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PHOTOGRAPHIC GUIDE TO THE LEAF LITTER ARTHROPOD COMMUNITY OF THE LOWLAND WET FOREST ECOSYSTEM OF THE ISLAND OF HAWAI'I

Trebor Hall[1], Robert Peck[2], Anuhea Robins[3], Maya Munstermann[2], Rebecca Ostertag[1,3], Esther Sebastián González[4], Nicole DiManno[1], Susan Cordell[5], and Paul Banko[6]

[1] Department of Biology, University of Hawai‘i at Hilo, 200 W. Kāwili Street, Hilo, HI 96720 USA

[2] Hawai‘i Cooperative Studies Unit, University of Hawai‘i at Hilo, P.O. Box 44, Hawaii National Park, HI 96718 USA

[3] Tropical Conservation Biology and Environmental Science Program, University of Hawai‘i at Hilo, 200 W. Kāwili Street, Hilo, HI 96720 USA

[4] Departamento de Ecología, Universidad de Alicante, Spain

[5] Institute of Pacific Islands Forestry, USDA Forest Service, 30 Nowelo Street, Hilo, HI 96720 USA

[6] U.S. Geological Survey, Pacific Island Ecosystems Research Center, Kīlauea Field Station, P.O. Box 44, Hawaii National Park, HI 96718

Hawai‘i Cooperative Studies Unit
University of Hawai‘i at Hilo,
200 W. Kāwili St.
Hilo, HI 96720
(808) 933-0706

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Abstract

Leaf litter arthropods are important components of the food web in forests, and their presence and diversity can provide information on forest health. There has been very little documentation of the leaf litter arthropods in Hawaiian forest ecosystems. This technical report is a photographic guide to some common arthropods collected from forest leaf litter at the Liko Nā Pilina Hybrid Ecosystems Project study site, a lowland wet forest in Hilo, Island of Hawaiʻi, USA. Leaf litter samples were collected from plots of invaded and experimental restoration communities using two complementary methods (litterbags and quadrats), and arthropods were extracted using Berlese funnels. The field site contained many morphospecies that were rare and locally distributed across plots, and only a few that were very common and widely distributed. The majority of the morphospecies identified were mites. This photoguide is designed to help identify arthropods found in plant litter in Hawaiian lowland forests and it may assist with research and education efforts concerned with the diversity, ecology, or conservation of litter arthropods across the Hawaiian archipelago and other Pacific islands.

Introduction

Animal diversity within above-ground terrestrial food webs is generally dominated by arthropods. Arthropods within detrital food webs directly affect litter decomposition through comminution of plant material and grazing on bacteria and fungi (Seastedt 1984, Moore *et al.* 1988). Acari and Collembola often make up most arthropods in detrital communities, although larger taxa such as Diplopoda and Araneae can also be important (Anderson 1975). As consumers and decomposers, litter arthropods are the backbone of a thriving forest ecosystem by contributing ecosystem services such as nutrient cycling and decomposition. Evaluating diversity and abundance of organisms in the litter layer is one way to assess the health and potential long-term sustainability of forest ecosystems (Hartshorn 2021).

The assessment of forest health is also important during the process of forest restoration. Typically, restoration projects focus on developing the plant community with relatively little emphasis on animal communities (Fraser *et al.* 2015). Restoration ecologists often postulate that animal communities will colonize restored habitat on their own, once conditions are appropriate. However, the composition of soil and litter animal communities is likely related to the composition of the plant community, particularly in terms of structural characteristics that influence the amount of litterfall, abiotic conditions, and litter chemistry (Cole *et al.* 2016). The ways in which plant characteristics influence the composition of the litter arthropod community during restoration may provide important clues into the recovery of forest ecosystem services.

The Liko Nā Pilina Hybrid Ecosystems Project is a long-term conservation effort in Hilo, Hawaii (USA), that aims to develop techniques with which to restore native Hawaiian lowland rainforest to a more sustainable state (Cordell *et al.* 2016). Because of the extensive colonization of highly invasive plant species in lowland rainforest in this region (Zimmerman *et al.* 2008), a hybrid ecosystem approach was used (Hobbs *et al.* 2014). In this experiment, native plants, canoe plants brought to the Hawaiian archipelago by the ancient Polynesians, and functionally appropriate non-invasive non-native (i.e., introduced) species were planted together to test hypotheses assessing how plant species' characteristics influence invasion resistance and ecosystem functioning. This manipulative restoration experiment in a lowland tropical wet forest was designed such that the experimental treatments were planted communities with the same species richness but with different functional diversity (Ostertag *et al.* 2015). The design capitalized on several years of forest development to examine linkages among plant functional diversity and arthropod species community composition, richness, and diversity. Preliminary results from this study showed that oribatid mites were responsive to differing plant species (Ostertag *et al.* 2020).

This technical report is a photographic guide to the most common arthropods collected from forest leaf litter at the Liko Nā Pilina Hybrid Ecosystems Project study site. This photoguide can serve multiple purposes. Relatively little information exists for researchers to identify Hawaiian litter arthropods, particularly those inhabiting the lowland wet forest ecosystem of the Island of Hawai‘i. This report provides pictorial documentation of many of the arthropods collected during our study. This photoguide can also assist other research or education efforts concerned with the diversity, ecology, or conservation of litter arthropods in Hawaii and other Pacific islands. Due to the heavily invaded nature of lowland forest on the Island of Hawai‘i, a vast majority of the arthropods represented in this photoguide are likely non-native, but for most of them we do not know their biological origin or their geographic range. A morphospecies (i.e., a species based on recognizable morphological characteristics) photoguide can spur further research, such as questions in biogeography and range shift. The morphospecies guide is also an important taxonomic reference, which can be improved upon as new technologies and methods in DNA barcoding, systematics, and taxonomy shed light on identifying many of these morphospecies to their proper scientific name. Finally, the photos are meant to be an easy entry point for those who want to learn more about arthropods for research, education, or outreach, providing a resource for beginners to learn about arthropods in the Hawaiian Islands and other areas in the Pacific Ocean.

In this photoguide, we identified each arthropod to morphospecies. Arthropods within each morphospecies are in form and function similar enough to one another and distinguishable from other morphospecies such that we assume they are the same species biologically. In some cases, different forms that appeared to be the same taxon (e.g., juvenile and adult forms) were grouped as one morphospecies. The morphospecies concept is an attempt to make ecological sense of the diversity of the experiment. Although 154 taxa are included in this photoguide, it only represents a subset of the many morphospecies found during the study.

METHODS

Study Area

The Liko Nā Pilina Hybrid Ecosystems Project was initiated with clearing and planting in 2013 and in field measurements in 2014 (Ostertag *et al.* 2015). The experiment is located within the Keaukaha Military Reservation (KMR; 19°42’15” N, -155°2’40” W) in Hilo, Hawaii, USA. The area has an elevation of 30 m, mean annual rainfall of approximately 3300 mm/yr, and mean annual temperature of approximately 23°C. KMR is classified as lowland wet forest (Price *et al.* 2007), and like many Hawaiian locations within this forest type, is heavily colonized by non-native (often invasive) plant species (Zimmerman *et al.* 2008, Ostertag *et al.* 2009; Figure 1). At the beginning of the project, all non-native plant species were cleared in 20 x 20 m plots with a 5 m perimeter buffer. The experimental setup consisted of four blocks (Figure 2). Four of the treatments are experimental plantings of 10 species per treatment, and the fifth treatment serves as a reference, which represents the forest without any clearing or planting (Figure 2).

Figure 1. Examples of lowland wet forest at the Liko Nā Pilina Hybrid Ecosystems Project study site. A reference treatment of invaded forest is shown in the left panel, and a restoration treatment is shown in the right panel. During project development, introduced plant species were removed from treatment plots and replaced with pre-determined suites of native and non-invasive introduced species. Photos by Nicole DiManno.

Field and Laboratory Protocols

The litter arthropods represented in this photoguide were collected from the field site in two ways: using litterbags and quadrats. The two sampling methods were designed to be complementary in our evaluation of the arthropod response to restoration at the study site. Litterbags allowed us to assess changes in the arthropod community over time as litter decomposed, but the arthropod community was restricted to those small enough to pass through the mesh. In contrast, quadrat samples collected all arthropods, regardless of size, but the decomposition stage of the litter within each sample was unknown.

Litterbags consisted of two 34 x 24 cm panels of mesh—the top made of white nylon with 6.35 mm holes, and the bottom made from black window screening with 1 mm holes. The larger openings at the top were designed to allow small arthropods to move freely into and out of the litterbags while the smaller openings on the bottom confined litter to the bag. Fifteen grams of oven-dried (70°C) leaf litter collected in the study plots was placed in each litterbag. The composition of litter within each bag represented litterfall for the combination of plants within the plots in which they were placed. Four prepared litterbags were placed near the center of each plot during July 2019 (Figure 3). One of the four bags was retrieved after 1, 2, 4, and 6 months to assess changes in the arthropod community associated with litter decomposition. Upon collection, litterbags were placed in a sealable plastic bag and transported back to the lab.

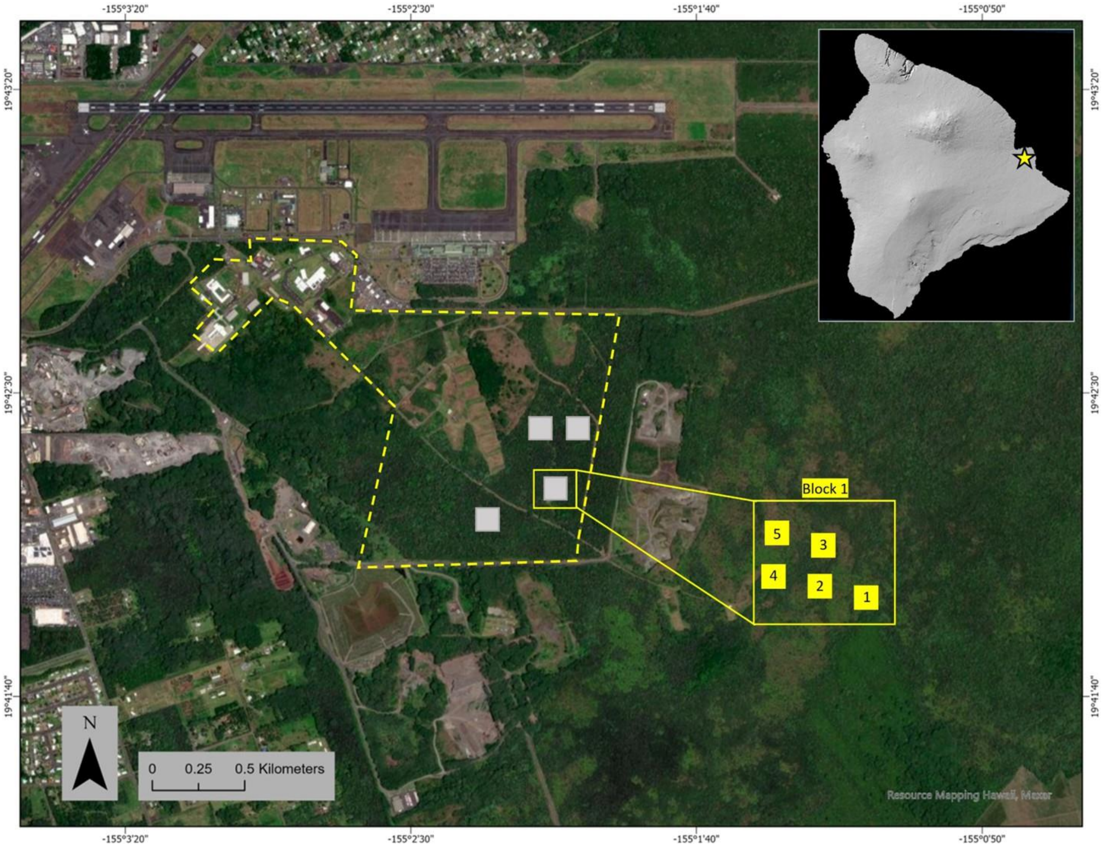


Figure 2. The Liko Nā Pilina Hybrid Ecosystems Project study site located within the Keaukaha Military Reservation (dotted polygon), Hilo, Hawaii. During 2013, non-native plant species were removed from experimental plots within the invaded lowland wet forest at the study site. An experimental design was established containing 20 plots arranged in four blocks (gray squares). Each block had four different combinations of outplanted species and an untreated reference plot (example of Block 1 expanded in yellow). World Imagery GIS layer provided by Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 3. Field and lab procedures used during the study. Litterbags were deployed in the field (left), retrieved after specified amounts of time, and placed into Berlese funnels (center) to extract arthropods. An example of the arthropods extracted from one litterbag is shown in the right panel. Photos by Trebor Hall.

For quadrat sampling, a 0.25 x 0.25 m PVC (polyvinyl chloride) frame was placed on the ground at four randomly identified locations within each plot during each sampling event, and all litter within the frame was collected using a putty knife and placed into a 1-gallon sealable plastic bag. Four samples were taken from each plot 1, 4, and 6 months after the study began (concurrent with litterbag collection).

For both sampling methods, plastic bags containing litter were immediately placed in a chilled cooler and returned to the lab where the arthropods were extracted from the litter with Berlese funnels (Figure 3). For the quadrat samples, the four samples from each plot were pooled for extraction.

Arthropods were extracted from litter by placing the contents of the plastic bags into Berlese funnel traps (Bioquip, Rancho Dominguez, California; Figure 3). Berlese funnels utilize heat generated by 43 W incandescent bulbs placed at the top of the funnel to drive arthropods out of the litter into a 9 g collection vial containing propylene glycol (50%) and a drop of dish soap located at the bottom of the trap. Extraction was allowed to proceed until the litter was dry to touch; typically, 3–5 days depending on the moisture content of the leaf litter. Arthropods were then separated from debris (generally small pieces of organic matter) and transferred to 2-dram vials containing isopropyl alcohol (70%) for preservation. Morphospecies level determinations and counts of individuals were made using stereomicroscopes (AmScope, Irvine, California; Leica Microsystems, Deerfield, Illinois).

Although some flying insects are common inhabitants of the litter, our sampling methods are generally ineffective at capturing these taxa. As a result, we did not include highly vagile, winged insects such as adult Diptera, Hymenoptera, and Lepidoptera in this photoguide.

Arthropods were identified using taxonomic keys (e.g., Zimmerman 1948a,b,c; Christiansen and Bellinger 1992; Krantz 2009; Behan-Pelletier and Lindo 2022) and comparison to previously identified reference material. The level of identification varied greatly among morphospecies, ranging from order to species. All taxa have been given a morphospecies name representing the highest level of identification obtained (Table 1). Acari were particularly difficult to identify due to their small size, morphological variability among life stages, and a generally poor taxonomic knowledge of the Hawaiian lowland fauna. Therefore, it is possible that one or more of our morphospecies represent the same species. Taxon names with only one undetermined morphospecies are followed by "sp." (e.g., Hemiptera sp., *Cylindroiulus* sp.). In contrast, taxon names with multiple undetermined morphospecies are followed by "sp. 1, sp. 2," etc. (e.g., Gamasina sp. 1, Gamasina sp. 2). In addition, some determinations are provisional, and in these cases, names are preceded by the qualifying terms "probably" (abbreviated "prob.") or "cf" (meaning "to compare"). The term "prob." indicates less certainty than "cf." and is used informally here to point the reader to a likely determination. In contrast, "cf." indicates that most morphological characteristics bear significant resemblance to the species name that follows, but requires further study, including comparison to known material (Sigovini *et al.* 2016). The use of "cf." is limited to species-level determinations. The taxonomic nomenclature used in the classification table follows the Integrated Taxonomic Information System (ITIS; www.itis.gov) and Catalogue of Life (www.catalogueoflife.org) databases. The majority of the morphospecies in this photoguide are mites, and having some reference on aspects of shape, size, and color can be helpful (Figure 4). Many of the arthropods collected during this study are shown in Figures 5–20.

Table 1. Classification, abundance, and occurrence of arthropods collected in litter at the Liko Nā Pilina Hybrid Ecosystems Project study site included in this photoguide. The abundance of each morphospecies was classified relative to the abundance of the most abundant morphospecies and categorized as abundant (making up >25% of the most abundant), common (10–25%), uncommon (1–10%), and rare (<1%). Occurrence (%) refers to the percentage of litterbags in which each morphospecies was found. Taxa indicated by “n/a” in the Abundance and Occurrence columns were only collected using the quadrat method and therefore not included in these metrics.

Class Order	Family	Genus	Species	Photoguide name	Abundance	Occurrence (%)
Arachnida						
Araneae	Anapidae	*Pseudanapis*	*aloha*	*Pseudanapis aloha*	rare	7.9
Araneae	Linyphiidae	unknown	unknown	Linyphiidae sp.	uncommon	50.8
Araneae	unknown	unknown	unknown	Araneae sp.1	rare	2.1
Araneae	unknown	unknown	unknown	Araneae sp. 2	rare	8.3
Mesostigmata	Ascidae	*Asca*	unknown	*Asca* sp.	common	72.5
Mesostigmata	Blattisociidae	*Cheiroseius*	unknown	*Cheiroseius* sp.	uncommon	47.1
Mesostigmata	Blattisociidae	unknown	unknown	Blattosociidae sp.	uncommon	45.0
Mesostigmata	Eviphididae	*Evimirus*	unknown	*Evimirus* sp.	uncommon	31.3
Mesostigmata	Laelapidae	*Pseudoparasitus*	unknown	*Pseudoparasitus* sp.	rare	14.6
Mesostigmata	Ologamasidae	unknown	unknown	Ologamasidae sp.	n/a	n/a
Mesostigmata	Parasitidae	prob. *Pergamasus*	unknown	prob. *Pergamasus* sp.	n/a	n/a
Mesostigmata	Parasitidae	unknown	unknown	Parasitidae sp.	n/a	n/a
Mesostigmata	Phytoseiidae	unknown	unknown	Phytoseiidae sp. 1	rare	5.4
Mesostigmata	Phytoseiidae	unknown	unknown	Phytoseiidae sp. 2	rare	4.6
Mesostigmata	Phytoseiidae	unknown	unknown	Phytoseiidae sp. 3	rare	2.1
Mesostigmata	Podocinidae	*Podocinum*	cf. *sagax*	*Podocinum* cf. *sagax*	uncommon	50.4
Mesostigmata	Triplogyniidae	unknown	unknown	Triplogyniidae sp. 1	rare	7.9
Mesostigmata	Triplogyniidae	unknown	unknown	Triplogyniidae sp. 2	rare	0.8
Mesostigmata	Uropodidae	unknown	unknown	Uropodidae sp. 1	rare	18.3
Mesostigmata	Uropodidae	unknown	unknown	Uropodidae sp. 2	n/a	n/a
Mesostigmata	Veigaiidae	unknown	unknown	Veigaiidae sp.	rare	7.5
Mesostigmata	Veigaiidae	*Veigaia*	unknown	*Veigaia* sp.	rare	67.1

Class Order	Family	Genus	Species	Photoguide name	Abundance	Occurrence (%)
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 1	uncommon	57.9
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 2	uncommon	54.6
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 3	uncommon	28.8
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 4	uncommon	27.5
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 5	rare	27.9
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 6	rare	11.3
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 7	rare	3.3
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 8	rare	0.4
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 9	rare	0.4
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 10	n/a	n/a
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 11	rare	0.4
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 12	rare	0.8
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 13	rare	13.3
Mesostigmata	unknown	unknown	unknown	Gamasina sp. 14	n/a	n/a
Mesostigmata	unknown	unknown	unknown	Mesostigmata sp.	rare	0.8
Mesostigmata	unknown	unknown	unknown	Uropodina sp.	rare	12.9
Pseudoscorpiones	unknown	unknown	unknown	Pseudoscorpiones sp.	rare	0.4
Sarcoptiformes	Autognetidae	*Autogneta*	unknown	*Autogneta* sp.	rare	0.4
Sarcoptiformes	Brachychthoniidae	*Liochthonius*	cf. *lapponicus*	*Liochthonius* cf. *lapponicus*	rare	0.4
Sarcoptiformes	Carabodidae	*Gibbicepheus*	unknown	*Gibbicepheus* sp.	rare	12.5
Sarcoptiformes	Cymbaeremaeidae	*Scapheremaeus*	unknown	*Scapheremaeus* sp.	rare	0.8
Sarcoptiformes	Eniochthoniidae	*Hypochthoniella*	unknown	*Hypochthoniella* sp.	n/a	n/a
Sarcoptiformes	Eniochthoniidae	prob. *Hypochthoniella*	unknown	prob. *Hypochthoniella* sp.	n/a	n/a
Sarcoptiformes	Eremulidae	*Eremulus*	cf. *truncatus*	*Eremulus* cf. *truncatus*	uncommon	68.8
Sarcoptiformes	Euphthiracaridae	*Acrotritia*	*ardua*	*Acrotritia ardua*	uncommon	63.3
Sarcoptiformes	Galumnidae	*Allogalumna*	cf. *upoluensis*	*Allogalumna* cf. *upoluensis*	rare	80.4

Class Order	Family	Genus	Species	Photoguide name	Abundance	Occurrence (%)
Sarcoptiformes	Galumnidae	*Pergalumna*	cf. *altera*	*Pergalumna* cf. *altera*	common	2.9
Sarcoptiformes	Haplozetidae	*Rostrozetes*	cf. *ovulum*	*Rostrozetes* cf. *ovulum*	rare	12.5
Sarcoptiformes	Hypochthoniidae	unknown	unknown	Hypochthoniidae sp.	n/a	n/a
Sarcoptiformes	Malaconothridae	*Malaconothrus*	prob. *monodactylus*	*Malaconothrus prob. monodactylus*	n/a	n/a
Sarcoptiformes	Malaconothridae	*Tyrphonothrus*	unknown	*Tyrphonothrus* sp. 1	uncommon	60.4
Sarcoptiformes	Malaconothridae	*Tyrphonothrus*	unknown	*Tyrphonothrus* sp. 2	uncommon	54.6
Sarcoptiformes	Microzetidae	*Berlesezetes*	unknown	*Berlesezetes* sp.	rare	22.1
Sarcoptiformes	Nanhermanniidae	*Masthermannia*	unknown	*Masthermannia* sp.	rare	7.1
Sarcoptiformes	Nanhermanniidae	*Nanhermannia*	unknown	*Nanhermannia* sp.	n/a	n/a
Sarcoptiformes	Nothridae	*Nothrus*	cf. *oceanicus*	*Nothrus* cf. *oceanicus*	common	72.1
Sarcoptiformes	Nothridae	prob. *Nothrus*	unknown	prob. *Nothrus*	n/a	n/a
Sarcoptiformes	Oribatellidae	*Lamellobates*	cf. *misella*	*Lamellobates* cf. *misella*	uncommon	31.3
Sarcoptiformes	Oribatulidae	*Gerloubia*	unknown	*Gerloubia* sp.	uncommon	55
Sarcoptiformes	Phthiracaridae	*Phthiracarus*	unknown	*Phthiracarus* sp.	common	82.9
Sarcoptiformes	Scheloribatidae	*Scheloribates*	unknown	*Scheloribates* sp. 1	uncommon	43.8
Sarcoptiformes	Scheloribatidae	*Scheloribates*	unknown	*Scheloribates* sp. 2	n/a	n/a
Sarcoptiformes	Suctobelbidae	*Suctobelbella*	unknown	*Suctobelbella* sp.	uncommon	64.2
Sarcoptiformes	Tectocepheidae	*Tectocepheus*	prob. *velatus*	*Tectocepheus* prob. *velatus*	n/a	n/a
Sarcoptiformes	Trhypochthoniidae	*Afronothrus*	*incisivus*	*Afronothrus incisivus*	uncommon	52.1
Sarcoptiformes	Trhypochthoniidae	*Allonothrus*	unknown	*Allonothrus* sp.	common	60.8
Sarcoptiformes	Trhypochthoniidae	*Archegozetes*	cf. *magnus*	*Archegozetes* cf. *magnus*	abundant	96.7
Sarcoptiformes	Trhypochthoniidae	unknown	unknown	Trhypochthoniidae sp. 1	rare	12.9
Sarcoptiformes	unknown	unknown	unknown	Cepheoidea sp.	rare	2.9
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 1	n/a	n/a

Class Order	Family	Genus	Species	Photoguide name	Abundance	Occurrence (%)
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 2	rare	12.5
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 3	rare	0.8
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 4	uncommon	56.7
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 5	rare	13.3
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 6	rare	8.8
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 7	rare	1.3
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 8	n/a	n/a
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 9	n/a	n/a
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 10	rare	5.4
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 11	rare	1.7
Sarcoptiformes	unknown	unknown	unknown	Oribatida sp. 12	n/a	n/a
Sarcoptiformes	unknown	unknown	unknown	Astigmata sp. 1	rare	1.3
Sarcoptiformes	unknown	unknown	unknown	Astigmata sp. 2	rare	5.8
Sarcoptiformes	unknown	unknown	unknown	Astigmata sp. 3	rare	0.4
Trombidiformes	Bdellidae	unknown	unknown	Bdellidae sp. 1	rare	56.7
Trombidiformes	Bdellidae	unknown	unknown	Bdellidae sp. 2	rare	2.5
Trombidiformes	Bdellidae	unknown	unknown	Bdellidae sp. 3	rare	16.3
Trombidiformes	Bdellidae	unknown	unknown	Bdellidae sp. 4	uncommon	37.5
Trombidiformes	Cunaxidae	*Armascirus*	unknown	*Armascirus* sp.	rare	4.2
Trombidiformes	Cunaxidae	*Cunaxa*	unknown	*Cunaxa* sp.	rare	0.4
Trombidiformes	Eupodidae	unknown	unknown	Eupodidae sp.	n/a	n/a
Trombidiformes	Penthalodidae	unknown	unknown	Penthalodidae sp. 1	n/a	n/a
Trombidiformes	Penthalodidae	unknown	unknown	Penthalodidae sp. 2	rare	1.3
Trombidiformes	Stigmaeidae	unknown	unknown	Stigmaeidae sp.	rare	2.9
Chilopoda						
Geophilomorpha	Mecistocephalidae	unknown	unknown	Mecistocephalidae sp.	rare	4.2
Scolopendromorpha	Scolopendridae	unknown	unknown	Scolopendridae sp.	rare	5

Class Order	Family	Genus	Species	Photoguide name	Abundance	Occurrence (%)
Diplopoda						
Polydesmida	Paradoxosomatidae	unknown	unknown	Paradoxosomatidae sp.	rare	5.4
Polydesmida	Pyrgodesmidae	unknown	unknown	Pyrgodesmidae sp.	uncommon	42.5
Polyzoniida	unknown	unknown	unknown	Polyzoniida sp.	n/a	n/a
Spirobolida	unknown	unknown	unknown	Spirobolida sp.	uncommon	50.0
Spirostreptida	Cambalopsidae	*Cylindroiulus*	unknown	*Cylindroiulus* sp.	rare	18.3
Collembola						
Entomobryomorpha	Entomobryidae	unknown	unknown	Entomobryidae sp.	uncommon	65.0
Entomobryomorpha	Isotomidae	unknown	unknown	Isotomidae sp.	uncommon	56.7
Poduromorpha	Hypogastruridae	unknown	unknown	Hypogastruridae sp.	rare	14.2
Poduromorpha	Neanuridae	unknown	unknown	Neanuridae sp.	uncommon	37.9
Poduromorpha	Onychiuridae	unknown	unknown	Onychiuridae sp.	common	63.3
Poduromorpha	Sminthuridae	unknown	unknown	Sminthuridae sp.	uncommon	41.3
Insecta						
Coleoptera	Coccinellidae	*Scymnus*	unknown	*Scymnus* sp.	n/a	n/a
Coleoptera	Corylophidae	unknown	unknown	Corylophidae sp.	rare	2.9
Coleoptera	Curculionidae	*Coccotrypes*	unknown	*Coccotrypes* sp.	rare	6.7
Coleoptera	Curculionidae	*Hypothenemus*	cf. *eruditus*	*Hypothenemus* cf. *eruditis*	n/a	n/a
Coleoptera	Curculionidae	*Hypothenemus*	unknown	*Hypothenemus* sp.	n/a	n/a
Coleoptera	Curculionidae	unknown	unknown	Curculionidae sp. 1	rare	6.7
Coleoptera	Curculionidae	unknown	unknown	Curculionidae sp. 2	rare	5.8
Coleoptera	Nitidulidae	*Stelidota*	*geminata*	*Stelidota geminata*	rare	2.9
Coleoptera	Ptiliidae	*Acrotrichis*	*discoloroides*	*Acrotrichis discoloroides*	rare	5.4
Coleoptera	Ptinidae	unknown	unknown	Ptinidae sp.	rare	0.4
Coleoptera	Staphylinidae	unknown	unknown	Staphylinidae sp.	rare	3.8

Class Order	Family	Genus	Species	Photoguide name	Abundance	Occurrence (%)
Diptera	unknown	unknown	unknown	Diptera sp. 1	rare	4.2
Diptera	unknown	unknown	unknown	Diptera sp. 2	n/a	n/a
Hemiptera	Derbidae	unknown	unknown	Derbidae sp.	uncommon	44.2
Hemiptera	Cydnidae	*Fromundus*	*pygmaeus*	*Fromundus pygmaeus*	rare	13.8
Hemiptera	Eriococcidae	unknown	unknown	Ericoccidae sp.	rare	4.6
Hemiptera	Lygaeidae	unknown	unknown	Lygaeidae sp. 1	rare	5.4
Hemiptera	Lygaeidae	unknown	unknown	Lygaeidae sp. 2	rare	1.3
Hemiptera	Reduviidae	unknown	unknown	Reduviidae sp.	rare	0.8
Hemiptera	unknown	unknown	unknown	Coccoidea sp. 1	rare	0.4
Hemiptera	unknown	unknown	unknown	Coccoidea sp. 2	rare	0.4
Hymenoptera	Formicidae	*Anoplolepis*	*gracilipes*	*Anoplolepis gracilipes*	rare	1.7
Hymenoptera	Formicidae	*Hypoponera*	*punctatissima*	*Hypoponera punctatissima*	rare	1.7
Hymenoptera	Formicidae	*Nylanderia*	*vaga*	*Nylanderia vaga*	rare	0.4
Hymenoptera	Formicidae	*Pheidole*	*megacephala*	*Pheidole megacephala*	rare	$5.0
Hymenoptera	Formicidae	*Solenopsis*	*papuana*	*Solenopsis papuana*	uncommon	55.8
Hymenoptera	Formicidae	*Strumigenys*	*rogeri*	*Strumigenys rogeri*	uncommon	55.4
Hymenoptera	Formicidae	*Tapinoma*	*melanocephalum*	*Tapinoma melanocephalum*	uncommon	3.3
Hymenoptera	Formicidae	*Wasmannia*	*auropunctata*	*Wasmannia auropunctata*	rare	2.1
Lepidoptera	unknown	unknown	unknown	Lepidoptera sp.	n/a	n/a
Psocodea	Liposcelididae	unknown	unknown	Liposcelididae sp.	rare	4.2
Psocodea	Trogiidae	unknown	unknown	Trogiidae sp.	rare	2.5
Psocodea	unknown	unknown	unknown	Psocodea sp. 1	rare	0.8
Psocodea	unknown	unknown	unknown	Psocodea sp. 2	uncommon	22.1
Psocodea	unknown	unknown	unknown	Psocodea sp. 3	rare	6.3
Thysanoptera	Phlaeothripidae	unknown	unknown	Phlaeothripidae sp.	rare	3.3

Class Order	Family	Genus	Species	Photoguide name	Abundance	Occurrence (%)
Thysanoptera	Thripidae	*Anisopilothrips*	*venustulus*	*Anisopilothrips venustulus*	rare	3.8
Thysanoptera	unknown	unknown	unknown	Thysanoptera sp. 1	rare	7.1
Thysanoptera	unknown	unknown	unknown	Thysanoptera sp. 2	rare	0.8
Thysanoptera	unknown	unknown	unknown	Thysanoptera sp. 3	rare	1.7
Malacostraca						
Isopoda	unknown	unknown	unknown	Isopoda sp.	uncommon	66.7
Undetermined						
Unknown	unknown	unknown	unknown	Unknown sp. 1	rare	3.8
Unknown	unknown	unknown	unknown	Unknown sp. 2	n/a	n/a
Unknown	unknown	unknown	unknown	Unknown sp. 3	n/a	n/a
Unknown	unknown	unknown	unknown	Unknown sp. 4	n/a	n/a

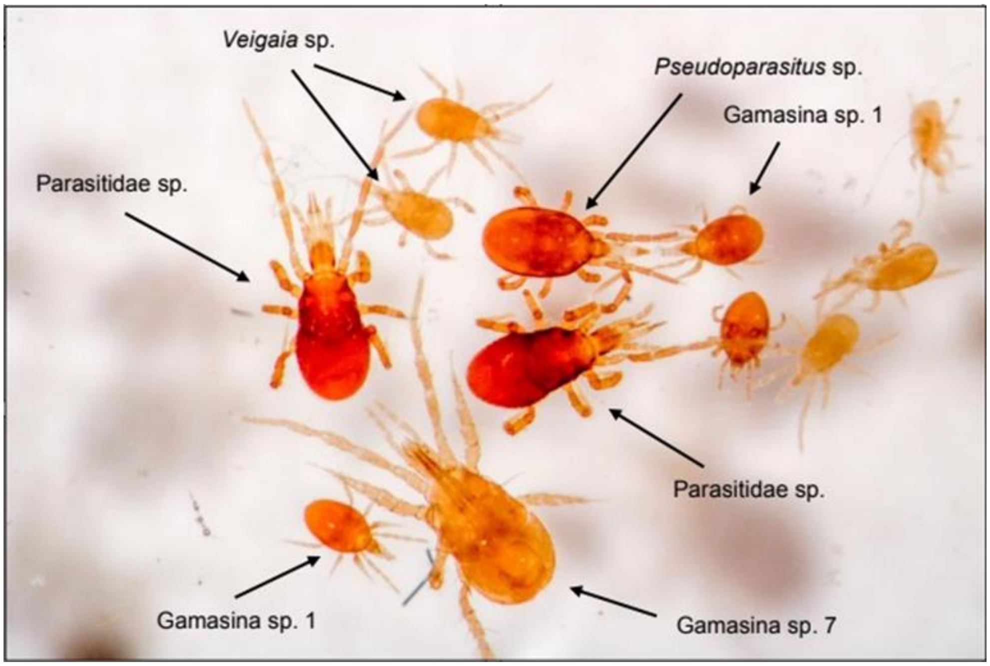


Figure 4. Comparison of mesostigmatid mites collected at the Liko Nā Pilina Hybrid Ecosystems Project study site. These five morphospecies illustrate the general similarity in body shape and color but highlight relative size differences among taxa. Photo by Robert Peck.

We report the abundance of arthropods found in litterbag samples in two ways: percent abundance and frequency of occurrence. Percent abundance is based on total numbers of individuals and indicates the abundance of an individual taxon relative to the abundance of the most abundant taxon (Sarcoptiformes, Trhypochthoniidae, *Archegozetes* cf. *magnus*). Percent abundance is represented as rare (<1%), uncommon (1–10%), or common (10–25%); no taxa comprised more than 25% of the most common taxon. In contrast, frequency of occurrence indicates the proportion of litterbag samples in which one or more individuals of a particular taxon was found among all litterbag samples. We excluded arthropods collected in quadrats in this quantitative summary because sampling methodology would be expected to yield different relative abundances than litterbags, and comparatively few quadrat samples were processed.

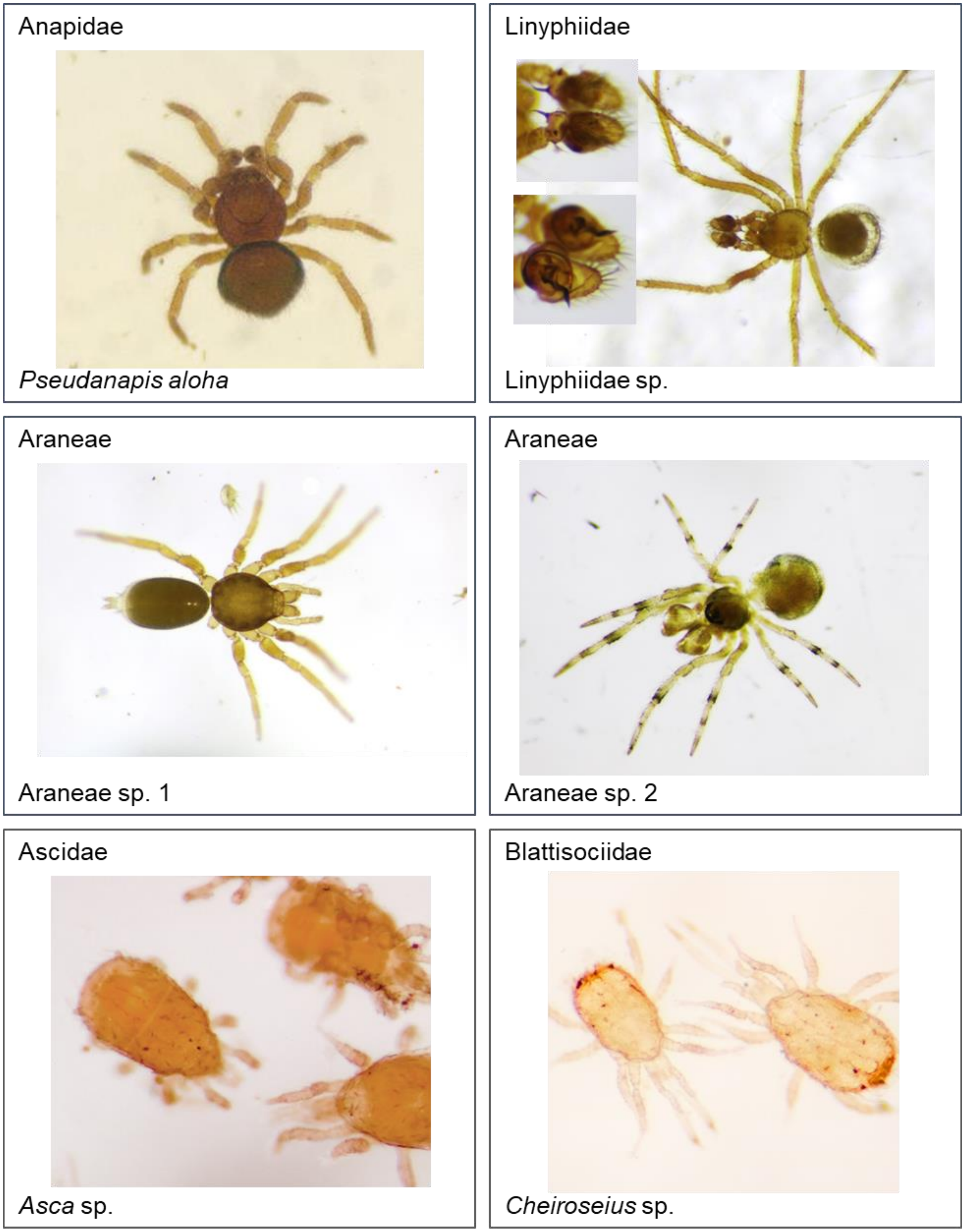


Figure 5. Arachnida (Araneae and Mesostigmata) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Blattisociidae

Blattisociidae sp.

Eviphididae

Evimirus sp.

Laelapidae

Pseudoparasitus sp.

Ologamasidae

Ologamasidae sp.

Parasitidae

Probably *Pergamasus* sp.

Parasitidae

Parasitidae sp.

Figure 6. Arachnida (Mesostigmata) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Phytoseiidae

Phytoseiidae sp. 1

Phytoseiidae

Phytoseiidae sp. 2

Phytoseiidae

Phytoseiidae sp. 3

Podocinidae

Podocinum cf. *sagax*

Triplogyniidae

Triplogyniidae sp. 1

Triplogyniidae

Triplogyniidae sp. 2

Figure 7. Arachnida (Mesostigmata) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

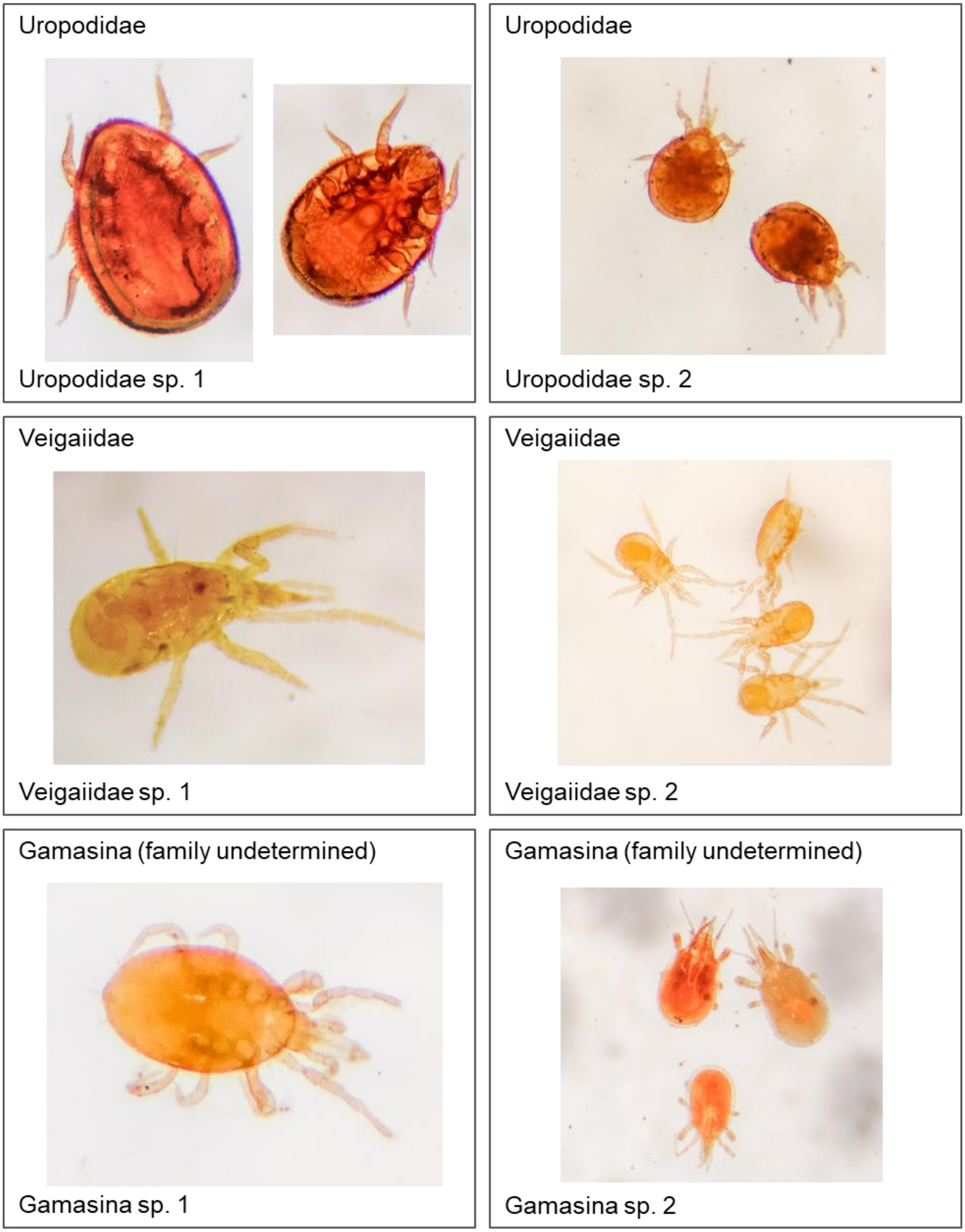
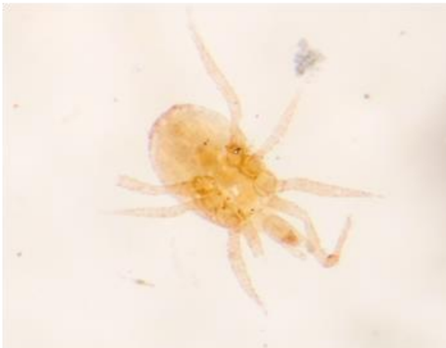


Figure 8. Arachnida (Mesostigmata) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Gamasina (family undetermined)



Gamasina sp. 3

Gamasina (family undetermined)

Gamasina sp. 4

Gamasina (family undetermined)

Gamasina sp. 5

Gamasina (family undetermined)

Gamasina sp.6

Gamasina (family undetermined)

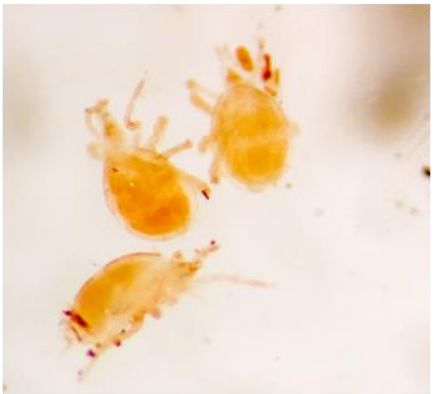
Gamasina sp.7

Gamasina (family undetermined)

Gamasina sp.8

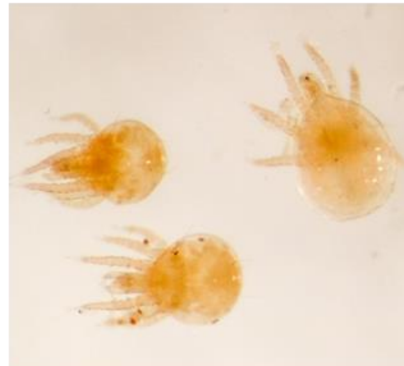
Figure 9. Arachnida (Mesostigmata) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Gamasina (family undetermined)



Gamasina sp.9

Gamasina (family undetermined)

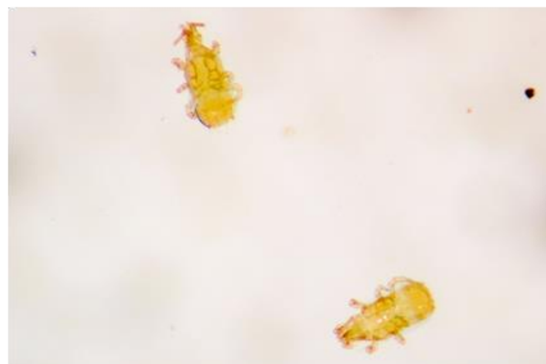


Gamasina sp. 10

Gamasina (family undetermined)

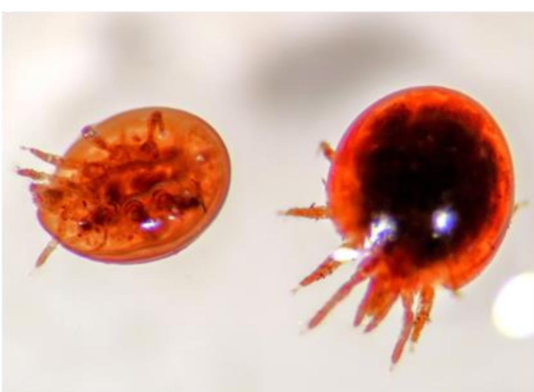
Gamasina sp. 11

Gamasina (family undetermined)



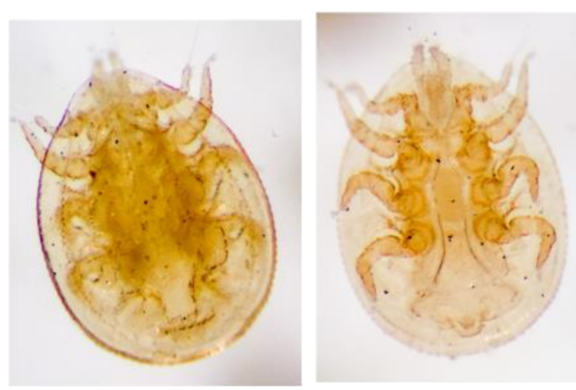
Gamasina sp. 12

Gamasina (family undetermined)



Gamasina sp. 13

Gamasina (family undetermined)



Gamasina sp. 14

Figure 10. Arachnida (Mesostigmata) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

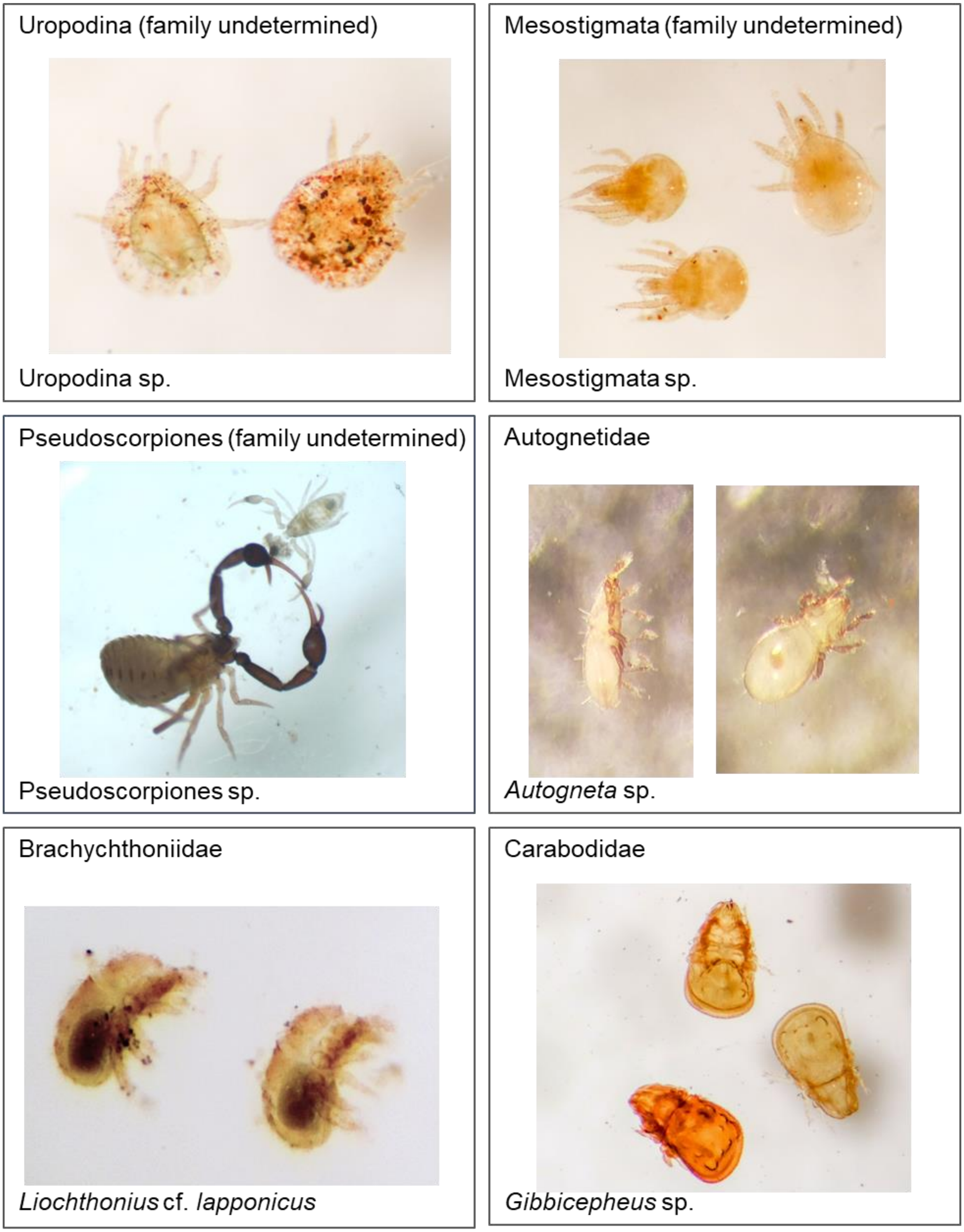


Figure 11. Arachnida (Mesostigmata, Pseudoscorpiones, and Sarcoptiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

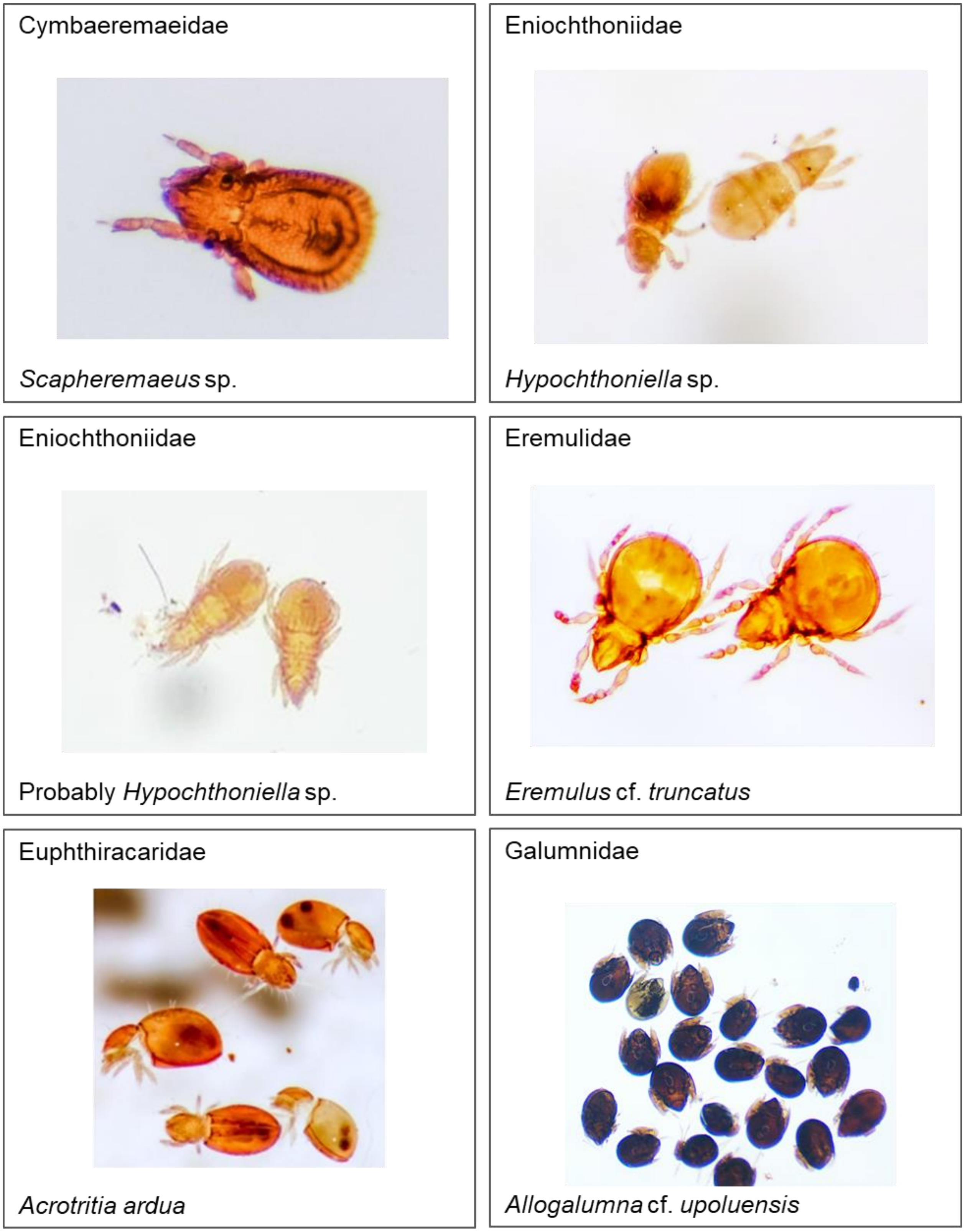
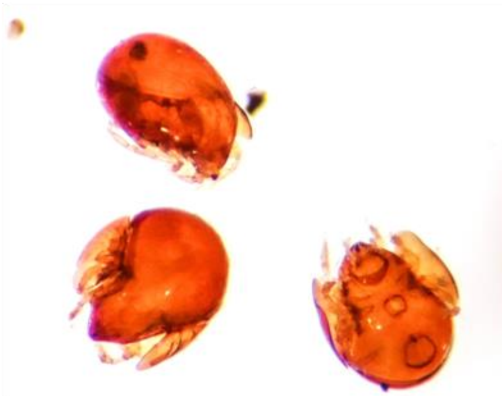


Figure 12. Arachnida (Sarcoptiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Galumnidae



Pergalumna cf. *altera*

Haplozetidae

Rostrozetes cf. *ovulum*

Hypochthoniidae

Hypochthoniidae sp.

Malaconothridae

Malaconothrus prob. *monodactylus*

Malaconothridae

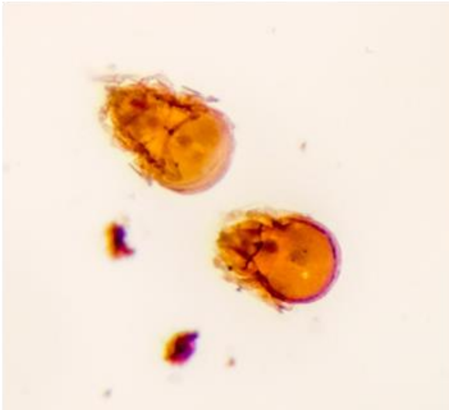
Tyrphonothrus sp. 1

Malaconothridae

Tyrphonothrus sp. 2

Figure 13. Arachnida (Sarcoptiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Microzetidae



Berlesezetes sp.

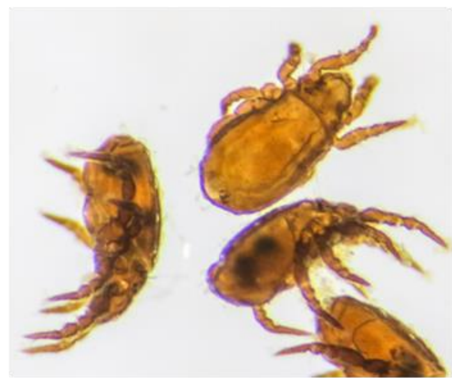
Nanhermanniidae

Masthermannia sp.

Nanhermanniidae

Nanhermannia sp.

Nothridae

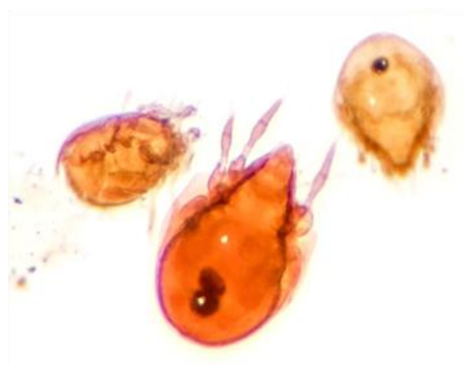


Probably *Nothrus* sp.

Nothridae

Nothrus cf. *oceanicus*

Oribatellidae



Lamellobates cf. *misella*

Figure 14. Arachnida (Sarcoptiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Oribatulidae

Gerloubia sp.

Phthiracaridae

Phthiracarus sp.

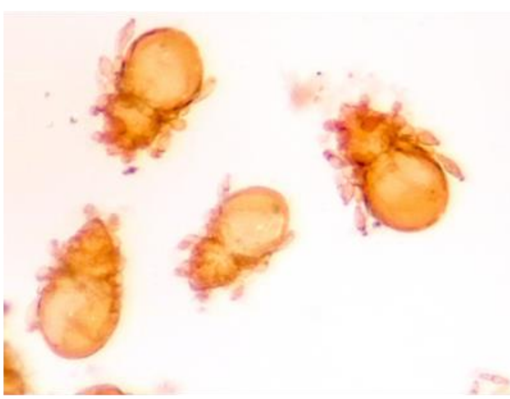
Scheloribatidae

Scheloribates sp. 1

Scheloribatidae

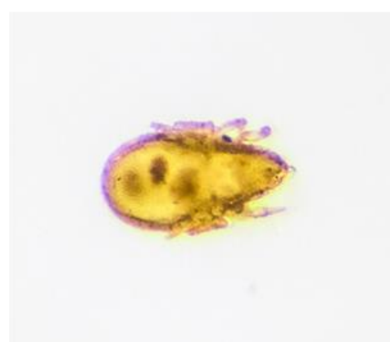
Scheloribates sp. 2

Suctobelbidae



Suctobelbella sp.

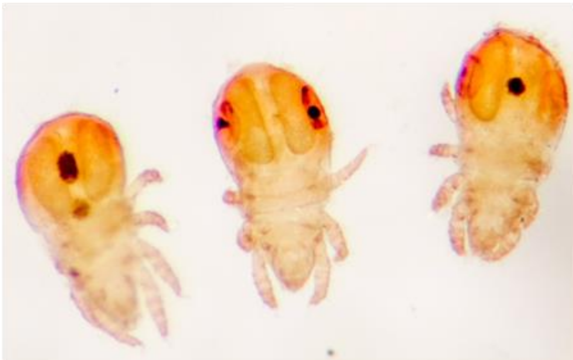
Tectocepheidae



Tectocepheus prob. *velatus*

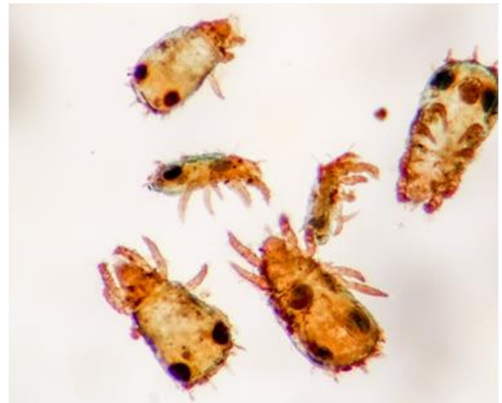
Figure 15. Arachnida (Sarcoptiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Trhypochthoniidae



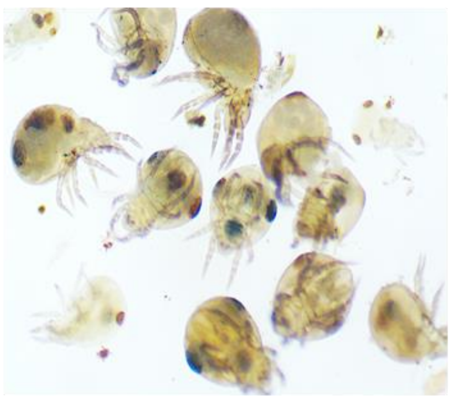
Afronothrus incisivus

Trhypochthoniidae



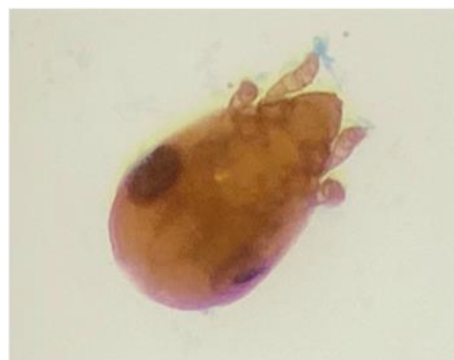
Allonothrus sp.

Trhypochthoniidae



Archegozetes cf. *magnus*

Trhypochthoniidae

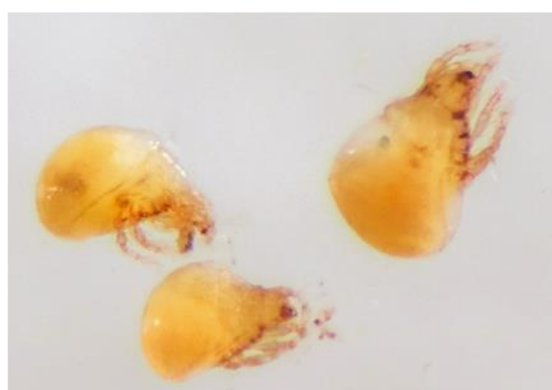


Trhypochthoniidae sp.

Cepheoidea (family undetermined)

Cepheoidea sp.

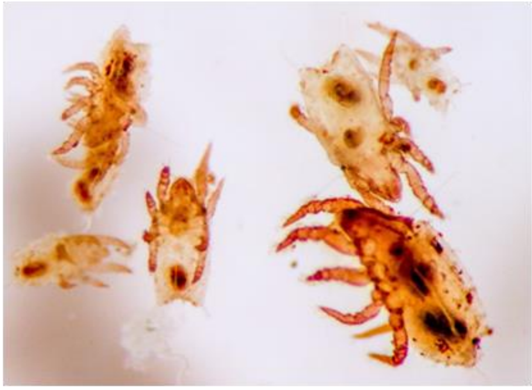
Sarcoptiformes (family undetermined)



Oribatida sp. 1

Figure 16. Arachnida (Sarcoptiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Sarcoptiformes (family undetermined)

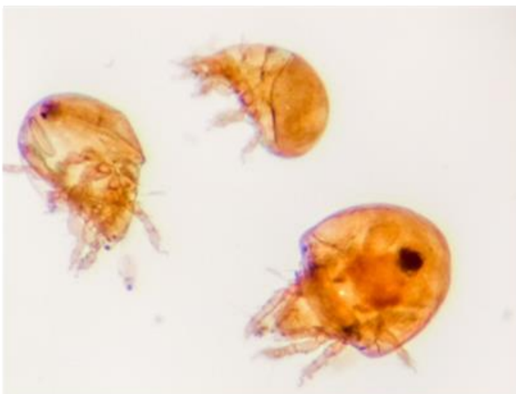


Oribatida sp. 2

Sarcoptiformes (family undetermined)

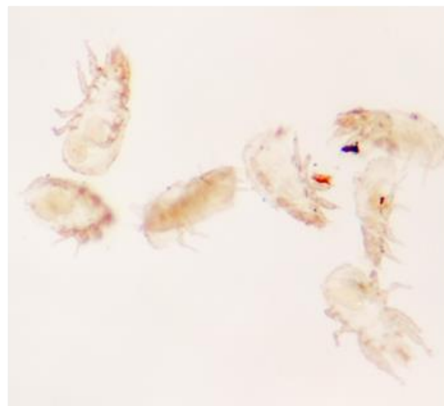
Oribatida sp. 3

Sarcoptiformes (family undetermined)



Oribatida sp. 4

Sarcoptiformes (family undetermined)

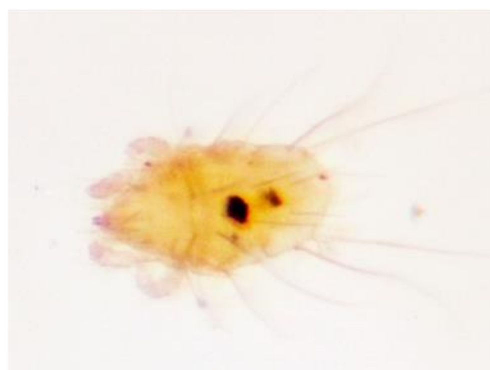


Oribatida sp. 5

Sarcoptiformes (family undetermined)

Oribatida sp. 6

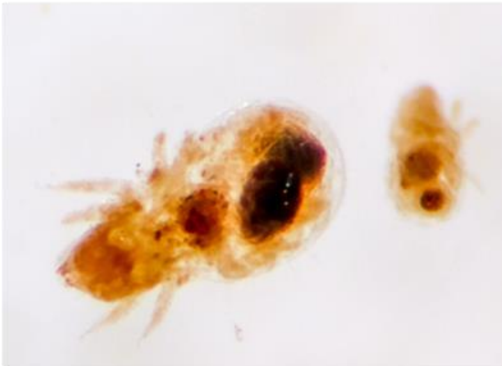
Sarcoptiformes (family undetermined)



Oribatida sp. 7

Figure 17. Arachnida (Sarcoptiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Sarcoptiformes (family undetermined)

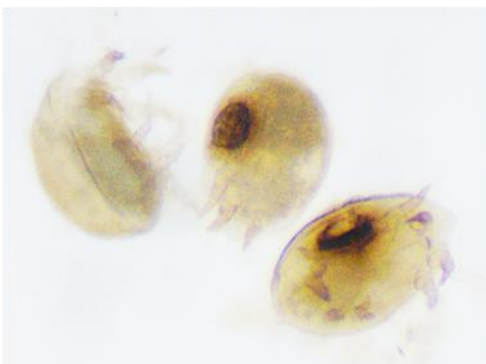


Oribatida sp. 8

Sarcoptiformes (family undetermined)

Oribatida sp. 9

Sarcoptiformes (family undetermined)

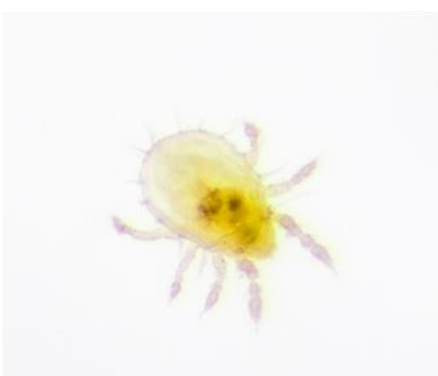


Oribatida sp. 10

Sarcoptiformes (family undetermined)

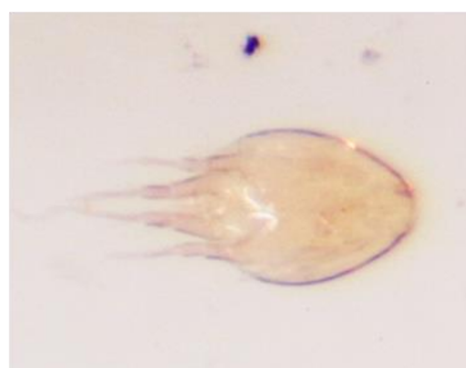
Oribatida sp. 11

Sarcoptiformes (family undetermined)



Oribatida sp. 12

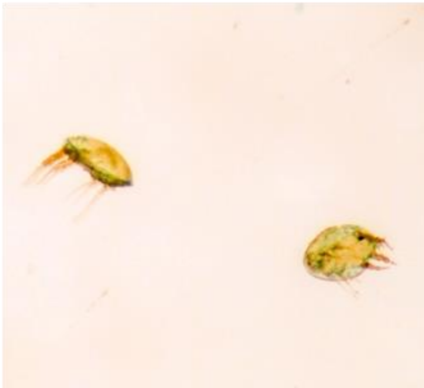
Sarcoptiformes (family undetermined)



Astigmata sp. 1

Figure 18. Arachnida (Sarcoptiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Sarcoptiformes (family undetermined)



Astigmata sp 2

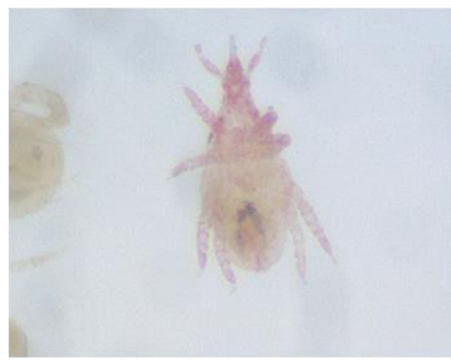
Sarcoptiformes (family undetermined)

Astigmata sp. 3

Bdellidae

Bdellidae sp. 1

Bdellidae



Bdellidae sp. 2

Bdellidae

Bdellidae sp. 3

Bdellidae

Bdellidae sp. 4

Figure 19. Arachnida (Sarcoptiformes and Trombidiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Cunaxidae

Armascirus sp.

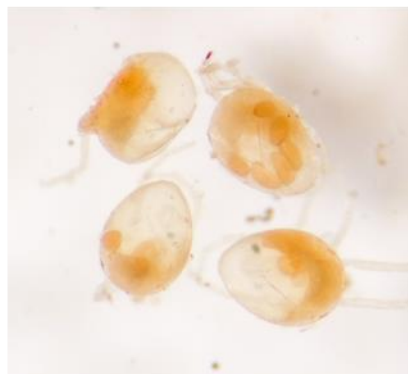
Cunaxidae

Cunaxa sp.

Eupodidae

Eupodidae sp.

Penthalodidae



Penthalodidae sp. 1

Penthalodidae

Penthalodidae sp. 2

Stigmaeidae

Stigmaeidae sp.

Figure 20. Arachnida (Trombidiformes) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

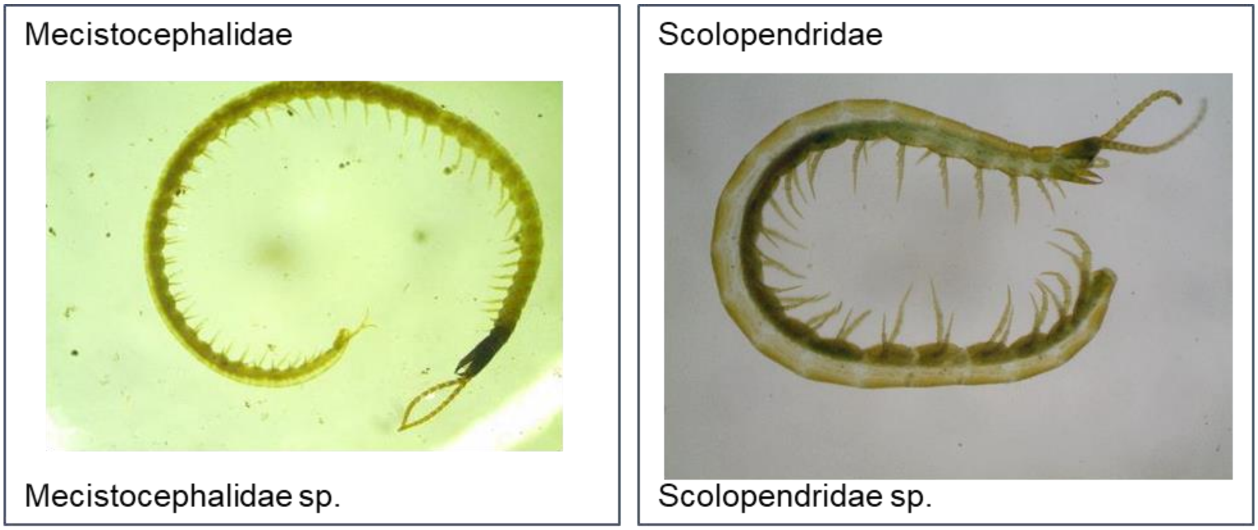


Figure 21. Chilopoda (Geophilomorpha and Scolopendromorpha) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

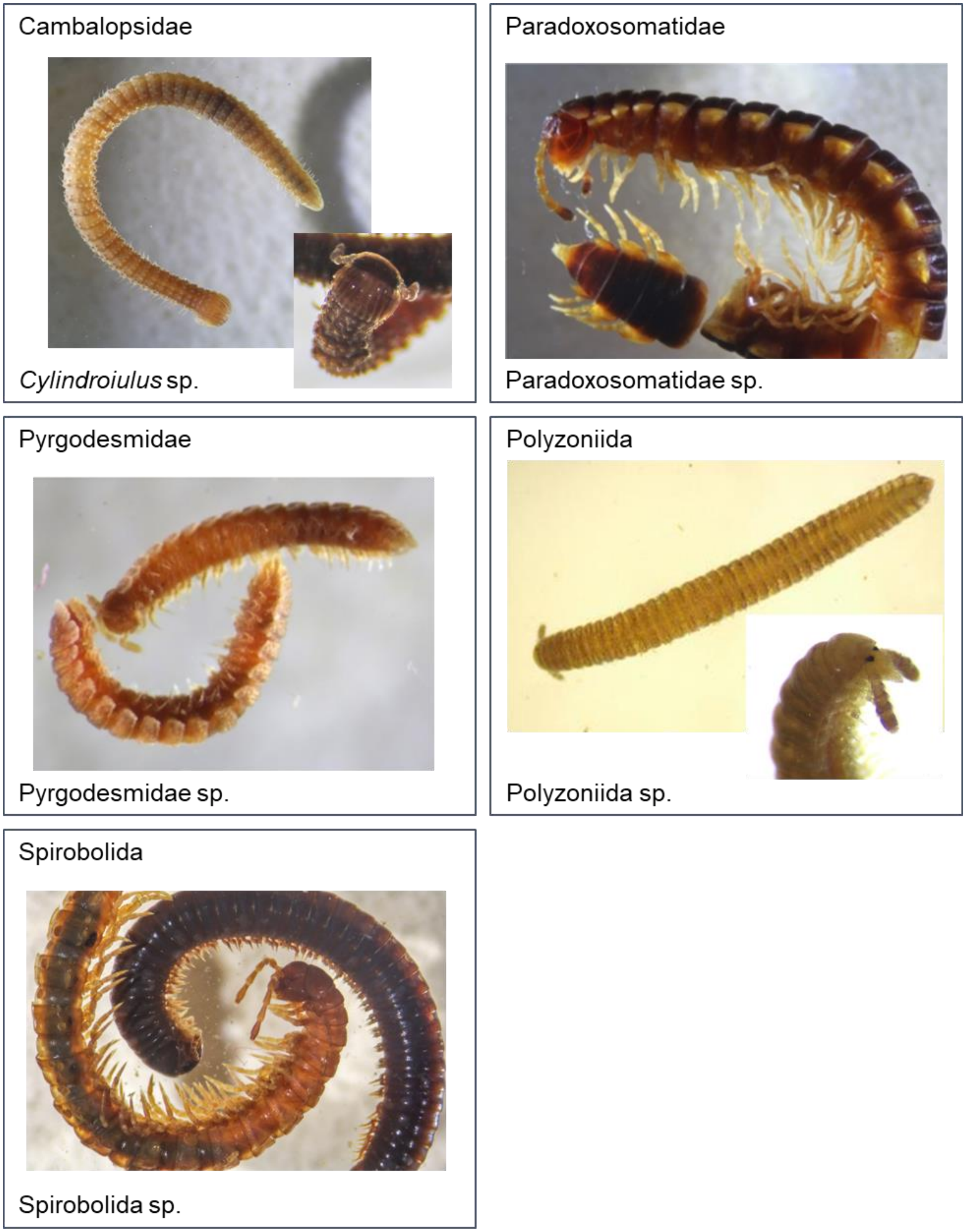
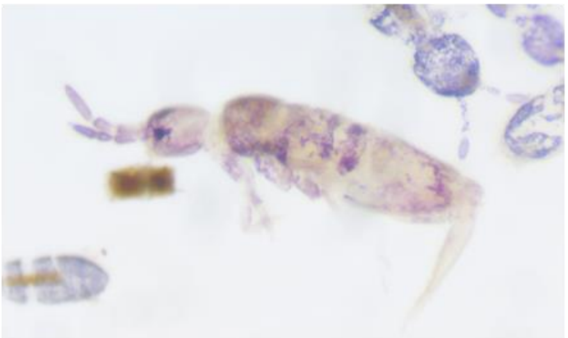


Figure 22. Diplopoda (Polydesmida, Polyzoniida, Spirobolida, and Spirostreptida) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Entomobryidae



Entomobryidae sp.

Hypogastruridae

Hypogastruridae sp.

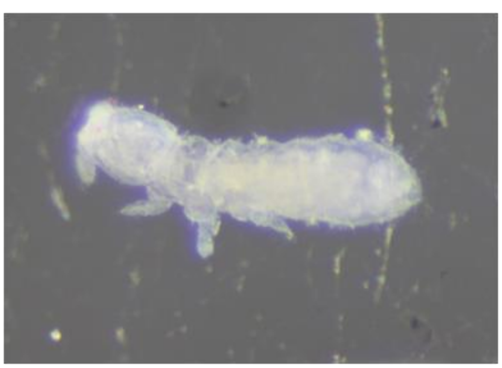
Isotomidae

Isotomidae sp.

Neanuridae

Neanuridae sp.

Onychiuridae



Onychiuridae sp.

Sminthuridae

Sminthuridae sp.

Figure 23. Entognatha (Collembola) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

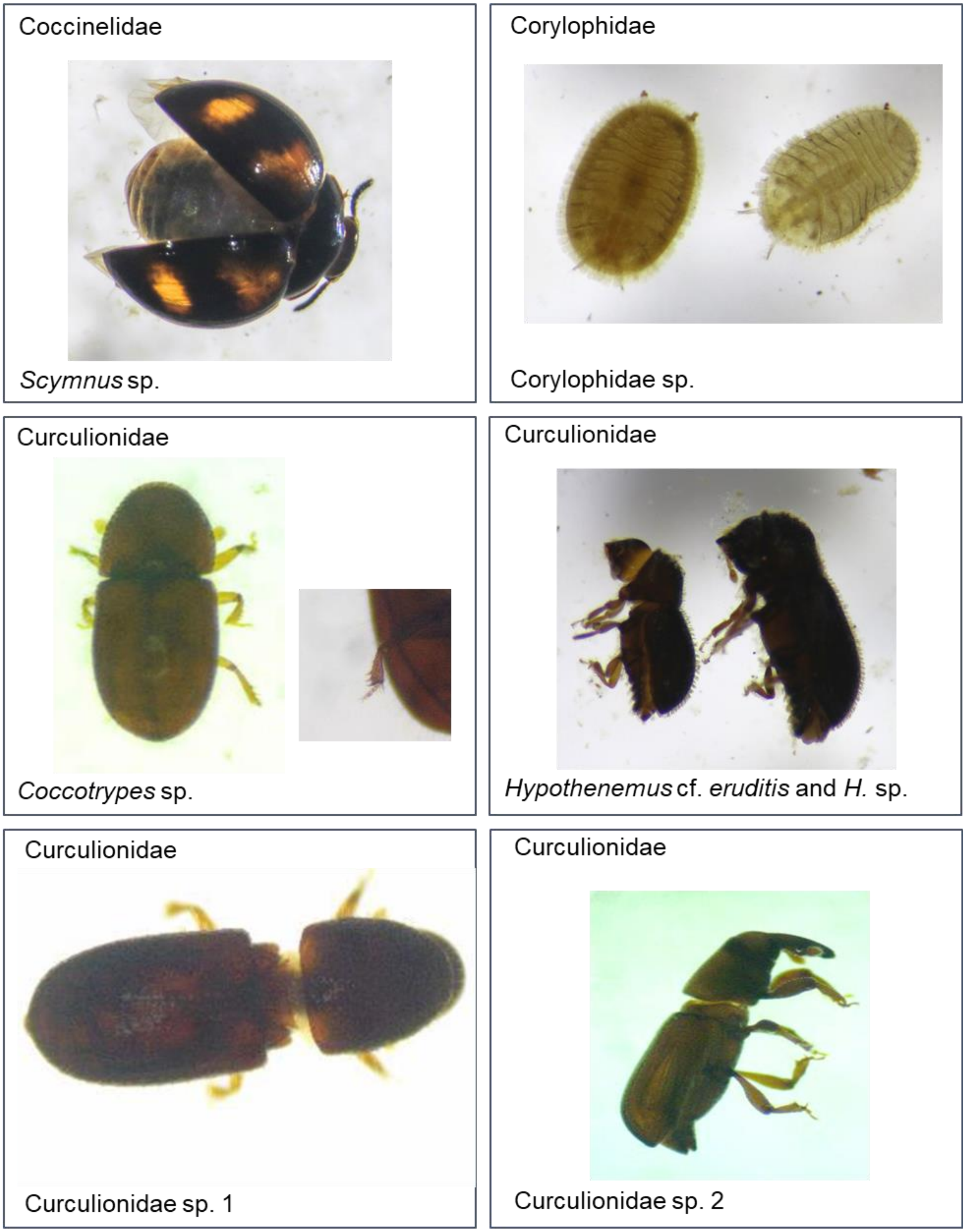


Figure 24. Insecta (Coleoptera) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

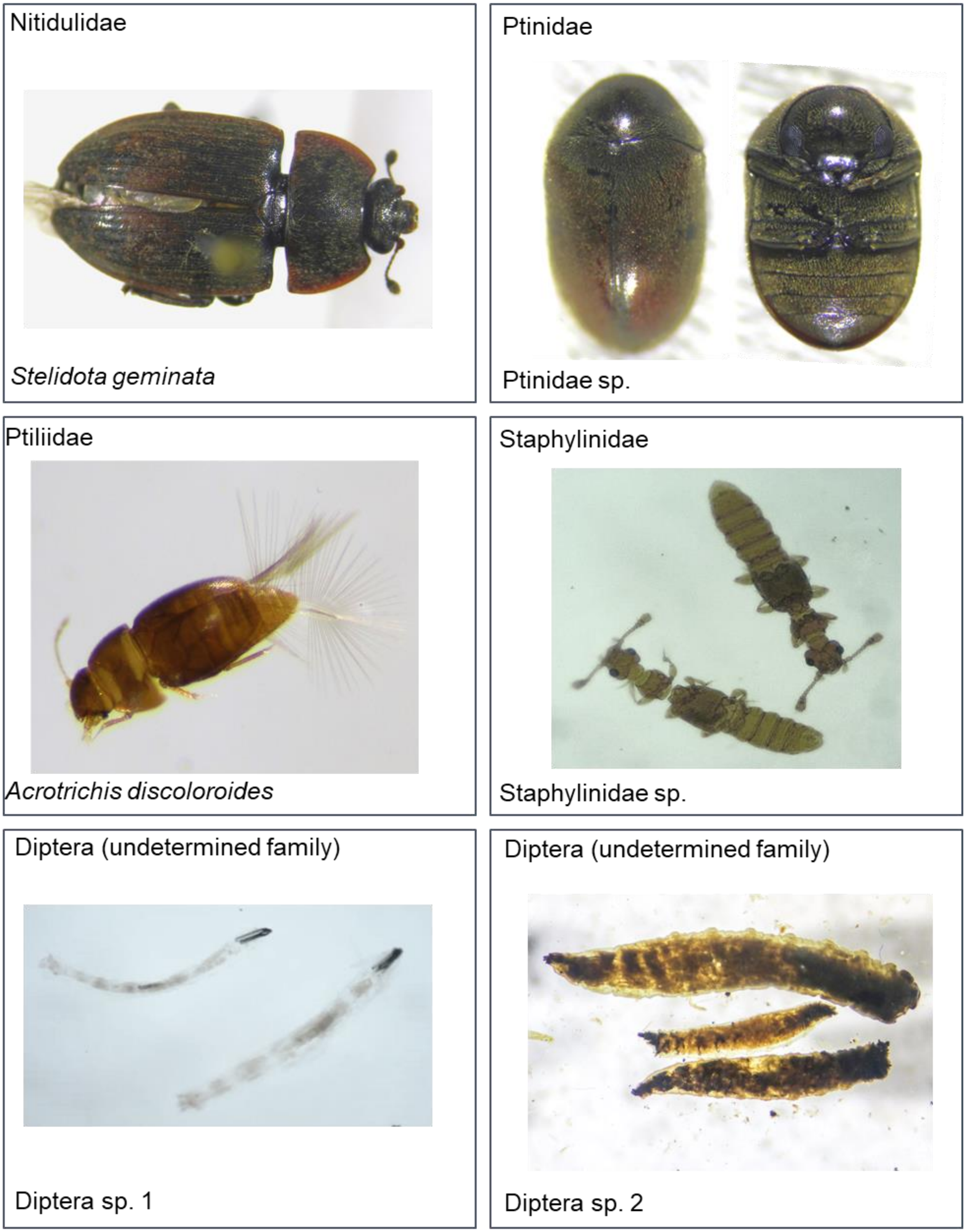


Figure 25. Insecta (Coleoptera and Diptera) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

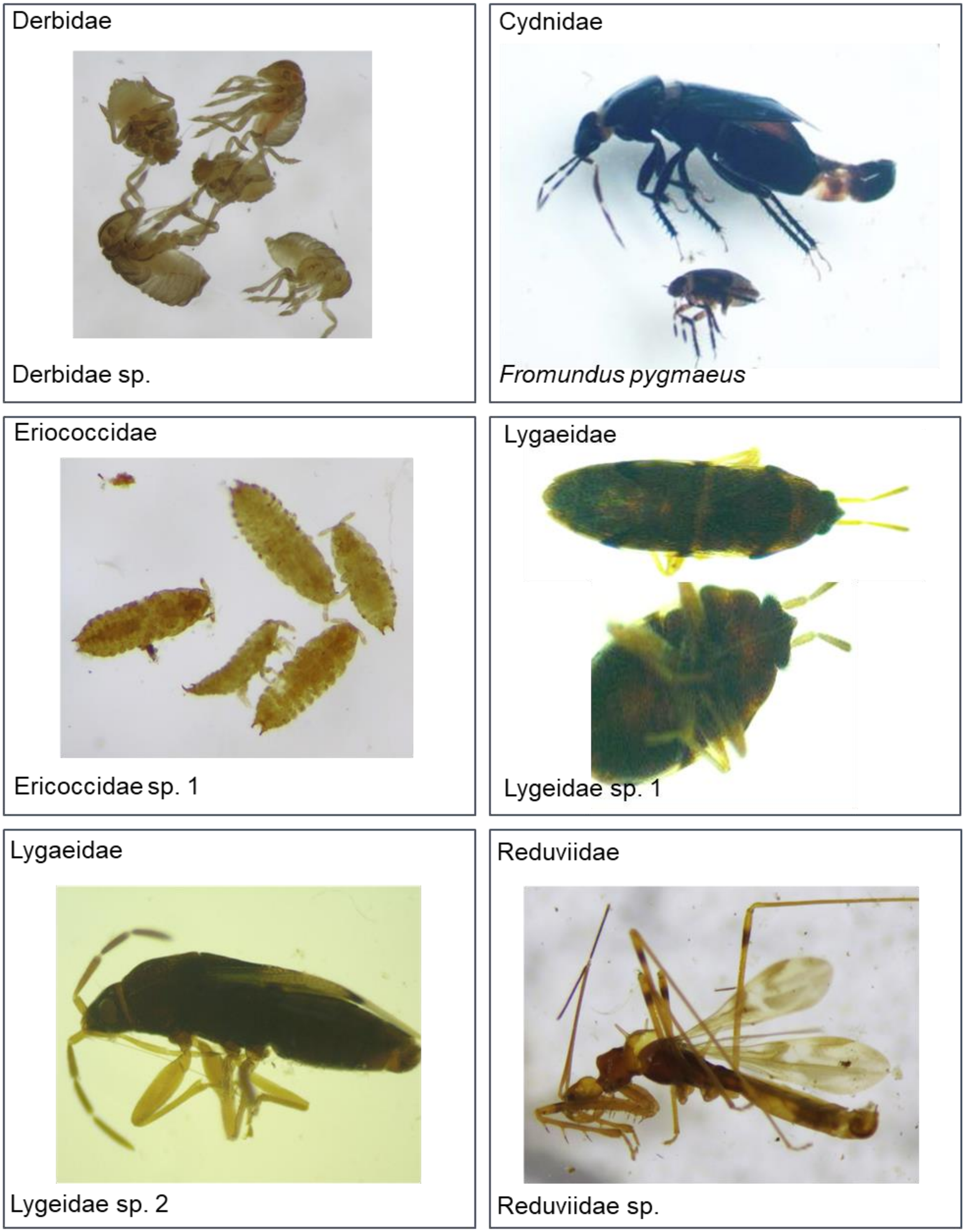


Figure 26. Insecta (Hemiptera) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

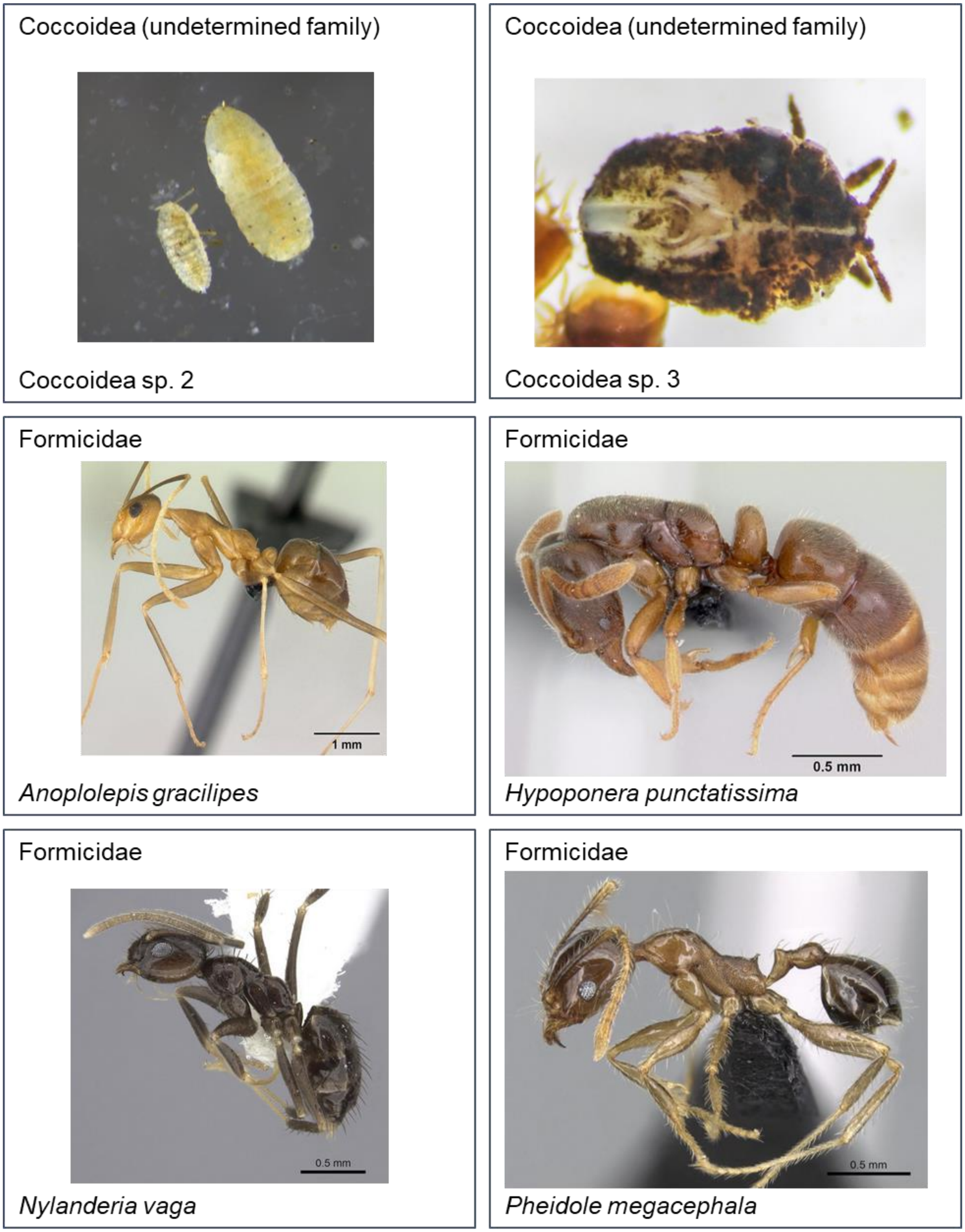


Figure 27. Insecta (Hemiptera and Hymenoptera) from the Liko Nā Pilina Hybrid Ecosystems Project study site. Formicidae photo credits: *A. gracilipes*, E. Prado (CASENT0125111); *H. punctatissima*, A. Nobile (CASENT0055938); *N. vaga*, W. Ericson (CASENT0219817); *P. megacephala*, S. Hartman (CASENT0056016). AntWeb. Version 8.109.1. https://www.antweb.org.

Formicidae

Solenopsis papuana

Formicidae

Strumigenys rogeri

Formicidae

Tapinoma melanocephalum

Formicidae

Wasmannia auropunctata

Lepidoptera (undetermined family)

Lepidoptera sp.

Liposcelididae

Liposcelididae sp.

Figure 28. Insecta (Hymenoptera and Lepidoptera) from the Liko Nā Pilina Hybrid Ecosystems Project study site. Formicidae photo credits: *S. papuana*, A. Nobile (CASENT0103246); *S. rogeri*, A. Nobile (CASENT0006035); *T. melanocephalum*, A. Nobile (CASENT0008659); *W. auropunctata*, A. Nobile (CASENT0039797). AntWeb. Version 8.109.1. https://www.antweb.org.

Trogiidae

Trogiidae sp.

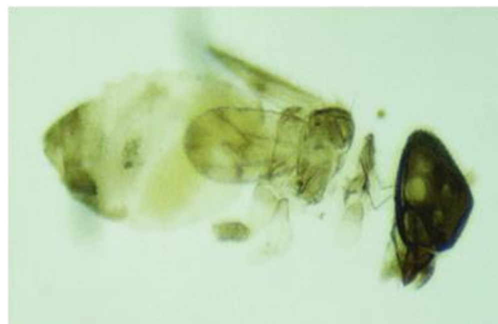
Psocodea (undetermined family)

Psocodea sp. 1

Psocodea (undetermined family)

Psocodea sp. 2

Psocodea (undetermined family)



Psocodea sp. 3

Phlaeothripidae

Phlaeothripidae sp.

Thripidae

Anisopilothrips venustulus

Figure 29. Insecta (Psocodea and Thysanoptera) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

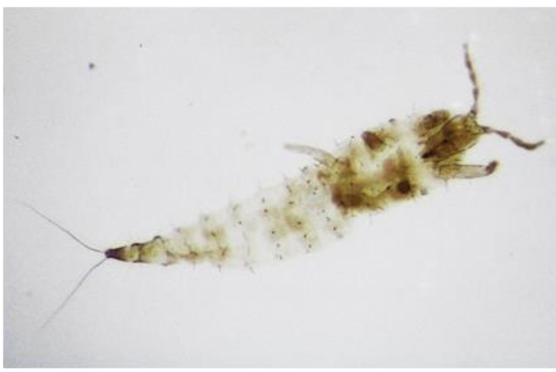
Thysanoptera (undetermined family)

Thysanoptera sp. 1

Thysanoptera (undetermined family)

Thysanoptera sp. 2

Thysanoptera (undetermined family)



Thysanoptera sp. 3

Isopoda (undetermined family)

Isopoda sp.

Undetermined order

Unknown sp. 1

Undetermined order

Unknown sp. 2

Figure 30. Insecta (Thysanoptera, Isopoda, and unidentified orders) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

Undetermined order

Unknown sp. 3

Undetermined order

Unknown sp. 4

Figure 31. Insecta (unidentified orders) from the Liko Nā Pilina Hybrid Ecosystems Project study site.

RESULTS AND DISCUSSION

This photoguide provides researchers and other interested parties with a tool to help identify arthropods found in plant litter in Hawaiian lowland forests. We consider it a starting point for many taxa because further taxonomic work would be needed to obtain species-level determinations. Regardless of identification level, morphospecies determinations are still useful for understanding the complexity of this ecologically important community and allows quantitative analyses of diversity patterns and food web dynamics.

This photoguide focuses on a relatively understudied portion of the Hawaiian arthropod fauna. This lack of study is pronounced in lowland forests, which have been highly disturbed and where less native vegetation resides. Most community level studies of Hawaiian arthropods have focused on areas dominated by native forests (e.g., Gagné 1979, Howarth *et al.* 2003, Gruner 2004). A notable exception to this was the comprehensive survey of the arthropod community around the Kahului, Maui, airport conducted by Howarth *et al.* (2012). The challenge, and success, of this remarkable study is underscored by the acknowledged contributions from 17 taxonomic collaborators. Howarth *et al.* (2012) provides photographs of 107 of 879 species collected during their survey but is primarily limited to “macroarthropods” (e.g., most arthropods larger in size than mites and Collembola) that represent new state records. This photoguide may serve as a starting point for other researchers to publish similar documents.

Diversity patterns observed in this study system are intriguing and deserve further study. Morphospecies richness is represented by at least 319 taxa (Peck *et al.* 2025). One morphospecies of oribatid mite (*Archegozetes* cf. *magnus*) dominated the fauna, being both abundant and nearly ubiquitous among litterbags (Table 1). In comparison, only 6 morphospecies were found to be common (comprising 10–25% of the total relative to the most abundant morphospecies) in the samples. Of the common morphospecies, 5 were frequently encountered in litterbags (found in >60% of the samples), and 1 was localized, found in <3% of the samples. Thus, a general pattern for the morphospecies that were abundant was that they were also widely distributed. In contrast, most of the morphospecies collected in litterbags were rare and occurred at low frequency (<10% of the samples). A few of these rare morphospecies were also frequent, meaning that they are distributed rather widely, but that was the exception. These results indicate that the study site has relatively high diversity, in a spatially heterogeneous way. In addition, litter production was patchy and morphospecies identity was related to plant species litter type (A. Robins, University of Hawaiʻi at Hilo, written communication, 2024).

Mites were also the most abundant group collected from litter at the study site. Within litterbags, mites comprised 56.3% of all morphospecies and 82.3% of all arthropods collected, and they were present in all samples. However, the high prevalence of mites may also be related to sampling methods. The litterbag collection method has a potential bias of excluding larger invertebrates, but because most of the morphospecies were found using both methods (Table 1), this sampling concern is somewhat allayed. Collectively, the data underscore the importance of mites within this community. Mites are functionally diverse, broadly serving as decomposers (including detritivores, fungivores, and microbivores) or predators. Recent studies of oribatid mites using stable isotopes of carbon and nitrogen to further dissect trophic positions have revealed considerably more complexity and dietary specificity than previously known (e.g., Krause *et al.* 2019, Tsurikov *et al.* 2019, Maraun *et al.* 2023).

While many of the morphospecies in Table 1 do not have formal scientific names, the taxonomy and nomenclature of this diverse litter arthropod community could be explored in the future. Species level identification was difficult given the lack of resources and depended on expert assessment. In addition, the lack of study of litter arthropods throughout the many habitats of the Hawaiian Islands means that the biological origin of these morphospecies is unknown. It is likely that many are non-native to the Hawaiian archipelago, given that their low elevation forest habitat is significantly composed of non-native vegetation (Ostertag *et al.* 2009). More research on litter arthropod communities using genetic techniques such as barcoding could help to advance taxonomic understanding.

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