which is not during the heavy rain period, and thus predation by *Anovia* sp. must have been the main factor controlling CFS. The Colombian Corporation for Agricultural Research (Corpoica) will keep monitoring the CFS in 2014 and will carry out research on the compatibility of *S. cocciphila* and the encyrtid parasitoids with *Anovia* sp. in case an introduction of additional natural enemies becomes necessary in the future.

The *Anovia* sp. found on San Andres is the same species as found in Cali and Palmira (GG, TK unpublished data) in continental Colombia, the area of origin of the CFS. *Anovia* sp. has been hitherto found only feeding on CFS. This is a very interesting case where a natural enemy of an invasive pest was controlled by a predator from its place of origin, but without it being deliberately introduced. It could be said that this is an example of a classical biological control that occurred spontaneously without deliberate human intervention. Furthermore, it is quite possible that *Anovia* sp. came onto San Andres island in a similar manner to the CFS, probably on ornamental plants infested with *C. multicicatrices* from mainland Colombia.

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