



Aspidiotus rigidus Reyne (Hemiptera: Diaspididae): a devastating pest of coconut in the Philippines

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- Abstract**
- 1 The Philippines is the second largest producer of coconut products and, in some areas, coconut farming is the main source of livelihood.
 - 2 A damaging armoured scale insect (Hemiptera: Diaspididae) infesting coconut palms was first found in the Philippines on Luzon Island (Batangas province) in 2009, and is now affecting most of the provinces of southern Luzon.
 - 3 The scale pest is still spreading in the Visayan Islands and Mindanao.
 - 4 Infestation stops photosynthesis; the leaves yellow and dry; fruits form less nutmeat and the coconut-water is sour; weak new leaflets bend over or break off; and the tree dies in 6 months or less.
 - 5 The scale pest is identified in the present study as *Aspidiotus rigidus* Reyne; it presents a significant quarantine threat to coconut-producing countries worldwide.
 - 6 Characters enabling the identification of *A. rigidus*, its host range and distribution are given.
 - 7 Some literature on the natural enemies and control of *A. rigidus* is reviewed briefly.

Keywords Damage, distribution, invasive species, mangosteen, outbreak.

Introduction

The Philippines has the world's largest agricultural area planted with coconut palms (3.1 million ha) and is second only to Indonesia as the world's top producer of coconut products. In some areas of the Philippines, coconut farming is the main source of livelihood (Lesaba, 2012; Anonymous, 2014). Most of the 3.5 million coconut farmers constitute the poorest farming sector in the country (Silverio, 2012).

In 2009, an armoured scale insect infestation was first noticed damaging coconut palms at Barangay Balele near Tanauan, Batangas Province, Luzon Island (Lesaba, 2012). By the time that the infestation was reported to the Philippines Coconut Authority (PCA) in March 2010, it had spread to more than 15 000 palms within a 15-km radius (Ranada, 2014). By early 2013, the scale had infested approximately 780 000 trees, affecting 50–70% of the coconut farms in Batangas and the nearby provinces: Laguna (20% of farms), Cavite (10% of farms) and Quezon (no data) (Argana, 2013; Ganzon, 2013). Spread of the pest is ongoing.

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The scale insect encrusts the lower leaf surfaces, blocking the stomata and stopping photosynthesis; the foliage yellows and dries (Fig. 1A); fruits form less nutmeat; the water inside the nuts tastes sour; and the tree dies in 6 months or less. In a span of 3 months, the infestation level increased from moderate to severe (Ranada, 2014). Some farmers have been forced to cut down dying trees and sell them as lumber to mitigate losses. It will not be easy for the farmers to recover because it takes at least 5 years after planting before a coconut tree bears fruit. In 2012, there was concern that the coconut pest might spread to other coconut-producing islands such as Leyte and Samar (Silverio, 2012), or even to other coconut-growing countries, and that the pest might attack other crop species.

In situations where an introduced species threatens the crops of poor farmers, the most cost-effective long-term control option is classical biological control. The first step in developing such control is to accurately identify the pest so that appropriate natural enemies can be found (Watson, 1999). Popular studies identify the pest insect as either *Aspidiotus* sp. or *Aspidiotus destructor* (Signoret) (Hemiptera: Diaspididae) (Luistro, 2012; Silverio, 2012; Ranada, 2014). However, *A. destructor* has been present in the Philippines from at least 1905 onward (Cockerell,

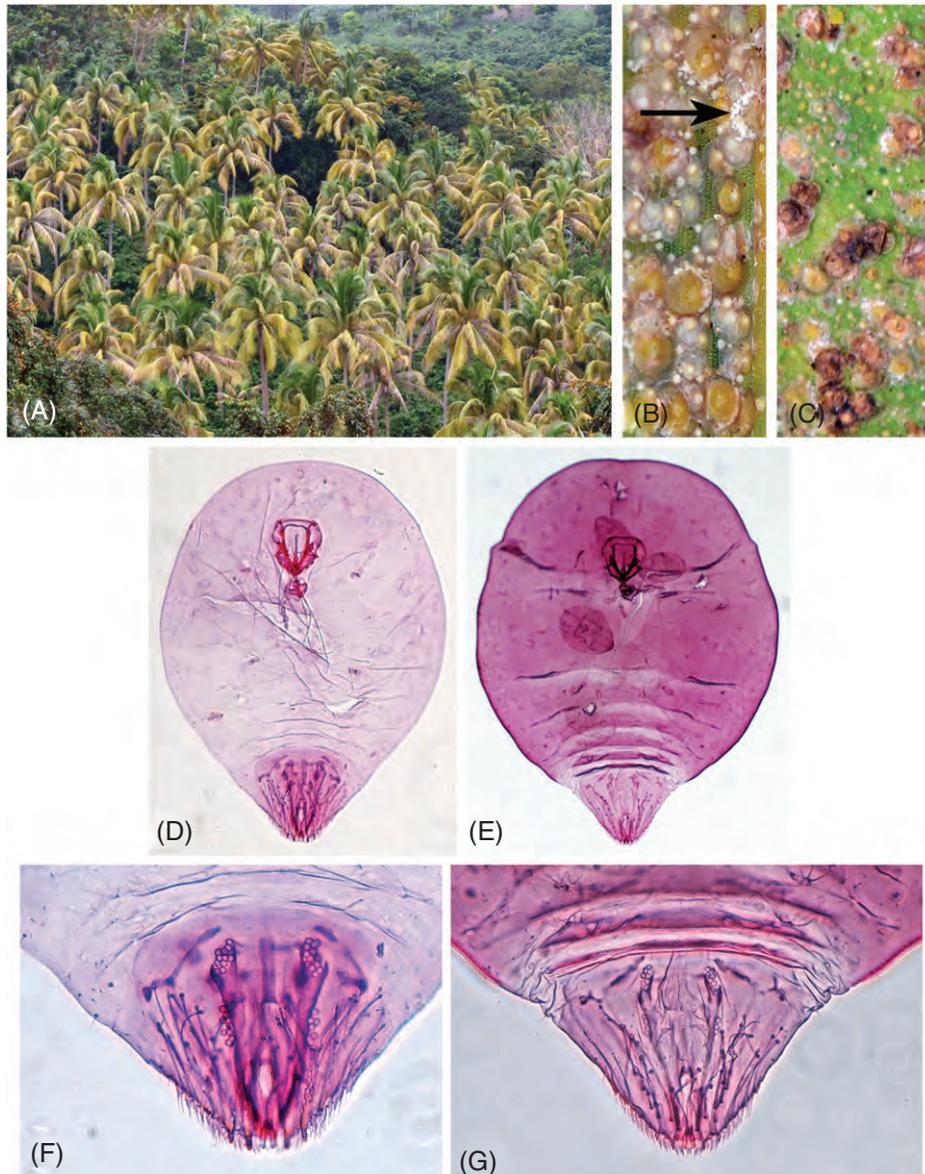


Figure 1 (A) *Aspidiotus rigidus* damage to coconut palms in Philippines (Luzon province). (B) An infestation of *A. rigidus* on *Cocos nucifera*, showing scale cover colour and (marked with an arrow) white egg-skin distribution. (C) *Aspidiotus rigidus* on *Garcinia mangostana*, showing variation in scale cover colour. (D) Slide-mounted, stained adult female *Aspidiotus destructor* showing membranous prosoma and prepygidial segments. (E) Slide-mounted, stained adult female *A. rigidus* showing sclerotized cuticle of prosoma and prepygidial segments. (F) Pygidium of *A. destructor*. (G) Pygidium of *A. rigidus*.

1905) and is normally not considered a problem because of the presence of effective natural enemies. The severity of the current outbreak suggested that a different species is responsible, which must have been introduced accidentally from elsewhere (Ranada, 2014).

Brief surveys of the pest scale insect were carried out in January 2014 at Malvar, Batangas Province, and Quezon City, Metro Manila. Reference specimens were studied at the California State Arthropod Collection (CSCA) at California Department of Food & Agriculture, Sacramento, California, U.S.A. (CDFA) and The Natural History Museum, London, U.K. (BMNH) and were compared with samples from the Philippines.

The present study records the outbreak and identity of this pest, provides characters enabling its identification, and outlines its host range, distribution and natural enemies, potential geographical range, and the plant quarantine threat that the pest presents. Natural enemy and control information in the literature is reviewed briefly.

Materials and methods

Permanent slide mounts of adult females and males were prepared at CDFa from alcohol-preserved samples (using the

method described in Sirisena *et al.*, 2013). Archival-quality preparations were deposited in CSCA and BMNH, and at the Museum of Natural History, University of the Philippines at Los Banos, Philippines (UPLBM) and the Museum Zoologicum Bogoriense, Research Center for Biology, Indonesian Institute of Sciences, Indonesia (MZB).

Adult females from the Philippines and Indonesia were identified authoritatively at CDFA Plant Pest Diagnostic Center based on their appearance in photographs and alcohol samples, their morphology in microscope slide mounts, information in the literature (Reyne, 1947, 1948) and a comparison with slide-mounted specimens of Reyne's material from Sangi Island in the BMNH collection.

Slide-mounted specimens were examined using a compound microscope (Zeiss, Germany) with phase contrast illumination and magnifications of $\times 25$ –800. The specimens were identified using keys, diagnoses and illustrations available in the literature (Reyne, 1947, 1948; Williams & Watson, 1988; Watson, 2002) and by comparison with Reyne's specimens in the BMNH. Specimens were photographed using a Digital Sight DS-5M camera in conjunction with NIS-ELEMENTS F, version 3.0, as well as SMZ1500 dissection and Eclipse 80i compound microscopes (Nikon, Japan). Automontage of some photograph series was carried out using COMBINE ZP (<http://www.hadleyweb.pwp.blueyonder.co.uk/>) and PHOTOSHOP (Adobe Systems, San Jose, California) was used to adjust colour balance and exposure levels in the photographs.

Results

Based on identification keys in the literature, slide-mounted specimens of the scale pest (Fig. 1E,G) appeared to be *A. destructor* (Signoret). However, a morphologically similar but biologically different armoured scale caused a highly damaging outbreak on coconut palms on Sangi Island (located between North Sulawesi, Indonesia, and Mindanao, Philippines) in 1925–1927 (Reyne, 1947). The species responsible was described as *Aspidiotus destructor* var. *rigidus* Reyne, based on specimens from Sangi I. (Reyne, 1947); it was elevated to species status (Borchsenius, 1966) and is now known as *Aspidiotus rigidus* (Ben-Dov, 2014a). It was possible that the same species might have been accidentally introduced to the Philippines and be causing the current problem on Luzon I. Although *A. rigidus* was described as morphologically inseparable from *A. destructor*, some aspects of the live appearance and biology of *A. rigidus* facilitate its identification (Reyne, 1947):

1. The cuticle of the adult female *A. rigidus* is extremely tough and rigid, which can be demonstrated by lifting the insect up off the leaf with the tip of a blunt needle, whereas the cuticle of *A. destructor* is delicate and flexible.
2. The life cycle is approximately 1.5 times longer than that of *A. destructor*.
3. The white egg skins left under the scale cover after hatching accumulate near the pygidium of *A. rigidus*, forming a white crescent under one-half of the scale cover. By contrast, in *A. destructor*, the white empty egg skins are distributed around the entire circumference of the scale cover.

Examination of alcohol-preserved samples from the Philippines showed that large adult females had a stiff cuticle, and the white egg skins were distributed in a crescent around the pygidium under one half of the scale cover (Fig. 1B). Stained, large adult females on microscope slides also had a sclerotized cuticle throughout the prosoma (Fig. 1E), confirming that the new coconut pest in the Philippines is *A. rigidus*.

Field diagnosis of *A. rigidus*

Scale cover broadly oval to circular, 1.5–3 mm across, fairly flat, very thin and transparent, with subcentral yellow exuviae; scale colour varying from pale yellow to (occasionally) chestnut brown (Fig. 1C). In mature specimens, white egg skins accumulate under one half of the scale cover, in a crescent shape (Fig. 1B) and the large female is stiff when pushed with a blunt needle. So far, the only recorded host plants of *A. rigidus* are palms (Arecaceae), *Musa* sp. (Musaceae) and *Garcinia mangostana* (Clusiaceae). By contrast, in *A. destructor*, the scale cover is very thin and transparent, off-white to slightly yellow, with white egg skins scattered in a ring or spiral around the entire circumference; the cuticle of a large female dents when pushed with a blunt needle (Reyne, 1948). *Aspidiotus destructor* feeds on many host-plants belonging to 67 families but does not thrive on *G. mangostana*.

Laboratory diagnosis

Morphological characters in common between A. destructor and A. rigidus. Body pyriform. Stigmatic pores and prepygidial ducts absent. Pygidium with three pairs of unilobulate lobes, each longer than wide, graded in size and degree of sclerotization with median lobes largest; lobes each notched once on the outer margin. Lateral marginal seta at outer basal corner of median lobe more than 1.4 times longer than the lobe. Pygidial macroducts usually more than 16 times longer than wide [measurements of a macroduct in the poriferous furrow between median and second lobes: *A. rigidus* 87.0–110.6 μm long, 4.4–6.0 μm wide, length : width 16.1–22.7 (mean 20.0, $n = 10$); *A. destructor* 69.6–98.5 μm long, 4.2–6.0 μm wide, length : width 11.5–22.4 (mean 17.1, $n = 10$)]. Marginal plates extending beyond lobe apices, finely fringed; eight plates present lateral to third lobe, each with outer margin oblique and fringed, never with clavate processes; outermost two or three plates simpler than the others. Perivulvar pores present in four groups. Anal opening elliptical, longer than median lobe, situated at approximately one-third the length of the pygidium from the apex. Vulva situated further forward, at approximately one-third the length of the pygidium from its anterior margin.

Identification of A. rigidus. Structural characteristics of the pygidium of the slide-mounted adult female are usually used to separate species of Diaspididae. However, the pygidial characters of *A. rigidus* (Fig. 1E,G) are indistinguishable from *A. destructor* (Fig. 1D,F), although *A. destructor* shows much more variation in the size of the median lobes and the length and width of the lateral lobes than is seen in *A. rigidus*. Variation in the relative

sizes of the pygidial lobes in *A. destructor* has been illustrated in the literature (Williams & Watson, 1988).

In very mature, slide-mounted females of *A. destructor*, the body remains membranous and stains lightly, apart from the pygidium (Fig. 1D), whereas, in *A. rigidus*, the whole prosoma becomes moderately sclerotized and takes up stain, leaving pale intersegmental transverse stripes of thinner cuticle across the prepygidial median areas of the abdomen (Fig. 1E). For separation of adult female *A. destructor* from *A. rigidus*, it is proposed that the following should be substituted for couplet (1) of the identification key to species of *Aspidiotus* on p. 49 of Williams & Watson (1988):

1. Prepygidial macroducts present; pygidial macroducts less than 13× as long as wide 2
– Prepygidial macroducts absent; most pygidial macroducts more than 16× as long as wide 1A

1A. Large adult female with body anterior to the pygidium sclerotized except for intersegmental lines between the prepygidial abdominal segments, giving a ladder-like stain pattern; restricted to palms, *Musa* sp. and *G. mangostana* *A. rigidus* Reyne
– Large adult female with body anterior to the pygidium entirely membranous, lacking a ladder-like stain pattern; on many hosts including palms and *Musa* sp. but not *G. mangostana*
..... *A. destructor* Signoret

Separation of the two tropical species, *A. destructor* and *A. rigidus*, from the similar species, *Aspidiotus cryptomeriae* Kuwana [found in northern Asia from Russia to the East coast, and no further south than South Korea and Japan, feeding on Pinopsida (Ben-Dov, 2014c)], is based on the relative lengths of the median lobe and the dorsal marginal seta at its outer basal corner; in *A. destructor* and *A. rigidus*, this seta is at least 1.4 times longer than the lobe, whereas, in *A. cryptomeriae*, it is shorter than the lobe. *Aspidiotus cryptomeriae* has a membranous prosoma similar to *A. destructor*, although with shorter pygidial macroducts [measurements of a macroduct in the poriferous furrow between median and second lobes: 48.2–84.4 µm long, 4.0–6.0 µm wide, length : width 9.3–17.2 (mean 13.1, n = 8)].

Material examined

Slide-mounted specimens are deposited at CSCA unless specified otherwise.

INDONESIA: Sangi I. near Celebes (=North Sulawesi), on *Cocos nucifera*, coll. A. Reyne, xi.1928 (at BMNH); North Sulawesi, Manado, on ornamental palm, coll. R. Muniappan, 26.vi.2013 (two slides at MZB).

PHILIPPINES: Luzon I., Batangas province: Santo Tomas, on *C. nucifera* (Palmae), coll. M. Shepard, 19.iv.2013 (one slide at BMNH); Malvar, on *C. nucifera* seedling, coll. M. Shepard, 15.iv.2013; in nursery, on *C. nucifera*, coll. M. Shepard, 19.iv.2013; on *G. mangostana* (Guttiferae), coll. M. Shepard, 19.iv.2013 (one slide at BMNH); near Malvar, SAGE demo farm, on *C. nucifera*, coll. M. Shepard, 19.iv.2013; Malvar, on *C. nucifera*, coll. B.M. Shepard, G. Carner, C.B. Adalla, 18.i.2014 (seven samples with same data); on *G. mangostana*, coll. B.M. Shepard, G. Carner, C.B. Adalla, 18.i.2014. Laguna

province: Los Banos, on *C. nucifera*, coll. M. Shepard, 18.ii.2013 (two slides at UPLBM); UPLB College of Forestry, on *C. nucifera*, coll. M. Shepard, 15.iv.2013; UPLB FFSRI, on *C. nucifera*, coll. M. Shepard, 15.iv.2013; UPLB Institute of Plant Breeding, on *C. nucifera*, coll. M. Shepard, 19.iv.2013; Bitin Bay near geothermal power plant, on *C. nucifera*, coll. M. Shepard, 19.iv.2013. Metro Manila province, Quezon City, on *G. mangostana*, coll. B.M. Shepard, G. Carner, C.B. Adalla, 19.i.2014.

From unknown origin, intercepted in California, San Francisco, U.S.A., on *G. mangostana* fruit at retail, coll. Pastalila & Copenhagen, 18.v.1995.

Host range

Aspidiotus rigidus has a much narrower range of hosts than *A. destructor*: Hosts that will support multiple generations of *A. rigidus* include *C. nucifera*, *Chrysalidocarpus lutescens*, *Cyrtostachys* sp., *Metroxylon* sp., *Nypa fruticans*, other ornamental palms (Arecaceae) and *Musa* sp. (Musaceae). Mangosteen (*G. mangostana* (Clusiaceae)) is a host for *A. rigidus* but will not support multiple generations of *A. destructor* (Reyne, 1948). The latter species has hosts in 69 plant families (Ben-Dov, 2014b). *Aspidiotus rigidus* will not feed on *Lansium* sp. (Meliaceae), although *A. destructor* is known to attack this host (Reyne, 1948).

In *A. rigidus* outbreak areas in the Philippines, both short and tall coconut cultivars were attacked equally severely and none appeared to show resistance.

Distribution of *A. rigidus*

INDONESIA: Sangi (=Sangir) I. (Reyne, 1947; specimens in BMNH collection, examined), parts of North (Reyne, 1947) and South (Voûte, 1937) Sulawesi, Flores (Wagiman, 2005), Bawean I. (Reyne, 1948), West and Central Java (Reyne, 1947) and Bali (Voûte, 1937; Kalshoven, 1981).

PHILIPPINES: Some provinces on the islands of Luzon, Mindoro, Leyte, Mindanao and Basilan are affected to varying degrees (Table 1). The distribution is very patchy within these provinces, with some areas being occupied by *A. rigidus*, some by *A. destructor*, and, occasionally, the two species occur in mixed infestations.

Based on the distribution of egg skins under the scale covers in a sample, Reyne recorded the possible presence of *A. rigidus* in the Pelew Islands (=Palau) (Reyne, 1947). No specimens from Palau were available for the present study. The hosts for *A. destructor* from Palau (listed by Beardsley, 1966) suggest that most, if not all, of the material Beardsley examined was true *A. destructor*, and not *A. rigidus*.

Biology

Aspidiotus rigidus produces yellow, winged adult males but the sex ratio varies widely and the males may be nonfunctional; the species may reproduce parthenogenetically (Reyne, 1948). In outbreak conditions, the rate of multiplication of *A. rigidus* was 5–10 times per generation, with approximately eight generations

Table 1 The known distribution of *Aspidiotus rigidus* in the Philippines in January 2014

Island, province	Location	Source
North Luzon I.		
Ilocos Norte	Batac; Paoay; Pagudpud; Mariano Marcos State University Campus	Report by Captain M. Baradas [UPLB Volunteers for Coconut Scale Insect (UPLB VCSI)]; observation by C.B. Adalla
Central Luzon I.		
Bulacan	San Miguel; San Ildefonso	Report by Captain M. Baradas (UPLB VCSI), who went to Ilocos by land as far as Pagudpud for the CSI survey
Metro Manila	Quezon City	Observation by C. B. Adalla, M. Shepard and G. Carner; specimens examined
Laguna	Bitin; Bay Laguna; University of the Philippines Campus; College Laguna; Calauan (along national highway to San Pablo); Nagcarlan, Laguna; Los Banos; Calamba	Observation by C. B. Adalla, M. Shepard and G. Carner; specimens examined
Batangas	Sto Tomas; Tanauan (Balele, Natatas, Santor); Talisay; Agoncillo; Lemery; Taal; Malvar; Lipa City	Reported by VCSI, who surveyed throughout the province; specimens examined
Quezon	Area by the boundary of Laguna Province	Report by Captain M. Baradas (UPLB VCSI)
Camarines Sur	Naga; Pili	Observation by C. B. Adalla
Mindoro I.		
Mindoro Oriental	—	Observation by C. B. Adalla
Mindoro Occidental		
Leyte I.	Baybay inside Visayas State University Campus; Tacloban	Observation by C. B. Adalla
Mindanao I.		
Campostela Valley	University of Southern Philippines campus	Observation by C. B. Adalla
Misamis Oriental	Cagayan de Oro City, and national road going to Iligan	Philippines Coconut Authority (PCA), per report of Dr B. Mailum (UPLB VCSI)
Cotabato	Sultan Kudarat; Datu Sinsuat; Maguindanao	Recorded as <i>Aspidiotus destructor</i> by Dr B. Mailum (UPLB VCSI)
Zamboanga	Zamboanga City	UPLB VCSI
	Basilan I.	Anonymous (2013)

UPLB VCSI, University of the Philippines at Los Banos, Philippines; PCA, Philippines Coconut Authority.

per year. The generation time for *A. rigidus* was approximately 46 days and is significantly longer than for *A. destructor* (approximately 32 days) (Reyne, 1948), which has approximately 10 generations per year (Kalshoven, 1981). *Aspidiotus rigidus* produces larger eggs and lays less frequently over a longer period than *A. destructor* (Reyne, 1948). *Aspidiotus rigidus* eggs are laid at an advanced stage of development, such that they hatch soon after being laid; consequently, only 10–12 eggs at a time are found under the scale cover, although a female may produce 50 or more eggs during her life. By contrast, *A. destructor* females each lay 40–100 small eggs all around the body over a very short period of time; the eggs are laid at an early stage of development and take 6–8 days to hatch (Reyne, 1947, 1948).

Environmental preferences

Aspidiotus rigidus thrives in high relative humidity and prefers to settle and feed on the lower leaf surfaces where stomata occur. It avoids exposed plant parts where the humidity is lower, except in extreme outbreak conditions when almost every part of the host may become incrustated with several layers of scale insects. The eggs and mobile larvae suffer high mortality in drought conditions; also, heavy rain causes high mortality in the adults, eggs and crawlers. The crawlers are wind dispersed, and, on Sangi I. in the 1920s, high winds facilitated the spread of the infestation even though the drying effect increased crawler mortality (Reyne, 1948). On Sangi I., *A. rigidus* colonized the humid river valleys first and any infestations found on hill ridges

were less intense than in the lower areas. Young palms growing in the shade were often the first to be attacked (Reyne, 1948).

Damage caused

Heavy infestations of *A. rigidus* (20–30 scales/cm² or 40–60 million per palm tree) destroy the chlorophyll, turning green leaves yellow (Fig. 1A,B); feeding punctures increase water loss from the leaves; the fruits form less nutmeat and the coconut-water becomes sour as a result of a lack of sugar content; new leaflets are stunted and weak, and tend to bend over strongly or break off; nut production falls and then stops; and, finally, the tree dries out and dies in 6 months or less (Reyne, 1948).

Natural enemies

In the Philippines, *A. destructor* is controlled by the hymenopteran parasitoid *Aphytis lingnanensis* Compere (Aphelinidae); this parasitoid has not been found attacking *A. rigidus*. The only natural enemies that have been identified in association with *A. rigidus* are the predatory beetles *Chilocorus nigrita* Fabricius, *Chilocorus melas* Weise and *Telsimia nitida* Chapin (Coleoptera: Coccinellidae) (PCA, 2013). However, the outbreak is continuing to spread despite their presence.

In samples of *A. rigidus* in the Philippines, a red entomophagous fungus had attacked a small proportion of the scales. On Sangi I. in the 1920s, *A. rigidus* was attacked by three

different species of fungus, including a red species of *Aschersonia* (Fungi: Clavicipitaceae); such fungi were unimportant in regulating the scale population (Reyne, 1948).

Insect natural enemies, including predatory coccinellid beetles, were of much greater importance than fungi in killing *A. rigidus* on Sangi I. The coccinellids *Telsimia nitida*, *Nephus luteus* Sicard, *Platynaspis* sp. and *C. nigrita* often attacked *A. destructor* but not *A. rigidus* because its cuticle is too tough to pierce with their mandibles (Reyne, 1948). *Chilocorus circumdatus* Gyllenhal killed approximately 100 specimens of *A. destructor* per day (Reyne, 1948), although this predator was not tested on *A. rigidus*. *Chilocorus politus* Mulsant was introduced to Sangi I. and North Sulawesi from Java. After 16 months, the beetle was very well established in parts of northern Sulawesi but had little effect on the population level of *A. rigidus*; it was recovered on Sangi I. also, although not in large numbers (Reyne, 1948).

The hymenopteran parasitoids recorded from *A. rigidus* on Sangi I. were the aphelinids *Spanioterus crucifer* Gahan and *Aphytis chrysomphali* (Mercet) and the encyrtids *Comperiella unifasciata* Ishii and another parasitoid tentatively identified (by Reyne, 1948) as the species now called *Encarsia aurantii* (Howard). *Spanioterus crucifer* occurred only locally and sporadically on both *A. destructor* and *A. rigidus* and had little impact on scale populations. *Aphytis chrysomphali* attacked *A. destructor* and other diaspidid scales, including *A. rigidus* but, in the latter species, the parasitization rate was low. *Comperiella unifasciata* attacked *A. rigidus* only, and not *A. destructor*, probably because the development time in *A. rigidus* is approximately 1.5 times longer than in *A. destructor*. Two and a half years after its introduction, 92% of *A. rigidus* samples were infested by this parasitoid at a mean rate of approximately 12% (Reyne, 1947, 1948). However, apparently *C. unifasciata* alone could not control an outbreak of *A. rigidus*; it could only slow down the rate of population growth (Reyne, 1947). Two other parasitoids also were found on Sangi I. but were unimportant in controlling *A. rigidus* (Reyne, 1948).

An outbreak of *Aspidiotus* scale on coconut palms in South Bali in 1934 was attributed to *A. destructor* (Voûte, 1937) but *A. rigidus* was probably responsible (Reyne, 1948). Several hymenopteran parasitoids were introduced from Java, including a species that was called '*Aspidiophagus citrinus*' (Voûte, 1937), which reproduced so rapidly that the scale was completely controlled by 1936. If the parasitoid involved was *Aspidiophagus citrinus*, this species is now known as *Encarsia citrina* (Craw) (Noyes, 2013).

Control activities against outbreaks of *A. rigidus* have been discussed in the literature (Reyne, 1947, 1948; Wagiman, 2005).

Discussion

The lack of morphological variation in *A. rigidus* may be a consequence of passing through the genetic bottleneck of a single introduction at one or multiple times in its history. The species has a very disjunct distribution in Indonesia; the absence of effective natural enemies on these islands, and the occurrence of its specific parasitoid *C. unifasciata* in Japan and much of China, suggests that the scale may have originated from somewhere else in East Asia (Reyne, 1948; Kalshoven, 1981; Noyes, 2013).

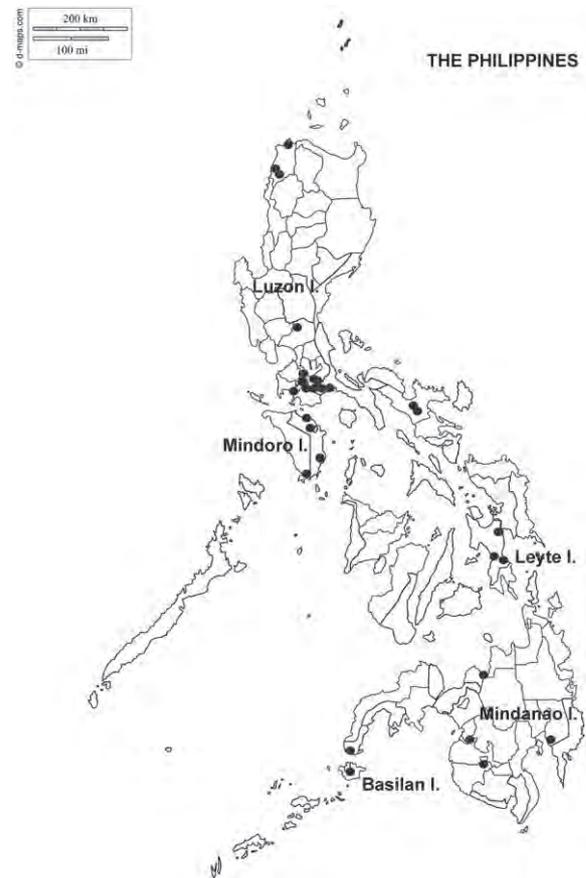


Figure 2 The known distribution of *Aspidiotus rigidus* in the Philippines in January 2014, based on information provided in Table 1 and records by the University of the Philippines at Los Banos, Philippines, Volunteers for Coconut Scale Insect. The map outline is available at: http://d-maps.com/carte.php?&num_car=26013&lang=en

The patchy distribution in the Philippines (Fig. 2) follows the same pattern, showing scattered points of probably accidental introduction by human activity in areas where the scale was not present before. The only mention in the literature of *A. rigidus* occurring in parts of the Philippines before the present outbreak was by Lever (1969), who provided no details.

Molecular characterization of *A. rigidus* was not attempted in the present study because such work is currently in progress at the University of the Philippines at Los Banos. Molecular information may suggest the degree of relationship between *A. rigidus* and *A. destructor*, and the amount of variation found between *A. rigidus* populations may indicate the amount of time elapsed subsequent to the species being introduced to the Philippines.

The host range of *A. rigidus* appears to be confined to monocotyledonous plants (palms and *Musa* sp.) apart from the single dicotyledonous host *G. mangostana*. Insufficient knowledge is available about the scale and its preferences to be able to explain this inconsistency. There has been concern in the Philippines that lanzones (*Lansium domesticum*) were being attacked by the coconut scale pest (Luistro, 2012), although *Lansium* is not a known host for *A. rigidus*; a sample of scales on lanzones

from Batangas province (Malvar, coll. B.M. Shepard, G. Carner and C.B. Adalla, 18.i.2014) was identified as *Unaspis citri* (Comstock) (Hemiptera: Diaspididae). *Unaspis citri* differs from *A. rigidus* in possessing elongate, dark brown, opaque female scale covers and white immature male scale covers, whereas the covers of both sexes in *A. rigidus* are circular, transparent and yellow to chestnut brown (Fig. 1B).

Aspidiotus rigidus outbreaks appear to occur when the scale is introduced to an area with favourable environmental conditions in the absence of its natural enemies. The new location appears to increase the scale's vitality for approximately 2 years. Densely planted coconut palms (particularly if growing in dense, semi-wild vegetation), a humid climate and strong winds that facilitate spread of the scale crawlers all favour the development of an outbreak. At any one locality, the outbreak appears to come to an end naturally after 2 years as a result of reduced fecundity in the females and heavy mortality in the immature stages for unknown reasons (Reyne, 1948). This does not agree with the situation in Batangas province in the Philippines, however, where the outbreak first noted in 2009 is still ongoing.

At least two outbreaks of *A. rigidus* have occurred on the Indonesian island of Bali, just before 1915 (Kalshoven, 1981) and again in 1934 (Voûte, 1937). The natural enemies introduced in 1915 appear to have died out before 1934, possibly because they reduced the scale population below a level that would sustain them. By contrast, *A. rigidus* has been present in Java for a long time but there are no records of it causing outbreaks there (Voûte, 1937; Reyne, 1947, 1948; Kalshoven, 1981; Wagiman, 2005). Java's large land mass possibly maintains a sufficiently large scale population to sustain the unknown, effective natural enemies over the long term.

Outbreaks of adventive alien insects are potentially suitable for classical biological control. To identify effective natural enemies, it is necessary to locate and search the pest's area of origin (Watson, 1999), although the area of origin of *A. rigidus* remains unknown. A number of natural enemies were recorded attacking *A. rigidus* in Indonesia, including the host-specific parasitoid *C. unifasciata* but, reportedly, none of them was capable of preventing or controlling an outbreak of the scale (Reyne, 1947, 1948). Perhaps this meant that no single natural enemy gave control in the studies by Reyne (1947, 1948), because better results than those on Sangi I. were achieved in Bali in 1915 (Kalshoven, 1981), when several species of natural enemies (including *Chilocorus* beetles and scales parasitized by *Aphytis* and *Comperiella*) were introduced from Java to control an outbreak. These introductions resulted in a slow rise in parasitization from 10% to 60%, and ultimate control of the pest.

The natural controls present in Java appear to be effective at controlling *A. rigidus* populations, so this might be an appropriate area to search for potential biological control agents for use in the Philippines. The scale is heavily parasitized by *C. unifasciata* in West Java (A. Rauf, Indonesia, pers. comm.).

The cause of the present outbreak in the Philippines was probably accidental importation of infested plants to an area with suitably humid climatic conditions and abundant coconut palms that lacked the scale's usual natural enemies. The information available suggests that classical biological control might be effective in reducing the current outbreak in the Philippines.

Free trade in fresh plant material by modern rapid transport methods increases the risk of future introductions and outbreaks compared with the past. *Aspidiotus rigidus* is therefore considered to be a significant quarantine threat to any tropical country where coconut palms are grown.

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