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Records of seven species of native and exotic bark beetles new to Pu'u Wa'awa'a Dry Forest Unit, Hawai'i Island (Coleoptera: Curculionidae, Scolytinae)

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Abstract
As part of ongoing surveys for native bark beetles (Coleoptera: Curculionidae: Scolytinae) across the Hawaiian Islands, we undertook targeted sampling at Pu'u Wa'awa'a Experimental Forest Unit, North Kona, on the northwestern part of Hawai'i Island during February to April of 2018 and 2019. This is one of the few areas containing remaining native dry forest on the leeward, dry side of the island. Our sampling revealed the presence of seven species of bark beetles not previously recorded from Pu'u Wa'awa'a. These included two native and endemic Hawaiian species belonging to the genus *Xyleborus* Eichhoff (tribe Xyleborini). The other five species are the exotic *Hypothenemus hampei* (Ferrari, 1867), or the coffee berry borer, belonging to the tribe Cryphalini, which is a serious pest of coffee in the Hawaiian Islands, and four widespread adventive species belonging to the tribe Xyleborini, including *Xyleborus ferrugineus* (Fabricius, 1801), whose frass has been demonstrated to be able to contain a fungus that is a causative agent of the plant disease Rapid 'Ōhi'a Death which currently poses a threat to native 'ōhi'a lehua trees. These records are presented and discussed in detail, and the newly recorded species are illustrated in colour photographs.

Key words: Hawaiian Islands, *Xyleborus dubiosus*, *Xyleborus nubilus*, *Xyleborus ferrugineus*, *Xyloberinus andrewesi*, *Xyleborinus saxesenii*, *Xylosandrus crassiusculus*, *Hypothenemus hampei*.

Introduction

The Ahupua`a (traditional Hawaiian land subdivision) of Pu'u Wa'awa'a is situated in North Kona District, on the western, or leeward, 'dry' side of Hawai'i Island. Named for the prominent furrowed cinder cone (Pu'u Wa'awa'a meaning 'furrowed hill' in the Hawaiian language) that is a distinctive landmark in the area, the site is located on the northern flank of Hualālai volcano, the third-youngest and the third most active volcano of the five on the island (Giffin 2003). Pu'u Wa'awa'a encompasses a total area of 15,743 ha, ranging from sea level at the coast to 1951 m about 1.6 km from the summit of Hualālai. The area is made up of public lands managed by the Divisions of Forestry and Wildlife (DOFAW) and State Parks, of the State of Hawai'i's Department of Land and Natural Resources (DLNR). Furthermore, it also constitutes the United States Forestry Service- (USFS) administered Pu'u Wa'awa'a Dry Forest Unit of the Hawai'i Experimental Forest (HETF), which overlays the Wildlife sanctuary (Forest Bird Sanctuary), Forest Reserve, and State Parks at Pu'u Wa'awa'a.

Once entirely covered with native plants, large-scale prehistoric conversion of lowland forests to agriculture, wildfires, and over a century of livestock grazing have resulted in the loss of most of the original vegetation cover at Pu'u Wa'awa'a (Olson & James 1982; Giffin 2003). Nevertheless, a variety of biotopes, including now-rare dry and mesic forests, in addition to exotic-dominated grasslands, are represented at the site, and the overarching management aim of its administration is the conservation of the historical, natural, cultural, and recreational resources contained within it.

A biological assessment of Pu'u Wa'awa'a published in 2003 contained an inventory of the fauna and flora then recorded, which included a preliminary checklist of insects collected there between 1993 and 2002, highlighting the significance of the area for biodiversity (Giffin 2003). Consequently, Pu'u Wa'awa'a is an important site for native Hawaiian plants and associated native invertebrates, including several federally listed endangered species such as both the smallflower aiea *Nothocestrum breviflorum* A. Gray. (Solanaceae), and the Blackburn's sphinx moth *Manduca blackburni* (Butler, 1880) (Sphingidae), whose larvae feed upon its leaves (Giffin 2003; Jamieson & Denny 2001). Other examples of insects with close associations to native plants present at Pu'u Wa'awa'a include 12 species of wood-boring longhorn beetles of the Hawaiian-

endemic genus *Plagithmysus* (Cerambycidae) recorded from Pu'u Wa'awa'a (Giffin 2003), which utilise endemic trees belonging to several families as larval host-plants, including *Diospyros sandwicensis* (A.DC.) Fosberg (Ebenaceae), *Myoporum sandwicense* A. Gray (Scrophulariaceae), *Charpentiera obovata* Gaudich. (Amaranthaceae), and the possibly already extinct in the wild *Hibiscadelphus hualalaiensis* Rock (Malvaceae) (Gressitt and Davis 1969).

Another group of native wood-boring beetles occurring in the Hawaiian Islands and associated with native trees is a small radiation of 21 species of endemic bark beetles of the genus *Xyleborus* Eichhoff (Xyleborini), that includes 11 species recorded from Hawai'i Island (Table 1), five of which are endemic to the island (Samuelson 1981; Wood & Bright 1992). These beetles feed on cultivated co-evolved ectosymbiotic fungi and not directly on woody plant tissue itself (Kirkendall et al. 2015), and have recently been shown to form a monophyletic group composed of the descendants of a single colonising ancestral species that arrived on the islands more than seven million years ago, before the formation of the present high islands (Cognato et al. 2018). However, despite the presence in Pu'u Wa'awa'a of substantial forested tracts containing a dominant cover of native trees such as *'ōhi'a* lehua (*Metrosideros polymorpha* Gaudich.) (Myrtaceae) in the drier lower sections of the reserve (Fig. 1A), and koa (*Acacia koa* A. Gray) (Fabaceae) in the more humid upper sections (Fig. 1B), none of the native bark beetle species have hitherto been recorded from Pu'u Wa'awa'a.

In addition to the native bark beetle species, a total of 20 adventive, exotic bark beetle species belonging to three tribes have been recorded from the island of Hawai'i, including a number of well-known, now pantropical pests, such as *Hypothenemus hampei* (Ferrari, 1867), the "Coffee Berry Borer" (Table 2). The previously published insect checklist for Pu'u Wa'awa'a (Griffin 2003) recorded only a single exotic bark beetle species, known from several of the main Hawaiian Islands: *Hypothenemus eruditus* 1836 (Cryphalini) (Nishida 2002; Bishop Museum 2018). Because of growing interest in bark beetles in general across Hawai'i, primarily on account of their potential association in the transmission of the fungal disease known as 'Rapid 'Ōhi'a Death', which threatens Hawai'i 's most widespread native tree species (Mortenson et al. 2016; Barnes et al. 2018; Roy et al. 2018), and due to the economic damage caused to coffee production by the coffee berry borer *H. hampei* (Burbano et al. 2011) and other pest species, it has become important to document the detailed distribution of bark beetles across the State. On a broader scale, contributing to the monitoring of insects in Hawai'i, which is home to 10,000 largely understudied species, including some facing a high risk of extinction (Howarth & Mull 1992; Rubinoff 2007), is an essential element in advancing scientifically well-informed conservation assessments and policies (Medeiros et al. 2013). The endemic Hawaiian bark beetles, owing their existence to the persistence of ever-threatened and contracting native forest biotopes containing their host plants, are one such understudied taxon, whose conservation will benefit from increased monitoring efforts. We present here the outcome of our targeted bark beetle survey for these beetles at Pu'u Wa'awa'a.

Materials and methods

As part of an ongoing survey for native bark beetles across the Hawaiian Islands, we identified Pu'u Wa'awa'a as an important site, owing to the fact that it is one of few remaining leeward-aspect areas in Hawai'i Island containing native forest trees and biotopes, especially in its upper sections on the flank of Hualālai volcano. We sampled for bark beetles at Pu'u Wa'awa'a during February to April of the years 2018 and 2019 by deploying five Lindgren-funnel traps, each baited with approximately 150 ml of an ethanol-methanol solvent lure containing between 40−50% ethanol and 50−55% methanol (Klean-Strip® Denatured Alcohol, W.M. Barr & Co., Inc., Memphis, TN, U.S.A.), and 50 ml of commercial anti-freeze car coolant containing ethylene glycol. We suspended the traps at approximately 2 m height, from living native tree branches in forest habitats containing native Hawaiian tree species. The traps were placed along an altitudinal gradient that rose from 700 to 1240 m. In 2018 the lower two traps were placed in areas of semi-arid forest dominated by 'ōhi'a lehua at elevations of 700 and 895 m, whilst the upper three traps were placed in more humid mesic forest dominated by koa, at elevations between 1215 and 1250 m. The traps were deployed over 73 days between the 5th February and the 19th April, or 365 trap-days (1 trap-day = 1 trap deployed for 24 hours), during which time they were checked on five occasions (on average every 15 days) before being dismantled. That first year's survey resulted in only two native Hawaiian scolytines being collected (see results below) from traps deployed in the upper, koa-dominated mesic forest. Correspondingly, because our aim was to find native scolytines, we focused the second year's survey to this same forest, albeit expanding the trapping to cover a greater area within it, deploying between three and five traps over 47 days between the 18th of February and the 6th of April (175 trap-days), which were checked on four occasions (on average every 12 days). All collected specimens were preserved in 95% ethanol and subsequently identified using the keys in Samuelson (1981), and by comparison to specimens held in the following three Honolulu-based entomological collections: University of Hawai'i Insect Museum (UHIM), Bernice Pauahi Bishop Museum (BPBM), and the State of Hawai'i Department of Agriculture (HDOA). Specimen length was measured from the elytral apices to the pronotal apex using a Micro Tools

Table 1 – Native Scolytinae occurring on Hawai'i island, with indication of island distribution and recorded host plant genera. The five species endemic to only Hawai'i island are underlined [data according to Samuelson (1981)].

Species	Island distribution	Host plant genera
X. agamus Perkins, 1900	Lana'i, Hawai'i	Unknown
X. arcturus Samuelson, 1981	Hawai'i	Unknown
X. dubiosus Perkins, 1900	O'ahu, Moloka'i, Lana'i, Maui, Hawai'i	*Bobea*, *Coprosma, Eugenia, Perrottetia, Physalis, Pipturus, Psychotria*
X. hawaiiensis Perkins, 1900	Kaua'i, O'ahu, Lana'i, Maui, Hawai'i	*Cheirodendron, Dubautia, Pipturus, Tetraplasandra*
X. hiiaka Samuelson, 1981	Hawai'i	*Cheirodendron*
X. ignobilis Perkins, 1900	O'ahu, Lana'i, Maui, Hawai'i	*Freycinetia*
X. nubilus Samuelson, 1981	Hawai'i	*Myrsine*
X. obliquus Sharp, 1885	O'ahu, Hawai'i	*Ilex*
X. pele Samuelson, 1981	Hawai'i	*Cheirodendron*
X. simillimus Perkins, 1900	Hawai'i	*Metrosideros*
X. vulcanus Perkins, 1900	Kaua'i, O'ahu, Lana'i, Maui, Hawai'i	*Acacia, Elaeocarpus, Melicope*

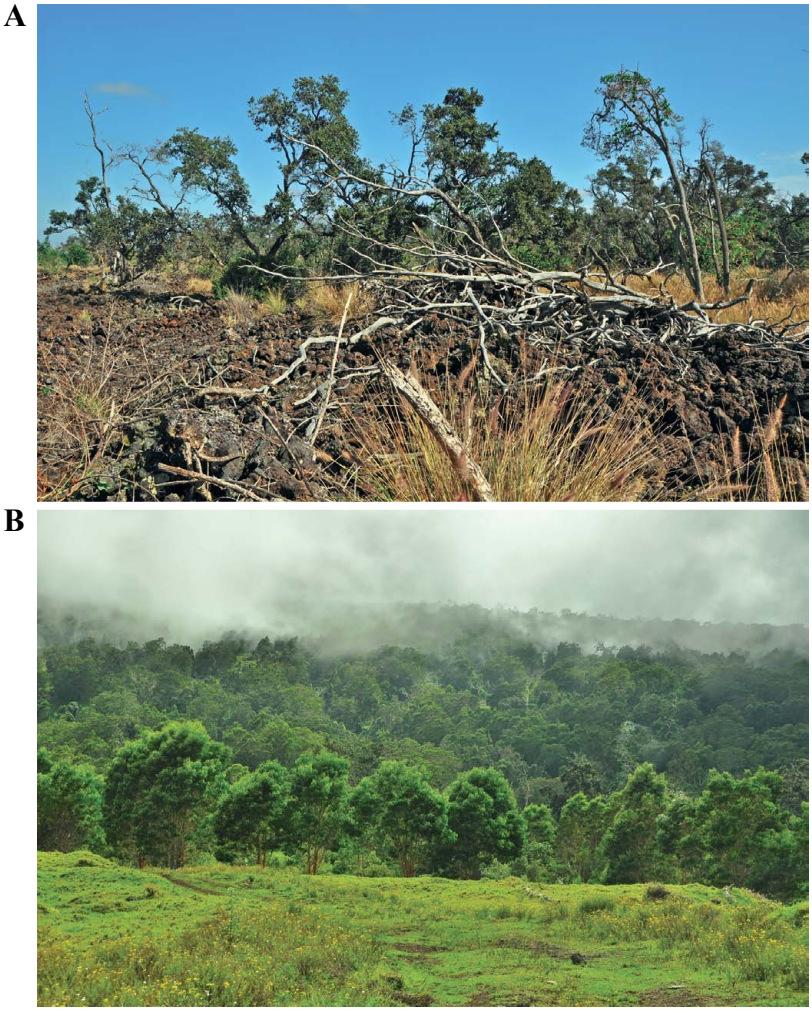

Fig. 1 – Forest biotopes containing native Hawaiian trees, where bark beetle sampling took place at Pu'u Wa'awa'a. **A**, Lower open dry forest area dominated by 'ōhi'a lehua (*Metrosideros polymorpha*), at approximately 700 m elevation. **B**, Upper mesic forest area dominated by koa (*Acacia koa*), at approximately 1250 m, on the edge of more humid forest.

Table 2 – Exotic bark beetles recorded from the island of Hawai'i with an indication of literature sources and their purported native distributional ranges.

Species	Literature source	Purported native range
Tribe Xyleborini LeConte, 1876		
Euwallacea fornicatus (Eichhoff, 1868)	Nishida (2002)	Tropical Asia
Xyleborinus andrewesi (Blandford, 1896)	Cognato & Rubinoff (2008)	Old World tropics
Xyleborinus saxesenii (Ratzeburg, 1837)	Nishida (2002)	Asia
Xyleborus affinis Eichhoff, 1867	Nishida (2002)	Neotropical
Xyleborus ferrugineus (Fabricius, 1801)	Nishida (2002)	Neotropical
Xyleborus perforans (Wollaston, 1857)	Nishida (2002)	Tropical Asia
Xylosandrus compactus (Eichhoff, 1875)	Nishida (2002)	Tropical Asia
Xylosandrus crassiusculus (Motschulsky, 1866)	Nishida (2002)	Asia
Xylosandrus morigerus (Blandford, 1894)	Cognato & Rubinoff (2008)	Tropical Asia
Tribe Dryocoetini Lindemann, 1877		
Coccotrypes advena Blandford, 1894	Nishida (2002)	Tropical Asia
Coccotrypes carpophagus (Hornung, 1842)	Nishida (2002)	Afrotropical
Coccotrypes cyperi (Beeson, 1929)	Nishida (2002)	Tropical Asia
Coccotrypes dactyliperda (Fabricius, 1801)	Nishida (2002)	Afrotropical
Cryphalus sylvicola (Perkins, 1900)	Nishida (2002)	Micronesia
Tribe Cryphalini Lindemann, 1877		
Hypothenemus birmanus (Eichhoff, 1878)	Nishida (2002)	Tropical Asia
Hypothenemus eruditus (Westwood, 1836)	Nishida (2002)	Tropical Asia
Hypothenemus hampei (Ferrari, 1867)	Burbano et al. (2011)	Aftrotropical
Hypothenemus obscurus (Fabricius, 1801)	Nishida (2002)	Neotropical
Hypothenemus pubescens Hopkins, 1915	Nishida (2002)	Neotropical
Hypothenemus seriatus (Eichhoff, 1872)	Nishida (2002)	Afrotropical?

micro-scale (Minitool, Inc., Los Gatos, CA, U.S.A.), and photographs of representative specimens were taken with a Nikon D-7100 DSLR camera mounted on an Olympus stereomicroscope. The images were subsequently focus-stacked using Helicon Focus (Helicon Soft Ltd., Kharkiv, Ukraine) running on an iMac computer, and digitally manipulated to improve clarity. Newly collected specimens are deposited in UHIM. The approximate location of Pu'u Wa'awa'a on Hawai'i Island is shown in the map in Figure 2.

Results

A total of 2,343 specimens of Scolytinae were collected and identified during the survey, representing seven species, all of which are new records for Pu'u Wa'awa'a. These included two native endemic Hawaiian species in the tribe Xyleborini, one of which (*Xyleborus nubilus* Samuelson, 1981) is endemic to Hawai'i Island. The other five species are four exotic xyleborines, and the coffee berry borer, *H. hampei* (Cryphalini), which are all today widespread pantropical species of actual or potential pest status that have previously been recorded from multiple Hawaiian Islands, including Hawai'i (Nishida 2002; Cognato & Rubinoff 2008; Haack & Rabaglia 2013; Gomez et al. 2018; Bishop Museum 2018). We present below detailed new records for all seven species.

Tribe Xyleborini LeConte, 1876

Xyleborus dubiosus Perkins, 1900 (Fig. 3A)

1 female: **USA**: Hawai'i Island, North Kona District, Pu'u Wa'awa'a Experimental Tropical Forest Unit, Outer edge of bird sanctuary, 19.7378; -155.8752, 1235 m, mixed mesic tropical forest, Lindgren-funnel trap, set on *Acacia koa*, 03. iii. – 05. iv. 2018, leg. C.P.D.T. Gillett & C. Elliott (UHIM). 1 female: data as above, except, 19.7377; -155.8754, 1238 m, 20.ii – 08. iii. 2019, leg. C.P.D.T. Gillett & C. Elliott (UHIM). 1 female: data as above, except, 19.740959; -155.865295, 1237 m, 13.iii – 06. iv. 2019, leg. C.P.D.T. Gillett & C. Elliott (UHIM).

***Xyleborus nubilus* Samuelson, 1981** (Fig. 3B)

1 female: **USA**: Hawai'i Island, North Kona District, Pu'u Wa'awa'a Experimental Tropical Forest Unit, Outer edge of bird sanctuary, 19.7379; -155.8752, 1235 m, mixed mesic tropical forest, Lindgren-funnel trap, set on *Acacia koa*, 17. ii. – 20. ii. 2018, leg. C.P.D.T. Gillett & C. Elliott (UHIM).

***Xyleborus ferrugineus* (Fabricius, 1801)** (Fig. 3C)

11 females: **USA**: Hawai'i Island, North Kona District, Pu'u Wa'awa'a Experimental Tropical Forest Unit, Outer edge of bird sanctuary, 19.793; -155.843, 700 m, mixed mesic tropical forest, Lindgren-funnel trap , set on *Metrosideros polymorpha*, 20. ii. – 03. iii. 2018, leg. C.P.D.T. Gillett & C. Elliott (UHIM). 1 female: data as above, except 05. iv. – 19. iv. 2018 (UHIM).

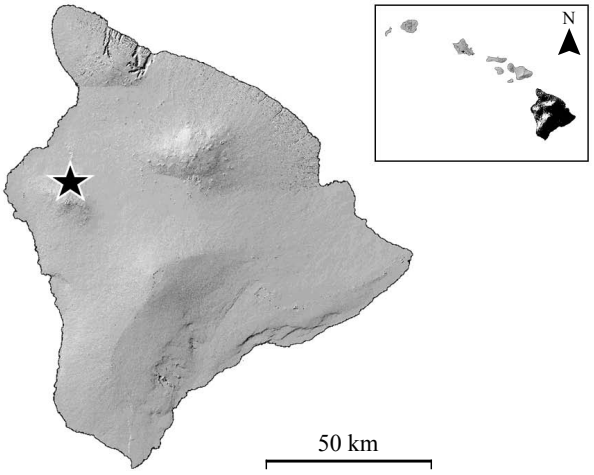

Fig. 2 – Map indicating the approximate location of the sampling sites at Pu'u Wa'awa'a Dry Forest Unit on the leeward side of Hawai'i Island.

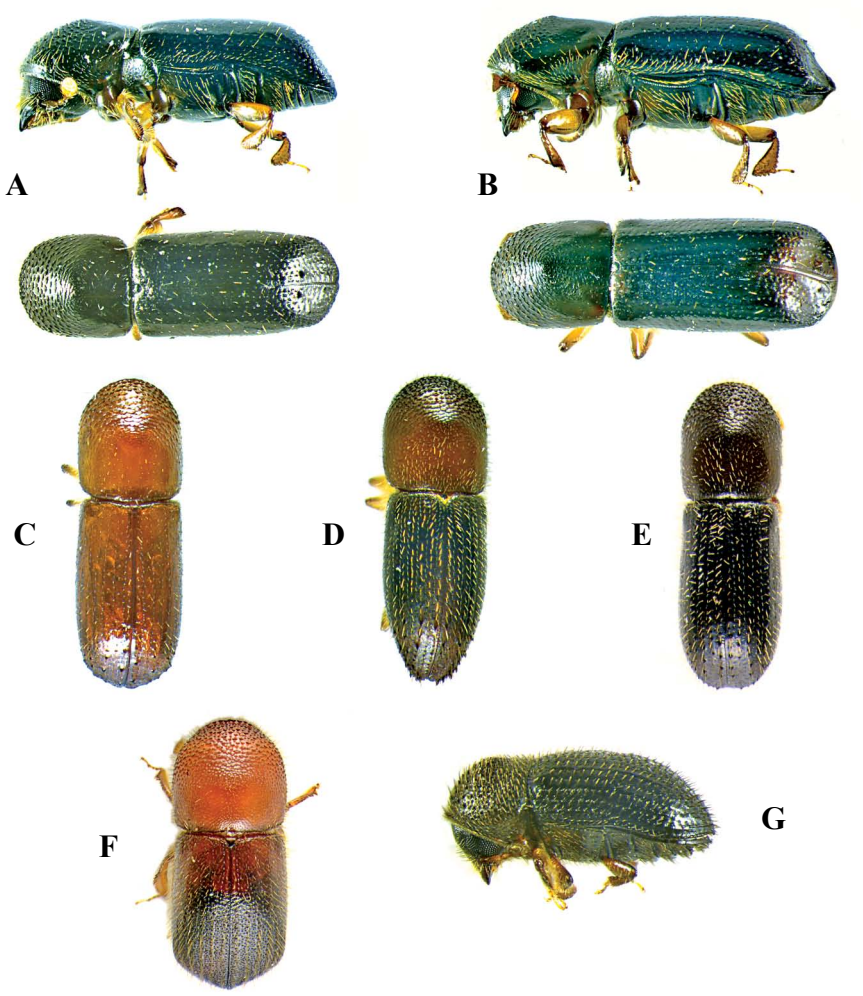

Fig. 3 – Newly recorded native and exotic bark beetle species sampled in Lindgren-funnel traps at Pu'u Wa'awa'a between February and April of 2018 and 2019. **A**, *Xyleborus dubiosus*, length: 2.9 mm. Lateral and dorsal views. **B**, *X. nubilus*, length: 3.2 mm. Lateral and dorsal views. **C**, *X. ferrugineus*, length: 2.3 mm. Dorsal view. **D**, *Xyleborinus andrewesi*, length: 1.9 mm. Dorsal view. **E**, *Xyleborinus saxesenii*, length: 1.9 mm. Dorsal view. **F**, *Xylosandrus crassiusculus*, length: 2.5 mm. Dorsal view. **G**, *Hypothenemus hampei*, length: 1.6 mm. Lateral view. Photographs by Conrad P.D.T. Gillett.

***Xyleborinus andrewesi* (Blandford, 1896)** (Fig. 3D)

40 females: **USA**: Hawai‘i Island, North Kona District, Pu’u Wa’awa’a Experimental Tropical Forest Unit, 19.793; -155.843, 700 m, semi-arid tropical forest, Lindgren-funnel trap , set on *Metrosideros polymorpha*, 20. ii. – 19. iv. 2018, leg. C.P.D.T. Gillett & C. Elliott (UHIM).

***Xyleborinus saxesenii* (Ratzeburg, 1837)** (Fig. 3E)

51 females: **USA**: Hawai‘i Island, North Kona District, Pu’u Wa’awa’a Experimental Tropical Forest Unit, 19.73; -155.87, 1216 – 1235 m, mixed mesic forest, Lindgren-funnel traps, set on *Acacia koa*, 05. ii. – 19. iv. 2018, leg. C.P.D.T. Gillett & C. Elliott (UHIM). 1 female: data as above, except, outer edge of bird sanctuary, 19.7377; -155.87549, 1238 m, mixed mesic tropical forest, Lindgren-funnel trap, set on *Acacia koa*, 20. ii. – 08. iii. 2019, leg. C.P.D.T. Gillett & C. Elliott (UHIM). 1 female data as above, except, ‘catchment area’, 19.741074; -155.865234, 1225 m, mixed mesic tropical forest, Lindgren-funnel trap, set on *Acacia koa*, 13. iii. – 06. iv. 2019, leg. C.P.D.T. Gillett & C. Elliott (UHIM).

***Xylosandrus crassiusculus* (Motschulsky, 1866)** (Fig. 3F)

2009 females: **USA**: Hawai‘i Island, North Kona District, Pu’u Wa’awa’a Experimental Tropical Forest Unit, 19.73; -155.87, 1216 – 1235 m, mixed mesic forest, Lindgren-funnel traps, set on *Acacia koa*, 05. ii. – 19. iv. 2018, leg. C.P.D.T. Gillett & C. Elliott (UHIM).

49 females: Hawai‘i Island, North Kona District, Pu’u Wa’awa’a Experimental Tropical Forest Unit, 19.7658; -155.8630, 895 m, semi-arid tropical forest, Lindgren-funnel trap, set on *Metrosideros polymorpha*, 05. ii. – 19. iv. 2018, leg. C.P.D.T. Gillett & C. Elliott (UHIM).

11 females: data as above, except 19.7933; -155.8430, 699 m, Lindgren-funnel trap, set on *Metrosideros polymorpha*, 05. ii. – 19. iv. 2018, leg. C.P.D.T. Gillett & C. Elliott (UHIM).

79 females: Hawai‘i Island, North Kona District, Pu’u Wa’awa’a Experimental Tropical Forest Unit, outer edge of bird sanctuary, 19.73; -155.87, 1216 – 1238 m, mixed mesic forest, Lindgren-funnel traps, set on *Acacia koa*, 18. ii. – 13. iii. 2019, leg. C.P.D.T. Gillett & C. Elliott (UHIM).

62 females: data as above, except, ‘catchment area’, 19.74; 155.87, 1219 – 1237 m, 13. iii. – 06. iv. 2019 leg. C.P.D.T. Gillett & C. Elliott (UHIM).

Tribe Cryphalini Lindemann, 1877

***Hypothenemus hampei* (Ferrari, 1867)** (Fig. 3G)

23 Females: **USA**: Hawai‘i Island, North Kona District, Pu’u Wa’awa’a Experimental Tropical Forest Unit, 19.737; -155.875, 1235 m, mixed mesic forest, Lindgren-funnel traps, set on *Acacia koa*, 20. ii. – 05. iv. 2018, leg. C.P.D.T. Gillett & C. Elliott (UHIM).

Discussion

As a result of the targeted survey, the bark beetle fauna of Pu’u Wa’awa’a has increased from a single species to eight. However, only four specimens of native Hawaiian scolytines were collected in our samples, representing a mere 0.17% of bark beetle abundance, and indicating that either they are present in proportionally very low abundance at Pu’u Wa’awa’a in comparison to the introduced exotic species or that they are ineffectively sampled by the traps we employed. The fact that we have collected native species in much higher abundance (more than two orders of magnitude higher in some cases) employing the same traps at other sites across Hawai‘i indicates that the lures can be effective in sampling for them (unpublished data), which leads us to conclude that the observed relative abundances of native and non-native beetles is real.

Other arguments can be made that the native beetles may have exhibited low flight activity during this period, thereby reducing their capture rate, or that there is a lack of suitable habitat or host trees for them in Pu’u Wa’awa’a. However, the large numbers of exotic bark beetles trapped indicate that climatic conditions did not seem to be an impediment to bark beetle activity in general, although we recognise that further sampling during the warmer “summer” months should be undertaken. These results are also in line with the very low native species abundances found across the State by Cognato & Rubinoff (2008). Furthermore, known host plants associated with the native scolytine species recorded from Hawai‘i Island (where known) occur at Pu’u Wa’awa’a, including the following genera belonging to diverse families: *Coprosma* J.R.Forst. & G.Forst. (Rubiaceae), *Cheirodendron* Nutt. ex Seem. (Araliaceae), *Ilex* Linnaeus (Aquifoleaceae), *Myrsine* Linnaeus (Primulaceae), and *Freycinetia* Gaudich. (Pandanaceae) (Giffin 2003).

Moreover, neither of the two native species of *Xyleborus* we collected utilise ‘ōhi‘a or koa - the two dominant native tree species at Pu’u Wa’awa’a - as hosts, although both those trees are hosts to other native *Xyleborus* species occurring on Hawai‘i Island, namely *X. simillimus* Perkins, 1900, and *X. vulcanus* Perkins, 1900, respectively. The known host plant genera for *X. dubiosus* (a species also recorded from the islands of O’ahu, Moloka’i, Lana’i, and Maui) occurring at Pu’u Wa’awa’a are *Coprosma*, *Perrottetia* Kunth (Dipentodontaceae), *Pipturus* Wedd. (Urticaceae), and *Psychotria* Linnaeus, whereas *X. nubilus* (a Hawai‘i Island endemic bark beetle) has only been associated with *Myrsine*, also present at the site (Samuelson 1981; Griffin 2003).

Many of these native plants are likely to be more abun-

dant in, or restricted to, the upper, more humid forest in Pu'u Wa'awa'a, which is best conserved within the Forest Bird Sanctuary, where we did not sample. Other recent surveys in similar, well-preserved Hawaiian rain forests, have resulted in interesting and surprising bark beetle discoveries (e.g. Gillett 2018; Gillett et al. 2019), and consequently we have identified the Forest Bird Sanctuary as an important area for potential future surveys.

Xylosandrus crassiusculus, originally a native of tropical Asia, and now a widespread pantropical adventive species, dominated our trap catches, representing 91% of specimens collected. This species appears to be extremely widespread in forest biotopes in Hawai'i, as we have encountered it in almost every forest we have sampled so far across five islands (unpublished data). It appears to be more abundant in higher and more humid forests, with 97% of the specimens trapped at Pu'u Wa'awa'a having been trapped in the uppermost traps, deployed above 1200 m in mesic koa-dominated forest.

Given the extensive presence of 'ōhi'a trees at Pu'u Wa'awa'a, it is important to point out that frass produced by *Xyleborus ferrugineus*, one of the newly recorded exotic xyleborine species, has very recently been found to be able to contain and to release into the environment *Ceratocystis lukuohia* (Barnes et al. 2018), a fungus in the family Ceratocystidaceae, that is a causative agent of Rapid 'Ōhi'a Death (Roy et al. 2018). *Xyleborus ferrugineus* was only collected in our lowest trap, deployed at 700 m in open 'ōhi'a forest.

The finding of *H. hampei* at Pu'u Wa'awa'a is also worth highlighting, even if it is perhaps not surprising, given the site's relative proximity to coffee-growing areas in Kona, where the species is a pest. Despite this, during our sampling the species was only encountered in the upper two traps, deployed above 1200 m. It is possible that forest populations of this species may serve as reservoirs for lowland populations in Kona.

In summary, we have demonstrated the presence of native bark beetle species in Pu'u Wa'awa'a, serving as an example of the importance of the site for insect conservation in Hawai'i. Further surveys, especially in the more stringently protected bird sanctuary area of the reserve, mostly composed of native mesic forest, should now be undertaken to further explore the bark beetle diversity in Pu'u Wa'awa'a. Less agreeably, we have also brought to attention the presence there of both the coffee berry borer and exotic bark beetle species recently associated with Rapid 'Ōhi'a Death, highlighting the importance of faunal surveys in the detection of actual or potential pest species.

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References

Barnes I., Fourie A, Wingfield M.J., Harrington T.C., McNew D.L., Sugiyama L.S., Luiz B.C., Heller W.P., Keith L.M. 2018. New *Ceratocystis* species associated with rapid death of *Metrosideros polymorpha* in Hawai'i. Persoonia, 40: 154–181, DOI: 10.3767/persoonia.2018.40.07

Bishop Museum. 2018. Hawaiian Arthropod Checklist. Available on-line at: http://hbs.bishopmuseum.org/checklist/query.asp?grp=Arthropod

Burbano E., Wright M., Bright D., Vega, F.E. 2011. New record for the coffee berry borer, *Hypothenemus hampei*, in Hawaii. Journal of Insect Science, 11: 117, DOI: 10.1673/031.011.11701

Cognato A.I., Rubinoff D. 2008. New Exotic Ambrosia Beetles Found in Hawaii (Curculionidae: Scolytinae: Xyleborina). Coleopterists Bulletin, 62: 421–424.

Cognato A.I., Jordal B.H., Rubinoff D. 2018. Ancient wanderlust leads to diversification of endemic Hawaiian *Xyleborus* species (Coleoptera: Curculionidae: Scolytinae). Insect Systematics and Diversity. 2: 1–9, DOI: 10.1649/1084.1

Giffin J. 2003. Pu'u Wa'awa'a biological assessment. Available on-line at: https://www.fs.fed.us/psw/ef/hawaii/documents/PWW_biol_assessment.pdf

Gillett C.P.D.T., Pulakkatu-thodi I., Rubinoff D. 2018. Rediscovery of an enigmatic bark beetle endemic to the Hawaiian Islands (Coleoptera: Curculionidae: Scolytinae). Coleopterists Bulletin, 72: 811–815.

Gillett C.P.D.T., Honsberger D., Rubinoff D. 2019. Rediscovery of the Hawaiian endemic bark beetle *Xyleborus pleiades* Samuleson, 1981 on Moloka'i, with records of three new exotic bark beetles for the island (Coleoptera: Curculionidae: Scolytinae: Xyleborini). Journal of Natural History, 53: 1481-1490.

Gomez D.F., Rabaglia R.J., Fairbanks K.E.O, Hulcr J. 2018. North American Xyleborini north of Mexico: a review and key to genera and species (Coleoptera, Curculionidae, Scolytinae). Zookeys, 768: 19–68, DOI: 10.3897/zookeys.768.24697

Gressitt J.L., Davis C.J. 1969. Studies in the Plagithmysines, endemic Hawaiian Cerambycidae (Coleopt.). Proceedings of the Hawaiian Entomological Society, 20: 331–393, DOI: hdl.handle.net/10125/10964

Haack R.A., Rabaglia R.J. 2013. Exotic bark and ambrosia beetles in the USA: potential and current invaders, pp. 48–74. In: Peña J. (ed.), Potential invasive pests of agricultural crops. CAB International.

Howarth F.G., Mull W.P. 1992. Hawaiian insects and their kin. University of Hawai‘i Press, Honolulu, 160 pp.

Jamieson D., Denny J. 2001. Hawaii’s butterflies and moths. Mutual Publishing, Honolulu, 112 pp.

Kirkendall L.R., Biedermann P.H., Jordal B.H. 2015. Evolution and diversity of bark and ambrosia beetles, pp. 85–156. In: Vega F.E., Hofstetter R.W. (eds), Bark beetles: biology and ecology of native and invasive species. Academic Press.

Medeiros M.J., Eiben J.A., Haines W.P., Kaholoaa R.L., King C.B.A., Krushelnycky P.D., Magnacca K.N., Rubinoff D., Starr F., Starr K. 2013. The importance of insect monitoring to conservation actions in Hawaii. Proceedings of the Hawaiian Entomological Society, 45: 149–166, DOI: hdl.handle.net/10125/31012

Mortenson L.A., Hughes R.F., Friday J.B., Keith L.M., Barbosa J.M., Friday N.J., Liu Z., Sowards T.G. 2016. Assessing spatial distribution, stand impacts and rate of *Ceratocystis fimbriata* induced ‘ōhi’a (*Metrosideros polymorpha*) mortality in a tropical wet forest, Hawai‘i Island, USA. Forest Ecology and Management, 377: 83-92, DOI: 10.1016/j.foreco.2016.06.026

Nishida G. 2002. Hawaiian terrestrial arthropod checklist, fourth edition. Bishop Museum Technical Report, 22: 1–313.

Olson S., James H. 1982. Fossil birds from the Hawaiian Islands: evidence for wholesale extinction by man before western contact, Science 217: 633-635, DOI: 10.1126/science.217.4560.633

Roy K., Ewing C.P., Hughes M.A., Keith L., Bennett G.M. 2018. Presence and viability of *Ceratocystis lukuohia* in ambrosia beetle frass from Rapid ‘Ōhi‘a Death-affected *Metrosideros polymorpha* trees on Hawai‘i Island. Forest Pathology, DOI:10.1111/efp.12476

Rubinoff D. 2007. Circling the wagons: agriculturalists and conservation biologists must cooperate to protect endemic Hawaiian invertebrate diversity and control invasive species. Proceedings of the Hawaiian Entomological Society, 39: 63-67, DOI: hdl.handle.net/10125/484

Samuelson G. A. 1981. A synopsis of Hawaiian Xyleborini (Coleoptera: Scolytidae). Pacific Insects, 23: 50–92.

Wood S.L., Bright D. 1992. A catalog of Scolytidae and Platypodidae (Coleoptera). Part 2: Taxonomic index. Great Basin Naturalist Memoirs, 13: 1–1553.