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Survey of palm-associated Fulgoroidea in Puerto Rico[1,2]

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ABSTRACT

We report results from a survey of palm-associated Fulgoroidea (planthoppers), following the recent discoveries of *Haplaxius crudus*, a known palm phytoplasma vector, and of other potential planthopper vectors in Puerto Rico. The survey, which sampled from 40 sites, resulted in the identification of 30 morpho-species belonging to eight Fulgoroidea families. The 10 most common species accounted for 93.9% of individuals, whereas near one third (n = 9) of the species were represented by single individuals. Derbids and cixiids accounted for 90% of collected individuals. The most common species were the derbids *Cedusa inflata* (Ball) and *Omolicna puertana* Caldwell, while the most common cixiids were *Bothriocera undata* (F.) and *Oliarus complectus* Ball; and the most common flatids were *Petrusa epilepsis* (Kirkaldy) and *Melornemis antillarum* (Kirkaldy). Three species are new records for Puerto Rico: the cixiids *Haplaxius crudus* Van Duzee and *Nymphomyndus caribbaea* (Fennah), and the derbid *Neocenchrea nr. pallida* Metcalf. Impact of polyphagy and of abundance-diversity patterns of this planthopper guild on phytoplasma epidemiology are briefly discussed.

Key words: Palmae, potential vectors, Fulgoroidea, Puerto Rico

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RESUMEN

Catastro de Fulgoroidea asociados a palmas en Puerto Rico

Luego de la reciente introducción en Puerto Rico del insecto vector del amarillamiento letal del cocotero, *Haplaxius crudus*, y de la identificación de un fitoplasma en palmas enfermas realizamos un catastro de potenciales vectores de la enfermedad en Puerto Rico. El catastro, que incluyó 40 localidades y cubrió toda la isla, resultó en la identificación de 30 morfoespecies de Fulgoroidea, pertenecientes a ocho familias. Entre los hallazgos se encuentra que el 93.9% de los individuos coleccionados pertenecen a una de las 10 especies más comunes, y que cerca de un tercio de las especies fueron coleccionadas tan solo una vez. El 90% de los individuos pertenecían a las familias Derbidae y Cixiidae. Las especies más comunes fueron los dérbidos *Cedusa inflata* (Ball) y *Omolicna puertana* Caldwell, seguidos por los cixiidos *Bothriocera undata* (F.) y *Oliarus complectus* Ball; los flátidos más comunes fueron *Petrusa epilepsis* (Kirkaldy) y *Melornemis antillarum* (Kirkaldy). Tres especies constituyen nuevos récords para Puerto Rico: los cixiidos *Haplaxius crudus* Van Duzee y *Nymphomyndus caribbaea* (Fennah), y el dérbido *Neocenchrea* ca. *pallida* Metcalf. Se discuten las posibles implicaciones de la polifagia, y de los patrones de abundancia y diversidad sobre la epidemiología de los fitoplasmas de palmas.

Palabras clave: Palmae, insectos vectores, Fulgoroidea, Puerto Rico

INTRODUCTION

Insect-vectored diseases, such as coconut lethal yellowing (CLY) and other emerging palm disorders, are considered significant threats to commercial production worldwide. The recent introduction of a key vector of coconut lethal yellowing disease into Puerto Rico, the palm cixiid *Haplaxius (=Myndus) crudus* (Segarra, unpublished), and the discovery of a previously unidentified palm 16SrIV-phytoplasma in diseased ornamental palms, as well as in a native derbid, *Cedusa inflata* (Rodrigues et al., 2010) have heightened concerns about the potential impact of these pests on landscaping industries, and on natural ecosystems.

Palm phytoplasmas are vectored almost exclusively by a group of insects known as planthoppers (Fulgoroidea), which are a small group of families abundant in tropical regions (Gitau et al., 2009). Vector species are found in four planthopper families: Cixiidae, Delphacidae, Derbidae, and one species in the Flatidae (Wilson and Weintraub, 2007). According to these authors, the majority of known phytoplasma-vector species occur in the Delphacidae, which are predominantly found on Poaceae. In addition, a few members of other hemipteran families, such as psyllids, pentatomids and tingids, have confirmed vector species (Wilson and Weintraub, 2007).

Recent evidence points to yet unforeseen vector-disease interactions. Since the pioneering work of Howard et al. (1983), which demonstrated CLY transmission by *Haplaxius crudus*, several new discoveries now lead to the possibility that complex local vector-host plant interactions may exist in palm-associated phytoplasma diseases. For example, the detection in Jamaica of CLY 16SrIV phytoplasma strains in the derbid planthopper *Cedusa* sp. by Brown et al. (2006), and the discovery of CLY in the cixiid planthopper *Nymphomyndus* (=*Nymphocixia*) *caribbaea* (Fennah) in Cuba (Dollet et al., 2010) open possibilities for new and undiscovered palm vector interactions. Other discoveries, such as the finding of new palm 16SrIV phytoplasmas in mixed infestations in Florida palms (Harrison et al., 2008), and the discovery of CLY phytoplasma in common dicotyledonous weeds (Brown et al., 2008a-b) hint at complex and yet unstudied biological interactions, and may suggest the likelihood that other 'non-palm specialist' Fulgoroidea may be part of yet undescribed epidemiological associations.

Given the recent discovery of palm phytoplasmas and new invasive planthopper vectors in Puerto Rico, we report on the results of an island-wide survey of palm-associated Fulgoroidea planthoppers, discussing species composition, abundance and diversity patterns.

MATERIALS AND METHODS

Starting in April 2010, we began a series of collections on sites containing concentrations of palms throughout Puerto Rico. At each site, we swept accessible foliage of assorted-sized palms. Number of sampled plants, palm species, fulgorid species, and GPS coordinates were recorded. Planthoppers were collected with aspirators and placed into labeled vials, and deposited in ice boxes for transport to laboratory. All hoppers were sorted, mounted and labeled for later identification. In most cases, and because of the excellent keys available, morphological examinations, and genitalia dissections were sufficient for species identification and confirmation. Genitalia dissections were performed by clearing male abdomens in a hot 10% potassium hydroxide solution for 1 h. Genital capsules were then washed with tap water, slide mounted in glycerin, and later examined under a compound microscope.

Collection sites included a representation of both coastal and mountain, both urban and forest, and both dry and moist locations throughout Puerto Rico. Most commonly we sampled coconut palms (*Cocos nucifera* L.), but also royal (*Roystonea borinquena* (O.F. Cook), foxtail palm (*Wodyetia bifurcata* Irvine), fishtail palm (*Caryota mitis* Lour), Christmas palm [*Veitchia merrillii* (Becc.)], MacArthur's palm [*Ptychosperma macarthurii* (Wendl.)], Puerto Rican Palmetto [*Sabal causiarum* (O.F. Cook)], and Sierra palm (*Prestoea montana* (R. Graham).

RESULTS

Species composition and abundance. A total of 40 sites, each containing between 15 and 150 palms, were visited during 18-day trips, conducted between April 2010 and March 2011. A total of 1,837 palm individuals were sampled, resulting in the collection of 1,031 individual planthoppers.

Thirty fulgorid species belonging to eight families were found associated with palms (See Table 1). One thousand thirty-one individuals belonging to 30 morpho-species were collected. The 10 most common species accounted for 93.9% of individuals, whereas near one third (n

TABLE 1—*List of morpho-species collected in palm-associated planthopper survey, and sorted by total number of individuals. (**) = New record for Puerto Rico.*

Species	Family	Total	Sites
Cedusa inflata (Ball)	Derbidae	237	11
Omolicna puertana Caldwell	Derbidae	204	11
Bothriocera undata (F.)	Cixiidae	157	13
Oliarus complectus Ball	Cixiidae	131	8
Haplaxius crudus Van Duzee (**)	Cixiidae	87	4
Patara albida Westwood	Derbidae	43	5
Melornemis antillarum (Kirkaldy)	Flatidae	36	8
Petrusa epilepsis (Kirkaldy)	Flatidae	27	7
Neocenchrea nr. pallida Metcalf (**)	Derbidae	25	2
Dawnariodes sordidulum (Muir)	Derbidae	21	2
Nymphomyndus caribbaea (Fennah) (**)	Cixiidae	11	4
Delphacodes spp.	Delphacidae	7	1
Cedusa wollcotti Muir	Derbidae	6	4
Flatormenis sp.	Flatidae	6	2
Colpoptera maculifrons Muir	Issidae	5	5
Otiocerus shoenherri Stal	Derbidae	5	5
Neocolpoptera sp.	Issidae	4	2
Quilessa sp.	Kinnaridae	3	1
Delphacid sp1	Delphacidae	3	2
Neurotmeta viridis (Walker)	Tropiduchidae	2	2
Sogota approximata (Crawford)	Delphacidae	2	1
Delphacid sp2	Delphacidae	1	1
Pintalia alta Osborne	Cixiidae	1	1
Catonia cinerea Osborne	Achilidae	1	1
Catonia sp1	Achilidae	1	1
Catonia sp2	Achilidae	1	1
Flatid sp1	Flatidae	1	1
Pissonotus albovenosus Osborn	Delphacidae	1	1
Delphacid sp3	Delphacidae	1	1
Delphacid sp4	Delphacidae	1	1
	Total	1,031	

TABLE 2—*Number of planthopper morpho-species and individuals collected during palm surveys.*

Family	No. Species	No. Individuals	% of Total
Derbidae	7	541	52.5
Cixiidae	5	387	37.5
Flatidae	4	70	6.8
Delphacidae	7	16	1.6
Issidae	2	9	0.9
Achilidae	3	3	0.3
Kinnaridae	1	3	0.3
Tropiduchidae	1	2	0.2
	30	1,031	

= 9) of the species were represented by singletons. Derbids and cixiids accounted for 90% of individuals, with 541 and 387 planthoppers, respectively (Table 2). Derbids accounted for the greater number of morpho-species (n = 7), but overall these species were collected rarely, with six species (66.7%) collected only from a single site each.

Derbids were the most numerous species, with *Cedusa inflata* (Ball) and *Omolicna puertana* Caldwell the most common. These species were collected abundantly from coastal to mid elevation sites (>400 m). Conversely, they were generally absent above that elevation. Similarly, the most numerous cixiids were *Bothriocera undata* (F.) and *Oliarus complectus* Ball. The former species was also the most common species (i.e., collected from 13 sites), and was collected from all elevations up to 1,200 m. Flatids such as *Melornemis antillarum* (Kirkaldy) and *Petrusa epilepsis* (Kirkaldy) were also common, but as in the case of derbids they were more commonly collected from coastal and mid elevations. Historical host-plant records for these planthoppers in Puerto Rico (Table 3) indicate that all species have been recorded on at least two plant families, with cixiids and flatids seeming to be more polyphagous.

Our collections included at least three new records for Puerto Rico: the cixiids *Haplaxius crudus* and *Nymphomyndus caribbaea*, both putative CLY vectors; and the derbid *Neocenchrea nr. pallida* Metcalf, a native of Central America and the Caribbean. Voucher specimens of these are deposited at the University of Puerto Rico's 'Museo de Entomología y Biodiversidad Tropical' with the accession numbers: METB-I-0001458, METB-I-0001464, METB-I-0002199, respectively. Observed clusters of *H. crudus* and of *N. caribbaea* were geographically localized, but not overlapping. On one hand, *H. crudus* was concentrated in the northeastern region (i.e., San Juan, Dorado, Toa Alta, and Caguas) whereas, on the other hand, *N. caribbaea* was found only in the western region of the Island (i.e., Mayagüez, Lajas, Isabela, and Quebradi-

TABLE 3.—*Number of host plant species and host plant families related to the most commonly found palm-associated planthoppers as listed by Martorell (1976) for Puerto Rico. (Number of species per family in parenthesis).*

Species of Fulgoroidea	Host plant species	Plant Families
Cedusa inflata (Ball)	4	Gramineae (1), Malvaceae (1), Mimosaceae (2)
Omolicna puertana Caldwell	4	Caricaceae (1), Cucurbitaceae (1), Meliaceae (1), Solanaceae (1)
Patara albida Westwood	5	Annonaceae (1), Guttiferae (1), Mimosaceae (1), Rutaceae (1), Sapotaceae (1)
Bothriocera undata (F.)	21	Annonaceae (1), Araliaceae (1), Convolvulaceae (1), Cucurbitaceae (1), Flacourtaceae (1), Gramineae (1), Magnoliaceae (1), Malpighiaceae (1), Malvaceae (1), Meliaceae (1), Mimosaceae (2), Musaceae (1), Piperaceae (2), Polygonaceae (1), Rosaceae (1), Rubiaceae (2), Rutaceae (2), Solanaceae (1)
Oliarus complectus Ball	19	Batidaceae (1), Caricaceae (1), Dioscoreaceae (1), Fabaceae (3), Gramineae (1), Lauraceae (1), Liliaceae (1), Malvaceae (1), Mimosaceae (1), Moraceae (1), Solanaceae (4), Verbenaceae (1), Vitaceae (1), Umbelliferae (1)
Melornemis antillarum (Kirkaldy)	24	Boraginaceae (2), Convolvulaceae (1), Chrysobalanaceae (1), Euphorbiaceae (1), Fabaceae (2), Flacourtaceae (1), Gramineae (1), Lauraceae (1), Malvaceae (1), Meliaceae (1), Piperaceae (2), Polygonaceae (2), Rosaceae (1), Rubiaceae (1), Rutaceae (2), Solanaceae (1), Ulmaceae (1), Verbenaceae (3)
Petrusa epilepsis (Kirkaldy)	26	Araceae (1), Boraginaceae (2), Combretaceae (1), Fabaceae (1), Lauraceae (2), Meliaceae (1), Mimosaceae (1), Myrtaceae (2), Nyctaginaceae (1), Oleaceae (1), Piperaceae (1), Polygonaceae (2), Rubiaceae (3), Rutaceae (3), Verbenaceae (4)

llas). *Nymphomyndus caribbaea* was also collected by the senior author, in 2008 and in 2013, while sweeping coconut foliage on Mona Island. Finally, the large and elongate derbid *N. pallida* was collected in Caguas, Utuado, and in Humacao. Another specimen, unrelated to this survey, was collected from Mayagüez in 2010 by the senior author.

Measures of species evenness and diversity. Figure 1 presents a species rarefaction curve for the cumulative number of fulgorid species found on palms during our survey. After sampling on 18 collection dates we can observe no asymptote in the number of species. The Heltske-Forrester jackknife estimate for species richness ($\hat{S}$) (Krebs, 1999) indicates that the number of palm-associated fulgorid species in Puerto Rico could reach 46.2 ± 4.4 species (mean ± SD). The survey contained 15 unique species (i.e., found only at one site). Simpson's Diversity measure (1-D) = 0.860 indicated high species diversity –this index ranges from 0 (low diversity) to almost 1 (high diversity) (Krebs, 1999). Camargo's Evenness Index (E') = 0.231, an indication that a few species dominate the samples.

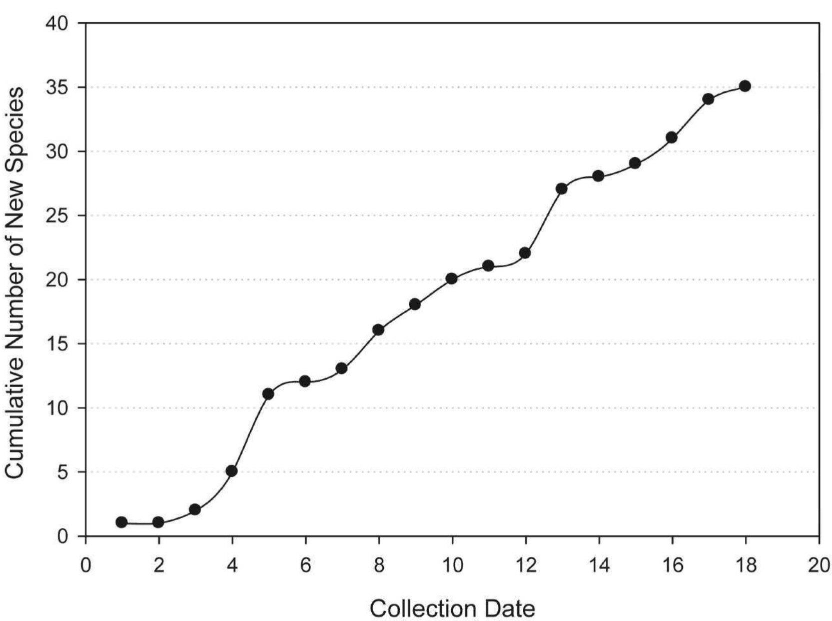

FIGURE 1. Cumulative number of new palm-associated fulgorid species found after each collection date during the survey.

DISCUSSION

Faunal surveys, such as the one reported here, often have several inherent problems that can weaken their interpretation and overall conclusions (Southwood and Henderson, 2000). Among these problems is the inability of plant-sweeping or insect-netting collection methods to distinguish true host plant associations from incidental visits of insect species to non-host plants. Another problem is that sampling from a highly heterogeneous set of habitats, where host plant and planthopper guilds can be dramatically different, can lead to increased sample noise and variability. Additional issues arise when comparing results from other studies, or from historical species lists, especially where sampling design (i.e., one host plant vs. multiple host plants) or study scope (i.e., agricultural vs. natural area) has not been carefully controlled.

Nevertheless, data reported here may allow certain conservative inferences about planthopper abundance in palms, and about the composition of planthopper-palm associations. First, contrary to existing literature, a diverse palm-associated planthopper guild does occur in Puerto Rico. Few islands in the Caribbean have better host plant records or taxonomical keys of Fulgoroidea than Puerto Rico, thanks to works by Osborne (1935), Wolcott (1948), Caldwell and Martorell (1950), Martorell (1976), and by Ramos (1957). However, it is surprising that no records exist of host association between planthoppers and palms. Likely, the scope of many of these works on agricultural pests may have led to a lower emphasis on ornamental and natural area plant species. Secondly, our data illustrate how a few species dominate the palm-associated planthopper species guild, whereas about a third of all species are rarely sampled, perhaps indicating their status as palm vagrants. Third, the most common planthopper species range from at least oligophagous to highly polyphagous, which may help explain the presence of 16SrIV palm-related phytoplasmas in other non-palm hosts (Brown 2008a, b). Finally, compared with similar palm Fulgoroidea surveys in Florida and Texas (e.g., Howard, 1980; Meyerdirk and Hart, 1982), our survey appears to show greater Fulgoroidea species diversity; this finding can be explained by the existence of higher species diversity in palm-rich tropical areas.

Another surprising finding of our study is that, with the exceptions of *Cedusa inflata* and *Haplaxius crudus*, little information exists on the biology, the behavior, or the life cycles of the most common palm-associated Fulgoroidea in Puerto Rico. For example, Lazell (2005) commented on that lack of information on *Petrusa epilepsis*, the most common planthopper collected by Bartlett (2000) on Guana Island. In fact, *P. epilepsis* is a ubiquitous ornamental insect pest in Puerto Rico (Caldwell and Martorell, 1950), and other than a brief mention on color morphs by Fennah (1941), nothing is known about its biology. In the same way, no life cycle data exist for commonly found Fulgoroidea like: *B. undata* (F.), *O. complectus*, *O. puertana*, *P. albida* or *M. antillarum*.

Often, knowledge of this kind of biological information is essential in developing sound palm planthopper management strategies. For example, management of *C. inflata* requires the avoidance of decaying organic debris (i.e., wood chip mulches) because, unlike adults its larvae are apparently fungivorous, and adults prefer to aggregate near palms close to debris piles (Howard et al., 2001). Similarly, management of *H. crudus* requires avoiding organic mulches (Howard and Oropeza, 1998). Knowledge of *H. crudus* has also led to useful management strategies. For example, while *H. crudus* adults use palms as hosts, its immature stages develop only on common grasses, such as St. Augustine grass (Howard, 1990). Howard (1999) demonstrated that the use of legume groundcovers, such as *Pueraria phasioloides* (Roxb.) and *Arachis pintoi* Kapov, could serve to discourage development of immature forms, and thus could be used as an effective population management strategy.

CONCLUSION

Surveys such as the one reported here are useful to gather basic information on species abundance and diversity patterns, especially when little or no data are available. We now have a better understanding of the potential complexity of vector relationships among palm-associated Fulgoroidea in Puerto Rico. Still needed are more direct ways of distinguishing true host-plant interactions from those of merely passing/resting insects, such as observations of direct feeding. Until then our results are to be considered preliminary.

Next steps must focus on two tracks: (1) To develop base biological and life cycle information for potential planthopper vectors. This approach will likely result in the development of population management strategies based on a thorough knowledge of key biological attributes. (2) The second track is to examine common palm-associated planthopper species to detect 16SrIV group phytoplasmas. This approach may lead to the potential identification of multiple vector species, to the documentation of complex vector plant associations with non-palm hosts, and to a more adequate understanding of the impact of polyphagous feeding habits on disease epidemiology (Maixner, 2010). Clearly, epidemiological analysis of host plant-phytoplasma systems based on polyphagous vectors must account for the existence of additional plant hosts, and also explain their significance as potential alternative sources of inoculum.

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