

# Small survivors: unexpected endemic diversity of *Hyposmocoma* (Lepidoptera: Cosmopterigidae) moths on Kaho‘olawe, a degraded Hawaiian island

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The island of Kaho‘olawe is one of the smallest and youngest Hawaiian Islands, and has suffered severe ecological damage. Restoration efforts are underway, yet little is known of what endemic arthropod fauna may exist on the island. We surveyed for moths in the megadiverse endemic radiation *Hyposmocoma*, and herein describe nine new species: *Hyposmocoma anoai* sp. nov., *Hyposmocoma hooilo* sp. nov., *Hyposmocoma kamaula* sp. nov., *Hyposmocoma kanaloa* sp. nov., *Hyposmocoma mahoepo* sp. nov., *Hyposmocoma nohomeha* sp. nov., *Hyposmocoma oolea* sp. nov., *Hyposmocoma pahanalo* sp. nov., and *Hyposmocoma waauihi* sp. nov. Although we did not collect larvae for many of these species, placement into a larger phylogeny of the group allows us to predict larval case types, and ecology. These species are remarkable in that they have persisted despite overgrazing, burning, ordinance explosion, and subsequent erosion and loss of most native vegetation on the island, and provide hope that other endemic insect species persist on Kaho‘olawe as well.

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## INTRODUCTION

Understanding and explaining patterns of species diversity and endemism are central tenants of the field of biogeography. The discrete spatial nature of islands makes them particularly well suited for biogeographical research, and volcanic islands provide special opportunities to examine the effects of area and age on the process of diversification (Bess, Catanach, & Johnson, 2014; Warren *et al.*, 2015). Broadly speaking, younger and smaller islands are expected to have lower levels of endemism and diversity than older and larger ones. This

pattern has been used to support mainland conservation planning favouring fewer, larger reserves for maintaining biodiversity, even for insects (e.g. Tscharrntke *et al.*, 2002). Further, areas that have suffered severe degradation are often considered the lowest priorities for inclusion in reserve planning.

The Hawaiian Islands are a widely cited model for biogeographical studies, yet almost all of that research has focused on the largest islands in the archipelago (e.g. Baldwin & Sanderson, 1998; Lerner *et al.*, 2011; Medeiros & Gillespie, 2011; Obbard *et al.*, 2012; Haines, Schmitz, & Rubinoff, 2014), although several species have been described from the tiny, remote, and arid north-western Hawaiian islands (Schmitz & Rubinoff, 2009). The island of Kaho‘olawe is one of the smallest of the main islands, at only 11 650 hectares. It has also suffered the most severe degradation of any Hawaiian island as a result of its arid climate

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paired with over a century of overgrazing by goats, and its use as a bombing range for the US military from World War II until the early 1990s (Kaho olawe Island Reserve Commission, <http://kahoolawe.hawaii.gov/history.shtml>). The combination of its very small size and arid climate would suggest that it supported an impoverished native fauna prior to human settlement, and that little or no endemic biodiversity may remain after its history of extensive anthropogenic disturbance. Understanding the level of diversity and the phylogenetic relationships on such an island would inform not only evolutionists concerned with the generation of endemic diversity on smaller, apparently lower diversity landmasses, but also those that seek to estimate the conservation value of degraded landscapes. The extended military occupation and use of Kaho'olawe as a bombing range left behind many unexploded ordinances making it an extremely hazardous environment; the island has been virtually unavailable to research until the past decade when ownership was transferred from the military to the State of Hawai'i.

The endemic Hawaiian moth genus *Hyposmocoma* Butler, 1881, is one of the most widespread and diverse lineages in the archipelago, with species occurring from sea level to over 3000 m elevation, and essentially 100% of these species being single-island endemics. Precious few island-endemic animals or plants have been found on Kaho'olawe [but see Lorence & Wood (1994) for a new genus within the plant family Fabaceae and Medeiros & Adamski (2012) for three new species of Lepidoptera]; thus, our recent surveys of the diversity of *Hyposmocoma* on Kaho'olawe might provide important information concerning the potential for such a small island to generate and maintain endemic diversity in the face of wholesale ecological destruction. As we know the ecological roles of *Hyposmocoma* species based on their larval case types, we can use the presence of species on Kaho'olawe as an indicator of which kinds of microhabitats still occur on the island – even when collecting adult moths. This information may be used to guide future surveys to locate those microhabitats that may harbour additional cryptic taxa that are not as well known as *Hyposmocoma*. Knowledge of the evolution of endemic *Hyposmocoma* species on Kaho'olawe will not only be important in understanding the evolution of this ultra-diverse lineage across the archipelago (e.g. Haines *et al.*, 2014), but also in assessing whether Kaho'olawe might still harbour endemic species in other cryptic arthropod groups. Perhaps more importantly, such data could guide conservation efforts by indicating how and where endemic species might have survived centuries of severe habitat alteration. Results from such research on a small, heavily impacted island could be directly translated to other regions where areas

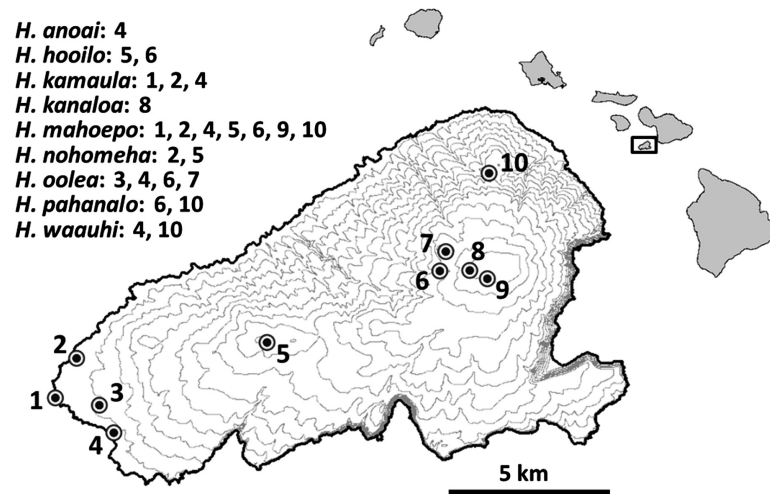
that are considered 'lost causes' might still hold promise, such as small patches of degraded habitat fragmented by development in urban areas.

## MATERIAL AND METHODS

Adult moth specimens were collected from sites around Kaho'olawe (Fig. 1) using UV lights (unless otherwise noted) over several nights in October 2008 (Medeiros), July 2011 (Medeiros), and March 2013 (Haines & Rubinoff). We also searched intensively for case-making larvae in March 2013, and attempted to rear them in the laboratory. Legs of adult moths were preserved in 95% ethanol for DNA extraction. Genitalia were prepared and mounted on slides using the following protocol: abdomens were soaked in simmering 10% KOH solution for 1 h, genitalia were removed, stained with lignin pink and chlorazol black, soaked in a sequence of 30% ethyl alcohol, 90% ethyl alcohol, 100% isopropyl alcohol, and Euparal essence (Bioquip, Rancho Dominguez, CA, USA), then spread on microscope slides and mounted in Euparal. Digital photographs were taken using an Olympus Q-Color3 camera mounted on an Olympus SZX10 light microscope.

DNA was extracted from the legs of field-caught and loaned specimens using the standard protocol described in Qiagen's (Valencia, CA, USA) DNeasy kits. Using PCR, we amplified fragments of four nuclear genes (elongation factor 1-a, carbamoyl-phosphate synthetase 2, aspartate transcarbamylase, and dihydroorotase, **malate dehydrogenase**, and ribosomal protein S5) and one mitochondrial gene (cytochrome oxidase 1). Primers and their annealing temperatures are listed in Appendix 1. Thermal profiles for PCR began with denaturation at 95 °C (2 min), followed by 35 cycles of denaturation at 95 °C (1 min), an annealing step (1 min), and elongation at 72 °C (1 min). Cycles were followed by a final extension step at 72 °C (12 min). Amplified PCR products were purified using the QIAquick PCR Purification Kit (Qiagen) and run on an ABI Prism 377 XL automated DNA sequencer. The final data set consisted of a total of 3993 bp, including the mitochondrial gene *CO1* (1422 bp) and the nuclear genes *EF-1α* (771 bp), *CAD* (705 bp), *MDH* (498 bp), and *RpS5* (597 bp).

New sequences from Kaho'olawe *Hyposmocoma* were added to many additional sequences of *Hyposmocoma* representing a diversity of larval case types and islands that had previously been published in Haines *et al.* (2014). The concatenated data matrix had 164 taxa and 3993 characters (see Appendix 2 for GenBank accession codes and for specimens with incomplete coverage in terms of the five gene regions used in this study). We used MrBayes 3.2.5



**Figure 1.** Map of collection sites on Kaho'olawe: (1) Kealaikahiki, (2) Kaukaukapapa, (3) drainage near Honokanai'a, (4) Honokanai'a base camp, (5) Keāliialalo, (6) Kaukamoku gulch, (7) base of Pu'u o Moa'ula Iki, (8) old *Erythrina* tree at Pu'u o Moa'ula Nui, (9) planting site Pu'u o Moa'ula Nui, and (10) planting area at Hakioawa. The Hawaiian Islands are shown in grey in the upper right (boxed area contains Kaho'olawe).

(Ronquist *et al.*, 2012) to conduct our final phylogenetic analysis. First, we selected the best model of molecular evolution for each of our three codon positions for each of the two gene types (mtDNA or nDNA, for a total of six partitions), using PartitionFinder v. 1.1.1 optimized for the Akaike information criterion (Lanfear *et al.*, 2014). Models for each codon position were symmetrical model + proportion of invariable sites + gamma distribution, general time reversible + I + G, and GTR + I + G for mtDNA and GTR + I + G, Hasegawa-Kishino-Yano + I + G, and GTR + I + G for nDNA. We ran two sets of four chains simultaneously, for 10 000 000 generations each, with a tree sampled every 1000 generations. A plot of tree likelihood vs. generation number reached stationarity after c. 100 000 generations, and we discarded these trees as 'burn-in'. We then computed a consensus tree with the remaining trees; posterior probabilities for each clade were based on the proportion of trees in which that particular clade occurred. We viewed and edited the final tree estimate with FigTree 1.4.2 (<http://tree.bio.ed.ac.uk/software/figtree/>).

## RESULTS

### PHYLOGENY

Bayesian analysis yielded a phylogeny (Fig. 2) that confirms the presence of at least nine *Hyposmocoma* species endemic to the island, all of which are new to science.

Although only two species were reared from larvae, phylogenetic data placed the adults that we

collected within species groups for which case types were known from rearing on other islands, and thus we hypothesized their ecologies based on sister-taxa relationships. For the two species that we did collect as larvae (see below), case type agreed with what would have been extrapolated based on the topology of the tree (Fig. 2).

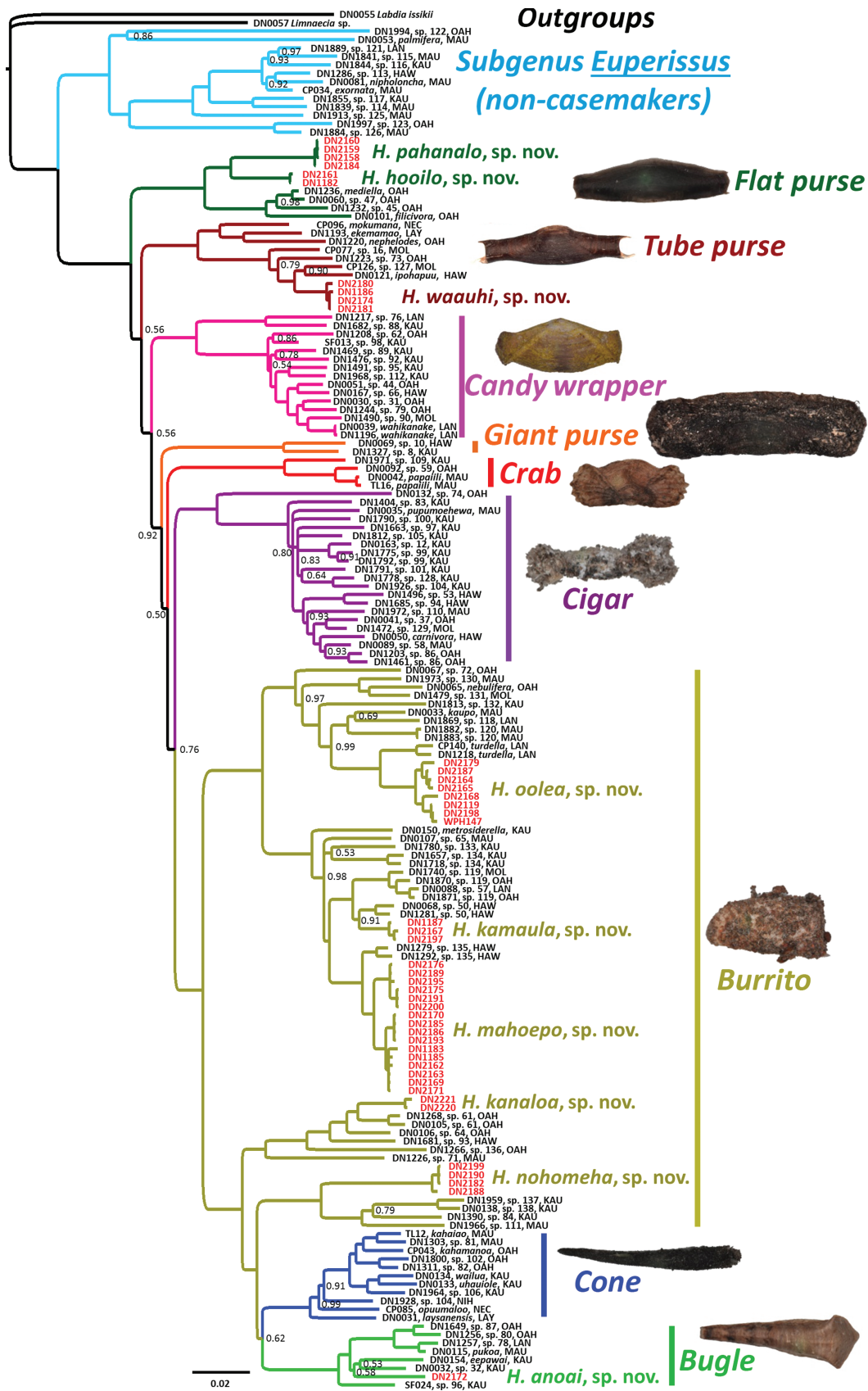
Adults from the other species fell within well-supported species groups for which case types were known from rearing on other islands. Thus we could infer case types and basic larval ecology from sister-taxa relationships.

Please note the following: diagnoses of each species are in comparison to morphologically similar Kaho'olawe species, regardless of phylogenetic placement, to aid in rapid identification. When referring to 'left' and 'right' when describing male genitalia, to minimize confusion, we are referring to their orientation on the figures as they are illustrated, not necessarily the sides that these structures would be on if the genitalia were *in situ*. All specimens are deposited in the University of Hawai'i Insect Museum (Mānoa, HI, USA) except for several paratypes of *Hyposmocoma mahoepo* that are deposited at the B.P. Bishop Museum (Honolulu, HI, USA).

### TAXONOMY

#### *HYPSMOCOMA ANOAI* MEDEIROS, HAINES & RUBINOFF SP. NOV. (FIGS 3A, 4A)

*Material examined:* HOLOTYPE: ♂: HI, Kaho'olawe, Honokanai'a camp. 20°30'54"N, 156°40'56"W. 5.iii.



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**Figure 2.** Bayesian phylogeny of Kaho'olawe *Hyposmocoma*, with selected *Hyposmocoma* from other islands, and of various case types, included. See Material and methods for details about tree construction. Branches coloured using the same case type colour scheme as in Haines *et al.* (2014). Within the ingroup, posterior probabilities are only labelled when values were < 1, and are not labelled for relationships amongst individuals within species. Scale bar indicates substitutions per site. New taxa from Kaho'olawe have extraction codes in red.

2013. W. Haines & D. Rubinoff, WHP055-13. DNA extraction DN2172. (UHIM).

**Diagnosis:** A Kaho'olawe *Hyposmocoma* species with male genitalia similar to *Hyposmocoma pahanalo* in terms of having nearly symmetrical valvae and spur-like setae that are hugely larger on the left valva as compared to the right, but without the nearly square bend of the valvae seen in *H. pahanalo*. The only Kaho'olawe species with a single band of dark scales extending from base to apex of forewing.

**Description:** ( $N = 1$ ) (Fig. 3A). Wingspan 9.2 mm. Head pale brown. Haustellum with beige scales. Maxillary palpus reduced. Recurved labial palpus pale brown with some darker scales scattered throughout. Antennal flagellomeres with alternating rings of dark and pale brown scales; scape dark brown; pecten absent. Thorax, tegula, and metascutellum pale brown. Foreleg coxa very pale brown; femur, tibia, and tarsomeres mostly dark brown with some lighter scales scattered throughout. Midleg as foreleg, except tarsomeres missing from specimen. Hindleg entirely very pale brown. Forewing ground colour very pale brown, with slightly darker scales near the costal margin; rough band of dark brown scales extending from base to apex with band closer to costal margin starting halfway along length of wing; fringe short and brown. Hindwing and fringe uniformly pale brown. Subcostal brush absent. Abdomen mounted on slide. Sclerotized hook (pseuduncus *sensu* Zimmerman, 1978) elongate, recurved, with blunt apex; distinct sclerotized ring on segment VII.

**Male genitalia:** ( $N = 1$ ) (Fig. 4A). Valvae roughly symmetrical, both with long and slender arms, enlarged apically, bent approximately 30° upward in the middle, with two heavy, sclerotized spur-like setae projecting dorsally near apex of left valva, and two much smaller and shorter, sclerotized spur-like setae on right valva; setae on left valva at least six times length of those on right. Anellus with two apically enlarged, asymmetrical lobes, left lobe being more robust generally, and more apically enlarged than right lobe. Phallus large, cylindrical, heavily sclerotized, curved near apex.

**Female genitalia:** Unknown.

**Etymology:** *Hyposmocoma anoai*, from the Hawaiian 'ano'ai (unexpected). We did not expect to find a representative of this predominantly aquatic or forest clade on Kaho'olawe.

**Biology:** Based on its position in the phylogenetic tree, we expect the larvae of *H. anoai* to construct 'bugle' case types, based on its being sister to another clade that makes this case type. This species is a member of a clade usually associated with streams or forests, neither of which are currently common on Kaho'olawe.

**Distribution:** Known only from Kaho'olawe Island, Hawai'i, where it is presumed to be endemic.

**Remarks:** This species is known only from the male holotype; the female of this species is unknown. We anticipate that the larvae will be found on woody vegetation.

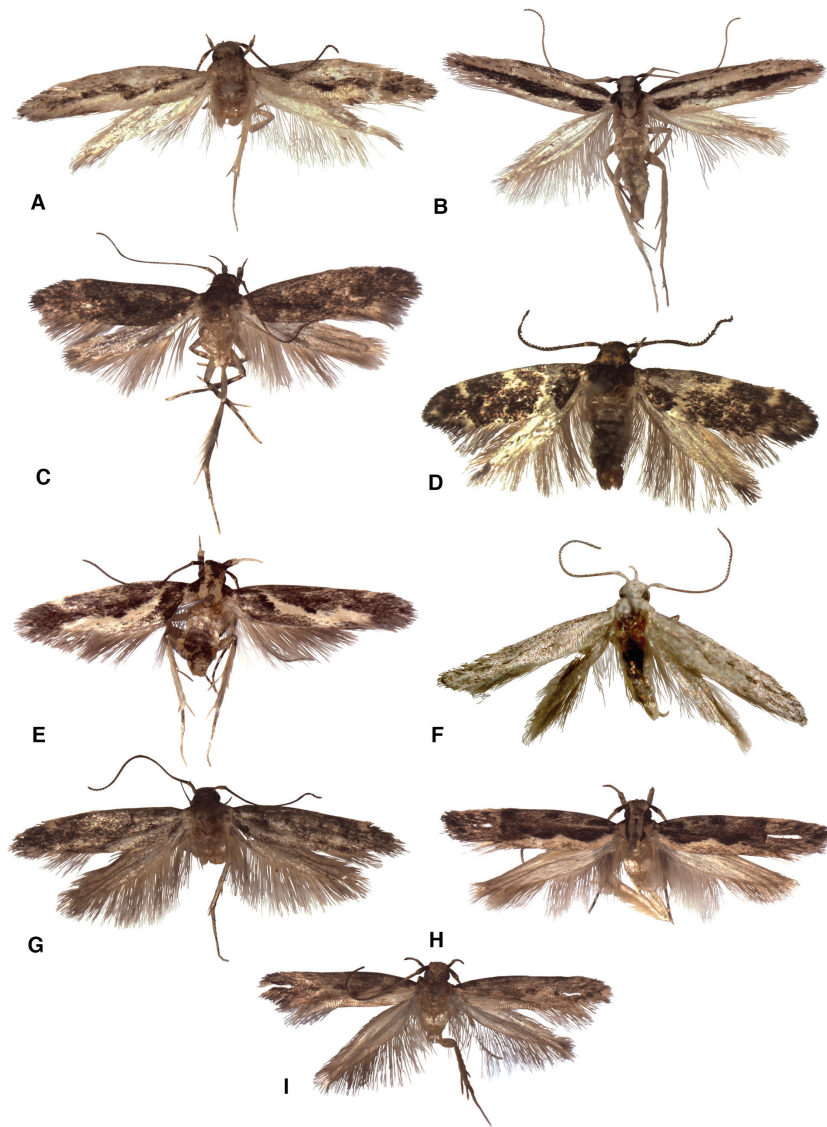
***HYPSMOCOMA HOOILO* MEDEIROS, HAINES & RUBINOFF SP. NOV. (FIGS 3B, 4B, 5A)**

**Material examined:** HOLOTYPE: HI: Kaho'olawe: Kaukamoku gulch, 20°33'33"N, 156°35'13"W. ♂, 7.iii.2013, W. Haines & D. Rubinoff, WPH040-13, DNA extraction 2159, slide WPH040-13 ♂.

PARATYPES: HI: Kaho'olawe: Kaukamoku gulch, 20°33'33"N, 156°35'13"W. 2 ♂, 2 ♀, 7.iii.2013, W. Haines & D. Rubinoff, WPH041-13, DNA extraction 2160; WPH043-13; WPH039-13, DNA extraction DN2158, slide WPH039-13 ♀; WPH042-13, slide WPH042-13 ♀. Kealialalo, 20°32'23"N, 156°38'15"W. 1 ♂, 5.iii.2013, W. Haines & D. Rubinoff, WPH078-13, DNA extraction DN2184.

**Diagnosis:** The only Kaho'olawe *Hyposmocoma* with the apically enlarged left anellus lobe of the male genitalia being notched, and with two distinct dark bands extending nearly parallel along the forewing.

**Description:** ( $N = 6$ ) (Fig. 3B). Wingspan 11.3–14.0 mm. Head very pale brown. Haustellum with very pale brown scales. Maxillary palpus reduced. Recurved labial palpus very light pale brown along third segment, and distal half of second segment; base of second segment dark brown. Antennal

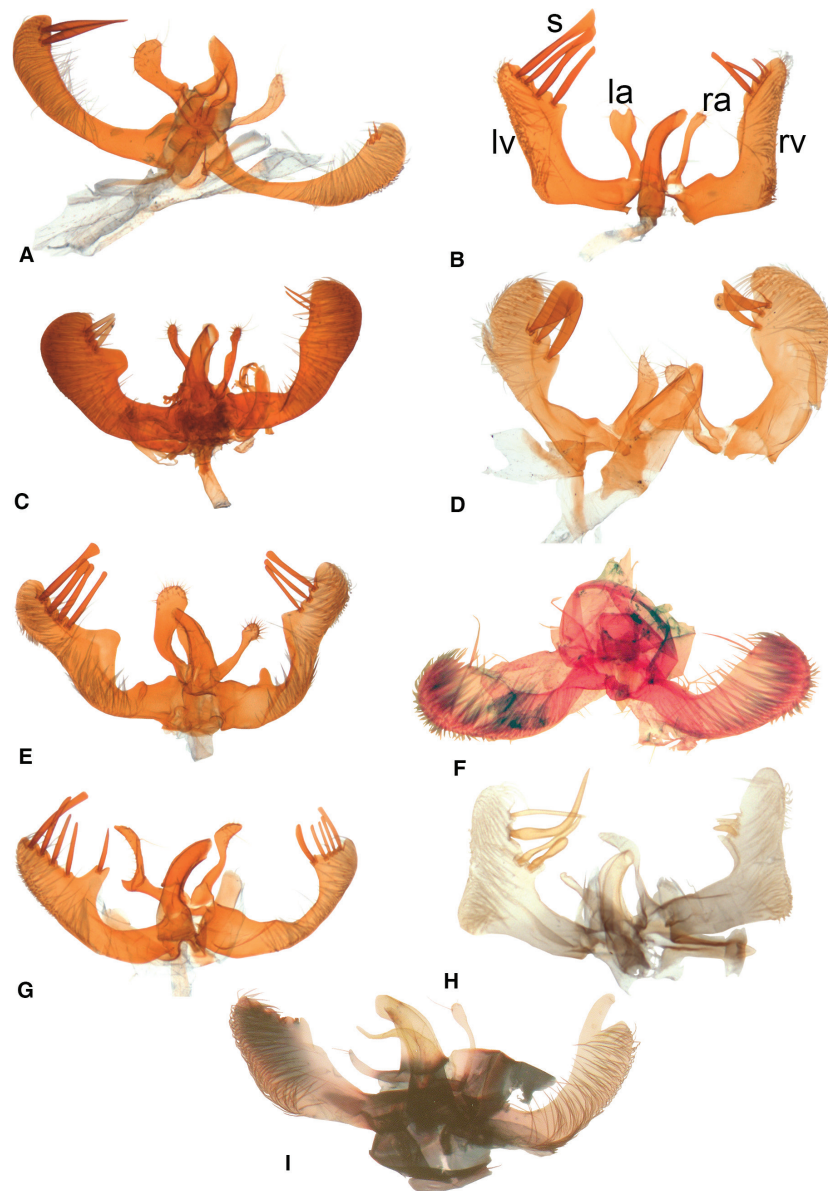


**Figure 3.** Adult *Hypsmocoma*. A, *Hypsmocoma anoai* sp. nov., holotype ♂, forewing = 4.5 mm; B, *Hypsmocoma hooilo* sp. nov., paratype ♀, forewing = 5.8 mm; C, *Hypsmocoma kamaula* sp. nov., paratype ♀, forewing = 4.5 mm; D, *Hypsmocoma kanaloa* sp. nov., holotype ♂, forewing = 3.2 mm; E, *Hypsmocoma mahoepe* sp. nov., paratype ♂, forewing = 5.6 mm; F, *Hypsmocoma nohomeha* sp. nov., holotype ♂, forewing = 4.3 mm; G, *Hypsmocoma oolea* sp. nov., holotype ♂, forewing = 5.0 mm; H, *Hypsmocoma pahanalo* sp. nov., holotype ♂, forewing = 5.8 mm; I, *Hypsmocoma waauihi* sp. nov., paratype ♂, forewing = 4.5 mm.

flagellomeres very pale brown; scape dark brown. Thorax, tegula, and metascutellum pale brown dorsally, dark brown along sides; abdomen nearly white. Foreleg brown with rings of lighter scales at distal end of each segment. Midleg and hindleg almost entirely nearly white, with some dark scales present on femur. Forewing ground colour pale brown, with very dark brown band extending from base of wing to termen; additional dark brown scales in thin band along costal margin; fringe pale brown. Hindwing and fringe pale brown with several brown

scales clustered near tip. Subcostal brush absent. Sclerotized hook (pseuduncus *sensu* Zimmerman, 1978) elongate, slightly curved, slender; distinct sclerotized ring on segment VII. Females similar to males except frenulum with three acanthae.

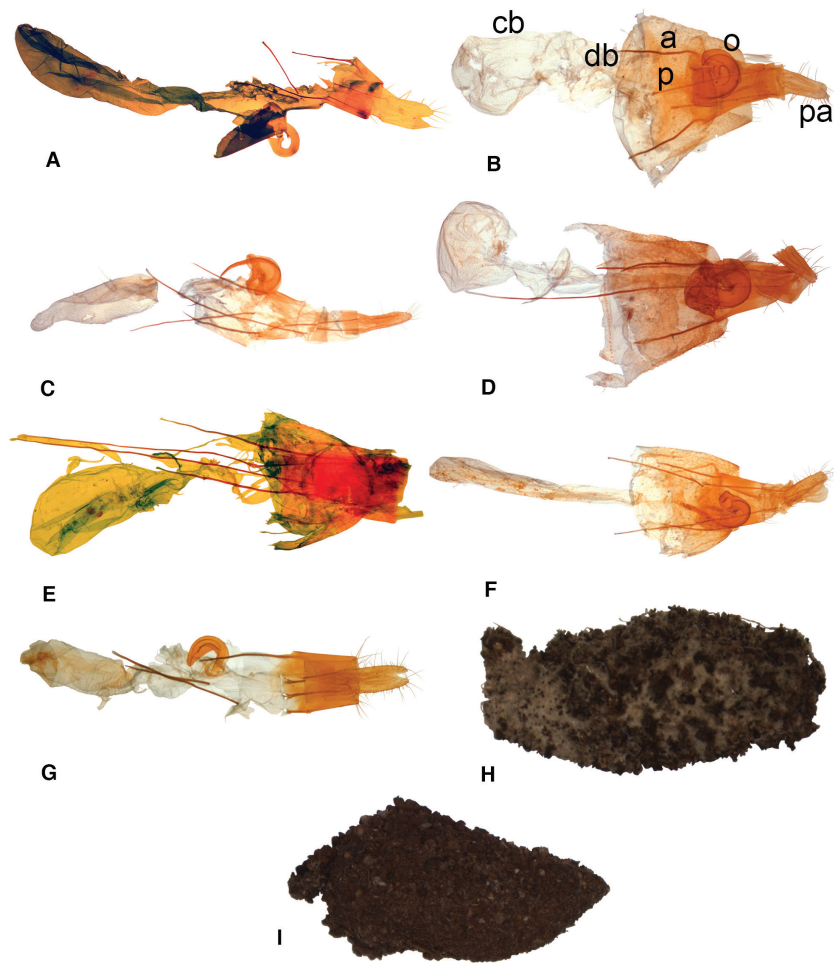
*Male genitalia:* ( $N = 1$ ) (Fig. 4B). Valvae roughly symmetrical, both with long and somewhat robust arms, although left valva slightly larger than right. Both valvae bent nearly 90° upward in the middle, with four heavy, long, sclerotized spur-like setae projecting dorsally near apex of left valva, the



**Figure 4.** Male genitalia of *Hyposmocoma*. A, *Hyposmocoma anoai* sp. nov., slide WPH055-13; B, *Hyposmocoma hooilo* sp. nov., slide WPH040-13; C, *Hyposmocoma kamaula* sp. nov., slide WPH095-13; D, *Hyposmocoma kanaloa* sp. nov., slide WPH122-13; E, *Hyposmocoma mahoepe* sp. nov., slide 11A02; F, *Hyposmocoma nohomeha* sp. nov., slide WPH084-13; G, *Hyposmocoma oolea* sp. nov., slide WPH047-13; H, *Hyposmocoma pahanalo* sp. nov., slide 08A42; I, *Hyposmocoma waauhi* sp. nov., slide WPH074-13. Abbreviations: la, left anellus lobe; lv, left valva; ra, right anellus lobe; rv, right valva; s, setae.

largest between two and four times the length of the longest setae on the right valva; right valva with four smaller setae near apex, the two most apical setae quite small. Apices of both valvae somewhat pointed and triangular. Anellus with two asymmetrical lobes; left lobe with rounded and notched apex, right lobe slender along entire length. Phallus large, cylindrical, heavily sclerotized, curved near apex.

*Female genitalia:* ( $N = 2$ ) (Fig. 5A). Papillae anales short. Apophyses thin and straight; posterior apophyses very long, about two times length of anterior apophyses. Ostium-bearing process heavily sclerotized and very large, externally protruding, snail-shell shaped and curled, with broad base. Ductus bursae long, about two times length of anterior apophysis. Corpus bursae oval, about  $2.5 \times$  length of anterior apophysis; signum absent. Inception of



**Figure 5.** Female genitalia and larval cases of *Hyposmocoma*. A, *Hyposmocoma hooilo* sp. nov., slide WPH042-13; B, *Hyposmocoma kamaula* sp. nov., slide WPH050-13; C, *Hyposmocoma kanaloa* sp. nov., slide WPH123-13; D, *Hyposmocoma mahoepo* sp. nov., slide WPH053-13; E, *Hyposmocoma nohomeha* sp. nov., slide WPH076-13; F, *Hyposmocoma oolea* sp. nov., slide WPH048-13; G, *Hyposmocoma pahanalo* sp. nov., slide WPH044-13; H, *Hyposmocoma kanaloa* sp. nov., larval case, dorsal view, length = 4 mm; I, *Hyposmocoma oolea* sp. nov., larval case, dorsal view, length = 6 mm. Abbreviations: a, anterior apophysis; cb, corpus bursa; db, ductus bursa; o, ostium-bearing process; p, posterior apophysis; pa, papillae anales.

ductus seminalis situated at posterior end of corpus bursae.

**Etymology:** *Hyposmocoma hooilo*, from the Hawaiian ho'oilō (to sprout/winter season of regrowth), so named because the presumed larval case of this species resembles a seed, and Kaho'olawe is recovering in response to ecological restoration efforts.

**Biology:** Based on its position in the phylogenetic tree, we expect larvae of *H. hooilo* to construct 'flat purse' case types, based on the sister clade that makes this case type. Flat purses seem to have

survived on all the islands, even Laysan Atoll in the far north-west, suggesting a tolerance for dry, flat habitats. It is possible that this larva is a scavenger.

**Distribution:** Known only from Kaho'olawe Island, Hawai'i, where it is presumed to be endemic.

***HYOSMOCOMA KAMAULA* MEDEIROS, HAINES & RUBINOFF SP. NOV. (FIGS 3C, 4C, 5B)**

**Material examined:** HOLOTYPE: HI: Kaho'olawe: Kaukaupapa, 20°32'7"N, 156°41'36"W. ♀, 5.iii.2013,



W. Haines & D. Rubinoff, WPH096-13, DNA extraction DN2198.

PARATYPES: HI: Kaho'olawe: Honokanai'a camp, 20°30'54"N, 156°40'56"W. 1 ♀, 5.iii.2013, W. Haines & D. Rubinoff, WPH050-13, DNA extraction DN2167, slide WPH050-13♀. Kaukaupapa, 20°32'7"N, 156°41'36"W. 1 ♂, 5.iii.2013, W. Haines & D. Rubinoff, WPH095-13, DNA extraction DN2197, slide WPH095-13♂. Kealaikahiki, Keanakeiki beach. 1 ♂, 2 ♀, 21.x.2008, M. J. Medeiros, slide 08A53♀ (two specimens missing abdomens).

*Diagnosis:* Of all the Kaho'olawe *Hyposmocoma* with a large lateral lobe on the valvae – in this case, the left valva – this species has the most robust valvae. Other species with prominent lateral lobes such as this have less robust valvae, including *H. mahoepo* and *Hyposmocoma oolea*. Forewing pattern is very similar to *H. oolea* and *Hyposmocoma waauhi* in being mostly brown with irregular darker spots and so the male genitalia are required to diagnose this species.

*Description:* ( $N = 6$ ) (Fig. 3C). Wingspan 9.5–12.5 mm. Head brown. Haustellum with nearly white scales. Maxillary palpus reduced. Recurved labial palpus dark brown with some white scattered throughout, especially on second segment. Antennal flagellomeres dark brown; pecten present near base; scape brown; pecten present. Thorax, tegula, metascutellum, and abdomen brown. Coxa, femur, tibia, and tarsomeres of all legs mostly dark brown with some lighter scales scattered throughout, especially as rings along tarsomeres. Forewing mostly dark brown, with light brown scales scattered throughout; one or more black postmedial spots present, fringe brown. Hindwing and fringe uniformly light brown. Subcostal brush present. Sclerotized hook (pseuduncus *sensu* Zimmerman, 1978) elongate and slightly curved; distinct sclerotized ring on segment VII. Females similar to males except frenulum with three acanthae and antennae slightly thinner than those of males.

*Male genitalia:* ( $N = 1$ ) (Fig. 4C). Valvae roughly symmetrical, both with long and somewhat robust arms, slightly enlarged apically, bent nearly 90° upward in the middle, with three heavy, short, sclerotized spur-like setae projecting dorsally near apex of left valva, and two much thinner, sclerotized spur-like setae of similar length on right valva. Left valva with a large lateral lobe, dorsal and caudal to the setae; right valva with much smaller lobe. Anellus with two roughly symmetrical lobes, each slightly apically enlarged and surrounded with setae. Phallus large, cylindrical, heavily sclerotized, curved near apex.

*Female genitalia:* ( $N = 2$ ) Fig. 5B). Papillae anales short. Apophyses thin and straight; posterior apophyses very long, about two times length of anterior apophyses (broken in illustration). Ostium-bearing process heavily sclerotized and very large, externally protruding, snail-shell shaped and curled, with broad base. Ductus bursae long, about same length as anterior apophysis. Corpus bursae oval, about same length as anterior apophysis; signum absent. Inception of ductus seminalis situated at posterior end of corpus bursae.

*Etymology:* *Hyposmocoma kamaula*, or 'ghost child', from the Hawaiian kama (child) and 'ula (ghost/spirit). This species is so named because despite our collecting efforts, we have not found the caterpillars for this species.

*Biology:* Based on its position in the phylogenetic tree, we expect larvae of *H. kamaula* to construct 'burrito' case types, based on its being sister to another clade that makes this case type. The phylogeny also suggests that it is a lichen feeder. This species was collected only in light traps from near sea level.

*Distribution:* Known only from Kaho'olawe Island, Hawai'i, where it is presumed to be endemic.

*Remarks:* We have designated a female holotype because the male used in the genitalia illustration has wings in very poor condition, and the other specimens in the type series either have missing abdomens or are females; this specimen is fully intact and the wings are not rubbed.

***HYPSMOCOMA KANALOA* MEDEIROS, HAINES & RUBINOFF SP. NOV. (FIGS 3D, 4D, 5C, H)**

*Material examined:* HOLOTYPE: HI: Kaho'olawe: Pu'u o Moa'ula Nui, 20°33'34"N, 156°34'41"W. 1 ♂, on bark of *Erythrina sandwicensis*, 'burrito' case, 6.iii.2013, emerged. 15.iii.2013, W. Haines & D. Rubinoff, WPH122-13, DNA extraction DN2220, DR13C6A, slide WPH122-13♂.

PARATYPE: HI: Kaho'olawe: Pu'u o Moa'ula Nui, 20°33'34"N, 156°34'41"W. 1 ♀, on bark of *Erythrina sandwicensis*, 'burrito' case, 6.iii.2013, em. 5.iv.2013, W. Haines & D. Rubinoff. WPH123-13, DNA extraction DN2221, DR13C6A, slide WPH123-13♀.

*Diagnosis:* This is the only Kaho'olawe *Hyposmocoma* with bands of pale scales extending fully or partially from costal margin to anal margin of forewing; most other species with bands of scales run

longitudinally along length of forewing. Although *H. oolea* and *H. waauhi* also have bands of scales orientated similarly, they are darker in colour than those of *H. kanaloa*. This species has quite robust valvae on the male genitalia, with spur-like setae that are close in size between the left and right valva; however, prominent lateral lobes on the valvae are not present as they are in *H. mahoepo* and *H. oolea*.

*Description:* ( $N = 2$ ) (Fig. 3D). Wingspan 8.0–8.2 mm. Head with both pale yellow and pale grey patches of scales. Haustellum with beige scales. Maxillary palpus reduced. Recurved labial palpus mostly pale grey with patches of nearly white scales. Antennal flagellomeres dark brown; pedicel pale brown; scape dark brown; pecten present. Thorax, tegula, and metascutellum dark grey. Legs mostly grey with numerous bands of pale yellow scales, especially at distal end of each segment. Forewings mostly grey, with several rough, wide bands of white scales extending either fully or partially from costal margin to anal margin; fringe nearly white. Hindwing and fringe uniformly pale brown. Subcostal brush absent. Abdomens mounted on slides. Sclerotized hook (pseuduncus *sensu* Zimmerman, 1978) elongate, nearly straight, apex blunt; distinct sclerotized ring on segment VII. Females similar to males except frenulum with three acanthae and antennae slightly thinner than those of males.

*Male genitalia:* ( $N = 1$ ) (Fig. 4D). Valvae roughly symmetrical, both with long arms bent nearly 90° halfway along length, enlarged and rounded apically, with three heavy, sclerotized spur-like setae projecting dorsally near apex of left valva, and three slightly smaller setae on right valva; both valvae broadly notched near apex. Anellus with two asymmetrical lobes, left lobe being robust and nearly straight, right lobe rounded apically. Phallus large, cylindrical, heavily sclerotized, curved near apex.

*Female genitalia:* ( $N = 1$ ) (Fig. 5C). Papillae anales short. Apophyses thin and straight; anterior and posterior apophyses both very long. Ostium-bearing process heavily sclerotized and very large, externally protruding, snail-shell shaped and curled, with broad base. Ductus bursae about 0.5 × length of anterior apophysis. Corpus bursae oval, about 0.75 × length of anterior apophysis; signum absent. Inception of ductus seminalis situated at posterior end of corpus bursae.

*Etymology:* *Hyposmocoma kanaloa* is named after the Hawaiian word Kanaloa, an ancient name for the presiding deity of Kaho'olawe.

*Biology:* Larvae of this species have a 'burrito' case type (Fig. 5H; Appendix 3), a brown, bag-like

structure constructed from silk, lichens, and other debris. The case tapers to a point and has a single entrance at the broader end. This species was not collected at lights, and the only known specimens were reared from case-making larvae found on bark of a very old wiliwili tree (*Erythrina sandwicensis*). There are very few 'old growth' stands of wiliwili on Kaho'olawe, although efforts are underway to restore more of this dry forest tree through extensive outplantings.

*Distribution:* Known only from Kaho'olawe Island, Hawai'i, where it is presumed to be endemic.

***HYPOSMOCOMA MAHOEPO* MEDEIROS, HAINES & RUBINOFF SP. NOV. (FIGS 3E, 4E, 5D)**

*Material examined:* HOLOTYPE: HI: Kaho'olawe: Hakioawa, D4 Planting Area. ♂, 19.vii.2011, M. J. Medeiros, slide 11A02♂.

PARATYPES: HI: Kaho'olawe: Hakioawa, Area 11. 1 ♂, 22.x.2008, M. J. Medeiros, slide 08A65♂. Hakioawa, D4 Planting Area. 1 ♂, 2 ♀, 19–20.vii.2011, M. J. Medeiros (specimens missing abdomens). Honokanai'a camp, 20°30'54"N, 156°40'56"W. 1 ♂, 4 ♀, 5.iii.2013, W. Haines & D. Rubinoff, WPH059-13, DNA extraction DN2176, slide♂ WPH059-13; WPH052-13, DNA extraction DN2169; WPH053-13, DNA extraction DN2170, slide♀ WPH053-13; WPH054-13, DNA extraction DN2171; WPH058-13, DNA extraction DN2175, slide♀ WPH058-13. Kaukamoku gulch, 20°33'33"N, 156°35'13"W. 2 ♂, 7.iii.2013, W. Haines & D. Rubinoff, WPH045-13, DNA extraction DN2162; WPH046-13, DNA extraction DN2163. Kaukaupapa, 20°32'7"N, 156°41'36"W. 2 ♀, 5.iii.2013, W. Haines & D. Rubinoff, WPH093-13, DNA extraction DN2195; WPH098-13, DNA extraction DN2200. Kealaikahiki. 1 ♀ (hand collected), 5–7.iii.2013, W. Haines & D. Rubinoff, WPH089-13, DNA extraction DN2191. Kealaikahiki, Keanakeiki beach. 3 ♂, 1 ♀, 21.x.2008, M. J. Medeiros, slides 08A49♂, 08A50♀, & 08A55♂. Keāliālalo, 20°32'23"N, 156°38'15"W. 3 ♂, 5.iii.2013, W. Haines & D. Rubinoff, WPH079-13, DNA extraction DN2185; WPH080-13, DNA extraction DN2186; WPH083-13, DNA extraction DN2189, slide WPH083-13. Pu'u o Moa'ula Nui, N20.55715 W156.57303. 1 ♂, 6.iii.2013, W. Haines & D. Rubinoff, WPH091-13, DNA extraction DN2193.

*Diagnosis:* The only Kaho'olawe *Hyposmocoma* with male genitalia having roughly symmetrical valvae, with three lobes on each dorsal edge, and robust setae on each side. The forewing pattern is similar to *H. pahanalo*, but *H. mahoepo* has a band of dark scales extending from base to anal margin, whereas

*H. pahanalo* has entirely white scales along anal margin near base.

**Description:** ( $N = 19$ ) (Fig. 3E). Wingspan 10.0–11.6 mm. Head dark brown. Haustellum with beige scales. Maxillary palpus reduced. Recurved labial palpus dark brown with some lighter scales scattered throughout, except third segment pale brown with several darker scales scattered throughout. Antennal flagellomeres with alternating rings of dark and light brown scales; scape dark brown; pecten present. Thorax pale brown, tegula, and metascutellum mostly dark brown. Coxa, femur, tibia, and tarsomeres of all legs mostly dark brown with some lighter scales scattered throughout, especially as rings along tarsomeres. Forewing ground colour pale brown; irregularly shaped band of dark brown scales extending from base to apex, sometimes approaching costa; a second band of dark brown scales extending from base to anal margin; fringe brown. Hindwing and fringe uniformly pale brown. Abdomen mottled light brown to brown. Subcostal brush present. Sclerotized hook (pseuduncus *sensu* Zimmerman, 1978) elongate, nearly straight, with a blunt apex; distinct sclerotized ring on segment VII. Females similar to males except frenulum with three acanthae and antennae slightly thinner than those of males.

**Male genitalia:** ( $N = 3$ ) (Fig. 4E). Valvae roughly symmetrical, both with long and somewhat robust arms, slightly enlarged apically, bent slightly upward in the middle, with three or four heavy, long, sclerotized spur-like setae projecting dorsally near apex of both valvae. Both valvae with a large lateral lobe, dorsal and caudal to the setae; two similarly shaped but smaller lobes near base of both valvae. Anellus with two lobes, each apically enlarged and surrounded with setae, left lobe significantly larger than right. Phallus large, cylindrical, heavily sclerotized, curved near apex.

**Female genitalia:** ( $N = 2$ ) (Fig. 5D). Papillae anales short. Apophyses thin and straight; posterior apophyses very long, about two times length of anterior apophyses. Ostium-bearing process heavily sclerotized and very large, externally protruding, snail-shell shaped and curled, with broad base. Ductus bursae long, about same length as anterior apophysis. Corpus bursae oval, about same length as anterior apophysis; signum minute and sickle shaped. Inception of ductus seminalis situated at posterior end of corpus bursae.

**Etymology:** This species is named *H. mahoepo*, or roughly 'hidden twins', from the Hawaiian mahoe (twin) and pō (obscurity); molecular data suggest that there may be two recently diverged yet cryptic species involved.

**Biology:** Based on its position in the phylogenetic tree, we expect larvae of *H. mahoepo* to construct 'burrito' case types, as it is nested within a clade that makes this case type. Further, the ecology of related taxa suggests that the larva is a lichen and detritus feeder, probably on rocks.

**Distribution:** Known only from Kaho'olawe Island, Hawai'i, where it is presumed to be endemic.

**Remarks:** This species was the most widespread and commonly collected *Hyposmocoma* on Kaho'olawe, occurring at sites across the island, from sea level to the summit (Fig. 1). Despite its abundance, it was surprisingly not reared from any of our larval collections. Molecular evidence suggests that *H. mahoepo* may consist of two cryptic species, or one species in the process of diverging, as the specimens fall into two distinct clades (Fig. 2). However, based on similarity of genitalia and wing pattern across these clades and lack of any diagnostic morphological characters to separate the two, we here describe only one species.

***HYPSMOCOMA NOHOMEHA* MEDEIROS, HAINES & RUBINOFF SP. NOV. (FIGS 3F, 4F, 5E)**

**Material examined:** HOLOTYPE: HI: Kaho'olawe: Keāliāloa, 20°32'23"N, 156°38'15"W. 1 ♂, 5.iii.2013, W. Haines & D. Rubinoff, WPH082-13, DNA extraction DN2188.

PARATYPES: HI: Kaho'olawe: Keāliāloa, 20°32'23"N, 156°38'15"W. 1 ♂, 5.iii.2013, W. Haines & D. Rubinoff, WPH084-13, DNA extraction DN2190, slide WPH084-13♂. Kaukaupapa, 20°32'7"N, 156°41'36"W. 2 ♀, 5.iii.2013, W. Haines & D. Rubinoff, WPH076-13 (this individual hand collected), DNA extraction DN2182, slides WPH076-13♀; WPH097-13, DNA extraction 2199, slide WPH097-13♀.

**Diagnosis:** The only Kaho'olawe *Hyposmocoma* with male genitalia remarkably simple and unornamented. The forewings are also simple compared with other known Kaho'olawe *Hyposmocoma*; nearly uniformly white with only small amounts of dark scales scattered throughout.

**Description:** ( $N = 4$ ) (Fig. 3F). Wingspan 9.5–10.5 mm. Head mostly white, some scales tipped with brown. Haustellum with white scales. Maxillary palpus reduced. Recurved labial palpus pale brown with a few darker scales scattered throughout, especially near base of second segment. Antennal flagellomeres brown; scape mottled white and brown;

pecten present. Thorax, tegula, and metascutellum mostly white, some scales tipped with brown; abdomen pale grey. Foreleg and midleg coxa, femur, tibia, and tarsomeres mostly dark brown with some lighter scales scattered throughout, especially as rings around tarsomeres. Hindleg entirely nearly white. Forewing ground colour white, with dark brown scales scattered throughout, especially near costal margin; fringe minimal, nearly white. Hindwing and fringe uniformly brown. Subcostal brush apparently absent. No sclerotized hook present on segment VII. Females similar to males except frenulum with three acanthae and antennae slightly thinner than those of males.

*Male genitalia:* ( $N = 1$ ) (Fig. 4F). Valvae symmetrical, simple, slightly upcurved, enlarged and rounded apically. Anellar lobes not visible. Phallus large, cylindrical, heavily sclerotized, straight.

*Female genitalia:* ( $N = 1$ ) (Fig. 5E). Papillae anales short. Apophyses thin and straight; posterior apophyses very long, about two times length of anterior apophyses. Ductus bursae long, about same length as anterior apophysis. Corpus bursae oval, about same length as anterior apophysis; two small circular signa present near centre of corpus bursa. Inception of ductus seminalis situated at posterior end of corpus bursae.

*Etymology:* *Hyposmocoma nohomeha*, or 'hermit', from the Hawaiian *noho* (reside) and *meha* (isolated/alone), so named because the phylogeny suggests that this species has been isolated from its nearest relatives for a long time on a small island.

*Biology:* Based on its position in the phylogenetic tree, we expect larvae of *H. nohomeha* to construct 'burrito' case types, as it is sister to another clade that makes this case type.

*Distribution:* Known only from Kaho'olawe Island, Hawai'i, where it is presumed to be endemic.

*Remarks:* This species is one of several independent lineages with the 'burrito' case type that inhabit Kaho'olawe. In the phylogeny, *H. nohomeha* is separated from its closest known relatives by a long branch (Fig. 2), implying either a long history of isolation, or extinction of related taxa.

***HYPOSMOCOMA OOLEA* MEDEIROS, HAINES & RUBINOFF SP. NOV. (FIGS 3G, 4G, 5F, I)**

*Material examined:* HOLOTYPE: HI: Kaho'olawe: Kaukamoku gulch, 20°33'33"N, 156°35'13"W. ♂, 7.iii.

2013, W. Haines & D. Rubinoff, WPH047-13, DNA extraction DN2164, slide WPH047-13♂.

PARATYPES: HI: Kaho'olawe: Base of Pu'u o Moa'ula Iki, N20.56457 W156.58519. 1 ♀, on boulders, 'burrito' case, 7.iii.2013, em. 26.iv.2013, W. Haines & D. Rubinoff, WPH147-13, DR13C7C, slide WPH147-13♀. Honokanai'a camp. 20°30'54"N, 156°40'56"W. 1 ♂, 1 ♀, 5.iii.2013. W. Haines & D. Rubinoff, WPH051-13. DNA extraction DN2168; WPH073-13, DNA extraction 2179. Kaukamoku gulch, 20°33'33"N, 156°35'13"W. ♀, 7.iii.2013, W. Haines & D. Rubinoff, WPH048-13, DNA extraction DN2165, slide WPH048-13♀. Keāliālalo, 20°32'23"N, 156°38'15"W. 1 ♀, 5.iii.2013, W. Haines & D. Rubinoff, WPH081-13, DNA extraction DN2187. Near Honokanai'a camp, N20.52256 W156.68657. 1 ♂, on boulder, 'burrito' case, 6.iii.2013, em. 9.iv.2013, W. Haines & D. Rubinoff, WPH121-13, DNA extraction DN2219.

*Diagnosis:* Of the *Kaho'olawe Hyposmocoma*, the forewing pattern of *H. oolea* is very similar to *H. kamaula* and *H. waauhi* in being mostly brown with irregular darker bands that appear as spots, and so the male genitalia are required to diagnose this species. The male genitalia have a crescent-shaped left lobe of the anellus, as well as a fifth seta on the lobe of the left valva; no other *Kaho'olawe Hyposmocoma* has this combination of characters.

*Description:* ( $N = 7$ ) (Fig. 3G). Wingspan 10.0–11.6 mm. Head dark brown. Haustellum with brown scales. Maxillary palpus reduced. Recurved labial palpus with second segment nearly white with darker scales scattered throughout; third segment dark brown. Antennal flagellomeres dark brown scales; scape dark brown; pecten present. Thorax, tegula, metascutellum, and abdomen dark brown. Fore-, mid-, and hindleg coxa dark brown; femur, tibia, and tarsomeres dark brown with each segment terminating with a light brown ring. Forewing ground colour brown, with several bands of darker scales extending from costal margin to anal margin, alternating with bands of lighter scales; fringe brown. Hindwing and fringe uniformly brown. Subcostal brush present. Sclerotized hook (pseuduncus *sensu* Zimmerman, 1978) elongate, slender, straight; distinct sclerotized ring on segment VII. Females similar to males except frenulum with three acanthae.

*Male genitalia:* ( $N = 1$ ) (Fig. 4G). Valvae asymmetrical, left valva robust and with four heavy, long, sclerotized spur-like setae projecting dorsally near apex of both valvae; one additional heavy seta projecting dorsally from an acute dorsal lobe located halfway along length of valva; right valva with five

heavy setae projecting dorsally from apex, although valva is less robust and setae are slightly smaller than on left valva; both valvae bent approximately 30° upward in the middle. Anellus with two lobes; left lobe with two apical projections, forming a crescent shape, with the posterior projection significantly longer than the anterior; right lobe bent halfway along length, with a slightly enlarged apex covered in small setae. Phallus large, cylindrical, heavily sclerotized, curved near apex.

*Female genitalia:* ( $N = 1$ ) Fig. 5F). Papillae anales short. Apophyses thin and straight; posterior apophyses very long, about two times length of anterior apophyses. Ostium-bearing process heavily sclerotized and very large, externally protruding, snail-shell shaped and curled, with broad base. Ductus bursae long, about same length as anterior apophysis. Corpus bursae oval, about same length as anterior apophysis; signum absent. Inception of ductus seminalis situated at posterior end of corpus bursae.

*Etymology:* *Hyposmocoma oolea*, or 'resilient survivor', from the Hawaiian 'o'ole'a (obstinate/strong/hard), honouring the fact that this species, like its congeners on Kaho'olawe, have survived on the island despite its history of severe ecological degradation.

*Biology:* Adults were reared from case-making larvae. The larvae of *H. oolea* live on boulders, and presumably graze on lichens and algae, possibly scavenging on other organic material. Larvae build brown, bag-like 'burrito' cases with a single entrance, incorporating fine sediment giving a 'dusty' appearance to the case. The case has a flap-like 'door' that can be pulled over the entrance (Fig. 5I; Appendix 3).

*Distribution:* Known only from Kaho'olawe Island, Hawai'i, where it is presumed to be endemic.

*Remarks:* Larvae of this species were found in some of the harshest and most barren environments on Kaho'olawe, with little to no vegetation and few boulders providing shelter. It is indeed a very resilient species.

***HYPSOCOMA PAHANALO* MEDEIROS, HAINES & RUBINOFF SP. NOV. (FIGS 3H, 4H, 5G)**

*Material examined:* HOLOTYPE: HI: Kaho'olawe: Hakioawa, D4 Planting Area. ♂, 20.x.2008, M. J. Medeiros, slide 08A42♂.

PARATYPES: HI: Kaho'olawe: Hakioawa, D4 Planting Area. 3 ♀, 8.x.2008 & 19.vii.2011, M. J.

Medeiros, slide 08A45♀ (two missing abdomens). Kaukamoku gulch, 20°33'33''N, 156°35'13''W. 1 ♀, 7.iii.2013, W. Haines & D. Rubinoff, WPH044-13, DNA extraction DN2161, slide WPH044-13♀.

*Diagnosis:* Of the Kaho'olawe *Hyposmocoma*, the forewing pattern of *H. pahanalo* is most similar to *H. mahoepo*, but *H. mahoepo* has a band of dark scales extending from base to anal margin, whereas *H. pahanalo* has entirely white scales along anal margin near base. The male genitalia are similar to *H. anoai* in terms of very asymmetrically sized spur-like setae on the left vs. the right valvae, but in *H. pahanalo*, the valvae themselves are bent at nearly right angles halfway along their length.

*Description:* ( $N = 5$ ) (Fig. 3H). Wingspan 11.2–12.8 mm. Head with pale brown scales tipped with dark brown. Haustellum with beige scales. Maxillary palpus reduced. Recurved labial palpus; second segment brown with two white rings near apex; third segment white with a few brown scales scattered throughout, especially near base. Antennal flagellomeres with alternating rings of dark and pale brown scales; scape dark brown; pecten present. Metascutellum dark brown along sides, pale brown dorsally; tegula dark brown proximally, light brown distally; thorax pale brown. Fore- and midlegs mostly brown with pale scales ventrally; femur, tibia, and tarsomeres with dark brown rings near tarsomeres, and legs generally darker in more distal segments; hindlegs mostly pale light brown with some brown rings near tarsomeres. Forewing ground colour brown, with a band of dark scales extending along base of wing, in a 'zig-zag' pattern, ending before termen; small spots present at tips of veins along apex and termen; larger antemedial, medial, and postmedial spots along costa; fringe pale brown. Hindwing uniformly pale brown; fringe pale brown. Subcostal brush absent. Abdomens mounted on slides. Sclerotized hook (pseuduncus *sensu* Zimmerman, 1978) elongate, slightly curved, with blunted apex; distinct sclerotized ring on segment VII. Females similar to males except frenulum with three acanthae and antennae slightly thinner than those of males.

*Male genitalia:* ( $N = 1$ ) (Fig. 4H). Valvae roughly symmetrical, both bent dorsally halfway along length at approximately 90°, tapering to rounded apices. Four heavy, sclerotized, spur-like setae of variable length projecting dorsally near apex of left valva, the longest over four times length of setae on right valva; four much shorter setae projecting from right valva. Anellus with two lobes, each apically enlarged and surrounded with setae, right lobe larger and enlarged area more elongate than left. Phallus large, cylindrical, heavily sclerotized, curved near apex.

*Female genitalia:* ( $N = 2$ ) (Fig. 5G). Papillae anales short. Apophyses thin and straight; posterior apophyses very long, about two times length of anterior apophyses. Ostium-bearing process heavily sclerotized and very large, externally protruding, snail-shell shaped and curled, with broad base. Ductus bursae long, about same length as anterior apophysis. Corpus bursae oval, about same length as anterior apophysis; signum absent. Inception of ductus seminalis situated at posterior end of corpus bursae.

*Etymology:* *Hyposmocoma pahanalo*, or 'hidden surfboard', from the Hawaiian paha (a kind of surfboard) and nalo (missing); this refers to the presumed larval case of this species, as the 'flat purse' cases in this clade are similar in shape to Hawaiian surfboards.

*Biology:* Based on its position in the phylogenetic tree, we expect larvae of *H. pahanalo* to construct 'flat purse' case types, based on its being sister to another clade that makes this case type.

*Distribution:* Known only from Kaho'olawe Island, Hawai'i, where it is presumed to be endemic.

**HYPOSMOCOMA WAAUHI MEDEIROS, HAINES & RUBINOFF SP. NOV. (FIGS 3I, 4I)**

*Material examined:* HOLOTYPE: HI: Kaho'olawe: Honokanai'a camp, 20°30'54"N, 156°40'56"W. ♂, 5.iii.2013, W. Haines & D. Rubinoff, WPH074-13, DNA extraction DN2180, slide WPH074-13♂.

PARATYPES: HI: Kaho'olawe: Hakioawa, D4 Planting Area. 1 ♂, 20.x.2008, M. J. Medeiros, slide 08A48♂. Honokanai'a camp, 20°30'54"N, 156°40'56"W. 1 ♂, 1 ♀, 5.iii.2013, W. Haines & D. Rubinoff, WPH057-13, DNA extraction DN2174, slide WPH057-13♂; WPH075-13, DNA extraction DN2181, slide WPH075-13♀.

*Diagnosis:* The forewing pattern is very similar to *H. kamaula* and *H. oolea*, in being mostly brown with irregular darker spots and irregular dark bands of scales extending from costal to anal margin of the forewing. The male genitalia are therefore required to diagnose this species. This is the only species of Kaho'olawe *Hyposmocoma* with the right valva deeply notched.

*Description:* ( $N = 4$ ) (Fig. 3I). Wingspan 9.2–10.1 mm. Head pale to medium brown. Haustellum with beige scales. Maxillary palpus reduced. Second segment of recurved labial palpus dark brown; third segment pale brown except with dark brown apex.

Antennal flagellomeres with alternating rings of dark and pale brown scales; scape dark brown; pecten absent. Thorax, tegula, and metascutellum mottled pale brown to brown. Foreleg and midleg coxa, femur, tibia, and tarsomeres mostly dark brown; fringe brown. Hindleg entirely nearly white. Forewing ground colour pale brown, with three or four wide bands of brown scales extending more or less vertically from costa to anal margin; several brown spots near cell; some scattered brown scales near anal margin. Hindwing and fringe uniformly pale brown. Subcostal brush absent. Abdomen brown. Sclerotized hook (pseuduncus *sensu* Zimmerman, 1978) elongate, slender, with pointed apex; distinct sclerotized ring on segment VII. Female similar to males except frenulum with apparently two acanthae and antennae slightly thinner than those of males.

*Male genitalia:* ( $N = 2$ ) (Fig. 4I). Valvae asymmetrical, left arm long and robust, enlarged apically, with four heavy, long, sclerotized spur-like setae projecting dorsally near apex (lost in Fig. 4I); right arm long and slender with no heavy setae, apex deeply notched resulting in the appearance of one large and one small apical lobe. Right valva with a small lateral lobe projecting from near base; left valva without such a lobe. Anellus with two roughly symmetrical lobes, both slender and slightly apically enlarged. Phallus large, cylindrical, heavily sclerotized, curved near apex.

*Female genitalia:* ( $N = 1$ ). Specimen is in unsatisfactory condition to illustrate, as the genitalia are damaged. Ductus bursa, corpus bursa, and ostium unavailable for study. Papillae anales short. Apophyses thin and straight; posterior apophyses long, about  $1.5 \times$  length of anterior apophyses. Inception of ductus seminalis situated at posterior end of corpus bursae.

*Etymology:* *Hyposmocoma waauihi*, or 'hidden canoe', from the Hawaiian wa'a (canoe) and uhi (concealed or hidden). This species is so named because we hypothesize that it builds 'tube purse' cases, their shapes resembling canoes, but we still have not collected the larvae.

*Biology:* Based on its position in the phylogenetic tree, we expect larvae of *H. waauihi* to construct a 'tube purse' case, based on its being nested within a clade that makes this case type. Larvae of other species in the 'tube purse' clade can be found in a diversity of habitats, including decaying logs and leaf litter. They presumably feed on decaying plant matter.

*Distribution:* Known only from Kaho'olawe Island, Hawai'i, where it is presumed to be endemic.

KEY TO THE SPECIES OF *HYPOSMOCOMA*  
FOUND ON KAHO‘OLAWÉ

This key uses forewing pattern when possible, but to separate several species, male genitalia dissections are required.

- 1a. Forewing almost entirely white..... *Hyposmocoma nohomeha* sp. nov.
- 1b. Forewing not almost entirely white.....2
- 2a. Forewing mostly brown, with irregular vertical brown bands and irregular dark spots .....3
- 2b. Forewing otherwise.....5
- 3a. Right valva of male genitalia deeply notched ..... *Hyposmocoma waauhi* sp. nov.
- 3b. Right valva of male genitalia not deeply notched .....4
- 4a. Left anellus lobe of male genitalia crescent shaped ..... *Hyposmocoma oolea* sp. nov.
- 4b. Anellus lobes of male genitalia nearly symmetrical ..... *Hyposmocoma kamaula* sp. nov.
- 5a. Forewing with vertical bands of light metallic scales ..... *Hyposmocoma kanaloa* sp. nov.
- 5b. Forewing otherwise .....6
- 6a. Forewing with two dark horizontal bands, one along centre of wing, one along costal margin ..... *Hyposmocoma hooilo* sp. nov.
- 6b. Forewing pattern otherwise .....7
- 7a. Forewing mostly pale brown with single brown horizontal band extending irregularly along length of wing ..... *Hyposmocoma anoai* sp. nov.
- 7b. Forewing pattern otherwise .....8
- 8a. Valvae of male genitalia with spur-like setae nearly equal in length ..... *Hyposmocoma mahoepo* sp. nov.
- 8b. Valvae of male genitalia with spur-like setae much longer on left valva than on right ..... *Hyposmocoma pahanalo* sp. nov.

DISCUSSION

The discovery of nine endemic species persisting on Kaho‘olawé, despite its history of ecological deterioration, offers hope that it may harbour undescribed endemic species in other groups of organisms, particularly small, cryptic taxa. These are the first *Hyposmocoma* discovered from Kaho‘olawé (Nishida, 2002). The Hawaiian biota is known for its remarkable hyperdiverse radiations, and many of these lineages are groups of small, cryptic insects, including tiny

flies, weevils, and parasitic wasps (Zimmerman, 1947). As Kaho‘olawé was, until recently, virtually unexplored by entomologists, it is quite possible that *Hyposmocoma* is not the only diverse insect lineage to have weathered the island’s devastating history. As the vegetation of the island continues to be restored, we predict that populations of *Hyposmocoma*, and hopefully additional hangers-on from other native invertebrate lineages, will benefit from and respond to recovering habitats. Recent work described four new Lepidoptera species from Kaho‘olawé: one from Xyloryctidae (Medeiros, 2009), one from Coleophoridae, and two from Crambidae (Medeiros & Adamski, 2012). Non-invertebrate groups may also await discovery on Kaho‘olawé as well, as evidenced by the discovery of a new endemic plant genus (*Kanaloa*, Fabaceae; Lorence & Wood, 1994). These discoveries suggest that additional collections-based fieldwork should take place on Kaho‘olawé in the near future.

As much previous phylogenetic research on *Hyposmocoma* has explored the evolution of caterpillar morphology and ecology (Schmitz & Rubinoff, 2011; Kawahara & Rubinoff, 2013; Dupont & Rubinoff, 2015), we are able to make inferences about the larval life history of these new Kaho‘olawé species, despite thus far collecting only the adult moths for seven of the nine new species described here. Based on their well-supported placement within distinct clades of the phylogeny, we can predict the case type constructed by the caterpillars of each species, with these predictions serving as testable hypotheses for future work. Of the seven new species whose larvae we did not collect, we predict three to have ‘burrito’ case types (*H. kamaula*; *H. mahoepo*; *H. nohomeha*), two to have ‘flat purse’ case types (*H. hooilo*; *H. pahanalo*), one to have a ‘bugle’ case type (*H. anoai*), and one to have a ‘tube purse’ case type (*H. waauhi*). As the ‘burrito’ case type species are paraphyletic (Fig. 2), we should ideally be able to predict which group of ‘burrito’ cases would be found based on the adult captured. However, the larval ‘burrito’ cases are so similar that they should be reared to adulthood to confirm the species present. Ecologically, almost all ‘burrito’ case types are expected to be found on lichen-covered rocks.

Our phylogenetic tree (Fig. 2) is intended to assist with new, cryptic species identification, as well as to facilitate predictions about larval case type. However, because this tree does not include all known species, and because these new species may represent only a fraction of the diversity once present on Kaho‘olawé, we hesitate to make inferences about overall biogeographical trends within *Hyposmocoma*. For instance, it is difficult to reconstruct dispersal or vicariance events between Kaho‘olawé and other

islands. Ongoing research aims to attain a complete understanding of the patterns and process of diversification within this hyperdiverse group.

We had limited time in the field, yet we were able to discover nine new species over the course of only several days of sampling, which suggests that additional *Hyposmocoma* species await discovery and description on the island of Kaho'olawe. Additionally, owing to the nature of the island's history, the risk of unexploded ordinance precluded access to much of Kaho'olawe, and we were able to sample on only small fractions of the total area of the island. Our results exemplify the conservation value of a small, heavily degraded landmass. Although these areas may not harbour as much endemic biodiversity as larger, more intact areas, they still hold a surprisingly rich and unique biodiversity. It is our hope that future fieldwork on Kaho'olawe will yield exciting new finds, not only for the sake of a deeper understanding of biogeographical processes across the Hawaiian Islands, but also to document new species and in turn, to raise awareness of the conservation importance of this highly degraded island.

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## APPENDIX 1

## PRIMERS USED IN THIS STUDY

Gene region	Primer direction	Name	Primer sequence (5' to 3')	Annealing temp. (°C)	Product length (bp)	References
COI	F	K485 "Jerry"	CAACATTTATTTTGATTTTTTGG	50	729	Simon <i>et al.</i> (1994)
COI	R	K837 "Pat2"	TCCATTACATATAATCTGCCATATTAG	50	729	Simon <i>et al.</i> (1994)
COI	F	LCO1490	GCTCAACAAATCATAAAGATATTGG	55	660	Folmer <i>et al.</i> (1994)
COI	R	HCO2198	TAAACTTCAGGGTGACCAAAAAATCA	55	660	Folmer <i>et al.</i> (1994)
MDH	F	Hypo_MDHF	GCTGACTGTGCTCTGCCHCT	56	414	Haines <i>et al.</i> (2014)
MDH	R	Hypo_MDHF	ACWGCAGCACCACGCTTTTGA	56	414	Haines <i>et al.</i> (2014)
EF1 $\alpha$	F	Coma	GGCCAGGAAATGGGCAAAGG	58	750	Rubinoff (2008)
EF1 $\alpha$	R	Toes	GGAGTCWCCAGCKACGTAACC	58	750	Rubinoff (2008)
RpS5	F	RpS5f	ATGGCNGARGARAAYTGGAAYGA	58	597	Wahlberg and Wheat (2008)
RpS5	R	RpS5r	CGGTTRGAYTTRGCAACACG	58	597	Wahlberg and Wheat (2008)
CAD	F	Cue	GGGATTTAGCAAAATTCAACCG	50	615	Kawahara and Rubinoff (2012)
CAD	R	Eh	CCTATCGCTCATATCATAATCGG	50	615	Kawahara and Rubinoff (2012)

## APPENDIX 2

SPECIMENS USED IN THIS STUDY. SPECIMENS SEQUENCED AND PUBLISHED FOR THE FIRST TIME HERE ARE IN BOLD.  
SEE MAIN TEXT FOR GENE NAMES IN FULL

Sort order	Extraction code	Rearing code	Species	Island	Clade	COI	EF-1 $\alpha$	CAD	MDH	RPS5
1	DN0055	N/A	<i>Labdia issikii</i>	N/A	Outgroup	KJ440168	GU560665	GU560347	KJ440320	KJ440412
2	DN0057	N/A	<i>Limnaecia</i> sp.	N/A	Outgroup	KJ440169	GU560666	GU560348	KJ440321	KJ440413
3	CP034	N/A	<i>Hypsmocoma exornata</i>	Maui	<i>Euperissus</i>	KJ440153	GU560573	GU560200	KJ440305	KJ440397
4	DN0081	N/A	<i>Hypsmocoma nipholoncha</i>	Maui	<i>Euperissus</i>	KJ440175	GU560688	GU560370	KJ440327	KJ440419
5	DN0053	N/A	<i>Hypsmocoma palmifera</i>	Maui	<i>Euperissus</i>	KJ440167	GU560663	GU560345	KJ440319	KJ440411
6	DN1286	N/A	<i>Hypsmocoma</i> sp. 113	Hawai'i	<i>Euperissus</i>	KJ440199	KJ440260	KJ440108	KJ440351	KJ440443
7	DN1839	N/A	<i>Hypsmocoma</i> sp. 114	Maui	<i>Euperissus</i>	KJ440222	KJ440283	KJ440131	KJ440374	KJ440466
8	DN1841	N/A	<i>Hypsmocoma</i> sp. 115	Maui	<i>Euperissus</i>	KJ440223	KJ440284	KJ440132	KJ440375	KJ440467
9	DN1844	N/A	<i>Hypsmocoma</i> sp. 116	Kauai	<i>Euperissus</i>	KJ440224	KJ440285	KJ440133	KJ440376	KJ440468
10	DN1855	N/A	<i>Hypsmocoma</i> sp. 117	Kauai	<i>Euperissus</i>	KJ440225	KJ440286	KJ440134	KJ440377	KJ440469
11	DN1889	N/A	<i>Hypsmocoma</i> sp. 121	Lanai	<i>Euperissus</i>	KJ440229	KJ440290	KJ440138	KJ440381	KJ440473
12	DN1994	N/A	<i>Hypsmocoma</i> sp. 122	Oahu	<i>Euperissus</i>	KJ440239	KJ440300	KJ440148	KJ440391	KJ440483
13	DN1997	N/A	<i>Hypsmocoma</i> sp. 123	Oahu	<i>Euperissus</i>	KJ440240	KJ440301	KJ440149	KJ440392	KJ440484
14	DN1913	N/A	<i>Hypsmocoma</i> sp. 125	Maui	<i>Euperissus</i>	<b>KX602354</b>	<b>KX602418</b>	<b>KX602462</b>	N/A	<b>KX602516</b>
15	DN1884	N/A	<i>Hypsmocoma</i> sp. 126	Maui	<i>Euperissus</i>	<b>KX602353</b>	<b>KX602417</b>	<b>KX602461</b>	N/A	<b>KX602515</b>
16	DN2172	N/A	<b><i>Hypsmocoma anoi</i> sp. nov.</b>	Kahoolawe	Bugle	<b>KX602370</b>	<b>KX602430</b>	<b>KX602472</b>	<b>KX602496</b>	<b>KX602521</b>
17	DN0154	DR09B7B	<i>Hypsmocoma eepawai</i>	Kauai	Bugle	KJ440183	KJ440248	KJ440096	KJ440335	KJ440427
18	DN0115	DR08K12C	<i>Hypsmocoma pukoa</i>	Maui	Bugle	KJ440178	GU560717	GU560399	KJ440330	KJ440422
19	DN0032	DR07J1A	<i>Hypsmocoma</i> sp. 32	Kauai	Bugle	KJ440160	GU560641	GU560321	KJ440312	KJ440404
20	DN1257	DR10C16A	<i>Hypsmocoma</i> sp. 78	Lanai	Bugle	KJ440197	KJ440258	KJ440106	KJ440349	KJ440441
21	DN1256	DR10C7	<i>Hypsmocoma</i> sp. 80	Oahu	Bugle	KJ440196	KJ440257	KJ440105	KJ440348	KJ440440
22	DN1649	DR11B23E	<i>Hypsmocoma</i> sp. 87	Oahu	Bugle	KJ440211	KJ440272	KJ440120	KJ440363	KJ440455
23	SF024	DR11D3D	<i>Hypsmocoma</i> sp. 96	Kauai	Bugle	KJ440242	KJ440303	KJ440151	KJ440394	KJ440486
24	DN1187	N/A	<b><i>Hypsmocoma kamaula</i> sp. nov.</b>	Kahoolawe	Burrito	<b>KX602334</b>	<b>KX602424</b>	<b>KX602468</b>	N/A	N/A
25	DN2167	N/A	<b><i>H. kamaula</i> sp. nov.</b>	Kahoolawe	Burrito	<b>KX602365</b>	<b>KX602429</b>	<b>KX602471</b>	<b>KX602495</b>	N/A
26	DN2197	N/A	<b><i>H. kamaula</i> sp. nov.</b>	Kahoolawe	Burrito	<b>KX602388</b>	N/A	N/A	N/A	N/A
27	DN2220	DR13C6A	<b><i>Hypsmocoma kanaloo</i> sp. nov.</b>	Kahoolawe	Burrito	<b>KX602393</b>	<b>KX602437</b>	<b>KX602479</b>	<b>KX602504</b>	<b>KX602527</b>
28	DN2221	DR13C6A	<b><i>H. kanaloo</i> sp. nov.</b>	Kahoolawe	Burrito	<b>KX602394</b>	<b>KX602438</b>	<b>KX602480</b>	<b>KX602505</b>	<b>KX602528</b>
29	DN0033	DR07L1A	<i>Hypsmocoma kauipo</i>	Maui	Burrito	KJ440161	EU812335	GU560322	KJ440313	KJ440405
30	DN1183	N/A	<b><i>Hypsmocoma mahoe</i> sp. nov.</b>	Kahoolawe	Burrito	<b>KX602331</b>	<b>KX602421</b>	<b>KX602465</b>	N/A	N/A
31	DN1185	N/A	<b><i>H. mahoe</i> sp. nov.</b>	Kahoolawe	Burrito	<b>KX602332</b>	<b>KX602422</b>	<b>KX602466</b>	N/A	N/A
32	DN2162	N/A	<b><i>H. mahoe</i> sp. nov.</b>	Kahoolawe	Burrito	<b>KX602361</b>	<b>KX602427</b>	<b>KX602469</b>	<b>KX602493</b>	N/A
33	DN2163	N/A	<b><i>H. mahoe</i> sp. nov.</b>	Kahoolawe	Burrito	<b>KX602362</b>	N/A	N/A	N/A	N/A

## APPENDIX 2. Continued

Sort order	Extraction code	Rearing code	Species	Island	Clade	COI	EF-1 $\alpha$	CAD	MDH	RPS5
34	DN2169	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602367</b>	N/A	N/A	N/A	N/A
35	DN2170	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602368</b>	N/A	N/A	N/A	N/A
36	DN2171	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602369</b>	N/A	N/A	N/A	N/A
37	DN2175	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602372</b>	<b>KX602431</b>	<b>KX602473</b>	<b>KX602497</b>	N/A
38	DN2176	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602373</b>	N/A	<b>KX602474</b>	<b>KX602498</b>	N/A
39	DN2185	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602379</b>	N/A	N/A	N/A	N/A
40	DN2186	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602380</b>	N/A	N/A	N/A	N/A
41	DN2189	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602383</b>	N/A	N/A	N/A	N/A
42	DN2191	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602385</b>	N/A	N/A	N/A	N/A
43	DN2193	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602386</b>	N/A	N/A	N/A	N/A
44	DN2195	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602387</b>	N/A	N/A	N/A	N/A
45	DN2200	N/A	<i>H. mahoeipo</i> sp. nov.	Kahoowawe	Burrito	<b>KX602391</b>	N/A	N/A	N/A	N/A
46	DN0150	DR09B12C	<i>Hypomocoma metrosiderella</i>	Kauai	Burrito	KJ440182	KC921371	KC921356	KJ440334	KJ440426
47	DN0065	DR08H1B	<i>Hypomocoma nebulifera</i>	Oahu	Burrito	KJ440171	GU560673	GU560355	KJ440323	KJ440415
48	DN2182	N/A	<i>Hypomocoma nohomaha</i> sp. nov.	Kahoowawe	Burrito	<b>KX602377</b>	<b>KX602433</b>	<b>KX602476</b>	<b>KX602500</b>	<b>KX602523</b>
49	DN2188	N/A	<i>H. nohomaha</i> sp. nov.	Kahoowawe	Burrito	<b>KX602382</b>	N/A	N/A	N/A	N/A
50	DN2190	N/A	<i>H. nohomaha</i> sp. nov.	Kahoowawe	Burrito	<b>KX602384</b>	N/A	N/A	N/A	N/A
51	DN2199	N/A	<i>H. nohomaha</i> sp. nov.	Kahoowawe	Burrito	<b>KX602390</b>	N/A	N/A	N/A	N/A
52	DN2164	N/A	<i>Hypomocoma oolea</i> sp. nov.	Kahoowawe	Burrito	<b>KX602363</b>	<b>KX602428</b>	<b>KX602470</b>	<b>KX602494</b>	<b>KX602520</b>
53	DN2165	N/A	<i>H. oolea</i> sp. nov.	Kahoowawe	Burrito	<b>KX602364</b>	N/A	N/A	N/A	N/A
54	DN2168	N/A	<i>H. oolea</i> sp. nov.	Kahoowawe	Burrito	<b>KX602366</b>	N/A	N/A	N/A	N/A
55	DN2179	N/A	<i>H. oolea</i> sp. nov.	Kahoowawe	Burrito	<b>KX602374</b>	N/A	N/A	N/A	N/A
56	DN2187	N/A	<i>H. oolea</i> sp. nov.	Kahoowawe	Burrito	<b>KX602381</b>	N/A	N/A	N/A	N/A
57	DN2198	N/A	<i>H. oolea</i> sp. nov.	Kahoowawe	Burrito	<b>KX602389</b>	<b>KX602435</b>	<b>KX602477</b>	<b>KX602502</b>	<b>KX602525</b>
58	DN2219	DR13C4A	<i>H. oolea</i> sp. nov.	Kahoowawe	Burrito	<b>KX602392</b>	<b>KX602436</b>	<b>KX602478</b>	<b>KX602503</b>	<b>KX602526</b>
59	WPH147	N/A	<i>H. oolea</i> sp. nov.	Kahoowawe	Burrito	<b>KX602395</b>	<b>KX602439</b>	N/A	N/A	N/A
60	CP140	DR05G10	<i>Hypomocoma turdella</i>	Lanai	Burrito	GU560417	GU560576	GU560215	N/A	N/A
61	DN1218	DR09I3A	<i>H. turdella</i>	Lanai	Burrito	KJ440189	KJ440253	KJ440101	KJ440341	KJ440433
62	DN0068	DR08H3B	<i>Hypomocoma</i> sp. 50	Hawai'i	Burrito	GU560516	GU560357	GU560357	N/A	N/A
63	DN1281	N/A	<i>H.</i> sp. 50	Hawai'i	Burrito	<b>KX602339</b>	<b>KX602403</b>	<b>KX602447</b>	N/A	N/A
64	DN0088	DR08C2B	<i>Hypomocoma</i> sp. 57	Lanai	Burrito	GU560533	GU560692	GU560374	N/A	N/A
65	DN1871	N/A	<i>H.</i> sp. 57	Oahu	Burrito	<b>KX602351</b>	<b>KX602415</b>	<b>KX602459</b>	<b>KX602488</b>	N/A
66	DN0105	DR08L2B	<i>Hypomocoma</i> sp. 61	Oahu	Burrito	<b>KX602327</b>	GU560707	GU560389	N/A	N/A
67	DN1268	DR09I8	<i>H.</i> sp. 61	Oahu	Burrito	<b>KX602337</b>	<b>KX602401</b>	<b>KX602445</b>	N/A	N/A
68	DN0106	DR08L2B	<i>Hypomocoma</i> sp. 64	Oahu	Burrito	GU560549	GU560708	GU560390	N/A	N/A
69	DN0107	DR08K6	<i>Hypomocoma</i> sp. 65	Maui	Burrito	GU560550	GU560709	GU560391	N/A	N/A
70	DN1226	DR08E1G	<i>Hypomocoma</i> sp. 71	Maui	Burrito	KJ440192	KJ440255	KJ440103	KJ440344	KJ440436

## APPENDIX 2. Continued

Sort order	Extraction code	Rearing code	Species	Island	Clade	COI	EF-1 $\alpha$	CAD	MDH	RPS5
71	DN0067	DR08H1G	<i>Hypsmocoma</i> sp. 72	Oahu	Burrito	KJ440172	KJ440245	KJ440093	KJ440324	KJ440416
72	DN1390	DR10L7C	<i>Hypsmocoma</i> sp. 84	Kauai	Burrito	KJ440203	KJ440264	KJ440112	KJ440355	KJ440447
73	DN1681	DR11C25L	<i>Hypsmocoma</i> sp. 93	Hawai'i	Burrito	KJ440213	KJ440274	KJ440122	KJ440365	KJ440457
74	DN1966	DR11K1I	<i>Hypsmocoma</i> sp. 111	Maui	Burrito	KJ440235	KJ440296	KJ440144	KJ440387	KJ440479
75	DN1869	N/A	<i>Hypsmocoma</i> sp. 118	Lanai	Burrito	KJ440226	KJ440287	KJ440135	KJ440378	KJ440470
76	DN1740	DR11C11K	<i>Hypsmocoma</i> sp. 119	Molokai	Burrito	<b>KX602346</b>	<b>KX602410</b>	<b>KX602454</b>	N/A	N/A
77	DN1870	N/A	<i>H.</i> sp. 119	Oahu	Burrito	KJ440227	KJ440288	KJ440136	KJ440379	KJ440471
78	DN1882	N/A	<i>Hypsmocoma</i> sp. 120	Maui	Burrito	KJ440228	KJ440289	KJ440137	KJ440380	KJ440472
79	DN1883	N/A	<i>H.</i> sp. 120	Maui	Burrito	<b>KX602352</b>	<b>KX602416</b>	<b>KX602460</b>	<b>KX602489</b>	<b>KX602514</b>
80	DN1973	DR11K15C	<i>Hypsmocoma</i> sp. 130	Maui	Burrito	<b>KX602356</b>	<b>KX602420</b>	<b>KX602464</b>	<b>KX602490</b>	N/A
81	DN1479	DR11C12A	<i>Hypsmocoma</i> sp. 131	Molokai	Burrito	<b>KX602342</b>	<b>KX602406</b>	<b>KX602450</b>	<b>KX602484</b>	N/A
82	DN1813	DR11H1Q	<i>Hypsmocoma</i> sp. 132	Kauai	Burrito	<b>KX602350</b>	<b>KX602414</b>	<b>KX602458</b>	N/A	N/A
83	DN1780	DR11D20B	<i>Hypsmocoma</i> sp. 133	Kauai	Burrito	<b>KX602348</b>	<b>KX602412</b>	<b>KX602456</b>	N/A	N/A
84	DN1657	DR11B28B	<i>Hypsmocoma</i> sp. 134	Kauai	Burrito	<b>KX602344</b>	<b>KX602408</b>	<b>KX602452</b>	N/A	N/A
85	DN1718	DR11C6E	<i>H.</i> sp. 134	Kauai	Burrito	<b>KX602345</b>	<b>KX602409</b>	<b>KX602453</b>	N/A	N/A
86	DN1279	N/A	<i>Hypsmocoma</i> sp. 135	Hawai'i	Burrito	<b>KX602338</b>	<b>KX602402</b>	<b>KX602446</b>	N/A	N/A
87	DN1292	N/A	<i>H.</i> sp. 135	Hawai'i	Burrito	<b>KX602340</b>	<b>KX602404</b>	<b>KX602448</b>	N/A	N/A
88	DN1266	DR09H4D	<i>Hypsmocoma</i> sp. 136	Oahu	Burrito	<b>KX602336</b>	<b>KX602400</b>	<b>KX602444</b>	N/A	<b>KX602509</b>
89	DN1959	DR12B2A	<i>Hypsmocoma</i> sp. 137	Kauai	Burrito	<b>KX602355</b>	<b>KX602419</b>	<b>KX602463</b>	N/A	N/A
90	DN0138	DR09B7D	<i>Hypsmocoma</i> sp. 138	Kauai	Burrito	<b>KX602328</b>	<b>KX602397</b>	<b>KX602441</b>	N/A	N/A
91	DN0039	DR08C4A	<i>Hypsmocoma wahikanake</i>	Lanai	Candy wrapper	<b>KX602326</b>	GU560646	GU560328	<b>KX602481</b>	<b>KX602506</b>
92	DN0030	DR06F2D	<i>Hypsmocoma</i> sp. 31	Oahu	Candy wrapper	KJ440158	GU560639	GU560319	KJ440310	KJ440402
93	DN0051	DR06D3C	<i>Hypsmocoma</i> sp. 44	Oahu	Candy wrapper	KJ440166	GU560661	GU560343	KJ440318	KJ440410
94	DN1208	DR09A3M	<i>Hypsmocoma</i> sp. 62	Oahu	Candy wrapper	KJ440187	KJ440251	KJ440099	KJ440339	KJ440431
95	DN0167	DR08J5B	<i>Hypsmocoma</i> sp. 66	Hawai'i	Candy wrapper	KJ440184	KJ440249	KJ440097	KJ440336	KJ440428
96	DN1196	DR09I5C	<i>Hypsmocoma</i> sp. 75	Lanai	Candy wrapper	KJ440186	KJ440250	KJ440098	KJ440338	KJ440430
97	DN1217	DR09I5D	<i>Hypsmocoma</i> sp. 76	Lanai	Candy wrapper	KJ440188	KJ440252	KJ440100	KJ440340	KJ440432
98	DN1244	DR10C1C	<i>Hypsmocoma</i> sp. 79	Oahu	Candy wrapper	KJ440195	KJ440256	KJ440104	KJ440347	KJ440439
99	DN1682	DR11B2M	<i>Hypsmocoma</i> sp. 88	Kauai	Candy wrapper	KJ440214	KJ440275	KJ440123	KJ440366	KJ440458

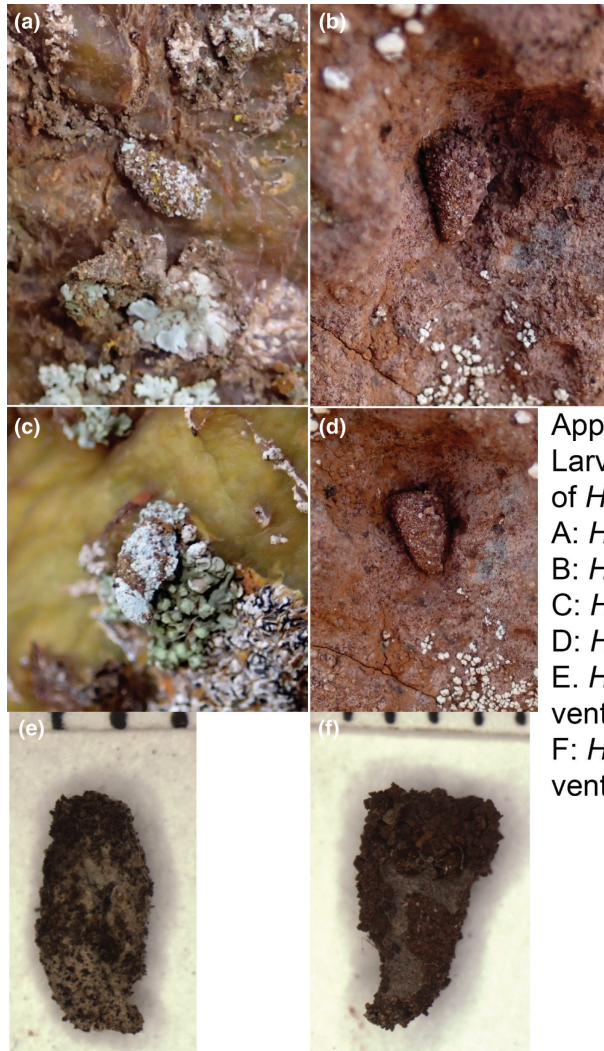
APPENDIX 2. *Continued*

Sort order	Extraction code	Rearing code	Species	Island	Clade	CO1	EF-1 $\alpha$	CAD	MDH	RPS5
100	DN1469	DR11B9C	<i>Hyposmocoma</i> sp. 89	Kauai	Candy wrapper	KJ440206	KJ440267	KJ440115	KJ440358	KJ440450
101	DN1490	DR11C12E	<i>Hyposmocoma</i> sp. 90	Molokai	Candy wrapper	KJ440209	KJ440270	KJ440118	KJ440361	KJ440453
102	DN1476	DR11C23H	<i>Hyposmocoma</i> sp. 92	Kauai	Candy wrapper	KJ440207	KJ440268	KJ440116	KJ440359	KJ440451
103	DN1491	DR11D11B	<i>Hyposmocoma</i> sp. 95	Kauai	Candy wrapper	KJ440210	KJ440271	KJ440119	KJ440362	KJ440454
104	SF013	DR11D3R	<i>Hyposmocoma</i> sp. 98	Kauai	Candy wrapper	KJ440241	KJ440302	KJ440150	KJ440393	KJ440485
105	DN1968	DR11L5A	<i>Hyposmocoma</i> sp. 112	Kauai	Candy wrapper	KJ440236	KJ440297	KJ440145	KJ440388	KJ440480
106	DN0050	DR08F5A	<i>Hyposmocoma carnivora</i>	Hawai'i	Cigar	KJ440165	GU560660	GU560342	KJ440317	KJ440409
107	DN0035	DR07K1B	<i>Hyposmocoma pupumoeheua</i>	Maui	Cigar	KJ440162	GU560642	GU560324	KJ440314	KJ440406
108	DN0163	DR09B12H	<i>Hyposmocoma</i> sp. 12	Kauai	Cigar	<b>KX602329</b>	<b>KX602398</b>	<b>KX602442</b>	<b>KX602482</b>	<b>KX602507</b>
109	DN0041	DR06F2E	<i>Hyposmocoma</i> sp. 37	Oahu	Cigar	KJ440163	GU560648	GU560330	KJ440315	KJ440407
110	DN1496	DR11C25U	<i>Hyposmocoma</i> sp. 53	Hawai'i	Cigar	<b>KX602343</b>	<b>KX602407</b>	<b>KX602451</b>	<b>KX602485</b>	<b>KX602511</b>
111	DN0089	DR08C12A	<i>Hyposmocoma</i> sp. 58	Maui	Cigar	KJ440176	GU560698	GU560375	KJ440328	KJ440420
112	DN0132	DR09A3R	<i>Hyposmocoma</i> sp. 74	Oahu	Cigar	KJ440179	KJ440246	KJ440094	KJ440331	KJ440423
113	DN1404	DR10L11H	<i>Hyposmocoma</i> sp. 83	Kauai	Cigar	KJ440204	KJ440265	KJ440113	KJ440356	KJ440448
114	DN1203	DR09L1D	<i>Hyposmocoma</i> sp. 86	Oahu	Cigar	<b>KX602335</b>	<b>KX602399</b>	<b>KX602443</b>	N/A	<b>KX602508</b>
115	DN1461	DR11B22F	<i>H.</i> sp. 86	Oahu	Cigar	KJ440205	KJ440266	KJ440114	KJ440357	KJ440449
116	DN1685	DR11C25U	<i>Hyposmocoma</i> sp. 94	Hawai'i	Cigar	KJ440215	KJ440276	KJ440124	KJ440367	KJ440459
117	DN1663	DR11D3N	<i>Hyposmocoma</i> sp. 97	Kauai	Cigar	KJ440212	KJ440273	KJ440121	KJ440364	KJ440456
118	DN1775	DR11D9C	<i>Hyposmocoma</i> sp. 99	Kauai	Cigar	KJ440217	KJ440278	KJ440126	KJ440369	KJ440461
119	DN1792	DR11E3D	<i>H.</i> sp. 99	Kauai	Cigar	<b>KX602349</b>	<b>KX602413</b>	<b>KX602457</b>	<b>KX602487</b>	<b>KX602513</b>
120	DN1790	DR11E3A	<i>Hyposmocoma</i> sp. 100	Kauai	Cigar	KJ440218	KJ440279	KJ440127	KJ440370	KJ440462
121	DN1791	DR11E3A	<i>Hyposmocoma</i> sp. 101	Kauai	Cigar	KJ440219	KJ440280	KJ440128	KJ440371	KJ440463
122	DN1926	DR11G4S	<i>Hyposmocoma</i> sp. 104	Kauai	Cigar	KJ440231	KJ440292	KJ440140	KJ440383	KJ440475
123	DN1812	DR11H1D	<i>Hyposmocoma</i> sp. 105	Kauai	Cigar	KJ440221	KJ440282	KJ440130	KJ440373	KJ440465
124	DN1972	DR11K14N	<i>Hyposmocoma</i> sp. 110	Maui	Cigar	KJ440238	KJ440299	KJ440147	KJ440390	KJ440482
125	DN1778	DR11D16B	<i>Hyposmocoma</i> sp. 128	Kauai	Cigar	<b>KX602347</b>	<b>KX602411</b>	<b>KX602455</b>	<b>KX602486</b>	<b>KX602512</b>
126	DN1472	DR11C11P	<i>Hyposmocoma</i> sp. 129	Molokai	Cigar	<b>KX602341</b>	<b>KX602405</b>	<b>KX602449</b>	<b>KX602483</b>	<b>KX602510</b>
127	TL12	N/A	<i>Hyposmocoma kahaiao</i>	Maui	Cone	KJ440243	GU560618	GU560298	KJ440395	KJ440487
128	CP043	N/A	<i>Hyposmocoma kahamanoa</i>	Oahu	Cone	KJ440154	EU697345	GU560219	KJ440306	KJ440398
129	DN0031	DR07I2D	<i>Hyposmocoma laysanensis</i>	Laysan	Cone	KJ440159	GU560640	GU560320	KJ440311	KJ440403
130	CP085	N/A	<i>Hyposmocoma opuimaloo</i>	Necker	Cone	KJ440156	EU697364	KJ440092	KJ440308	KJ440400
131	DN0133	DR09B4A	<i>Hyposmocoma uhauiole</i>	Kauai	Cone	KJ440180	KJ440247	KJ440095	KJ440332	KJ440424

## APPENDIX 2. Continued

Sort order	Extraction code	Rearing code	Species	Island	Clade	COI	EF-1 $\alpha$	CAD	MDH	RPS5
132	DN0134	DR09B4B	<i>Hyposmocoma waitua</i>	Kauai	Cone	KJ440181	KC921369	KC921355	KJ4440333	KJ440425
133	DN1303	DR10F3B	<i>Hyposmocoma</i> sp. 81	Maui	Cone	KJ440200	KJ440261	KJ440109	KJ4440352	KJ440444
134	DN1311	DR10H1E	<i>Hyposmocoma</i> sp. 82	Oahu	Cone	KJ440201	KJ440262	KJ440110	KJ4440353	KJ440445
135	DN1800	DR11G1D	<i>Hyposmocoma</i> sp. 102	Oahu	Cone	KJ440220	KJ440281	KJ440129	KJ4440372	KJ440464
136	DN1964	DR11J26B	<i>Hyposmocoma</i> sp. 106	Kauai	Cone	KJ440234	KJ440295	KJ440143	KJ4440386	KJ440478
137	DN1928	DR11J3A	<i>Hyposmocoma</i> sp. 107	Nihoa	Cone	KJ440232	KJ440293	KJ440141	KJ4440384	KJ440476
138	DN0042	DR06F6	<i>Hyposmocoma papaiili</i>	Maui	Crab	KJ440164	GU560649	GU560331	KJ4440316	KJ440408
139	DN0092	DR08H1C	<i>Hyposmocoma</i> sp. 59	Oahu	Crab	KJ440177	GU560695	GU560377	KJ4440329	KJ440421
140	DN1971	DR11K12G	<i>Hyposmocoma</i> sp. 109	Kauai	Crab	KJ440237	KJ440298	KJ440146	KJ4440389	KJ440481
141	TL16	N/A	<i>Hyposmocoma</i> sp. 124	Maui	Crab	KJ440244	KJ440304	KJ440152	KJ4440396	KJ440488
142	DN0101	DR08J7D	<i>Hyposmocoma flicivora</i>	Oahu	Flat purse	GU560545	GU560704	GU560386	N/A	N/A
143	DN1182	N/A	<b><i>Hyposmocoma hooilo</i> sp. nov.</b>	Kahoolawe	Flat purse	<b>KX602330</b>	KC921362	KC921350	N/A	<b>KX602517</b>
144	DN2161	N/A	<b><i>H. hooilo</i> sp. nov.</b>	Kahoolawe	Flat purse	<b>KX602360</b>	<b>KX602426</b>	N/A	<b>KX602492</b>	<b>KX602519</b>
145	DN1236	DR09L3A	<i>Hyposmocoma mediella</i>	Oahu	Flat purse	KJ440194	KC921366	KC921353	KJ4440346	KJ440438
146	DN2158	N/A	<b><i>Hyposmocoma pahanalo</i> sp. nov.</b>	Kahoolawe	Flat purse	<b>KX602357</b>	N/A	N/A	N/A	N/A
147	DN2159	N/A	<b><i>H. pahanalo</i> sp. nov.</b>	Kahoolawe	Flat purse	<b>KX602358</b>	N/A	N/A	N/A	N/A
148	DN2160	N/A	<b><i>H. pahanalo</i> sp. nov.</b>	Kahoolawe	Flat purse	<b>KX602359</b>	<b>KX602425</b>	N/A	<b>KX602491</b>	<b>KX602518</b>
149	DN2184	N/A	<b><i>H. pahanalo</i> sp. nov.</b>	Kahoolawe	Flat purse	<b>KX602378</b>	<b>KX602434</b>	N/A	<b>KX602501</b>	<b>KX602524</b>
150	DN1232	DR09H1B	<i>Hyposmocoma</i> sp. 45	Oahu	Flat purse	KJ440193	KC921364	KC921351	KJ4440345	KJ440437
151	DN0060	DR06F2F	<i>Hyposmocoma</i> sp. 47	Oahu	Flat purse	KJ440170	GU560668	GU560350	KJ4440322	KJ440414
152	DN1327	DR10C12F	<i>Hyposmocoma</i> sp. 8	Kauai	Giant Purse	KJ440202	KJ440263	KJ440111	KJ4440354	KJ440446
153	DN0069	N/A	<i>Hyposmocoma</i> sp. 10	Hawai'i	Giant Purse	KJ440173	GU560676	GU560358	KJ4440325	KJ440417
154	DN1193	DR09H6A	<i>Hyposmocoma ehemamao</i>	Laysan	Tube purse	KJ440185	JQ231027	JQ182753	KJ4440337	KJ440429
155	DN0121	DR08K8C	<i>Hyposmocoma ipohapuu</i>	Hawai'i	Tube purse	JQ231056	GU560723	GU560405	N/A	N/A
156	CP096	N/A	<i>Hyposmocoma mokumana</i>	Necker	Tube purse	KJ440157	GU560601	GU560267	KJ4440309	KJ440401
157	DN1220	DR09J2B	<i>Hyposmocoma nephelodes</i>	Oahu	Tube purse	KJ440190	JQ231031	JQ182757	KJ4440342	KJ440434
158	DN1186	N/A	<b><i>Hyposmocoma waauhi</i> sp. nov.</b>	Kahoolawe	Tube purse	<b>KX602333</b>	<b>KX602423</b>	<b>KX602467</b>	N/A	N/A
159	DN2174	N/A	<b><i>H. waauhi</i> sp. nov.</b>	Kahoolawe	Tube purse	<b>KX602371</b>	N/A	N/A	N/A	N/A
160	DN2180	N/A	<b><i>H. waauhi</i> sp. nov.</b>	Kahoolawe	Tube purse	<b>KX602375</b>	<b>KX602432</b>	<b>KX602475</b>	<b>KX602499</b>	<b>KX602522</b>
161	DN2181	N/A	<b><i>H. waauhi</i> sp. nov.</b>	Kahoolawe	Tube purse	<b>KX602376</b>	N/A	N/A	N/A	N/A
162	CP077	N/A	<i>Hyposmocoma</i> sp. 16	Molokai	Tube purse	KJ440155	GU560580	GU560227	KJ4440307	KJ440399
163	DN1223	DR09A3I	<i>Hyposmocoma</i> sp. 73	Oahu	Tube purse	KJ440191	KJ440254	KJ440102	KJ4440343	KJ440435
164	CP126	N/A	<i>Hyposmocoma</i> sp. 127	Molokai	Tube purse	<b>KX602325</b>	<b>KX602396</b>	<b>KX602440</b>	N/A	N/A

**APPENDIX 3**  
LARVAL CASES OF *HYPOSMOCOMA*



Larval cases of *Hyposmocoma*. A: *H. kanaloa*; B: *H. oolea*; C: *H. kanaloa*; D: *H. oolea*; E: *H. kanaloa*, ventral view; F: *H. oolea*, ventral view.