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Descriptions, Ecological Associations and Predictive Species Distribution Models of New Species of *Psilochalcis* Kieffer (Hymenoptera; Chalcididae) Occurring in Utah's Eastern Great Basin

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A dissertation submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

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ABSTRACT

Descriptions, Ecological Associations and Predictive Species Distribution Models of New Species of *Psilochalcis* Kieffer (Hymenoptera; Chalcididae) Occurring in Utah's Eastern Great Basin

Mark J. Petersen
Department of Plant and Wildlife Sciences, BYU
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The genus *Psilochalcis,* of the Family Chalcididae, was originally described in 1905 by Kieffer. Mainly considered an Old-World taxon, the first North American *Psilochalcis* were not identified until 1981 by Grissell and Schauff. Little is known about the species distributions, biologies and ecological relationships of these parasitic wasps. This dissertation describes research conducted in central Utah setting arrays of Malaise traps in 4 different habitat types common to the Great Basin at three separate locations. A result of this sampling revealed a high abundance of multiple species of *Psilochalcis* wasps, particularly from one location and two habitat types. Chapter 1 describes three new species of *Psilochalcis* wasps namely; *P. adenticulata* Petersen, *P. minuta* Petersen, and *P. quadratis* Petersen. A review of all North American *Psilochalcis* species explains their distribution in Utah and throughout the surrounding western United States. A taxonomic key for all North American *Psilochalcis* species is given. Chapter 2 examines the seasonal abundance of *P. minuta* and *P. quadratis* and their associations with two common Great Basin habitat types. Both species show their highest abundance from late June through early August. Their peak abundance is shown to change dependent on the environmental conditions of temperature and precipitation. *Psilochalcis minuta* is significantly associated with pinyon/juniper (*Pinus edulis* or *P. monophylla* and *Juniperus osteosperma*) and *P. quadratis* is significantly associated with cheatgrass (*Bromus tectorum).* Chapter 3 describes the building of species distribution models for *P. minuta* and *P. quadratis* using a maximum entropy (Maxent) approach. Ten environmental variables were used to predict areas of optimal suitable habitat for each species. Multiple predicted sites were field sampled to test each model's effectiveness. *Psilochalcis minuta* occurred at nearly 90% of predicted sites, and *P. quadratis* occurred at 50% of predicted sites. Both species occurred at some non-predicted sites in other habitat types. Model analyses and field-testing results show the *P. minuta* model to be reliable in predicting areas of probable species occurrence, while the *P. quadratis* model is much less reliable in doing so. Aspect and fire disturbance show the highest percent contribution to both species' models. Slight differences in variable percent contribution between models suggest these species have sympatric distributions. Soil and slope are more important predictors of optimal suitable habitat for each species. Maintaining integrity between model predictions and field testing gave insights into other factors contributing to probable occurrence of *Psilochalcis* species.

Keywords: new species, chalcidid wasps, *Psilochalcis*, ecological associations, optimal suitable habitat, species distribution model, pinyon/juniper, cheatgrass.

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CHAPTER 1

A Review of *Psilochalcis* Kieffer (Hymenoptera: Chalcidoidea: Chalcididae) from the Western United States with Descriptions of Three New Species from Utah and Surrounding States

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ABSTRACT

A review of *Psilochalcis* Kieffer (Hymenoptera: Chalcididae) species in the western United States is presented, with the addition of three new species: *Psilochalcis adenticulata* Petersen new species, *Psilochalcis minuta* Petersen new species, and *Psilochalcis quadratis* Petersen new species. Morphological diagnoses and distributions are given for each species. A dichotomous key to the *Psilochalcis* species of North America is presented.

INTRODUCTION

Chalcidid wasps (Hymenoptera: Chalcididae) are distinguishable from most other Chalcidoidea by their enlarged hind femora with a row of ventral teeth and a small, indistinct prepectus. The body color is usually nonmetallic and entirely black, entirely yellow, or black and yellow (Narendran and van Achterberg 2016), often with yellow or red patches on the legs (Stringer et al. 2012). Chalcididae are similar to Leucospidae, having previously been combined (Bouček 1997), but can be distinguished from them by having the forewing flat over gaster when not in flight, an exposed labrum, a broad, oval tegula, and sexual dimorphic differences in the antennae (Bouček 1974, Bouček and Halstead 1997). According to Bouček and Halstead (1997), the understanding of the family Chalcididae, including its division into subfamilies and genera, has changed little for at least 150 years. These authors recognize 15 genera of Chalcididae in North America, one of which is *Psilochalcis* Kieffer.

Jean–Jaques Kieffer (1905) described the genus *Psilochalcis* (Hymenoptera; Chalcididae). Within Chalcididae, *Psilochalcis* is distinguished by the apex of the hind tibia, which is truncate and has two spurs. The marginal vein does not reach the anterior margin of the forewing, and a transverse carina occurs on the prosternum. In males, the antennal scape usually has a protruding denticle and the first flagellomere is anelliform. In females, the ovipositor usually reaches or exceeds the apex of the gaster. Nikol'skaya's (1960) revision of *Psilochalcis* included 17 species worldwide. Bouček (1984) documented *Psilochalcis* as having 20 described species worldwide. More recently, new species of *Psilochalcis* have been documented from Iran (Delvare et al. 2011) and India (Narendran and Kahn 2011). Delvare (2017) listed 51 species worldwide, and the Universal Chalcidoid Database (Noyes 2019) currently reports 60 species of *Psilochalcis*, with two names unavailable. Palearctic and Nearctic *Psilochalcis* species show no indication of overlap in their distributions (Johnson et al. 2001). The literature suggests that less than 20 species of *Psilochalcis* are known from the Western Hemisphere (Bouček 1992), with an estimate of ten undescribed species occurring in the Nearctic Region (Bouček and Halstead 1997). Wall and Berberet (1975) reported *P. mirabilis* (Bouček) from North America. However, Grissell and Schauff (1981) determined this to be based on a misidentification, while confirming that *P. mirabilis* is a valid species, known only from the Palearctic Region. Ultimately (prior to the present study), five *Psilochalcis* species are documented to occur in North America, all from the United States. *Psilochalcis deceptor* (Grissell and Schauff), *P. threa* (Grissell and Schauff), and *P. usta* (Grissell and Schauff) are known from Texas and Oklahoma, parasitizing pupae of Pyralidae and Gelechiidae (Grissell and Schauff 1981). *Psilochalcis hespenheidei* (Bouček) is known from Arizona and Hawaii, with no hosts reported (Bouček 1984). *Psilochalcis brevialata* Grissell and Johnson is known only from California, parasitizing pupae of Pyralidae (Johnson et al. 2001). No *Psilochalcis* species have been reported as occurring in Utah (Noyes 2019).

Currently, little taxonomic work is being conducted on *Psilochalcis*. Most university and institutional collections still use the antiquated name *Invreia* Masi in referencing their holdings of *Psilochalcis*. Bouček (1992) synonymized *Invreia* with *Psilochalcis* nearly 30 years ago. The extent of *Psilochalcis* is poorly understood, particularly within the western United States. We review known *Psilochalcis* species of the western United States, including descriptions of three new species, and we provide a taxonomic key for species identification.

MATERIALS AND METHODS

Specimen Collecting

Malaise traps (Malaise 1937, Townes 1962) are utilized extensively for surveying insects (Skvarla et al. 2021), predominantly trapping day-flying Hymenoptera and Diptera (van Achterberg 2009). Malaise trap samples from a 2006–2007 insect-habitat study in the eastern Great Basin of Utah (Johnson et al. 2008) were examined for *Psilochalcis* specimens. A total of 677 specimens were retrieved, representing three undescribed *Psilochalcis* species, as determined by the taxonomic key of Grissell and Schauff (1981). Subsequent Malaise trapping conducted from 2019–2021 yielded 610 additional specimens representing two of the same three undescribed species retrieved previously. In total, the first undescribed species is represented by only seven specimens, whereas the second and third species are represented by 773 and 507 specimens respectively.

We also examined *Psilochalcis* specimens from Brigham Young University, Provo, Utah (BYUC); Utah State University, Logan, Utah (EMUS); University of Idaho, Moscow, Idaho (WFBM); Washington State University, Pullman, Washington (WSU); Colorado State University, Fort Collins, Colorado (CSUC); California Academy of Sciences, San Francisco, California (CAS); Texas A & M University, College Station, Texas (TAMU). Because two of the three undescribed species aligned closest to *P. usta* in the key (Grissell and Schauff 1981), type specimens of *P. usta* were obtained from the Smithsonian, National Museum of Natural History (USNM). Repository abbreviations follow Evenhuis (2021).

Morphological Traits

Specimens of known *Psilochalcis* species were compared against those of the three undescribed species, noting the morphological differences. Specimen morphology was examined using an Olympus SZX16 stereomicroscope (5.25X–120.75X), in combination with cellSens Standard version 1.8 (Olympus Corporation) for taking measurements. Morphological characters (Fig. 1) were selected for species comparison, based on those commonly used in the original descriptions of the five described North American *Psilochalcis* species. Morphological terminology follows that of Gibson et al. (1997).

RESULTS AND DISCUSSION

***Psilochalcis adenticulata* Petersen, new species**

(Figs. 2–4, 5a, 6a, 7a, 8)

Diagnosis. Male distinguished by the following: 1) antennal scape without a protruding denticle; 2) vertex, and mesosoma with noticeably erect pilosity; 3) gastral tergum 1 is dorsally reticulate, with a narrow sulcus within a thin polished band along dorsal posterior margin.

Description. Male- Length 3.2–4.0 mm (holotype 3.7 mm).

Color. Black except the following: radicle, apex of clava brown; teeth of mandible, apex of procoxa, apex and base of profemur, metatrochanter, apex of metafemur, tibiae, tarsi orange to red brown (variation – tegula orange to brown, 1/4–1/3 of apical inner surface of metafemur orange to red brown, outer surface orange, sometimes with black patch in basal half); body setae white; forewing hyaline; submarginal vein light brown; marginal and stigmal veins brown.

Head. Face width nearly equal to height (1.0:1.1); eye with sparse setae 1.0–1.5x ommatidia diameters in length, 1.5–2x own length apart; MS 0.5–0.7x eye EH (2:3), with punctures nearly contiguous, with dense appressed setae, malar carina present, not reaching inferior margin of eye, inferiorly joining with inferior margin of MS producing a triangular panel (variation – malar carina curving posteriorly but not reaching posterior genal margin); scrobe transversely rugulose, nearly reaching anterior ocellus; face with nearly contiguous setigerous punctures, with setae ca. 4x own puncture diameter in length, becoming erect at midpoint of eye along preorbital carina up to and including vertex; vertex flattened, densely reticulate throughout, medially punctate, posterolaterally sparsely punctuate (Fig. 4); POL 3.0–4.5x OOL; AOL 1.5–2.4x OOL; posterior ocellus diameter slightly less than OOL (4:5); inferior margin of clypeus rounded between lateral margins of toruli, protruding slightly outward; torulus diameter 0.6–1.0x ITD; antennomeres length ratio, beginning with scape 50:11:2:18:16:14:14:15:13:14:28; scape ca. 4.7x longer than wide, narrowing in apical fourth, widening again at apex, apex roundly truncate, without incised denticle on exterior margin (Fig. 5a), not reaching anterior ocellus, in lateral view reaching midpoint of eye (Fig. 2); pedicel slightly shorter than wide (2:3).

Mesosoma. Pronotum:mesoscutum:mesoscutellum:propodeum ratio ca. 6:9:10:6 in dorsal view; pronotum dorsally with setigerous punctures less than one puncture diameter apart, with erect setae 4–5x own puncture diameter in length, interstices reticulate, lateral panel punctate, interstices reticulate, polished ventrally, ventral strip reticulate; mesoscutum and mesoscutellum with same setigerous sculpture (Fig. 6a) and setae length as dorsal pronotum; mesoscutellum setae noticeably erect in lateral view, posterior margin rounded; propodeum with submedian, accessory, sublateral, and lateral carinae, accessory carina arching posteriorly and medially, joining submedian carina circa midpoint of propodeum, forming a distinctive cell (Fig. 7a), weak transverse carinae, interstices reticulate, posterolateral margin slightly acute, posteriorly not reaching the extent of petiolar foramen; metafemur ca 1.7x longer than wide, outer surface reticulate and setose; forewing ca. 2.5x longer than wide (5:2), submarginal:marginal:stigmal veins ratio ca. 30:6:1.

Gaster. Tergum 1 in dorsal view ca. 0.5x gaster length (4:9), dorsally reticulate, the posterior margin with a transverse sulcus within a polished band ending at dorsolateral margin, laterally polished with sparse setigerous punctures anteriorly; tergum 2 posterior margin dorsally polished, without setae, laterally, anterior portion polished becoming reticulate and setose posteriorly.

Female – not known.

Comments. The most unique diagnostic character of *P. adenticulata* is the lack of a protruding denticle on the male antennal scape. All other North American *Psilochalcis* species possess a protruding denticle in males. In *P. hespenheidei*, the scape is broadly triangular (Fig. 5f); *P. brevialata*, *P. deceptor* (Fig. 5e), and *P. threa* have the scape incised with an upward pointing denticle; *P. minuta* new species (Fig. 5b), *P. quadratis* new species (Fig. 5c), and *P. usta* (Fig. 5g) have the scape incised with outward pointing denticle.

In Bouček's revision (1951) of European *Psilochalcis* species, four *Psilochalcis* species are described as lacking a denticle on the antennal scape: 1) *P. rufitarsis* (Illiger); 2) *P. immaculata* (Rossi); 3) *P. ligustica* (Masi); 4) *P. subaenea* (Masi). A thorough review of species descriptions (Masi 1929) places *P. adenticulata* most similar to *P. rufitarsis* with respect to the antennal scape, but differs from this species in shape of the scape apex, length of anellus, shape of mesofemur, and coloration of legs and metafemur (Bouček, 1951). Running *P. adenticulata* through Nikol'skaya's (1960) key places it with *P. novitzkyi* (Bouček) with respect to the shape of the mesofemur. However, *P. novitzkyi* is described as having a protruding denticle on the antennal scape. Moreover, *P. rufitarsis* and *P. novitzkyi* are known only from the Palearctic region (Noyes 2019).

Etymology. Species epithet references the antennal scape lacking a protruding denticle.

Material Examined.

Holotype – "Utah, Juab Co., Tintic Valley, 39.72314°N, 112.20226°W, 5233 ft., 26 Jul. 2006, coll. R.L. Johnson/ malaise trap, sagebrush habitat" (♂ BYUC).

Paratypes – **New Mexico:** Eddy Co.: Sitting Bull Falls, 17 May 1988, N. Jorgensen (2♂ WSU). **Nevada:** Clark Co.: Hidden Valley, Moapa, 36.6539°N, 114.6011°W, 1565 ft., 1-15 Aug. 2011, R.L. Johnson & J.A. Sharp (7♂ BYUC); same data except, 15-31 Aug. 2011 (4♂ BYUC); 1-15 Sep. 2011 (1♂ BYUC). **Utah:** Juab Co.: Tintic Valley, 39.71356N, 112.16980W, 5336 ft., 8 Jun. 2006, R.L. Johnson (2♂ BYUC); Tintic Valley, 39.71475°N, 112.16943°W, 5338 ft., 8 Jun. 2006 (1♂ BYUC); Tintic Valley, 39.72314°N, 112.20226°W, 5233 ft., 26 Jul. 2006 (2♂ BYUC); Tintic Valley, 39.75257°N, 112.20272°W, 5248 ft., 26 Jul. 2006 (1♂ BYUC). Utah Co.: W. side Utah Lake, 1 Jul. 1979, S.M. Clark (1♂ BYUC). Washington Co.: Pintura, 10 Jul. -14 Aug. 1986, W.J. Hanson (1♂ EMUS); Beaver Dam Slope, 16 Jun. 1983 (1♂ EMUS); Lytle Ranch, 1-4 Jul. 1992, D. Judd & D. Feener (1♂ EMUS).

Distribution. *Psilochalcis adenticulata* is known from a few counties in New Mexico, Nevada, and Utah (Fig. 8).

Psilochalcis brevialata **Grissell and Johnson**

Psilochalcis brevialata Grissell and Johnson, *in* Johnson et al. 2001:779

(Fig. 8)

Type Locality. USA, California, Fresno County, Horticulture Crops Research Lab, 10 Jan. 2000.

Diagnosis. Distinguished by the following: 1) eye with setae 2–3 ommatidia diameters in length, 1–1.5x own length apart; 2) punctures of upper face with carinate walls; 3) malar space rugulose with dense appressed silvery white setae; 4) female, forewing barely reaching the dorsal posterior margin of tergum 3.

Comments. *P. brevialata* has the longest eye setae length of any North American *Psilochalcis* species. Females of *P. brevialata* are most similar to females of *P. quadratis* new species with both having the forewing not reaching the gaster apex. In *Psilochalcis brevialata,* the forewing barely reaches the dorsal posterior margin of tergum 3, while *P. quadratis* new species has the forewing reaching and usually extending well beyond the dorsal margin of tergum 3.

Distribution. *Psilochalcis brevialata* is known only from laboratory reared material collected from a culled fig warehouse in Fresno County, California (Johnson et al. 2001). No material has been reported outside of this setting. It is not known if this species occurs naturally in the United States. See Fig. 8.

Psilochalcis deceptor **(Grissell and Schauff)**

Invreia deceptor Grissell and Schauff 1981:2

(Fig. 5e, 8)

Type Locality. USA, Texas, Comanche Co., 3 mi. W. DeLeon, 10 Aug. 1978.

Diagnosis. Distinguished by having tergum 1 polished, without sculpture, both dorsally and laterally.

Comments. *Psilochalcis deceptor* is most similar to *P. threa* with both having a thin protruding flange on posterolateral margin of prosternum. Males of both species have an upward pointing denticle on the antennal scape. *Psilochalcis deceptor* differs from *P. threa* in having tergum 1 polished both dorsally and laterally (*P. threa* with tergum 1 reticulate both dorsally and laterally).

Material examined.

Texas: Comanche Co.: 3 mi. W. DeLeon, Laboratory cultured stock, 1978, S. Johnson (2♀, 1♂ TAMU).

Distribution. *Psilochalcis deceptor* is known only from cultured material collected from cultivated peanut crop from **Oklahoma:** Bryan, Grady, Hughes, and Marshall Counties; **Texas:** Comanche County (Fig. 8). It is not known if this species occurs naturally in the United States.

***Psilochalcis hespenheidei* (Bouček)**

Invreia hespenheidei Bouček 1984:59

(Fig. 5f, 8)

Type Locality. USA, Arizona, Cochise County, Cave Creek Canyon, Chiricahua Mountains, Southwest Research Station, 5 July 1981.

Diagnosis. Female distinguished by 1) gaster apex rounded; 2) ovipositor shifted ventrally, positioned well short of gaster apex, never visible from above; 3) tergum 3 in dorsal view longest of any gastral tergite; 4) prominent triangular clypeal projection extending outward over labrum. Male distinguished by 1) antennal scape triangular, ca. 2x longer than width at apex (Fig. 5f)); 2) pedicel in anterior view rounded medially, ca. 1.5x wider than 1st funicular antennomere.

Comments. *P. hespenheidei* has clearly observed and unique characters that are not easily confused with any other North American *Psilochalcis* species. As discussed by Bouček (1984), it forms its own distinct species group.

Material examined.

Arizona: Cochise Co.: Portal, 26 Jun. 1958, W.F. Barr (1♀ WFBM); Miller Canyon, Huachuca Mountains, 10 Aug. 19♂89, W.F. Barr (1♀ WFBM); Bog Spring, Madera Canyon, 25 Jun. 1985, W.F. Barr (1♂ WFBM); Madera Canyon Lodge, 5 Jun. 1989, W.F. Barr (17♂ WFBM); Pima Co.: Tucson, 3 Jun. 1998, R.S. Beal (1♀ CSUC); Santa Cruz Co.: 24.5 km E. Amado, 22 Jul.

1987, W.F. Barr (2♀, 1♂ WFBM). **California:** Santa Clara Co.: San Antonio Valley, W.F. Barr (1♀ WFBM). **Oregon:** Josephine Co.: 3 mi. N. O'Brien, 28 Aug. 1963, W.F. Barr (1♀ WFB7M). **Nevada:** Clark Co.: Logandale, 19-21 Jun. 1981, R. Nelson (1♀ BYUC); Hidden Valley, Moapa, 36.6539°N, 114.6011°W, 15-30 Jun. 2012, R.L. Johnson (1♀, 1♂ BYUC). **New Mexico:** Lea Co.: 32°24.7N, 103°40.9W, Site #2, 20 Jun. 1979, D.R. Delorme & H.L. Carrola (1♀ TAMU); Luna Co.: Columbus, June 1931, Beck & Call (1♀ BYUC). **Texas:** Frio Co.: 6 mi. SE. Pearsall, 7 Jul. 1972, E.E. Grissell & J. Smith (4♂ TAMU); Jeff Davis Co.: 5 mi. S. Ft. Davis, 6 Jun. 1972, W.E. Clark (1♂ TAMU); Kinney Co.: 15 m. SE. Del Rio, 20 Aug. 1965, J.C. Shaffner (1♂ TAMU); Travis Co.: Heap Farm, 11 mi. S. Austin, 2 Aug. 1972, E.E. Grissell (3♀, 4♂ TAMU); Vale Verde Co.: Turo, 29 May 1989, W.F. Barr (1♀ WFBM); 18 mi. NE. Juno, 29 May 1989, W.F. Barr (1♀ WFBM). **Utah:** Cache Co.: Four-Mile Canyon, 2-11 Jul. 1992, W. Hanson & S. Keller (1♀ USU); Emery Co.: Wild Horse Creek, Goblin Valley, 26-28 Jul. 1982, Parkers & Griswold (4♂ USU); Kane Co.: Glendale, 8 Jun. 1966, G.F. Knowlton (1♀ USU); Utah Co.: Goshen Canyon, 39.9016°N, 111.8935°W, 4747 ft., 29 Jul. 2015, S.M. Clark (1♀ BYUC); Provo, Slate Canyon, 29 Jun. 1998, S.M. Clark (1♀ BYUC); Washington Co.: Santa Clara, 30 May 1973, F. Parker & P. Torchio (1♀ USU). **Washington:** Whitman Co.: Almota, 22 Aug. 1987, W.J. Turner (1♀ WSU). **Mexico: Coahuila:** 6.2 mi. SE. Emiliano Zapata, 17 Aug. 1983, W.F. Barr (1♀ WFBM).

Distribution. *Psilochalcis hespenheidei* is known from Arizona and Hawaii (Bouček 1984), and now is reported as occurring in two new counties in Arizona and several counties in California, Oregon, Nevada, New Mexico, Texas, Utah, and Washington (Fig. 8). Also, now reported as occurring in Coahuila, Mexico.

Psilochalcis minuta Petersen, new species

(Figs. 5b, 6b, 7b, 9–11, 14)

Diagnosis. *Psilochalcis minuta* is distinguished by the following: 1) body length no greater than 2.5 mm; 2) mesosoma punctate, interstices reticulate-aciculate; 3) female – antennal scape apex reaching and/or exceeding vertex (Fig. 9); 4) apex of ovipositor sheath truncate (Figs. 9, 11).

Description. Female – Length 1.8–2.3 mm (holotype 1.9 mm).

Color. Black except the following: antennal scape through clava, mandibles, pro and mesocoxae, profemur, margins of mesofemur, metatrochanter, apex of metafemur, base of mesotibia, exterior 3/4th of metatibia brown; pro and mesotrochanters, apex of profemur, apex, median, and base of mesofemur, protibia, base and apex of mesotibia, apical ¼ and interior of metatibia, tarsi, hypopygium light brown/yellow; forewing hyaline; submarginal vein whitish yellow; marginal and stigmal veins brown.

Head. Face width equal to face height (1:1); eye with setae ca 1.5 ommatidia diameters in length, ca 1.5x own length apart; MS 0.7–0.9x EH (5:6), densely punctate, finely setose, without malar carina; scrobe rugulose, not reaching anterior ocellus; face with setigerous punctures, setae 2–3x own puncture diameter in length, becoming erect at inferior margin of eye along preorbital carina up to and including vertex; vertex rounded, reticulate/punctate, especially posteromedial; POL 4.0–6.0x OOL; AOL 1.5–2.7x OOL; posterior ocellus diameter slightly longer than OOL (4:3); clypeus inferior margin straight between medial margins of toruli, not protruding outward (variation- some with short clypeal projection over labrum); torulus diameter 0.6–1.0x ITD; antennomere length ratio, beginning with scape 47:20:8:7:9:8:8:9:8:8:20; scape in lateral view reaching or exceeding vertex.

Mesosoma. Pronotum mesoscutum:mesoscutellum:propodeum ratio ca. 2:3:3:2 in dorsal view; pronotum with setigerous punctures ca. 1x puncture diameter apart, setae 1.5–2x own puncture diameter in length, interstices reticulate–aciculate, lateral panel sparsely punctate to ventral margin, ventral strip reticulate; mesoscutum with same setigerous sculpture and setae length as dorsal pronotum; mesoscutellum with setigerous punctures 1x puncture diameter apart, interstices reticulate–aciculate throughout, median without punctures, posterior margin rounded (Fig. 6b); propodeum with submedian, accessory, sublateral, and lateral carinae present, accessory carina diagonal, joining with sublateral carina near midpoint of propodeum (Fig. 7b) (variation – some with accessory carina not reaching sublateral carina), weak transverse carinae, interstices finely punctate, posterolateral margin acute, not reaching extent of petiolar foramen; metafemur ca. 1.9 x longer than wide, outer surface finely reticulate, setose; forewing ca. 2.4x longer than wide (7:3), submarginal:marginal:stigmal veins ratio ca. 15:3:1.

Gaster. In lateral view ovate, posteriorly acuminate (Fig. 11); tergum 1 dorsally ca. 0.5x gaster length (5:9), 4/5th coarsely reticulate, with wide polished band at posterior margin, polished laterally; tergum 2 dorsally ca. 0.4x length of tergum 1, reticulate to posterior margin (variation – some with dorsal median polished at posterior margin), dorsal posterior margin emarginate, laterally reticulate; tergum 3 dorsal posterior margin emarginate; tergites 3–6 dorsal 3/4th polished, with thin reticulate setigerous posterior band; tergum 6 acutely inclined, clearly visible from above (Fig. 11); ovipositor sheath with dorsal margin concave to straight, apex truncate, ventral margin convex, clearly visible from above (Fig. 11).

Male – Length 1.5–2.5 mm (allotype 1.7 mm).

Color. Black except the following: metafemur dark brown to black; radicle, scape, pedicel, pro and mesocoxae, apex of metacoxa, pro and mesofemora, base and apex of metafemur dark brown; labrum, mandible orange to brown; denticle, anellus, funicular antennomeres, apices of pro and mesofemora, apices of tibiae, light brown; tarsi, yellow to light brown.

Body. Sculpture, setae and structure same as for female except the following: Face width slightly greater than face height (8:7); MS 0.6–0.9x EH (4:5); POL 4.0–9.0x OOL; AOL 2.0–4.5x OOL; antennal scape ca. 6x longer than wide, apex rounded, denticle emerging from exterior margin at 2/3 scape length; denticle equal to or slightly wider than width of scape at apex, point of denticle pointing outward (Fig. 5b); antennomere length ratio, beginning with scape 27:8:2:8:8:6:7:7:6:9:15; face and MS setae appressed; mesoscutellum sculpture punctate throughout (female without punctures in median).

Comments. *P. minuta* runs to *P. usta* in Grissell and Schauff (1981) but differs from it in having the lateral panel of the pronotum and ventral strip punctate. In *P. usta*, the lateral panel of the pronotum is polished and the ventral strip reticulate. In females of *P. minuta*, the apex of the ovipositor sheath is truncate (Figs. 9, 11) and rounded in *P. usta* (Fig. 12). In males of *P. minuta,* the denticle width is subequal to the apical width of the scape (Fig. 5b). In *P. usta,* the denticle width exceeds the apical width of the scape (Fig. 5g).

Etymology. Species epithet references the small size.
Material Examined.

Holotype – "Utah, Juab Co., Yuba, 39.45430°N, 111.96667°W, 5292 ft., 10 Aug. 2006, coll. R.L. Johnson/malaise trap, pinyon/juniper habitat" (♀ BYUC).

Allotype – "Utah, Juab Co., Yuba, 39.45350°N, 111.96699°W, 5297 ft., 26 Jul. 2006, coll. R.L. Johnson/ malaise trap, pinyon/juniper habitat" (♂ BYUC).

Paratypes – Utah: Iron Co.: Cedar City, 37.43848°N, 113.22392°W 5974 ft., 3-10 Aug. 2019, M.K & J.E Sanders (1♂); same data except, 11-17 Aug. 2019 (1♀, 1♂); 1-6 Sep. 2019 (1♀, 1♂). Juab Co.: Gilson Mountains, 39.65849°N, 112.24926°W, 5381 ft., 29 Jul.-6 Aug. 2021, M.J. Petersen & R.L. Johnson (6♀); same data except, 7-20 Aug. 2021 (10♀); 21 Aug.-1 Sep. 2021 (4♀, 1♂); Sage Valley, 39.34207°N, 112.05164°W 5355 ft., 17-27 Jul. 2020 (1♀, 2♂); same data except, 28 Jul.-7 Aug. 2020 (14♀, 2 ♂); 8-18 Aug. 2020 (2♀, 1♂); Sage Valley, 39.31385°N, 112.04212°W, 5055 ft., 28 Jul.-7 Aug. 2020 (1♀); Tintic Valley, 39.78396°N, 112.15729°W, 5750 ft., 26 Jul. 2006, R.L. Johnson (1♀); same data except, 3-17 Jul. 2007 (1♀); Tintic Valley, 39.78422°N, 112.15594°W, 5750 ft., 10 Aug. 2006 (1♂); same data except, 5-19 Jun. 2007 (1♀ BYUC); 3-17 Jul. 2007 (1♀); Tintic Valley, 39.78431°N, 112.15489°W, 5762 ft., 5-19 Jun. 2007 (1♀); same data except, 19 Jun.-3 Jul. 2007 (1♀); 3-17 Jul. 2007 (1♀); 14-28 Aug. 2007 (1♀); Tintic Valley, 39.75257°N, 112.20272°W, 5248 ft., 19 Jun.-3 Jul. 2007 (1♀); Yuba, 39.45350°N, 111.96699°W, 5297 ft., 8 Jun. 2006 (1♂); same data except, 26 Jul. 2006 (5♀, 2♂); 1 Jul. 2007 (2♀); 28 Aug.-11 Sep. 2007 (2♀); Yuba, 39.45380°N 111.96674°W 5300 ft., 26 Jul. 2006 (22♀, 10♂); same data except, 10 Aug. (15♀, 1♂); 9 Sep. 2006 (1♀); 5-19 Jun. 2007 (1♀); 19 Jun.-3 Jul. 2007 (1♀, 1♂); 3-17 Jul. 2007 (8♀, 2♂); 17-31 Jul. 2007 (2♀); 14-28 Aug. 2007 (2♀, 1♂); Yuba, 39.45430°N, 111.96667°W, 5292 ft., 8 Jun. 2006 (1♂); same data except, 26 Jul. 2006 (29♀, 22♂); 10 Aug. (25♀, 6♂); 9 Sep. 2006 (4♀); 5-19 Jun. 2007 (3♂); 19 Jun.-3 Jul., 2007 (1♀, 2♂); 3-17 Jul. 2007 (1♀, 1♂); 17-31 Jul. 2007 (1♀); 28 Aug.-11 Sep. 2007 (1♀); 11-25 Sep. 2007 (6♀, 1♂); Yuba, 39.27123°N, 111.58028°W, 5280 ft., 7-27 Jul. 2020, M.J. Petersen & R.L. Johnson (5♀, 2♂); same data except, 28 Jul.-7 Aug. 2020 (44♀, 9♂); 8-18 Aug. 2020 (30♀, 2♂); Yuba, 39.23087°N, 111.57473°W, 5251 ft., 17-27 Jul. 2020 (62♀, 36♂); 28 Jul.-7 Aug. 2020 (189♀, 35♂); 8-18 Aug. 2020 (66♀, 5♂); Yuba, 39.23102°N, 111.57254°W, 5166 ft., 17-27 Jul. 2020 (1♀); same data except, 28 Jul.-7 Aug. 2020 (1♀); 8-18 Aug. 2020 (1♀, 1♂). Millard Co.: Oak Creek Sinks, 39.48876°N, 11235678°W, 4774 ft., 29 Jul.-6Aug. 2021, M.J. Petersen & R.L. Johnson (3♀, 2♂); same data except, 7-20 Aug. 2021 (4♀); 7-20 Aug. 2021 (1♀). San Pete Co.: Antelope Valley, 39.23526°N, 111.75134°W, 5750 ft., 5-19 Jun. 2007, R.L. Johnson (1♂); Antelope Valley, 39.23594°N, 111.75281°W, 5776 ft., 9 Sep.

2006 (1♀); same data except, 24 Apr.-5 May 2007 (1♀); 17-31 Jul. 2007 (2♀); Antelope Valley, 39.23655°N, 111.75351°W, 5790 ft., 24 Apr.-5 May 2007 (1♀); same data except, 14-28 Aug. 2007 (1♀). Utah Co.: Lake Mountain, 40.21209°N, 111.97083°W, 5308 ft., 21 Aug.-1 Sep. 2021, M.J. Petersen & R.L. Johnson (2♀). *(All cited material resides at BYUC.)

Distribution. *Psilochalcis minuta* is only known to occur in Utah. It is predominantly known from Juab, Millard, Utah, and San Pete Counties in central Utah. It is also known from Iron County in southern Utah (Fig. 14).

Psilochalcis quadratis Petersen, new species

(Figs. 5c–d, 6c, 7c, 13, 15–18)

Diagnosis. Distinguished by the following: 1) body length usually greater than 3.5 mm; 2) malar space with polished triangular tooth-like panel along inferior margin from which malar carina emerges; 3) female – gaster apex truncate, tergum 6 vertical or nearly so.

Description. Female – Length 3.7–4.9 mm (holotype 4.3 mm).

Color. Black except the following: antennal scape through clava, labrum, mandible, tegula, pro and mesolegs, basal ½ of metacoxa, metafemur, tibae (except black marginal carinae), tarsi, hypopygium, ovipositor orange; forewing hyaline; submarginal vein light yellow; marginal and stigmal veins brown; translucent area below marginal vein orange brown.

Head. Face width nearly equal to face height (1:1.1); eye with setae ca. 2 ommatidia diameters in length, 1–1.5x own length apart; MS 0.5–0.7x EH (2:3), punctate, sparsely setose, malar carina not reaching inferior margin of eye, inferiorly joining with inferior margin of MS producing a rounded tooth-like polished panel (Fig. 17), (variation – some with a few setigerous punctures on panel's lateral margin); scrobe finely rugulose, superiorly punctate, nearly reaching anterior ocellus; face with setigerous punctures, setae 2x own puncture diameter in length, becoming erect at midpoint of eye along preorbital carina up to and including vertex; vertex somewhat flattened, punctate throughout; POL 3.0–3.5x OOL; AOL ca. 1.5x OOL; posterior ocellus diameter equal to OOL (1:1); clypeus inferior margin rounded beyond lateral margins of toruli, slightly projecting outward; torulus diameter ca. 0.5x ITD; antennomere length ratio, beginning with scape 51:20:10:10:10:9:9:9:8:8:15; scape in lateral view reaching midpoint of eye (Fig. 15).

Mesosoma. Pronotum:mesoscutum:mesoscutellum:propodeum ratio ca. 6:7:6:5 in dorsal view; pronotum dorsally with setigerous punctures less than one puncture diameter apart, setae ca. 3x own puncture diameter in length, interstices anteriorly reticulate–aciculate, median polished, lateral panel punctate to ventral margin, ventral strip punctate; mesoscutum with same setigerous sculpture and setae length as dorsal pronotum, interstices anteriorly reticulate–aciculate, posteriorly polished, lateral lobe with punctures 1–2 puncture diameters apart; mesoscutellum with setigerous punctures 1–2 puncture diameters apart, median polished, interstices anteriorly polished to aciculate, posterior margin rounded (Fig. 6c); propodeum with submedian, accessory, sublateral, and lateral carinae, accessory carina posteriorly reaching midpoint of propodeum, strong transverse carina, interstices polished to sparsely punctate, posterolateral margin slightly acute, nearly reaching extent of petiolar foramen (Fig. 7c); metafemur ca. 1.9x longer than wide, sparsely setose, outer surface sparsely punctate/aciculate; forewing ca. 2.5x longer than wide (5:2), submarginal:marginal:stigmal veins ratio ca. 22:4:1.

Gaster. In lateral view quadrate, dorsal posterior apex strongly convex (Fig. 13, 15); tergum 1 dorsally 0.3–0.6x gaster length, reticulate to posterior margin, laterally with faint minute reticulations making surface slightly dull (variation – some with lateral surface polished); tergum 2 in dorsal view ca. 0.6x length of tergum 1, posterior margin emarginate, laterally punctate, with some punctures petal-like; tergum 3 dorsal posterior margin emarginate; tergum 6 vertical or nearly so (Fig. 13, 15); ovipositor sheath with dorsal margin straight, apex pointed, apex to ventral margin convex (Fig. 13, 15); epipygium and ovipositor sheath barely visible from above.

Male – Length 3.1–3.9 mm (allotype 3.8 mm).

Color. Same as for female. Additionally, interior scape margin dark brown; exterior scape margin and denticle orange to brown; funicular antennomeres exteriorly gray/brown, interiorly orange.

Body. Sculpture and structure same as for female except the following: Face width equal to face height (1:1); POL 3.0–3.5x OOL; AOL 1.4–2.0x OOL; antennal scape 3x longer than broad, apex truncate, denticle emerging at 3/5 scape length; denticle 1.3x wider than width of scape at apex, point of denticle pointing outward (Fig. 5c); antennomere length ratio, beginning with scape: 53:15:3:22:17:16:17:16:16:15:28; MS 0.5x EH (1:2); face and MS setae densely appressed; pronotum, mesoscutum, and mesoscutellum setae more erect; mesoscutellum setae ca. 4x own puncture diameter in length.

Comments. *Psilochalcis quadratis* runs to *P. usta* in Grissell and Schauff (1981) but differs from it in having the lateral panel of the pronotum and ventral strip punctate. In *P. usta*, the lateral panel of the pronotum is polished and the ventral strip reticulate. Tergum 1 of *P. quadratis* is dorsally reticulate to posterior margin. In *P. usta,* tergum 1 is dorsally reticulate with a polished posterior band. Females of *P. quadratis* have the gaster apex truncate. *Psilochalcis usta* females have the gaster apex acuminate.

Females of *P. quadratis* are similar to *P. brevialata* in having the forewing reaching the posterior margin of tergum 3. However, this trait is quite variable in *P. quadratis* with some specimen forewings reaching and many extending well beyond tergum 3.

Etymology. Species epithet references the shape of the gaster.

Material Examined.

Holotype – "Utah, Juab Co., Yuba, 39.44125°N, 112.00100°W, 5047 ft., 9 Sep. 2006, coll. R.L. Johnson/ malaise trap, cheatgrass habitat" (♀ BYUC).

Allotype – "Utah, Juab Co., Yuba, 39.44125°N, 112.00100°W, 5047 ft., 26 Jul. 2006, coll. R.L. Johnson/ malaise trap, cheatgrass habitat" (♂ BYUC).

Paratypes – Utah: Box Elder Co.: Corrine, 13 Aug. 1929, G.F. Knowlton (1♀ USU); same date except, 22 Aug. 1929 (1♂ USU); Lampo, 8 Aug. 1931, G.F. Knowlton (1♀ USU). Cache Co.: Petersboro, 6 Jul. 1948, G.E. Bohart (1♀ USU). Juab Co.: Gilson Mountains, 39.65849°N, 112.24926°W, 5381 ft., 29 Jul.-6 Aug. 2021, M.J. Petersen & R.L. Johnson (1♀, 1♂); same data except, 7-20 Aug. 2021 (2 ♂); 21 Aug.-1 Sep. 2021 (1♀); Sage Valley, 39.31385°N, 112.04212°W, 5055 ft., 17-27 Jul. 2020, M.J. Petersen & R.L. Johnson (2♀, 1♂); same data except, 28 Jul.-7 Aug. 2020 (3♀); 8-18 Aug. 2020 (1♀); Sage Valley, 39.34207°N, 112.05164°W, 5355 ft., 8-18 Aug. 2020 (1♂); Tintic Valley, 39.72314°N, 112.20226°W, 5233 ft., 10 Aug. 2006, R.L. Johnson (1♂); same data except, 28 Aug.-11 Sep. 2007 (1♂); Tintic Valley, 39.75257°N, 112.20272°W, 5248 ft., 9 Sep. 2006 (1♂); same data except, 3-17 Jul. 2007 (1♂); Yuba, 39.43857°N, 112.0024°W, 5041 ft., 8 Jun. 2006, R.L. Johnson (1♂); same data except, 26 Jul. 2006 (54♀, 33♂); 10 Aug. 2006 (31♀, 30♂); 9 Sep. 2006 (3♀, 5♂); 30 May-5 Jun. 2007 (7♂); 5-19 Jun. 2007 (1♀, 4♂); Yuba, 39.46994°N, 112.0047°W, 5054 ft., 26 Jul. 2006 (30♀, 49♂); same data except, 10 Aug. 2006 (25♀, 35♂); 9 Sep. 2006 (5♀, 9♂); 22-30 May 2007 (4♂); 19 Jun.-3 Jul. 2007 (1♂); Yuba 39.44125°N, 112.00100°W, 5047 ft., 8 Jun. 2006 (1♀); same data except, 26 Jul. 2006 (23♀, 27♂); 10 Aug. 2006 (24♀, 17♂); 9 Sep. 2006 (2♀, 4♂); 30 May-5 Jun. 2007 (8♂); Yuba, 39.41016°N, 111.99285°W, 5096 ft., 10 Aug. 2006 (1♂); same data except, 14-28 Aug. 2007 (1♂); Yuba, 39.45201°N, 111.99307°W, 5136 ft., 17-

31 Jul. 2007 (1♀); Yuba, 39.45618°N, 111.99165°W, 5156 ft., 26 Jul. 2006 (1♀); Yuba, 39.45763°N, 111.99073°W, 5146 ft., 26 Jul. 2006 (2♀); same data except, May-5 Jun. 2007 (1♀, 1♂); 28 Aug.-11 Sep. 2007 (1♀); Yuba, 39.26229°N, 112.00220°W, 5063 ft., 17-27 Jul. 2020, M.J. Petersen & R.L. Johnson (2♀, 8♂); same data except, 28 Jul.-7 Aug. 2020 (9♀, 10♂); 8-18 Aug. 2020 (1♀, 2♂); Yuba, 39.23102°N, 111.57254°W, 5166 ft., 28 Jul.-7 Aug. 2020 (1♀, 1♂); Yuba, 39.27123°N, 111.58028°W, 5280 ft., 17-27 Jul. 2020 (1♀); same data except, 28 Jul.-7 Aug. 2020 (1♀); 8-18 Aug. 2020 (5♀); Yuba, 39.23087°N, 111.57473°W, 5251 ft., 17-27 Jul. 2020 (3♀); same data except, 28 Jul.-7 Aug. 2020 (1♀, 1♂). Tooele Co.: Lake Point, 27 Aug. 1929, G.F. Knowlton (1♀ USU); Orr's Ranch Skull Valley, 12 Aug. 1949, G.F. Knowlton (1♀ USU). Utah Co.: Lake Mountain, 40.24126°N, 111.98340°W, 5031 ft., 7-20 Aug. 2021, M.J. Petersen & R.L. Johnson (1♀). *(All cited material resides at BYUC unless otherwise noted.)

Distribution. *Psilochalcis quadratis* is only known to occur in Utah. It is known from Box Elder, Cache, Juab, Utah, and Tooele Counties in central and northern Utah (Fig. 18).

***Psilochalcis threa* (Grissell and Schauff)**

Invreia threa Grissell and Schauff 1981:8

(Fig. 8)

Type Locality. Oklahoma, Marshall Co., 9 Sept. 1978.

Diagnosis. Distinguished by having tergum 1 evenly reticulate both dorsally and laterally.

Material Examined.

Texas: Comanche Co.: 3 mi. W. DeLeon, 10 Aug. 1978, R.L. Sams (1♀ paratype no. 134, TAMU).

Distribution. *Psilochalcis threa* is known only from cultured material collected from cultivated peanut crop from Oklahoma, Marshall Co. and Texas, Comanche Co. (Fig. 8). It is not known if this species occurs naturally in the United States.

***Psilochalcis usta* (Grissell and Schauff)**

Invreia usta Grissell and Schauff 1981:6

(Figs. 5g, 8, 12)

Type Locality. Texas, Comanche Co., 3 mi. W. DeLeon, 14 Aug. 1978.

Diagnosis. Distinguished by the following: 1) lateral panel of pronotum polished, ventral strip reticulate; 2) female – mesoscutellum punctate except for median area polished, interstices polished; 3) ovipositor sheath apically rounded (Fig. 12).

Comments. *P. usta* comes nearest to *P. minuta* with both having tergum 1 reticulate dorsally, and a wide polished posterior band, but differs from it as aforementioned under *P. minuta*.

Material examined.

Texas: Comanche Co.: 3 mi. W. DeLeon, 14 Aug. 1978, R.L. Sams (♀, holotype no.76488, USNM); same data except, 20 Jul. 1978 (♀ paratype); 17 Aug. 1978 (♂ allotype).

Distribution. *Psilochalcis usta* is known only from cultured material collected from cultivated peanut crop from Texas, Comanche Co. (Fig. 8). It is not known if this species occurs naturally in the United States.

KEY TO *PSILOCHALCIS* SPECIES OF THE WESTERN UNITED STATES

1a Male, antennal pedicel 1–2x longer than wide; scape outer margin usually with projecting denticle (Figs. 5a-c, e-g) ..…………...…………………..……………………..…………..…. 2

1b Female, antennal pedicel 3–5x longer than wide; scape without projecting denticle (Fig. 5d) ……………………………………………………………………………………..…… 9

Male

2a Scape elongate, at least 3 times longer than wide; pedicel nearly equal in length and width ……………………..............……………………..…………………………………….......................... 3

2b Scape triangular, 2x longer than wide at apex (Fig. 5f); pedicel 1.5x wider than 1st funicular antennomere, forming a rounded medial flap ………………...… ***P. hespenheidei*** **(Bouček)**

3a Scape with denticle produced on outer margin (Figs. 5b, c, e, g) ……...……...……... 4

3b Scape without protruding denticle (Fig. 5a) ...…… ***P. adenticulata*** **Petersen, new species**

4a Point of denticle projecting toward apex of scape (Fig. 5e) .....…………….………… 5

4b Point of denticle projecting outward (Figs. 5b, c, g) 6

5a Tergum 1 dorsally reticulate, laterally polished without sculpture

....………………………………………….……... ***P. brevialata*** **Grissell and Johnson**

5b Tergum 1 dorsally and laterally polished without sculpture

.... ***P. deceptor*** **(Grissell and Schauff)**

6a Tergum 1 dorsally and laterally reticulate ……….......…. ***P. threa*** **(Grissell and Schauff)**

6b Tergum 1 dorsally reticulate, laterally polished or dull with faint sculpture …….....……... 7

7a Lateral panel of pronotum punctate dorsally, median area to ventral carina highly polished without punctures, ventral strip reticulate ...……..……...….. ***P. usta*** **(Grissell and Schauff)**

7b Lateral panel of pronotum entirely punctate including ventral strip ...…………............... 8

8a Scape 3x longer than width at denticle; denticle 1.3x wider than width of scape at apex; tergum 1 reticulate to posterior margin ……………..... ***P. quadratis*** **Petersen, new species**

8b Scape 6x longer than width at denticle; denticle equal to or slightly wider than width of scape at apex; tergum 1 reticulate, wide polished band at posterior margin

……………………….……………………....…… ***P. minuta*** **Petersen, new species**

Female

9a Ovipositor sheath in lateral view reaching and/or exceeding apex of gaster ....…... 10

9b Ovipositor sheath in lateral view positioned anteroventrally, not reaching apex of gaster

....…. ***P. hespenheidei*** **(Bouček)**

10a Gaster apex acuminate; tergum 6 acutely inclined; ovipositor sheath extending beyond gaster apex (Figs. 11, 12) ..…………………..…….……...……...…….……...………. 11

10b Gaster apex truncate; tergum 6 vertical or nearly so; ovipositor sheath usually reaching or exceeding gaster apex (Fig. 13) ………………..…. ***P. quadratis*** **Petersen, new species**

11a Upper face with evenly to irregularly spaced punctures, flat interstices either polished or with sculpture; forewing usually reaching or exceeding apex of gaster ....…….…….. 12

11b Upper face with evenly spaced punctures separated by carinate walls; forewing barely reaching dorsal posterior margin of tergum 3 …....… ***P. brevialata*** **(Grissell and Johnson)**

12a Tergum 1 laterally polished, without sculpture, dorsally either polished or with reticulate sculpture …………………………………...……………………….……………………. 13

12b Tergum 1 laterally and dorsally reticulate ………....……. ***P. threa*** **(Grissell and Schauff)**

13a Tergum 1 dorsally 3/4th reticulate with polished posterior band ....………… 14

13b Tergum 1 dorsally and laterally polished, without sculpture .... ***P. deceptor*** **(Grissell and Schauff)**

14a Scutellum with irregularly spaced punctures, median polished without punctures, interstices polished; apex of ovipositor sheath rounded (Fig. 12) ……… ***P. usta*** **(Grissell and Schauff)**

14b Scutellum with irregularly spaced punctures throughout, interstices reticulate/aciculate (Fig. 6b); apex of ovipositor sheath truncate (Fig. 11) ….. ***P. minuta*** **Petersen, new species**

SUMMARY

With the addition of *P. adenticulata*, *P. minuta*, and *P. quadratis*, eight species of *Psilochalcis* are known to occur in the United States and *P. hespenheidei* is reported for the first time as occurring in Mexico. *Psilochalcis adenticulata* is unique among them being the first species known to have males lacking a protruding denticle on the antennal scape. This morphological trait had previously only been documented in a few species known from the Old World. It is expected that other undescribed *Psilochalcis* species have yet to be discovered in North America particularly in the western deserts. Expanding the extent of Malaise trapping to these areas will likely be rewarded with new discoveries. The use of Malaise traps for collecting is a highly effective method of obtaining specimens of *Psilochalcis* and other chalcidoids.

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LITERATURE CITED

Bouček, Z. 1951. The first revision of the European species of the family Chalcididae (Hymenoptera). Acta Entomologica Musei Nationalis Pragae 27(Suppl. No.1:1-124).

Bouček, Z. 1974. A revision of the Leucospidae (Hymenoptera: Chalcidoidea) of the world. Bulletin of the British Museum of Natural History, Supplement 23: 1–241.

Bouček, Z. 1984. On *Schwarzella*, *Invreia* and some other Hybothoracini (Hym. Chalcididae). Bollettino del Laboratorio di Entomologia Agraria'Filippo Silvestri', Portici. 41:53–64.

Bouček, Z. 1992. The new world genera of Chalcididae. On the New World Chalcididae (Hymenoptera). Memoirs of the American Entomological Institute 53:49–117.

Bouček, Z. 1997. Leucospidae. Pages 496–498 *in* G.A. Gibson, J.T. Huber, J.B. Woolley editors, Annotated Keys to the Genera of Nearctic Chalcidoidea (Hymenoptera). Research Press, National Research Council of Canada, Ottawa, Ontario.

Bouček Z. and J. Halstead. 1997. Chalcididae. Pages 151–164 *in* G.A. Gibson, J.T. Huber, J.B. Woolley editors, Annotated Keys to the Genera of Nearctic Chalcidoidea (Hymenoptera). Research Press, National Research Council of Canada, Ottawa, Ontario.

Delvare, G. 2017. Order Hymenoptera, family Chalcididae. Pages 225–274 *in* van Harten A, editor. Arthropod fauna of the UAE (Vol. 6). Abu Dhabi: Dar Al Ummah Printing, Publishing, Distribution & Advertising.

Delvare, G., L. Talaee, and S.H. Goldansaz. 2011. New Chalcididae (Hymenoptera: Chalcidoidea) of economic importance from Iran. Annales Zoologici 61:789–802.

Evenhuis, N.L. 2021. The insect and spider collections of the world website. Available at: http://hbs.bishopmuseum.org/codens/ (accessed: 1 February 2022).

Gibson, G.A. 1997. Morphology and Terminology. Pages 16–44 *in* G.A. Gibson, J.T. Huber, J.B. Woolley editors, Annotated Keys to the Genera of Nearctic Chalcidoidea (Hymenoptera). Research Press, National Research Council of Canada, Ottawa, Ontario.

Grissell, E.E., and M.E. Schauff. 1981. New Nearctic *Invreia* (Hymenoptera: Chalcididae) from lepidopterous pests of peanut. Proceedings of the Entomological Society of Washington 81:1–12.

Johnson, J.A., E.E. Grissell, V.E. Gokhman, and K.A. Valero. 2001. Description, biology, and karyotype of a new *Psilochalcis* Kieffer (Hymenoptera: Chalcididae) from Indianmeal moth pupae (Lepidoptera: Pyralidae) associated with culled figs. Proceedings of the Entomological Society of Washington 103:777–787.

Johnson, R.L., V.J. Anderson, and S.M. Clark. 2008. Impact of Habitat Alterations to Bee Diversity in Sagebrush and Pinyon/Juniper Communities of the Eastern Great Basin. Chapter 1, Unpublished dissertation, Department of Plant and Wildlife Sciences, Brigham Young University, Provo, Utah, 1–52.

Kieffer, J.J. 1905. New Eucharinae and Chalcidinae. Berlin Entomological Journal 49:240–265.

Malaise, R. 1937. A new insect trap. Entomologisk tidskrift 58:148–160.

Masi, L. 1929. Sopra un nuovo genere di Haltichellini e sulle diverse forme attribute al genere Euchalcis Duf. (Hymen. Chalcididae). Memorie della Società Entomologica Italiana 6:208–222.

Narendran, T.C., and F.R. Khan. 2011. Two new species of Chalcididae (Hymenoptera: Chalcidoidea) from India. Journal of Threatened Taxa 3:1506–1513.

Narendran, T.C., and C. van Achterberg. 2016. Revision of the family Chalcididae (Hymenoptera, Chalcidoidea) from Vietnam, with the description of 13 new species ZooKeys 576:1–202.

Nikol'skaya, M.N. 1960. Chalcididae and Leucospidae in Central Asia (Hymenoptera, Chalcidoidea). Trudy Zoologicheskogo Instituta, Akademiya Nauk SSSR, Leningrad 27:220–246).

Noyes, J.S. 2019. Universal Chalcidoidea Database. World Wide Web electronic publication. http://www.nhm.ac.uk/chalcidoids (accessed: 18 June 2022).

Skvarla, M.J., J.L. Larson, J.R. Fisher, and A.P. Dowling. 2021. A review of terrestrial and Canopy Malaise Traps. Annals of the Entomological Society of America 114:27–47.

Stringer D., S. Mantel, J. Jennings, and A. Austin. 2012. Family Chalcididae, Australian Centre for Evolutionary Biology and Biodiversity, and the School of Earth and Environmental Science, The University of Adelaide, South Australia, Australia. Available from: URL https://www.researchgate.net/publication/268212136_Family Chalcididae (accessed: 3 August 2022).

Townes, H. 1962. Design for a Malaise trap. Proceedings of the Entomological Society of Washington 64:253–262.

van Achterberg, C. 2009. Can Townes type Malaise traps be improved? Some recent developments. Entomologische berichten 69:129–135.

Wall, R., and R.C. Berberet. 1975. Parasitoids associated with lepidopterous pests on peanuts; Oklahoma fauna. Environmental Entomology 4:877–882.

FIGURES

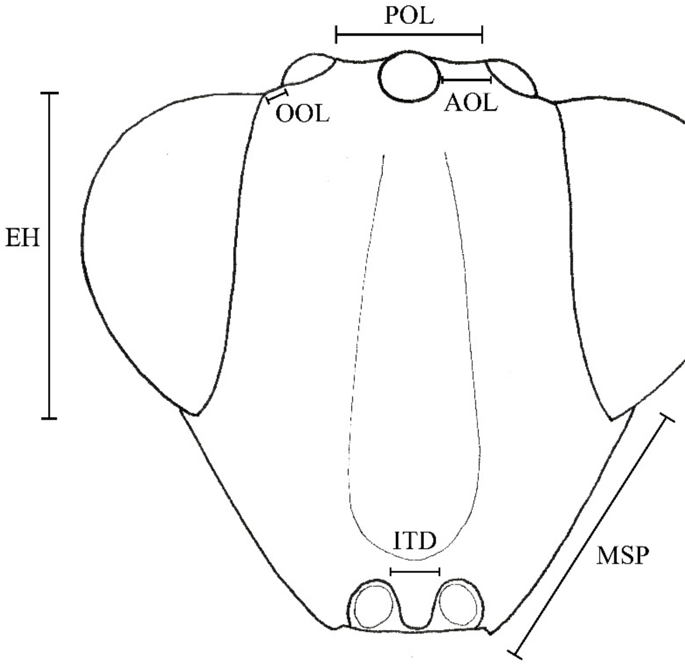

Fig. 1. Generalized *Psilochalcis* head, anterior view. EH = eye height, ITD = intertorular distance, MSP = malar space, AOL = anterior ocellar line, POL = posterior ocellar line, OOL = ocular ocellar line.

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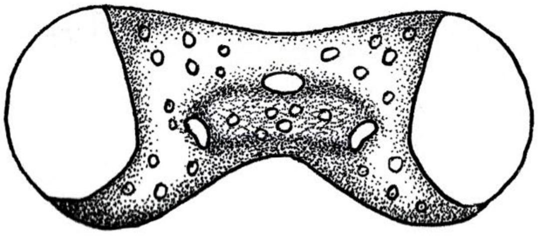

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Figs. 2–4. *Psilochalcis adenticulata* new species, male. 2, Lateral habitus. 3, Dorsal habitus. 4, Vertex, dorsal view.

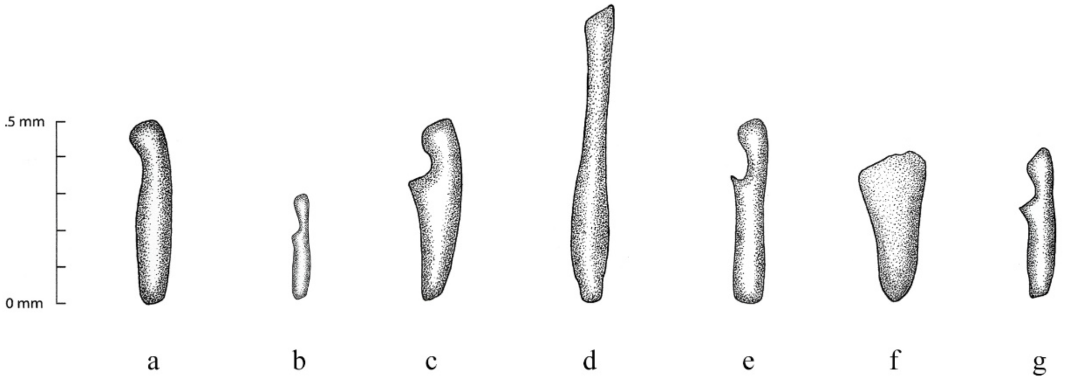

Fig. 5. *Psilochalcis* spp. antennal scape, dorsal view. a, *P. adenticulata* new species, male. b*, P. minuta* new species, male. c, *P. quadratis* new species, male. d, *P. quadratis* new species, female. e, *P. deceptor*, male. f, *P. hespenheidei*, male. g, *P. usta*, male.

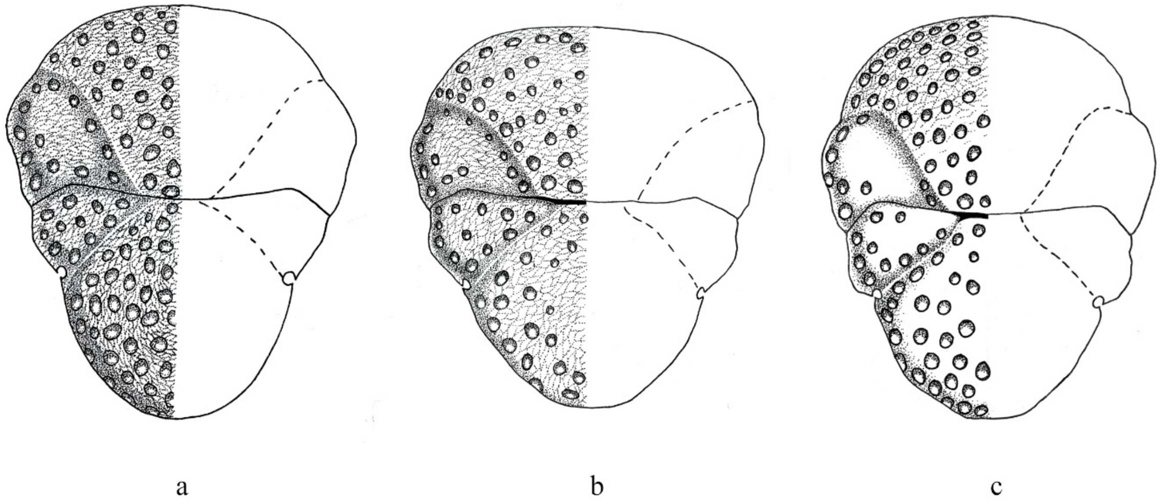

Fig. 6. *Psilochalcis* spp. mesoscutum and mesoscutellum, dorsal view. a, *P. adenticulata* new species, male. b, *P. minuta* new species, female. c, *P. quadratis* new species, female.

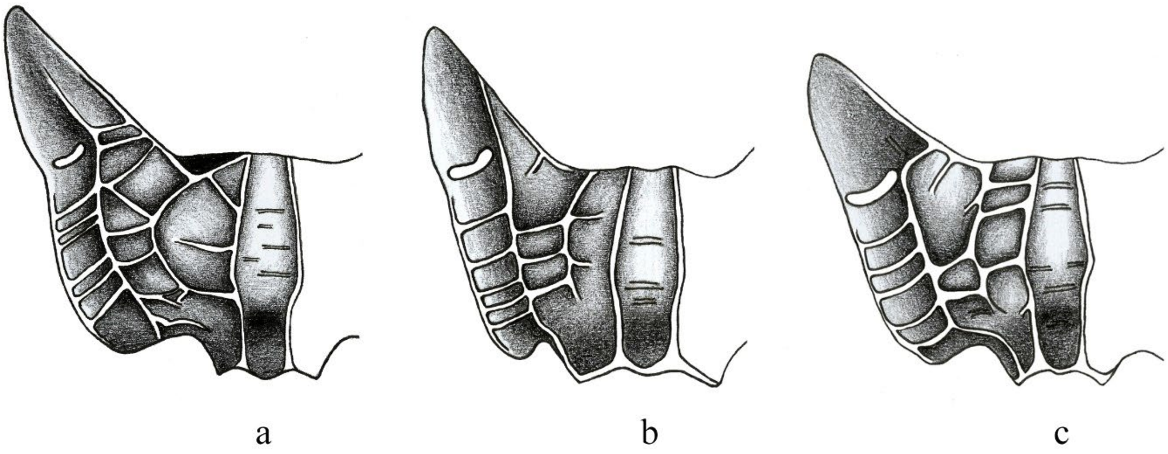

Fig. 7. *Psilochalcis* spp. propodea, dorsal view. a, *P. adenticulata* new species, male. b, *P. minuta* new species, female. c, *P. quadratis* new species, female.

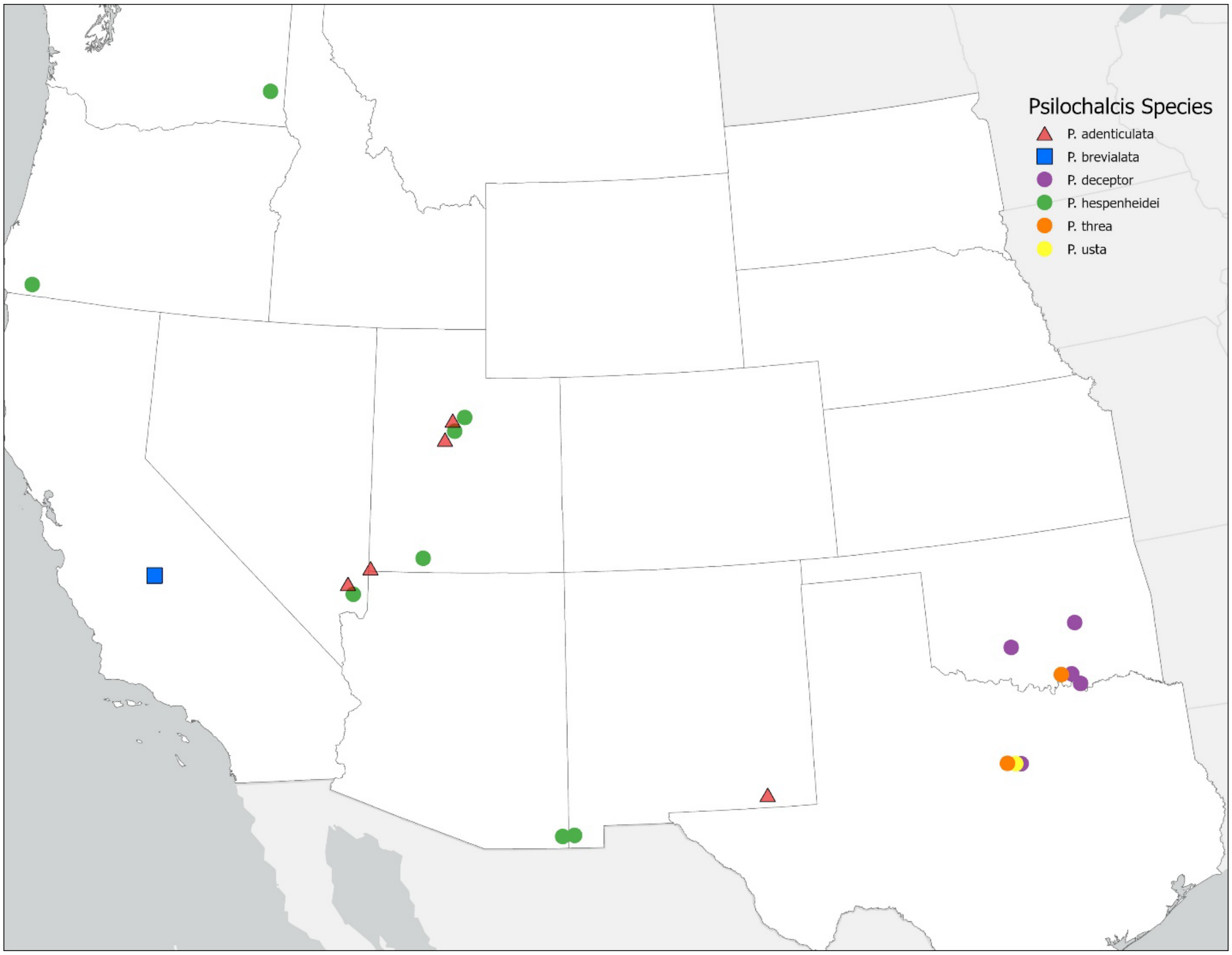

Fig. 8. Western United States distribution of *Psilochalcis adenticulata* new species, *P. brevialata*, *P. deceptor*, *P. hespenheidei*, *P. threa*, and *P. usta*.

Note: *P. brevialata* is known only from material reared from a culled fig warehouse in Fresno County, California. *Psilochalcis deceptor*, *P. threa*, and *P. usta* are known only from cultured laboratory stock from cultivated peanut crop. It is not known if these species occur naturally in the United States. The occurrence of *P. hespenheidei* is shown only for the western United States. It is also known to occur in Oahu, Hawaii (Boŭcek 1984), and for the first time it is reported from Coahuila, Mexico (not shown).

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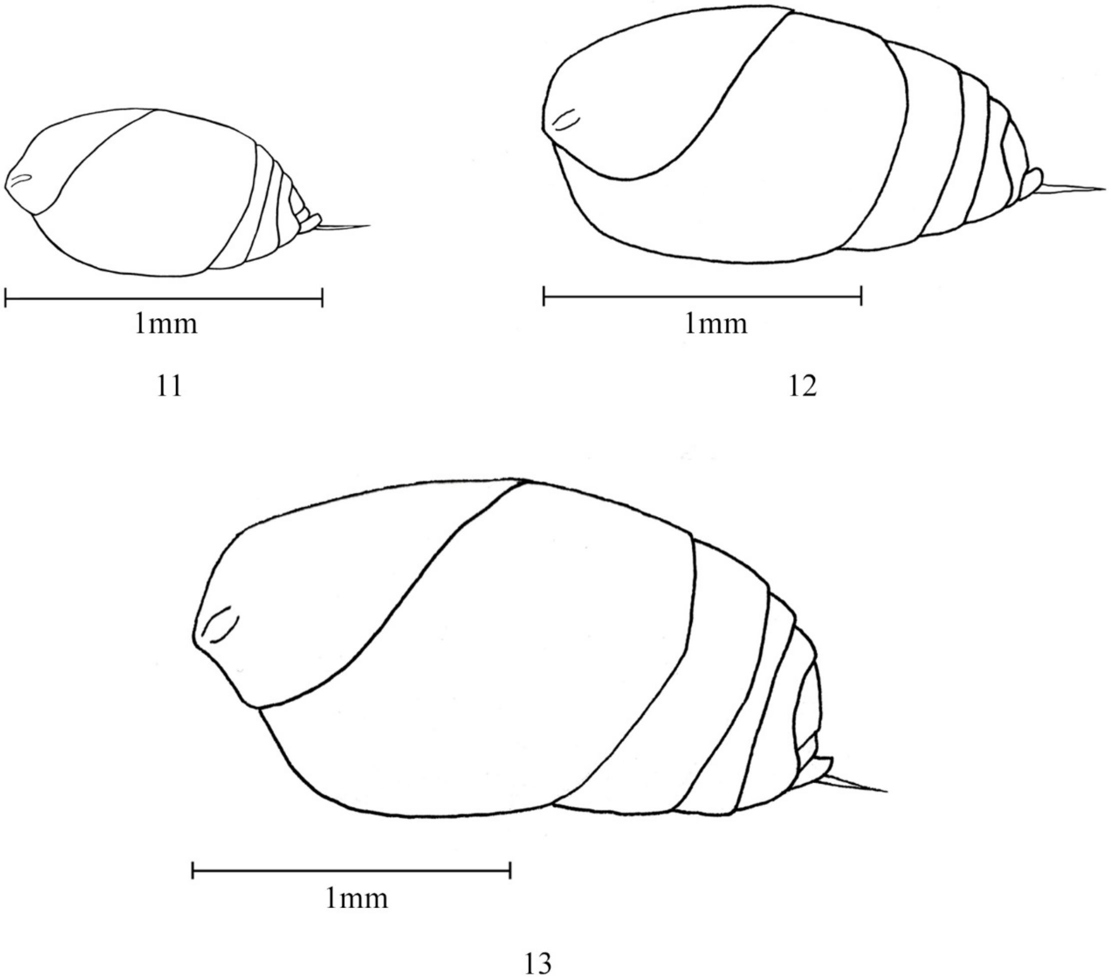
Figs. 9–10. *Psilochalcis minuta* new species, female. 9, Lateral habitus. 10, Dorsal habitus.



Figs. 11–13. *Psilochalcis* spp. female gaster, lateral view. 11, *P. minuta*, new species. 12, *P. usta*. 13, P. quadratis, new species.

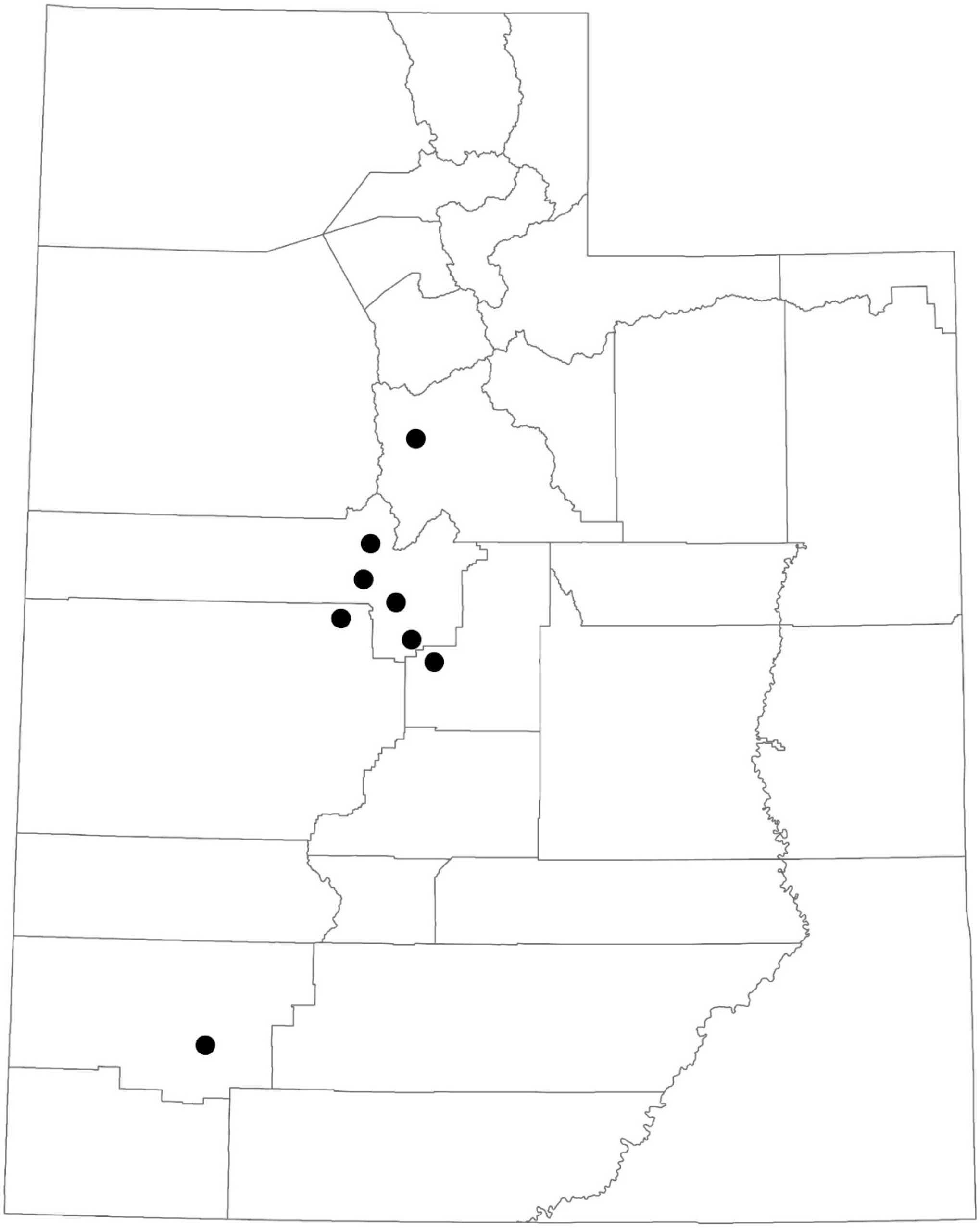


Fig. 14. Utah distribution of *Psilochalcis minuta* new species. This species occurs predominantly in central Utah but is also known from Iron County in southern Utah.

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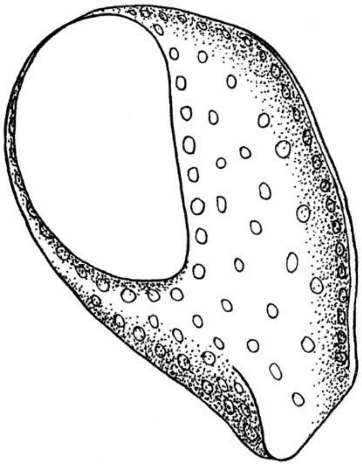

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Figs. 15–17. *Psilochalcis quadratis* new species, female. 15, Lateral habitus. 16, Dorsal habitus. 17, Head, lateral view.

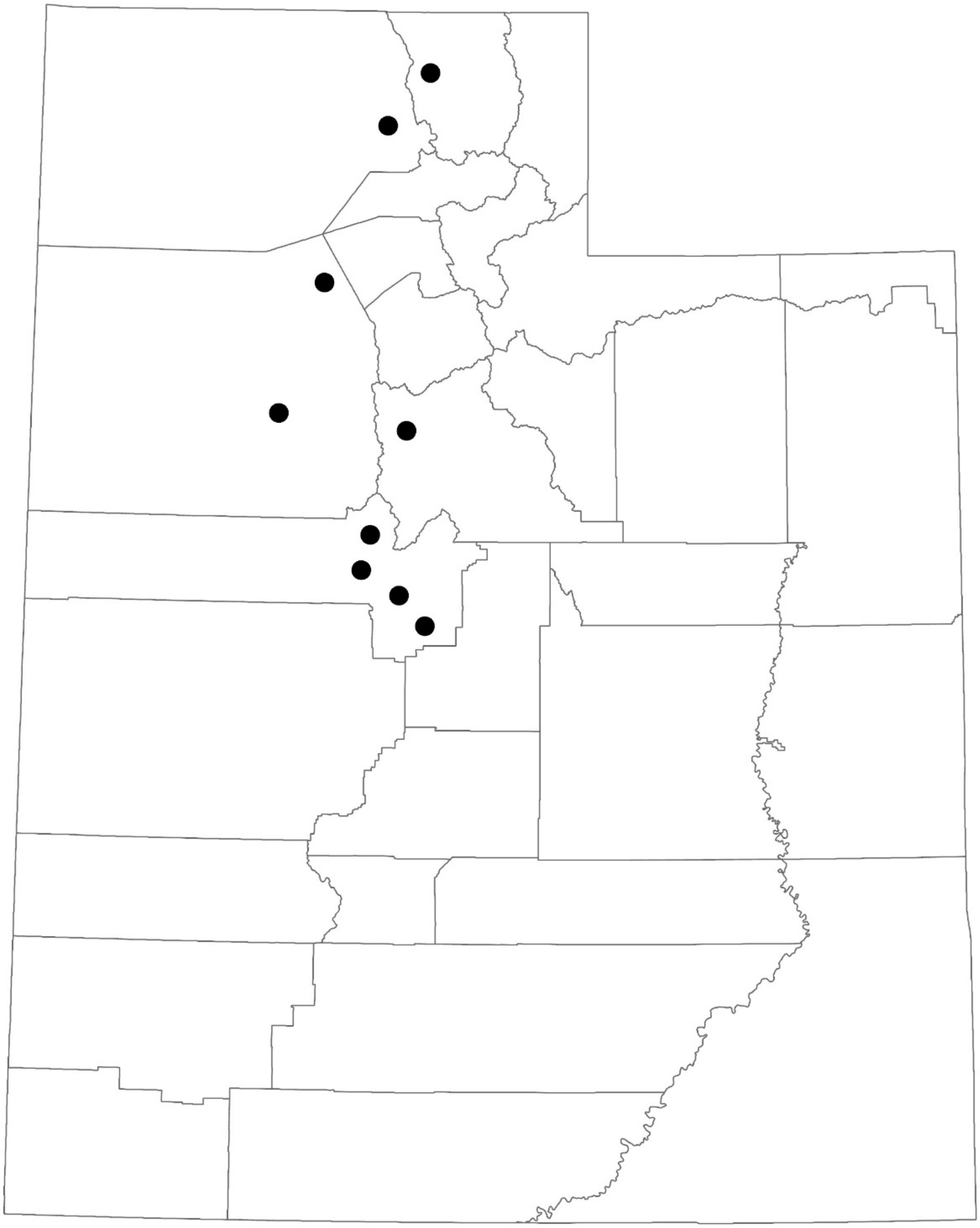

Fig. 18. Utah distribution of *Psilochalcis quadratis* new species. This species is only known from counties in central and northern Utah.

CHAPTER 2

Seasonal Trap Abundance of Two Species of *Psilochalcis* Kieffer (Hymenoptera: Chalcididae) in Rangelands of the Eastern Great Basin of Utah, USA

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ABSTRACT

Two species of *Psilochalcis* (Hymenoptera: Chalcididae) wasps occurring in the Great Basin region of the western United States were sampled from three locations in central Utah (USA) over a two-year period using Malaise traps. Each location is composed of four contiguous habitat types: pinyon/juniper (*Pinus edulis* or *P. monophylla* and *Juniperus osteosperma*), sagebrush (*Artemisia tridentata*), cheatgrass (*Bromus tectorum*), and crested wheatgrass (*Agropyron cristatum*). Seasonal trap abundance for each *Psilochalcis* species was determined. *Psilochalcis minuta* Petersen and *Psilochalcis quadratis* Petersen occur in highest abundance from mid-May to early August. *Psilochalcis minuta* demonstrates a significant association with pinyon/juniper habitat, specifically at the Utah; Juab County, Yuba Valley sample site, whereas *P. quadratis* demonstrates a significant association with cheatgrass (*Bromus tectorum*) habitat at the same location.

Keywords: chalcidid wasps; malaise trap; pinyon/juniper; cheatgrass; crested wheatgrass; habitat; ecological relationships

INTRODUCTION

The Great Basin is a region of north and south running mountain ranges and valleys that extend from the Wasatch Mountains of Utah in the east to the Sierra Nevada Mountains in the west. The northern border is the Snake River Plain extending south to the Mohave Desert. It is characterized as a cold desert with hot summers and freezing winters. Precipitation ranges from 125 to 500 mm annually [1]. Two common habitat types found throughout the region are pinyon/juniper *(Pinus edulis* Engelm. or *P. monophylla* Torr. and Frem. and *Juniperus osteosperma* (Torr.) Little) woodland and sagebrush (*Artemisia tridentata* Nutt.) steppe. In Utah, these two habitat types compose nearly 40 percent of the semi-arid region of the state [2]. These habitats have become fragmented due to frequent wildfires, leaving a habitat mosaic across the region. Subsequent to wildfire, they are often replaced by introduced exotic species, especially annual cheatgrass (*Bromus tectorum* L.), which is native to Eurasia. A regional model suggests that nearly one-third of the Great Basin (210,000 km2) has cheatgrass cover of at least 15 percent [3]. Crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), a perennial grass native to Russian and Siberia, has been used extensively in post wildfire reseeding efforts across the region. While it is an introduced species, it is considered preferable to cheatgrass. Like cheatgrass, it forms monotypic stands. The impact of these habitat alterations from native to nonnative plant communities on insect communities is poorly understood. We are interested in the effect this might have on chalcidid wasps that occur in these habitats.

The family Chalcididae is a taxon of parasitic Hymenoptera. These wasps most often parasitize pupae of Lepidoptera [4]. As such, they are typically studied for their potential use as biological control agents in areas where their lepidopteran hosts are important economic insect pests. The taxonomy of Chalcididae has changed very little in the past 150 years, including divisions into subfamilies and genera [4], a 1992 revision of the new world Chalcididae being the most recent [5]. Recently, three species of chalcidid wasps were described from rangelands of the eastern Great Basin in Utah, two of which were collected in enough abundance to warrant further investigation [6]. These two species belong to the subfamily Haltichellinae.

Haltichellinae is comprised of six chalcidid genera that occur in the United States and Canada [4]. The most recent report of Haltichellinae species that occur in the Great Basin describes the distribution of species in the genus *Psilochalcis* Kieffer [6]. The Universal Chalcidoidea Database [7] currently reports 60 species of *Psilochalcis* worldwide. Old world and new world distributions are not known to overlap [8]. The literature suggests that less than 20 species of *Psilochalcis* are known from the Western Hemisphere [5]. In general, *Psilochalcis* species occur in arid to semi-arid areas across the southwest and western United States [6]. Biological observations are rare, with only a few host species reported [8,9]. Of the eight species of *Psilochalcis* wasps known to occur in the United States [6], four are associated with agricultural environments. *Psilochalcis brevialata* Grissell and Johnson is known from a culled fig warehouse in California [8]. *Psilochalcis deceptor* (Grissell and Schauff), *P. threa* (Grissell and Schauff), and *P. usta* (Grissell and Schauff) occur in cultivated peanut crop in Oklahoma and Texas [9]. *Psilochalcis hesphenheidei* (Boŭcek) occurs in natural areas across the western United States [10], but no habitat associations are reported. *Psilochalcis adenticulata* Petersen is known from multiple natural habitat types based on label information from collection sites in New Mexico, Nevada, and Utah [6]. The paucity of ecological data associated with *Psilochalcis* is understandable, due to their being rarely collected and the lack of interest in adding ecological data to collection labels. This paper is unique, relative to all other publications on North American *Psilochalcis*, because it links two *Psilochalcis* species with specific ecological data.

Using Malaise trap capture data, we evaluate the changes in seasonal abundance over time for *P. minuta* Petersen and *P. quadratis* Petersen and their associations within distinct habitat types of the eastern Great Basin.

METHODS AND MATERIALS

In 2019, we were able to examine and extract chalcid wasps from historic Malaise trap samples collected in 2006 and 2007. These samples were originally used to study different insect groups with the remaining material stored in 500 ml Nalgene bottles with 70% ethanol at 2 ◦C. The sample sites were originally selected in areas where native and nonnative plant communities formed contiguous boundaries representing; native shrubland, native woodland, introduced annual grassland, and introduced perennial grassland.

Site Descriptions

In 2006, a study was established to examine insect diversity in native pinyon/juniper and sagebrush habitats relative to those in the non-native conversion habitats of cheatgrass or crested wheatgrass. From these samples, we are able to test the effect of habitat on the presence of *Psilochalcis* wasps. Malaise traps were set up in four contiguous habitat types common to the Great Basin at three different locations. Locations are (1) Utah, Juab County, Tintic Valley; Utah, Juab County, Yuba Valley; and Utah, Sanpete County, Antelope Valley. The habitat types at these locations are defined by the dominant plant species, namely (1) pinyon/juniper (*Pinus edulis* or *P. monophylla* and *Juniperus osteosperma*), (2) sagebrush (*Artemisia tridentata*), (3) cheatgrass (*Bromus tectorum*) and (4) crested wheatgrass (*Agropyron cristatum*) (Figure 1). Both the cheatgrass and crested wheatgrass sites were either native shrubland or woodland prior to wildfires. Crested wheatgrass sites were reseeded after fire disturbance whereas cheatgrass sites were untreated or failed reseedings. These two altered plant communities formed the dominant habitat type at each location with sagebrush comprising much smaller remnant patches. The overall topography was relatively flat except where dry washes bisected the study site or where slopes gradually gain elevation. The Antelope Valley site has abundant pinyon/juniper on the adjacent slopes to the west and north. At the Tintic Valley site, pinyon/juniper is abundant to the north, and at the Yuba Valley site, pinyon/juniper is abundant to the east (Figure 1). Within habitat types, exact trap locations were based partly on road accessibility and the logistics of regular retrieval of trap samples. Though some trap sites appear close to habitat boundaries, they were still placed a minimum distance of 100 meters from the habitat edge, to reduce the effect of edge bias.

Sampling Method

Townes-style malaise traps [11,12] were installed at three different sites. At each site, three traps were set up in each of the four habitats. Within each habitat, the three traps were installed 120° opposing each other thus effecting a full 360° sample orientation. A total of 36 traps were installed in 2006 and repeated in 2007. Samples from each trap were retrieved biweekly from 1 April to 1 October (Spring through Fall). Trap setup required two eight-foot T-posts pounded into the soil on either side of trap, securing trap to posts, and staking the trap to the ground (Figure 2).

Malaise trapping is the prevailing method for collecting chalcidid wasps [13–15]. Malaise traps have been shown to be more effective in trapping chalcidoids than other style traps and are preferred when time and/cost are major constraints [16]. Due to the remoteness of our trap locations, it was not feasible to check traps more frequent than biweekly. Malaise traps passively capture through flight interception, which allows to them to be left unattended between sample retrieval for longer periods relative to other style traps without the concern of sample degradation. Preliminary examination of chalcidid wasp captures indicated two *Psilochalcis* species almost exclusively occurring in pinyon/juniper and cheatgrass habitats. This discovery prompted us to set up a few additional traps during the summers of 2020 through 2022 to see if we could predictably recapture the two wasp species in the same habitats but from different locations. Eleven traps were set up in pinyon/juniper and four traps in cheatgrass.

Plant Composition

In 2007, aerial plant cover was estimated at each trap location using a half-square meter quadrat placed every 5 m (excluding point 0) along a 45 m transect in each cardinal direction from the Malaise trap center. This yielded 32 sample quadrats for each trap with the sample area being a 45-m radius around each trap.

Seasonal Abundance

Malaise trap data were used to calculate species trap abundance by location, habitat type and collection year. For each *Psilochalcis* species, we produced annual species abundance graphs using Microsoft Excel 2016 to visualize seasonal trends.

Statistical Analysis

The trap abundance data for both *P. minuta* and *P. quadratis* were highly skewed having a large number of zeros from several traps across habitat type, site, and collection year. The data were transformed to a log scale before analysis to account for this. A separate two-way analysis of variance (ANOVA) and logistic regression were conducted for *P. minuta* and *P. quadratis* using the Statistical Analysis System (SAS) version 9.4 to determine the likelihood of each species occurring at each location and habitat type.

Climate Data Analysis

To assess any impact of climate on seasonal abundance, we analyzed both county [17] and local [18] temperature and precipitation data to visualize climate trends at collection sites. The weather stations in closest proximity to each location were chosen. Stations are Little Sahara for Tintic Valley, Scipio for Yuba Valley, and Manti for Antelope Valley.

RESULTS

Seasonal Trap Abundance

In 2006, 99.24 percent of *P. minuta* specimens were collected in pinyon/juniper habitat, while 0.76 percent of specimens were collected in crested wheatgrass habitat. Total number of specimens collected was 131, and only at the Yuba Valley site. In 2006, 96.75 percent of *P. quadratis* specimens were collected in cheatgrass habitat, 3.0 percent in crested wheatgrass habitat and 0.25 percent in sagebrush habitat. Total number of specimens collected was 401, with 400 specimens collected at Yuba Valley, and 1 collected at Tintic Valley. The 2006 seasonal trap abundance for both *P. minuta* (Figure 3) and *P. quadratis* (Figure 4) peaked from mid-July to early August.

Collection data for 2007 showed a decrease in seasonal abundance and a time shift in the peak abundance for both *Psilochalcis* species. The total number of *P. minuta* specimens collected in 2007 decreased to 52, with all specimens collected in pinyon/juniper habitat at Yuba Valley. The seasonal abundance for *P. minuta* peaked one month earlier in mid-June (Figure 3). The total number of *P. quadratis* specimens collected decreased to 33, with 75.8 percent of specimens collected in cheatgrass habitat, 12.1 percent in crested wheatgrass habitat and 12.1 percent in sagebrush habitat. Thirty *P. quadratis* specimens were collected at Yuba Valley, with 2 specimens collected at Antelope Valley and 1 specimen collected at Tintic Valley. The seasonal abundance for *P. quadratis* peaked two months earlier in mid-May (Figure 4).

Subsequent Malaise trapping from other locations in 2020 through 2022 revealed similar *Psilochalcis* affinities to habitat. *Psilochalcis minuta* was predominantly found in traps placed in pinyon/juniper habitat. All eleven traps placed in pinyon/juniper yielded specimens of *P. minuta* totaling 348. Five *P. minuta* specimens were retrieved from two traps placed in cheatgrass habitat. Three of four traps placed in cheatgrass habitat yielded specimens of *P. quadratis* totaling 10. Additionally, 18 *P. quadratis* specimens were retrieved from five traps placed in pinyon/juniper.

Plant Composition

Pinyon/juniper habitat sites are characterized by the dominant species Utah juniper (*Juniperus osteosperma*). The percent cover of Utah Juniper was 10.9% at Tintic Valley, 19.4% at Yuba, and 17.3% at Antelope Valley. Only the Antelope Valley site had cover of pinyon pine (*Pinus edulis*) at 6.0%. Cheatgrass is present in the understory at all three locations but with extremely low cover. Tintic Valley had cheatgrass cover of 0.1%, Yuba Valley had 1.5% and Antelope Valley had 0.1%. Other plants varied amongst the three locations (Table 1). Cheatgrass habitat sites are characterized by the dominant species cheatgrass (*Bromus tectorum*). The percent cover of cheatgrass at Tintic Valley was 16.1%, 1.3% at Yuba, and 42% at Antelope Valley. *Eremopyrum triticeum* (Gaertn.) Nevski had a slightly greater percent cover than cheatgrass at the Yuba site. It should be noted that the Yuba cheatgrass site experienced cheatgrass die-off in 2007, a phenomenon that occurs sporadically but regularly throughout the Great Basin [19]. No other species were sampled at the Antelope Valley site. Other plants varied amongst the other two locations (Table 2).

In general, sagebrush habitat sites are characterized by the dominant species Big Sagebrush (*Artemisia tridentata*) comprising slightly more than 12% of the total plant cover. Cheatgrass (*Bromus tectorum*) is present in the understory comprising approximately 7.5% total cover. Other forbes found were *Elymus elymoides* and *Chrysothamnus viscidiflorus*, both approximately 0.3% total cover.

Crested wheatgrass habitat sites are characterized by the dominant species Crested wheatgrass (*Agropyron cristatum*) comprising slightly more than 4% of the total plant cover. Cheatgrass (*Bromus tectorum*) is present in the understory comprising approximately 0.7% total cover. Other forbes found were *Stipa hymenoides*, slightly less than 1%, and *Elymus elymoides*, less than 0.5 % total cover.

Statistical Results

Psilochalcis minuta demonstrated a significant interaction in trap abundance for habitat type by location (F6, 60 = 120.97 ($p < 0.0001$). The least square means analysis shows a significant interaction with pinyon/juniper habitat at Yuba Valley ($p < 0.0001$, t value 38.53). All other habitat type and location combinations were insignificant. An odds ratio estimate was not obtained for *P. minuta* due to it being collected only at the Yuba Valley location. *Psilochalcis quadratis* also demonstrated a significant interaction in trap abundance for habitat type by location (F6, 60 = 20.06 ($p < 0.0001$). The least square means combination of cheatgrass at Yuba Valley shows a significant interaction of these two variables ($p < 0.0001$, t value 16.83). Crested wheatgrass at Yuba Valley also shows significance ($p < 0.0001$) but with a much lower t value (t value 5.07). With zeros so prevalent in our data set, this significant interaction between Crested wheatgrass habitat at Yuba Valley is to be expected. The number of *P. quadratis* specimens collected from Crested wheatgrass habitat at Yuba Valley were 16 out of 401. *Psilochalcis quadratis* was collected at all three locations. From the logistic regression we obtained an odds ratio estimate that *P. quadratis* is 63.46 times more likely to be present at Yuba Valley than Antelope Valley (confidence interval from 6.13 to 656.88), and 29.73 times more likely to be present at Yuba Valley than Tintic Valley (confidence interval from 4.53 to 195.08).

Climate Data Results

For Juab County Utah, monthly mean temperatures for 2006 and 2007 were compared to the 20th century average. In 2006, February and March temperatures were at or slightly below the 20th century average. April through July temperatures were consistently warmer. In 2007, the February temperature was slightly above average and rose more above average in March. April through July temperatures were consistently above average. The temperatures for these months were slightly higher when compared to the same months in 2006. In 2006, monthly precipitation was greater from February through September when compared to 2007. The three weather stations closest to each of our collection sites showed the same trends with minor differences becoming apparent. In 2006, all three stations were lower than the 30-year normal, the greatest deviation occurred at Little Sahara, which was 5.5 degrees below the 30-year normal. Scipio recorded a difference of 3.8 degrees and Manti was 4.1 degrees lower. In 2007, all three stations were higher than the 30-year normal. Temperatures ranged from 4.6 degrees higher at Manti up to 5.0 higher at Little Sahara. April through July in both years were consistently above the 30-year normal. The 30-year normal, 2006, and 2007 mean maximum temperatures from July through December were very similar with only minor fluctuations. The three weather stations reported lower monthly precipitation than the 30-year normal. All three stations also reported slightly higher precipitation in March and April of 2006 compared to the same months in 2007. Scipio showed the greatest difference between years, followed by Manti. Overall, the precipitation records for Little Sahara were spotty for both years, so a comparison was not easily made.

DISCUSSION

We collected *P. minuta* predominantly from areas of pinyon/juniper habitat, with rare collections in cheatgrass. *Psilochalcis quadratis* was collected primarily from cheatgrass habitat, with occasional collections in pinyon/juniper. The occasional occurrence of *Psilochalcis* species in adjacent habitat types is either due to their close proximities or the host plant of their host moth co-occurring in both habitats. Both *Psilochalcis* species are highly mobile. There is no reason not to expect flight across plant community boundaries. Our results suggest biological and/or ecological factors are driving the associations of *P. minuta* within pinyon/juniper habitat and *P. quadratis* within cheatgrass habitat and not trap placement within the habitat, but we are uncertain what the key host plant is within either habitat.

Plant composition in the same habitat across sites was not always uniform. The variability seen in trap capture between sites is likely due to differences in plant community compositions. The presence or absence of a particular plant species in a given habitat could be the primary factor influencing the presence of *P. minuta* and *P. quadratis* in those areas. This might account for the stark absence of *P. minuta* and *P. quadratis* in Antelope Valley, it being the most different in plant composition.

Psilochalcis are known parasitoids of lepidopterans in the families Pyralidae and Gelechiidae [4]. One particular species, *P. brevialata*, has been documented parasitizing the pupal stage of pyralid moths infesting stored figs [20]. Reports of host associations between dominant plant species occurring in our sampled habitats and pyralid moths are lacking, however; it is interesting to note that the pyralid *Dioryctria albovitella* (Hulst) was reported as attacking pinyon pine [21]. The pupal stage of *D. albovitella* has been documented as occurring from mid-July through September [22]. This timing of pupal abundance coincides with the peak abundance of *P. minuta* and *P. quadratis* adult wasps observed in our study. We observed both pyralid and gelichiid moth species in the same Malaise trap samples in which *P. minuta* and *P. quadratis* specimens were retrieved though they are yet to be quantified or identified to species. They were similarly observed in our subsequent Malaise trap samples. It is therefore likely that the abundance of *P. minuta* in pinyon/juniper habitat and *P. quadratis* in cheatgrass habitat is directly related to the abundance of their lepidopteran hosts occurring in each of these habitat types.

There are many variables affecting the phenology of living organisms, in particular environmental factors. Temperature and precipitation have been shown to play a role in the phenology of plants [23]. This pattern extends to plant/insect associations. The countywide differences in temperature and precipitation between 2006 and 2007 could account for the shift in observed phenology in *P. minuta* and *P. quadratis*. In 2007, warmer than average temperatures were recorded in February and March as well as from July through September when compared to 2006. Less than average precipitation was recorded from January through October when compared to 2006. We hypothesize that the warmer and drier spring of 2007 accelerated the phenology of the plant communities at the Yuba location. This could have altered the timing of the peak abundance of the host moth pupae within those habitats, and in turn resulted in the shift in seasonal abundance observed for both *P. minuta* and *P. quadratis* that parasitize those moths.

CONCLUSIONS

Psilochalcis minuta and *P. quadratis* are the first North American *Psilochalcis* species for which seasonal abundance has been associated with a specific habitat type. While *P. minuta* is strongly associated with pinyon/juniper habitat and *P. quadratis* is with cheatgrass habitat, the exact plant species accounting for these relationships remains unknown. The associations with habitat type were however, further confirmed by the additional Malaise traps placed in multiple areas beyond the original trap sites in multiple subsequent years.

We recognize there are still many unknown ecological relationships of *Psilochalcis* species. While Malaise traps can be a useful tool for determining species/habitat associations, trap costs and trap maintenance are often unfeasible. The simple addition of habitat information to collection labels would significantly contribute to our increased understanding of *Psilochalcis* and our ability to predict future occurrences through the development of species distribution models. We encourage collectors to include ecological data along with location data to increase our understanding of the ecological relationships of *Psilochalcis* species in their natural habitats. This study uniquely ties two *Psilochalcis* species' seasonal abundance to particular habitats of the Great Basin.

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REFERENCES

1. Belesky, D.P.; Malinowski, D.P. Grassland communities in the USA and expected trends associated with climate change. *Acta Agrobotanica*. 2016, 69, 1–25.
2. Banner, R.E.; Baldwin, B.D.; Leydsman-McGinty, E.I. *Rangeland Resources of Utah*; USU Cooperative Extension: Logan, UT, USA, 2009; pp. 1–188.
3. Bradley, B.A.; Curtis, C.A.; Fusco, E.J.; Abatzoglou, J.T.; Balch, J.K.; Dadashi, S.; Tuanmu, M.N. Cheatgrass (Bromus tectorum) distribution in the intermountain Western United States and its relationship to fire frequency, seasonality, and ignitions. *Biological invasions*. 2018, 20, 1493–1506.
4. Boŭcek, Z.; Halstead, J.A. Chalcididae. In *Annotated Keys to the Genera of Nearctic Chalcidoidea (Hymenoptera)*; Gibson, G.A., Huber, J.T., Woolley, J.B., Eds.; NRC Research Press: Ottawa, ON, Canada, 1997; pp. 151–164.
5. Boŭcek, Z. The new world genera of Chalcididae. In On the New World Chalcididae (Hymenoptera). *Memoirs of the American Entomological Institute.* 1992, 53, 49–117.
6. Petersen, M.J.; Johnson, R.L.; Anderson, V.J. A review of known Psilochalcis Kieffer (Hymenoptera: Chalcidoidea: Chalcididae) from the western United States with descriptions of three new species from Utah and surrounding states. *Western North American Naturalist.* 2022, 82, 704–718.
7. Universal Chalcidoidea Database. Available online: http://www.nhm.ac.uk/chalcidoids (accessed on 15 December 2022).

8. Johnson, J.A.; Grissell, E.E.; Gokhman, V.E.; Valero, K.A. Description, biology, and karyotype of a new Psilochalcis Kieffer (Hymenoptera: Chalcididae) from Indainmeal Moth pupae (Lepidoptera: Pyralidae) associated with culled figs. *Proceedings of the Entomological Society of Washington.* 2001, 103, 777–787.

9. Grissell, E.E.; Schauff, M.E. New Nearctic Invreia (Hymenoptera: Chalcididae) from lepidopterous pests of peanut. *Proceedings of the Entomological Society of Washington.* 1981, 83, 1–12.

10. Boŭcek, Z. On Schwarzella, Invreia and some other Hybothoracini (Hym. Chalcididae). *Bollettino del laboritorio di entomologia agrarian, Fillippo Silvestri.* 1984, 41, 53–64.

11. Townes, H.E. Design for a Malaise trap. *Proceedings of the Entomological Society of Washington.* 1962, 64, 253–262.

12. Malaise, R. A new insect-trap. *Entomologisk Tidskrift.* 1937, 58, 148–160.

13. Preethi, N.; Menon, P.L.D. Diversity and distribution of chalcid wasps in Kerala: Key biological control agents in cultivated ecosystems. In *Arthropod Diversity and Conservation in the Tropics and Sub-Tropics*; Chakravarthy, A.K., Sridhara, S., Eds.; Springer: Singapore, 2016; pp. 213–226.

14. Tavakoli Roodi, T.; Fallahzadeh, M.; Lotfalizadeh, H. Fauna of chalcid wasps (Hymenoptera: Chalcidoidea, Chalcididae) in Hormozgan province, southern Iran. *Journal of Insect Biodiversity and Systematics*. 2016, 2, 155–166.

15. Noyes, J.S. Collecting and preserving chalcid wasps (Hymenoptera: Chalcidoidea). *Journal of Natural History.* 1982, 16, 315–334.

16. Schoeninger, K.; Souza, J.L.; Krug, C.; Oliveira, M.L. Diversity of parasitoid wasps in conventional and organic guarana (Paullinia cupana var. sorbilis) cultivation areas in the Brazilian Amazon. *Acta Amazonica.* 2019, 49, 283–293.
17. USAFACTS. Available online: https://usafacts.org/issues/climate/state/utah/county/juab-county (accessed on 16 December 2022).
18. National Weather Service. Available online: https://weather.gov/wrh/climate (accessed on 18 December 2022).
19. Boyte, S.P.; Wylie, B.K.; Major, D.J. Mapping and monitoring cheatgrass dieoff in rangelands of the Northern Great Basin, USA. *Rangeland Ecology & Management.* 2015, 68, 18–28.
20. Johnson, J.A.; Valero, K.A.; Hannel, M.M.; Gill, R.F. Seasonal occurrence of postharvest dried fruit insects and their parasitoids in a culled fig warehouse. *Journal of Economic Entomology.* 2000, 93, 1380–1390.
21. Negron, J.F. Cone and Seed Insects Associated with Piñon Pine. In *Proceedings of the Desired Future Conditions for Piñon-Juniper Ecosystems*, Flagstaff, AZ, USA, 8–12 August 1994; Volume 258, pp. 97–104.
22. Jenkins, M.J. Seed and cone insects associated with Pinus monophylla in the Raft River Mountains, Utah. *Great Basin Naturalist* 1984, 44, 349–356.
23. Zachmann, L.J.; Wiens, J.F.; Franklin, K.; Crausbay, S.D.; Landau, V.A.; Munson, S.M. Dominant Sonoran Desert plant species have divergent phenological responses to climate change. *Madroño* 2021, 68, 473–486.

FIGURES

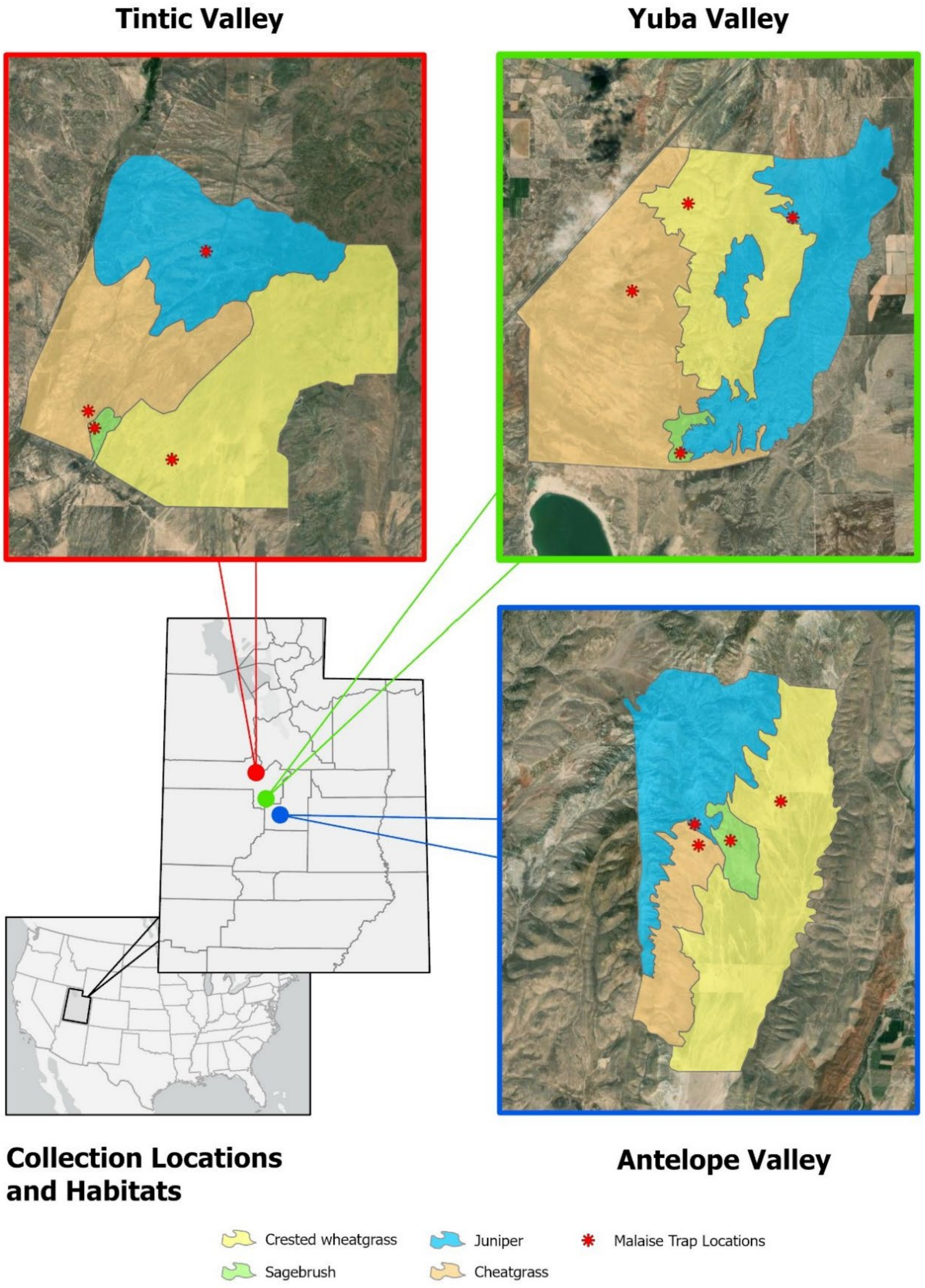

Figure 1. Placement of Malaise traps within four contiguous habitat types at three locations in central Utah. Tintic Valley and Yuba Valley are in Juab County. Antelope Valley is in San Pete County.

Figure 1. Malaise trap setup. Trap shown in pinyon/juniper habitat.

Figure 2. Relative seasonal trap abundance for *Psilochalcis minuta* over a two-year period at Utah; Juab County, Yuba Valley.

Note that peak abundance shifted one month earlier between years.

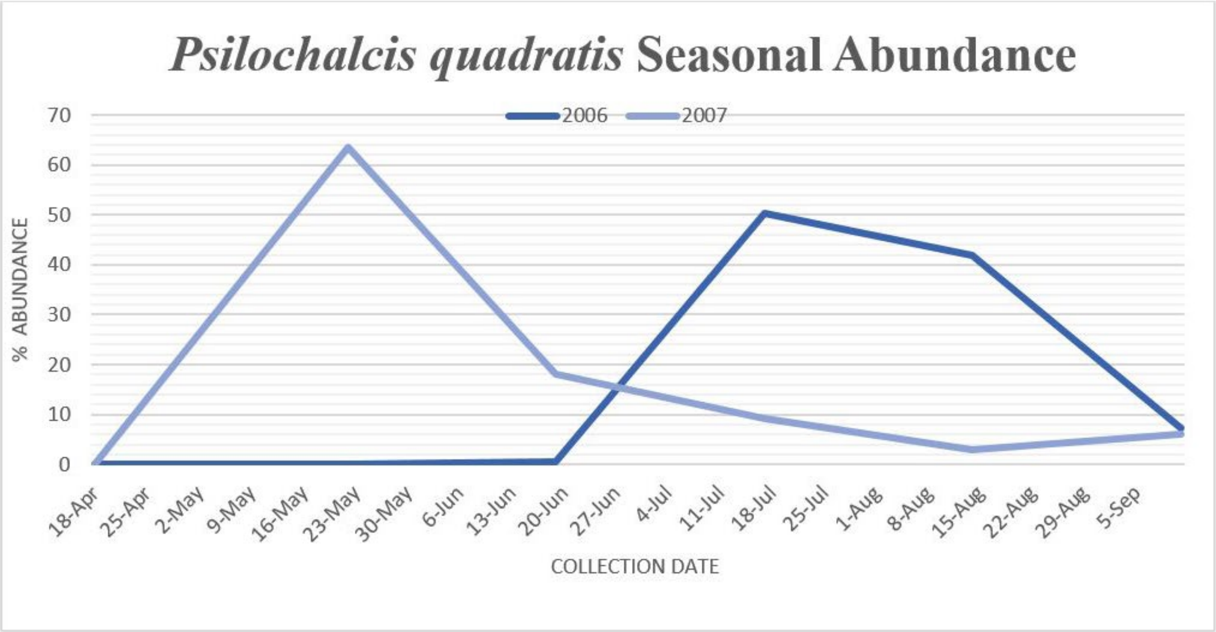

Figure 3. Relative seasonal trap abundance for *Psilochalcis quadratis* over a two-year period at Utah; Juab County, Yuba Valley.

Note that peak abundance shifted two months earlier between years.

TABLES

Table 1. Species Composition in Pinyon/Juniper Habitat Type.

Antelope Valley	Percent Cover
Bromus tectorum L.	0.05 %
Ceratocephala testiculata (Crantz) Besser	0.27 %
Chaetopappa ericoides (Torr.) G.L. Nesom	0.02 %
Chrysothamnus viscidiflorus (Hook.) Nutt.	0.03 %
Eriocoma hymenoides (Roem. & Schult.) Rydb.	0.01 %
Gutierrezia sarothraea (Pursh) Britton & Rusby	0.04 %
Hesperostipa comata (Trin. & Rupr.) Barkworth	0.01 %
Juniperus osteosperma (Torr.) Little	17.26 %
Pinus edulis Engelm.	6.77 %
Total	24.46%
Tintic Valley	
Alyssum desertorum Stapf	0.15 %
Artemisia tridentata Nutt.	0.31 %
Astagalus eurekensis M.E. Jones	0.08 %
Astragalus calycosus Torr. ex S. Wats.	0.25 %
Astragalus lentiginosus Douglas	0.04 %
Bromus tectorum L.	0.09 %
Chaenactis douglasii (Hook.) Hook. & Arn.	0.01 %
Elymus elymoides (Raf.) Swezey	0.21 %
Eriocoma hymenoides (Roem. & Schult.) Rydb.	0.61 %
Juniperus osteosperma (Torr.) Little	10.86 %
Pseudoroegneria spicata (Pursh) Á. Löve	0.85 %
Total	13.46 %
Yuba Valley	
Artemisia tridentata Nutt.	0.31 %
Bromus tectorum L.	1.48 %
Ceratocephala testiculata (Crantz) Besser	0.03 %
Chaetopappa ericoides (Torr.) G.L. Nesom	0.01 %
Chrysothamnus viscidiflorus (Hook.) Nutt.	0.07%
Eriocoma hymenoides (Roem. & Schult.) Rydb.	0.02 %
Hesperostipa comata (Trin. & Rupr.) Barkworth	0.01 %
Juniperus osteosperma (Torr.) Little	19.40 %
Linanthus pungens (Torr.) J.J. Porter & L. A. Johnson	0.05 %
Oreocarya humilis (A. Gray) Greene	0.02 %
Total	21.40%

Table 2. Species Composition in Cheatgrass Habitat Type.

Antelope Valley	Percent Cover
Alyssum desertorum Stapf	0.03 %
Bromus tectorum L.	42.14 %
Ceratocephala testiculata (Crantz) Besser	0.01 %
Total	42.18 %
Tintic Valley	
Agropyron cristatum (L.) Gaertn.	0.31 %
Bromus tectorum L.	16.14 %
Eriocoma hymenoides (Roem. & Schult.) Rydb.	0.01 %
Pascopyrum smithii (Rydb.) Barkworth& D.R. Dewey	0.26 %
Pseudoroegneria spicata (Pursh) Á. Löve	0.31 %
Salsola kali L.	0.01 %
Sisymbrium altissimum L.	0.01 %
Total	17.05%
Yuba Valley	
Bromus tectorum L.	1.31 %
Ceratocephala testiculata (Crantz) Besser	0.84 %
Ceratoides lanata Krascheninnikovia lanata (Pursh) A.D.J Meeuse & Smit	0.08 %
Chorispora tenella (Pall.) DC	0.14 %
Elymus elymoides (Raf.) Swezey	0.20 %
Eremopyrum triticeum (Gaertn.) Nevski	1.36 %
Eriocoma hymenoides (Roem. & Schult.) Rydb.	0.05 %
Total	3.98%

ABSTRACT

We explored the potential distributions of two recently discovered *Psilochalcis* wasp species in Utah's eastern Great Basin through species distribution modelling and subsequent field testing to evaluate model performance. It has been demonstrated that *P. minuta* Petersen is associated with pinyon/juniper *(Pinus edulis* or *P. monophylla* and *Juniperus osteosperma)* habitat and *P. quadratis* Petersen is associated with cheatgrass (*Bromus tectorum*) habitat. Using Maxent modelling software, we constructed species distribution models (SDM's) for both *Psilochalcis* species. Maxent has proven effective in producing reliable models estimating areas of suitable habitat and probable species occurrence, particularly when the number of occurrence data points is low. We used six occurrence data points for *P. minuta* and eight occurrence data points for *P. quadratis* along with ten environmental variables as inputs into the Maxent modelling software. Model predicted areas of suitability greater than 69% were mapped using ArcGIS Pro to help identify and select field testing locations. Employing Malaise traps, eighteen sites were sampled for occurrence of *Psilochalcis* species. The *P. minuta* model results yielded an AUC value of 0.71 and P-value of 0.02 with *P. minuta* occurring in eight of nine predicted sampling locations composed of pinyon/juniper habitat. The *P. quadratis* model had an AUC of 0.68 and P-value of 0.02 with *P. quadratis* occurring in one of three predicted cheatgrass locations. Of selected environmental variables, aspect, historic fire disturbance, and elevation, yielded the greatest percent contributions to both species' models. Sympatric distributions are observed for *P. minuta* and *P. quadratis*. Elevation, vegetation type, NDVI, and soil type are the most important environmental variables in differentiating areas of optimal suitable habitat for the two species.

CHAPTER 3

Field Testing Maxent Predictive Species Distribution Models for Two Species of *Psilochalcis* Kieffer (Hymenoptera; Chalcididae) Occurring in the Eastern Great Basin of Utah.

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INTRODUCTION

The arid Great Basin has experienced significant habitat fragmentation due to the encroachment of cheatgrass (*Bromus tectorum* L.), fire frequency, and revegetation with non-native perennial grasses (Johnson et al. 2008). Commonly, the resulting landscape is segregated into four ubiquitous habitat types made of remnant native or introduced plant assemblages, namely; (1) pinyon/juniper (*Pinus edulis* Engelm. or *P. monophylla* Torr. & Frem. and *Juniperus osteosperma* (Torr.) Little), (2) sagebrush (*Artemisia tridentata* Nutt.), (3) cheatgrass (*Bromus tectorum* L.) and (4) crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) (Johnson et al. 2008). In Utah's eastern Great Basin three locations containing these four contiguous habitats were sampled for the occurrence of two recently described species of *Psilochalcis* Kieffer (Hymenoptera; Chalcididae); *P. minuta* Petersen and *P. quadratis* Petersen (Petersen et al. 2022). The distributions, biologies, and ecological relationships of *P. minuta* and *P. quadratis* are just beginning to be explored (Petersen et al. 2023; Petersen et al. 2022). Because these wasps are rarely collected and show high habitat fidelity, we determined to use habitat modeling tools to better predict areas of suitable habitat and potential sites for study. We are interested in understanding the distribution patterns of these two *Psilochalcis* species beyond that of their initial discovery.

Species distribution models (SDM's) correlate environmental and ecological variables with species occurrence data to predict potential suitable habitat areas with highest probability of species occurrence. They have a wide range of applications in wildlife management, invasive species risk assessment, climate change response detection, habitat management and restoration, and biodiversity assessment (Franklin 2010). These models help explain ecological processes as well as predict future species distributions in areas that have yet to be sampled (Wiersma et al.

2011). For uncommon species, predictive models can identify areas of suitable habitat for further study (Davies et al. 2008, Ulrichs and Hopper 2008). Creating a predictive SDM with this intent is the primary purpose of our study.

Maximum entropy (Maxent) (Philips et al. 2006) is a widely used modeling tool for creating SDM's (Yoon and Lee 2021, Byeon et al. 2018). It has been shown to outperform other different modeling methods (Sunil and Stohlgren 2009, Elith et al. 2006) using presence only data. Maxent maintains predictive reliability for species where the number of known occurrence data points are very small (Senula et al. 2019,van Proosdij et al. 2016, Hernandez et al, 2006). It has been used successfully in predicting areas of suitable habitat for various threatened and endangered species including frogs and damselflies (Mafuwe et al. 2022), freshwater mussels (Walters et al. 2017), trees (Sunil and Stohlgren, 2009) and geckos (Pearson et al. 2007).

The primary objective of our study is to construct SDM's for *P. minuta* and *P. quadratis* to identify areas of suitable habitat with the highest potential of occurrence for these species using the Maxent approach. Additionally, we will test the predictive effectiveness of these models through field sampling areas of predicted suitable habitat for *P. minuta* and *P. quadratis* occurrence.

METHODS AND MATERIALS

Species occurrence data

We examined collection data for both *P. minuta* and *P. quadratis* from 2006 and 2007 (Petersen et al. 2022). Three locations were sampled: Utah, Juab County, Tintic Valley; Juab County, Yuba Valley, and Sanpete County, Antelope Valley. At each location, twelve Malaise traps were setup, three in each of four contiguous habitat types. The habitats were pinyon/juniper, sagebrush, cheatgrass, and crested wheatgrass . It became apparent that *P. minuta* occurred predominantly in pinyon/juniper habitat and *P. quadratis* occurred predominantly in cheatgrass habitat. The associations of these two species with these respective habitat types have been shown to be statistically significant (Petersen et al. 2023). These few data points represent the extent of the known distribution for each species.

During the summer of 2020, Malaise traps were set up in four new locations to acquire additional occurrence data points. One pinyon/juniper and one cheatgrass site as chosen at the south end of Yuba Valley, just east of Yuba Reservoir. One pinyon/juniper and one cheatgrass site as chosen in Sage Valley, the next valley northwest to Yuba Valley in Juab County. Additionally, two traps were set at the original Yuba Valley pinyon/juniper and cheatgrass sites. This was done to take into account the thirteen-year gap between samplings and verify the continued presence of *P. minuta* and *P. quadratis* in those areas. Incorporating all geographic occurrence data points for *P. minuta* and *P. quadratis,* csv files were created for input into Maxent for building the SDM's for each species using Microsoft Excel 2016.

Environmental variables

A review of pertinent literature helped guide our selection of environmental variables for model construction. Temperature, and precipitation are known to have an effect on insect distributions (Ulrichs and Hopper 2008, Zhu et al. 2014). These environmental variables in turn affect the structure and composition of plant communities that insect populations are a part of. Vegetation type is closely associated with soil composition. Elevation, slope, and aspect also have an effect on vegetation type and plant community structure. This suite of variables is widely used in almost all terrestrial species distribution modelling. Specific to this study, the occurrence of *P. minuta* and *P. quadratis* have been associated with pinyon/juniper and cheatgrass habitats, respectively (Petersen et al. 2023). Fire disturbance has also been shown to affect insect distributions (Rohde et al. 2019, Wenninger & Inouye 2008). It is well documented that cheatgrass rapidly invades native habitat areas, particularly after disturbance by wildfire

(Bradley et al. 2018). The cheatgrass areas in which *P. quadratis* were predominantly collected all originated from historic fire disturbance (Johnson et al. 2008). Thus, fire disturbance was selected as potentially affecting *Psilochalcis* species distributions. The water source variable was selected based on the specific environmental conditions at the original occurrence sites. *Psilochalcis minuta* and *P. quadratis* were almost exclusively collected from the Yuba Valley site. The Yuba Valley and Antelopes Valley sites were the only sites close to a body of water, namely Yuba Reservoir and Gunnison Reservoir. We therefore included "distance to nearest water source" as a variable having a potential effect on these species' distributions.

Data for ten environmental variables were downloaded from various sources (Table 1) and imported into ArcGIS Pro version 3.0.0 for visualization and preparation for input into Maxent to create the SDM's. A digital elevation model (DEM) was obtained from the Shuttle Radar Topography Mission (SRTM) (U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center). Four 30-meter tiles were downloaded to cover all portions of the area of interest; N40W113, N40W112, N39W112, N39W113. Rasters were mosaicked and clipped to the model testing boundary. Elevation, slope and aspect were generated from the DEM producing three corresponding data layers in ArcGIS Pro. Historical disturbance by wildfire data was obtained from LANDFIRE (Landfire$_a$) as well as vegetation type data (Landfire$_b$). Both layers were clipped to the model testing boundary. Precipitation (monthly total precipitation) and temperature (daily mean temperature) data were obtained from Parameter-elevation Regressions on Independent Slopes Model (PRISM) (PRISM Climate Group) and clipped to the sampling boundary. Water feature data for lakes and rivers, streams, and springs were obtained from the Utah Geospatial Resource Center's (UGRC) State Geographic Information Database (SGID) (State Geographic Information Database). A small buffer was created around streams and springs data which are point features allowing their conversion into polygon features. These were merged with the lakes data polygon features to make a single "distance to closest water source" data layer. The distance tool was used to calculate the distance to the closest water source, and the layer was clipped to the model testing boundary. A Landsat normalized difference vegetation index (NDVI) was downloaded for the area of interest courtesy of the U.S. Geological Survey Earth Resources Observation and Science Center. This was imported into ArcGIS Pro and clipped to the model testing boundary. Soil data were obtained from Web Soil Survey (WSS) (Soil Survey Staff, National Resource Conservation Service (NRCS)). Six soil data files were downloaded that covered the area of interest: Tooele, Millard and Juab, Fairfield Nephi, Fishlake National Forest Tushar Pavant Division, Millard County Utah, and Sanpete Valley. Files were combined using the mosaic tool and clipped to the model testing boundary. All environmental layers were resampled to be in the same projection (WGS 1984 UTM Zone 12N) and resolution (30 meters).

Species distribution model construction

A species specific Maxent model was constructed for *P. minuta* and *P. quadratus* to identify areas of highest potential habitat suitability and identify the environmental variables that have the greatest effect on probability of occurrence of each species. Model boundaries were established on two criteria. First, we observed that *P. minuta* and *P. quadratis* were not collected at the Antelope Valley site. We therefore expanded the sampling boundary to the west and north of Yuba Valley for field testing of the SDM's. Second, the boundary needed to be within a five-to-eight-hour roundtrip drive of potential sampling locations to accommodate Malaise trap setup and sample retrieval during field testing. This was necessary due to time, manpower, and budget constraints.

From the sampling data of 2006-07and 2020, we used six occurrence data points for *P. minuta* and 8 occurrence data points for *P. quadratis* along with the ten environmental variable data layers as inputs (Merow et al, 2013) to the Maxent modeling software (Philips et al, 2017) to create SDM's for both species. Due to the low number of occurrence data points, a bias file was created and used for background points for model testing. We used the area under the receiver operating curve (AUC) approach to evaluate each model's predictive accuracy. We examined percent contribution to determine which environmental variables contributed most to model performance. We analyzed jackknife test outputs to better understand the relative importance of single explanatory variables in species model creation (Liao et al. 2017), evaluate model sensitivity by variable, and analyze variable effects on predicting species niche (Elith et al. 2011). Variable response graphs were created to visualize and compare trends of species responses to environmental variables.

Sampling location selection and model field testing

The potential suitable habitat maps generated in Maxent for *P. minuta* and *P. quadratis* were imported into ArcGIS Pro. From these, a map of potential sampling areas was created. Areas with a potential suitable habitat value estimate greater than 0.69 were mapped to better visualize potential sampling locations for each species. The selection of sample sites was not randomly assigned because of accessibility issues. The setup of Malaise traps required road access as well as a topography which obscured the trap from visual observation. Our experience with Malaise traps set up in highly visible areas frequently led to vandalism. These factors guided us to select the following sample sites that could be weekly monitored across a two-day period; nine sites with high suitability predicted for *P. minuta*, four sites with high suitability predicted for *P. quadratis*, and five sites with zero predicted suitability for either species (Fig. 3.1). Appropriate sample sites for *P. minuta* were much more common than for *P. quadratis*.

During the summers of 2021-2022, the 18 sites were sampled for occurrence of *Psilochalcis* species by setting up one Malaise trap within the habitat boundary. Sampling ran continuously from the beginning of July through mid-August. The time of peak abundance of both species (Petersen et al., 2023) was used to determine the midpoint of the sampling period. Trap samples were retrieved weekly.

RESULTS

Field sampling summary

Our model assessments of the 2021-22 Malaise trap sampling showed *P. minuta* occurred at eight of nine model predicted locations for this species. (Table 2). Ground truth observations revealed that one of the predicted sites was compose primarily of greasewood *(Sarcobatus vermiculatus* (Hook.) and not pinyon/juniper as at all other predicted sites for this species.

Psilochalcis quadratis occurred at two of four predicted locations for this species (Table 2). We observed thee of the sites were composed of cheatgrass and one composed primarily of greasewood. To maintain the testing validity of the predictive models, Malaise traps were set at these sites even though they were not composed of the predicted dominant vegetation.

Sampling conducted at the five sites with zero predicted suitability for either species showed various results (Table 2). Two sites, characterized by pinyon/juniper and pinyon/juniper sagebrush edge, showed presence of both species, with higher numbers of *P. minuta* collected than *P. quadratis.* The third site was characterized as barren, with only one specimen of *P. quadratis* retrieved. Site four was not easily characterized by habitat type, comprised of native shrubs and native and non-native grasses. Neither *Psilochalcis* species were collected at this site.

The fifth site was composed primarily of greasewood, from which five specimens of *P. minuta* and four specimens of *P. quadratis* were retrieved.

Modeling results

Two Maxent models were produced to evaluate the potential species distribution of both *P. minuta* and *P. quadratis* in the study area. The potential suitability maps show areas of predicted suitable habitat within the study boundary (Fig. 3.2). Areas with a potential suitable habitat value estimate greater than 0.77 were relatively low for both species.

The AUC values for the *P. minuta* model and the *P. quadratis* models were 0.701 and 0.680 respectively (Table 3). Model p-values were calculated based on the maximum test sensitivity plus specificity threshold to assess model performance. The calculated p-values for *P. minuta* and *P. quadratus* (Table 3) are considered statistically significant, indicating a low degree of variation between the sensitivity of the test and the estimation of the suitability of the two species. Additional model metrics and features are given in Table 3.

Environmental variable analyses

Model percent contributions for environmental variables are divided into three categories; high (< 10%), moderate (1-10%), and low (> 1%). Aspect (40.8%), fire disturbance (14.3%), elevation (13.4%), and soil (10.1%) are considered the most important environmental predictors of suitable habitat for the occurrence of *P. minuta.* (Table 4). The same variables in the same order are considered important predictors of suitable habitat for *P. quadratis*, with small differences in actual percent contribution values (Table 4).

Jackknife tests show the trends in test AUC gain for environmental variables through the "leave one out" method. The three single most important environmental predictors for modeling were temperature, fire disturbance, and distance to closest water source (all_water) for both *P. minuta* (Fig. 3.3a) and *P. quadratis* (Fig. 3.3b). Many predictor variables had a small to minimum impact for estimating the suitability of occurrence of either *Psilochalcis* species. Precipitation had the least impact on model AUC gain. Temperature provided the most information to the model, relative to the other variables in the study, particularly for *P. minuta*.

Variable response graphs

The predicted areas of suitable habitat for *P. minuta* and *P. quadratis* have a high degree of overlap as demonstrated by the variable response curves for aspect, elevation, slope, and NDVI (Fig. 3.4). Only one set of graphs is shown since the variable responses were nearly identical for both *P. minuta* and *P. quadratis.* Both *Psilochalcis* species are likely to occur in areas with a southwest aspect, with slopes less than 2.5 degrees, and between 1500 – 1650 meters elevation. An NDVI range between 0.05–0.075 indicates both species are likely to occur in areas with sparse vegetation as open grassland, shrubland or woodland. Temperature, precipitation, and distance to water were fairly evenly distributed throughout the range of variable grid predictions with no distinct range in variable response.

DISCUSSION

When inspecting a sampling site, the most visible and quickly characterized environmental variable is vegetation type. Vegetation type has been shown to be significantly associated with *Psilochalcis* species occurrence in central Utah amongst four ubiquitous Great Basin vegetation types (Petersen et al. 2023). Our field sampling results reflect a similar association for *P. minuta*. The *P. minuta* model was reliable in predicting probable areas of occurrence. *Psilochalcis minuta* occurred at ≈ 89 % of model predicted sites and also at non-predicted sites composed of pinyon/juniper habitat. Localized variations may explain why some areas of pinyon/juniper were not predicted by the model. It is very likely that within apparently uniform vegetation communities, microclimate conditions, local geologic and geographic features, and biological composition will vary. The age of pinyon/juniper stands may also be contributing to this localized variation.

The *P. quadratis* model was much less reliable in predicting probable areas of occurrence for this species. *Psilochalcis quadratis* occurred at 50% of predicted sites of cheatgrass habitat and also occurred at many sites not predicted for this species . Differences in cheatgrass community structure may be a contributing factor to this model's poor reliability. During field sampling, we observed predicted cheatgrass areas that were in a state of die off when compared to more robust areas of heterogenous composition at the original occurrence sites.

The occurrence of *P. quadratis* in areas other than predominant cheatgrass, is possibly a byproduct of the widespread invasion of cheatgrass into different habitat types throughout the Great Basin (Bradley et al. 2018) and helps answer the question why the *P. quadratis* model was less effective in predicting occurrence of this species. Cheatgrass has a low fidelity to specific site criterion and has been documented to quickly expand into multiple habitat types, particularly after fire disturbance (Merrill et al. 2012). Studies have shown that cheatgrass alters and accelerates the fire cycle in these areas (Balch et al. 2013, Whisenant 1990), perpetuating more frequent disturbance due to its' high flammability, giving itself an advantage for establishment over native species, due to its greater seed production capacity (Meyer & Leger 2010). *Psilochalcis quadratis* is most likely occurring in native habitat types the have experienced fire disturbance and subsequent cheatgrass invasion. This may also help to explain the observed anomaly of a likely endemic wasp species occurring in areas now dominated by an introduced exotic species such as cheatgrass.

Our field sampling results showed both *Psilochalcis* species occurred in areas of greasewood habitat. Greasewood is a native species which is less affected by fire disturbance. It is capable of vegetative regeneration through new shoot production, quickly growing back after fire disturbance (Paysen et al. 2000). We gained valuable insights from maintaining Malaise trap placement for model field testing according to model predictions, even when the associated vegetation types were not present. Finding both *Psilochalcis* species in sites composed of greasewood vegetation which is not typically associated with either species, led us to realize that these *Psilochalcis* species occur in native vegetation types other than those originally sampled. This suggests that our modelling would be improved if additional samplings were conducted in areas of persistent salt desert shrub like greasewood, as well as areas of salt desert shrub that have experienced fire disturbance and are now predominantly cheatgrass.

The two species models are statistically very similar. P- values for the individual species models were identical (Table 3.), suggesting that although there were limited occurrence data used as inputs for the two species models, Maxent was able to estimate the potential habitat suitability of the two species within the study area. The model AUC for *P. minuta* is higher than the AUC for the *P. quadratis* model (Table 3), indicating a greater reliability in predicting potential areas of probable occurrence for *P. minuta* than *P. quadratis* (Ardestani et al. 2015). This is confirmed in the results of our model field testing.

The jackknife analyses (Fig. 3) showed strong discrimination between single environmental variables for the two species. Moreover, the individual effect of temperature, fire disturbance, and distance to closest water source observed in both species, highlight how each species sensitivity of occurrence and ecological niche are affected by climate. Although drought was not included in this study, prolonged extreme temperatures and erratic precipitation amounts in the region are likely affecting suitable habitat for *Psilochalcis* species found in central Utah.

The spatial distributions observed in the models for *P. minuta* and *P. quadratis* (Fig. 2) suggest sympatric distributions with very similar environmental and ecological characteristics for the two species. *Psilochalcis minuta* and *P. quadratis* likely occupy similar ecological niches in the study area. Our results indicate aspect, elevation, and fire disturbance as being the most important variables when modeling *Psilochalcis* wasp' habitat in Utah. These three variables are known to directly and indirectly affect the vegetation type of a particular area. Aspect and elevation have an effect on vegetation type, plant density, and community structure (Westerband et al. 2015, Petersen & Stringham 2008, Pinder et al. 1997). Specifically, pinyon/juniper's ecological niche is associated with a distinct range in elevation (Bradley & Fleishman 2008). Habitat disturbance due to wildfire is well documented throughout the study area, so its' contribution to each model's performance is to be expected.

We note that both species models were similar in variable percent contributions, with only slight differences observed between environmental variables selected for this study. The overlapping distribution of these two species can be explained by these slight differences in percentage contribution by variables used to create their suitability of occurrence models. The difference in aspect between the *P. minuta* and *P. quadratis* models was only 0.5%. For fire disturbance, no difference in percent contribution was found between the two species models. This suggests that the probability of either species occurrence is less sensitive to the range of aspect and degree of historic fire disturbance in the region, even though both variables show a greater percent contribution to the overall models. There was a 0.5% difference between species models for temperature, with only a 4.5% and 4.0% contribution to each species model respectively. Similarly, precipitation and distance to water source showed an even smaller difference of 0.1% between species models. This suggests that species occurrences are less sensitive overall to the effects of these variables throughout the study area.

We observed greater differences in the percent contributions between the *P. minuta* and *P. quadratis* models for elevation, vegetation, NDVI, and soil. The difference in elevation between the *P. minuta* and *P. quadratis* models was 0.8%. This greater difference suggests that the two species are somewhat affected by the elevation gradient. Due to the relatively small study area (approximately 9400 km^2), and where *P. minuta* and *P. quadratis* have been found in previous studies (Petersen et al. 2022, Petersen et al. 2023), it is likely this difference in elevation is ecologically important to differentiate the optimal suitable habitat of the two species. Similar results are seen for vegetation and NDVI that yielded 0.8% and 0.9% differences between species models. This suggests that vegetation type, principally *P. minuta* in pinyon/juniper and *P. quadratis* in cheatgrass as demonstrated previously (Petersen et al., 2023), as well as the degree of openness or sparsity of vegetation within these areas are ecologically important in differentiating areas of suitable habitat of these species. *Psilochalcis* are known parasitoids of moths in the families Pyralidae and Gelechiidae (Boŭcek & Halstead 1997). We do not yet know what the host moth species are for *P. minuta* and *P. quadratis*, as well as the host plant species of these moths. It is possible that the plant host of the host moth species' may not be cheatgrass or pinyon/juniper, but currently we do not have a different vegetation metric to look at other than the dominant plant species in areas where *P. minuta* and *P. quadratis* occur. Interestingly, the difference in soil for the two species was 1.3%, being slightly higher for *P. quadratis* (10.1%) than for *P. minuta* (8.8%), likely indicating that soil type is an important ecological factor for each species dynamic in the region. This is likely related to the unknown moth hosts and their plant host's interactions with soil type in completing their life cycles (Wall

& Berberet 1975). Slope should also be considered an important environmental factor affecting *Psilochalcis* species distribution with a 1.5% difference between models, being slightly higher for *P. quadratis* (6.8%) than for *P. minuta* (5.3%). This suggests that each species is occupying areas of differing slope within the 0–2.5% range, which is mostly likely associated with differences in vegetation type throughout the study area; pinyon/juniper tending to be found on foothills whereas cheatgrass tends to be found in flatter valley areas.

The greater differences in soil type and slope over vegetation type and NDVI may indicate these variables are the underlying predominant factor at an ecological site, which in turn affects not only the dominant vegetation type that occurs, but all plant species occurring at the site. It is possible that early spring ephemeral forbe species are the plant hosts that the host moth species are utilizing. Different forbe species and/or combination of species occur or do not occur at all sites due to soil and slope differences between sites. This is supported by the differences in plant species composition observed between the Yuba Valley site, where both *Psilochalcis* species were abundant, and the Antelope Valley site where both species were starkly absent (Petersen et al. 2023). Historic grazing practices may also be contributing to the differences seen in plant species composition between these two sites. It is known that sheep facilities have been operated continually at Antelope Valley for many decades, where rangelands at Yuba Valley have been used for cattle grazing. Unlike cattle, sheep are indiscriminate grazers, eating shrubs, forbes and grasses. It is likely that forbe species utilized by host moth species are greatly reduced or even absent in Antelope Valley sites due to sheep grazing, and are still present or even prevalent at Yuba Valley.

Other studies have used MaxEnt to describe the ecological niches of wasp species with much broader distributions than those of *P. minuta* and *P. quadratis*. The ecological niche for the invasive species *Vespula germanica* L., was strongly affected by humidity and mean annual temperature (Veldtman et al. 2021). Likewise, the distribution of the widely ranging *Polistes dominula* Christ was shown to be affected by annual mean temperature, seasonal variation of summer temperatures, and precipitation (Howse et al. 2020). Unlike these species affected by moisture and temperature which are likely thriving in mesic habitats, our Maxent modelling results highlights the endemism and adaptations to high temperatures and low moisture of *P. minuta* and *P. quadratis* within their narrow distribution ranges in central Utah. Moreover, microhabitats with particular topographic, vegetation composition and climate have a greater effect on the ecological niches of these species.

CONCLUSION

This study is a reasonable first effort in modelling newly described species distributions. We demonstrated that the potential distribution of two *Psilochalcis* species in specific habitat types can be adequately modelled using Maxent when occurrence data points are low. Field testing of model predictions through Malaise trap sampling, was an effective method of confirming *Psilochalcis* species presence in sampled areas. We recognize the benefit that field testing of the *Psilochalcis* species models gave us in understanding model performance. By maintaining the integrity between model predictions and field sampling, additional insights were gained about different factors that potentially affect the probable occurrence of *Psilochalcis* species in native habitats. We suggest that model field testing be considered in study design and utilized more often as a valuable method of Maxent model evaluation.

We recognize the benefit that Maxent modelling affords in identifying environmental variables that are important predictors of potential suitable habitat for species with sympatric distributions, thus giving a more complete picture of each species ecological niche.

We better understand that ecological site and disturbance history are critically important in species distribution modelling and managing for organisms that may be relatively endemic to Great Basin rangelands and potentially being at risk of being eliminated.

LITERATURE CITED

Ardestani E. G., Tarkesh M., Bassiri M., & Vahabi M. R. 2015. Potential habitat modeling for reintroduction of three native plant species in central Iran Journal of Arid Land 7: 381–390.

Balch, J. K., Bradley, B. A., D'Antonio, C. M., & Gómez-Dans, J. (2013). Introduced annual grass increases regional fire activity across the arid western USA (1980–2009). *Global Change Biology*, *19*(1), 173-183.

Boŭcek, Z.; Halstead, J.A. Chalcididae. In Annotated Keys to the Genera of Nearctic Chalcidoidea (Hymenoptera); Gibson, G.A., Huber, J.T., Woolley, J.B., Eds.; NRC Research Press: Ottawa, ON, Canada, 1997; pp. 151–164.

Bradley, B. A., Curtis, C. A., Fusco, E. J., Abatzoglou, J. T., Balch, J. K., Dadashi, S., & Tuanmu, M. N. (2018). Cheatgrass (Bromus tectorum) distribution in the intermountain Western United States and its relationship to fire frequency, seasonality, and ignitions. *Biological invasions*, *20*(6), 1493-1506.

Bradley, B. A., & Fleishman, E. (2008). Relationships between expanding pinyon–juniper cover and topography in the central Great Basin, Nevada. *Journal of Biogeography*, *35*(5), 951-964.

Byeon, D. H., Jung, S., & Lee, W. H. (2018). Review of CLIMEX and MaxEnt for studying species distribution in South Korea. *Journal of Asia-Pacific Biodiversity*, *11*(3), 325-333.

Davies, A. J., Wisshak, M., Orr, J. C., & Roberts, J. M. (2008). Predicting suitable habitat for the cold-water coral Lophelia pertusa (Scleractinia). *Deep Sea Research Part I: Oceanographic Research Papers*, *55*(8), 1048-1062.

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E., & Yates, C. J. (2011). A statistical explanation of MaxEnt for ecologists. *Diversity and distributions*, *17*(1), 43-57.

Elith, J., Graham, C. H., Anderson, R. P., Dudík, M., Ferrier, S., Guisan, A., ... & Zimmermann, N. E. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, *29*(2), 129-151.

Franklin, J. (2010). *Mapping species distributions: spatial inference and prediction*. Cambridge University Press.

Hernandez, P. A., Graham, C. H., Master, L. L., & Albert, D. L. (2006). The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography*, *29*(5), 773-785.

Howse, M. W., Haywood, J., & Lester, P. J. (2020). Bioclimatic modelling identifies suitable habitat for the establishment of the invasive European paper wasp (Hymenoptera: Vespidae) across the southern hemisphere. *Insects*, *11*(11), 784.

Johnson, R. L., Anderson, V. J., Clark, S. M. (2008) Impact of Habitat Alterations to Bee Diversity in Sagebrush and Pinyon/Juniper Communities of the Eastern Great Basin. Chapter 1, Unpublished dissertation, Department of Plant and Wildlife Sciences, Brigham Young University, Provo, Utah.

LANDFIREa (LF), us_200 Existing Vegetation Type Layer, LF 2016 Remap, U.S. Department of the Interior, Geological Survey, and U.S Department of Agriculture. Available online: https://www.landfire.gov/viewer/. Accessed on 1/08/2023.

LANDFIREb (LF), us_ Historical Disturbance LF 2016 Remap, U.S. Department of the Interior, Geological Survey, and U.S Department of Agriculture. Available online: https://www.landfire.gov/viewer/. Accessed on 1/08/2023.

Liao, Y., Lei, Y., Ren, Z., Chen, H., & Li, D. (2017). Predicting the potential risk area of illegal vaccine trade in China. *Scientific Reports*, *7*(1), 1-10.

Mafuwe, K., Broadley, S., & Moyo, S. (2022). Use of maximum entropy (Maxent) niche modelling to predict the occurrence of threatened freshwater species in a biodiversity hotspot of Zimbabwe. *African Journal of Ecology*, *60*(3), 557-565.

Merow, C., Smith, M. J., & Silander Jr, J. A. (2013). A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography*, *36*(10), 1058-1069.

Merrill, K. R., Meyer, S. E., & Coleman, C. E. (2012). Population genetic analysis of Bromus tectorum (Poaceae) indicates recent range expansion may be facilitated by specialist genotypes. *American Journal of Botany*, *99*(3), 529-537.

Meyer, S. E., & Leger, E. A. (2010). Inbreeding, genetic variation, and invasiveness: the strange case of Bromus tectorum. *Rangelands*, *32*(1), 6-11.

Paysen, T. E., Ansley, R. J., Brown, J. K., Gottfried, G. J., Haase, S. M., Harrington, M. G., ... & Wilson, R. C. (2000). Fire in western shrubland, woodland, and grassland ecosystems. *Wildland fire in ecosystems: Effects of fire on flora*, *2*, 121-59.

Pearson, R. G., Raxworthy, C. J., Nakamura, M., & Townsend Peterson, A. (2007). Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of biogeography*, *34*(1), 102-117.

Petersen M.J., Anderson V.J., Johnson R.L., Eggett D.L. (2023) Seasonal Trap Abundance of Two Species of *Psilochalcis* Kieffer (Hymenoptera: Chalcididae) in Rangelands of the Eastern Great Basin of Utah, USA. *Land*, 12(1):54. https://doi.org/10.3390/land12010054

Petersen, M. J., Johnson, R. L., & Anderson, V. J. (2022). A review of *Psilochalcis* Kieffer (Hymenoptera: Chalcidoidea: Chalcididae) from the western United States with descriptions of three new species from Utah and surrounding states. *Western North American Naturalist*, *82*(4), 704-718.

Petersen, S. L., & Stringham, T. K. (2008). Infiltration, runoff, and sediment yield in response to western juniper encroachment in southeast Oregon. *Rangeland Ecology & Management, 61*(1), 74-81.

Phillips, S. J., Anderson, R. P., Dudík, M., Schapire, R. E., & Blair, M. E. (2017). Opening the black box: An open-source release of MaxEnt. *Ecography*, *40*(7), 887-893.

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological modelling*, *190*(3-4), 231-259.

Phillips, S. J. (2017). A Brief Tutorial on MaxEnt. Available from url: http://biodiversityinformatics.amnh.org/open_source/MaxEnt/. Accessed on 1/12/2022.

Pinder, J. E., Kroh, G. C., White, J. D., & Basham May, A. M. (1997). The relationships between vegetation type and topography in Lassen Volcanic National Park. *Plant ecology*, *131*, 17-29.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu. Data created 20 Sept. 2020, accessed 9 May 2022.

Rohde, A. T., Pilliod, D. S., & Novak, S. J. (2019). Insect communities in big sagebrush habitat are altered by wildfire and post-fire restoration seeding. *Insect Conservation and Diversity*, *12*(3), 216-230.

Senula, S. F., Scavetta, J. T., Banta, J. A., Mueller, U. G., Seal, J. N., & Kellner, K. (2019). Potential distribution of six north American higher-attine fungus-farming ant (Hymenoptera: Formicidae) species. *Journal of Insect Science*, *19*(6), 24.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online: https://websoilsurvey.sc.egov.usda.gov/. *Accessed 1/7/2023.*

State Geographic Information Database. *NHD Lakes* (data layer), *NHD Streams* (data layer), NHD *Springs* (point layer). Utah Geospatial Resource Center. Available online: https://gis.utah.gov/data/water/lakes-river-dams/. Accessed 1/7/2023.

Sunil, K., & Stohlgren, T. J. (2009). MaxEnt modeling for predicting suitable habitat for threatened and endangered tree Canacomyrica monticola in New Caledonia. *Journal of Ecology and the Natural Environment*, *1*(4), 094-098.

Ulrichs, C., & Hopper, K. R. (2008). Predicting insect distributions from climate and habitat data. *BioControl*, *53*(6), 881-894.

U.S. Geological Survey, Earth Resources Observation and Science Center. U.S. Landsat Analysis Ready Data (ARD DOI): doi.org/10.5066/F7319TSJ. Available online at: https://dwtkns.com/srtm30m/.

van Proosdij, A. S., Sosef, M. S., Wieringa, J. J., & Raes, N. (2016). Minimum required number of specimen records to develop accurate species distribution models. *Ecography*, *39*(6), 542-552.

Veldtman, R., Daly, D., & Bekker, G. F. V. G. (2021). Spatio–environmental analysis of Vespula germanica nest records explains slow invasion in South Africa. *Insects*, *12*(8), 732.

Wall, R., & Berberet, R. C. (1975). Parasitoids associated with lepidopterous pests on peanuts; Oklahoma fauna. *Environmental Entomology*, *4*(6), 877-882.

Walters, A. D., Ford, D., Chong, E. T., Williams, M. G., Ford, N. B., Williams, L. R., & Banta, J. A. (2017). High-resolution ecological niche modelling of threatened freshwater mussels in east Texas, USA. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *27*(6), 1251-1260.

Wenninger, E. J., & Inouye, R. S. (2008). Insect community response to plant diversity and productivity in a sagebrush–steppe ecosystem. *Journal of Arid Environments*, *72*(1), 24-33.

Westerband, A., Dovčiak, M., La Quay-Velázquez, G., & Medeiros, J. S. (2015). Aspect reduces soil moisture and tree cover, but not nitrogen mineralization or grass cover, in semiarid pinyon-juniper woodlands of the Southwestern United States. *The Southwestern Naturalist*, *60*(1), 21-29.

Whisenant, S. G. (1990). Changing Fire Frequencies on Idaho's Snake River Plains: Ecological and Management. In *Proceedings--Symposium on Cheatgrass Invasion, Shrub Die-off and Other Aspects of Shrub Biology and Management: Las Vegas, NV, April 5-7, 1989* (No. 276, p. 4). Intermountain Research Station, Forest Service, US Department of Agriculture.

Wiersma, Y. F., Huettmann, F., & Drew, C. A. (2011). Introduction. landscape modeling of species and their habitats: history, uncertainty, and complexity. In *Predictive species and habitat modeling in landscape ecology* (pp. 1-6). Springer, New York, NY.

Yoon, S., & Lee, W. H. (2021). Methodological analysis of bioclimatic variable selection in species distribution modeling with application to agricultural pests (Metcalfa pruinosa and Spodoptera litura). *Computers and Electronics in Agriculture*, *190*, 106430.

Zhu, H., Wang, D., Wang, L., Fang, J., Sun, W., & Ren, B. (2014). Effects of altered precipitation on insect community composition and structure in a meadow steppe. *Ecological Entomology*, *39*(4), 453-461.

FIGURES

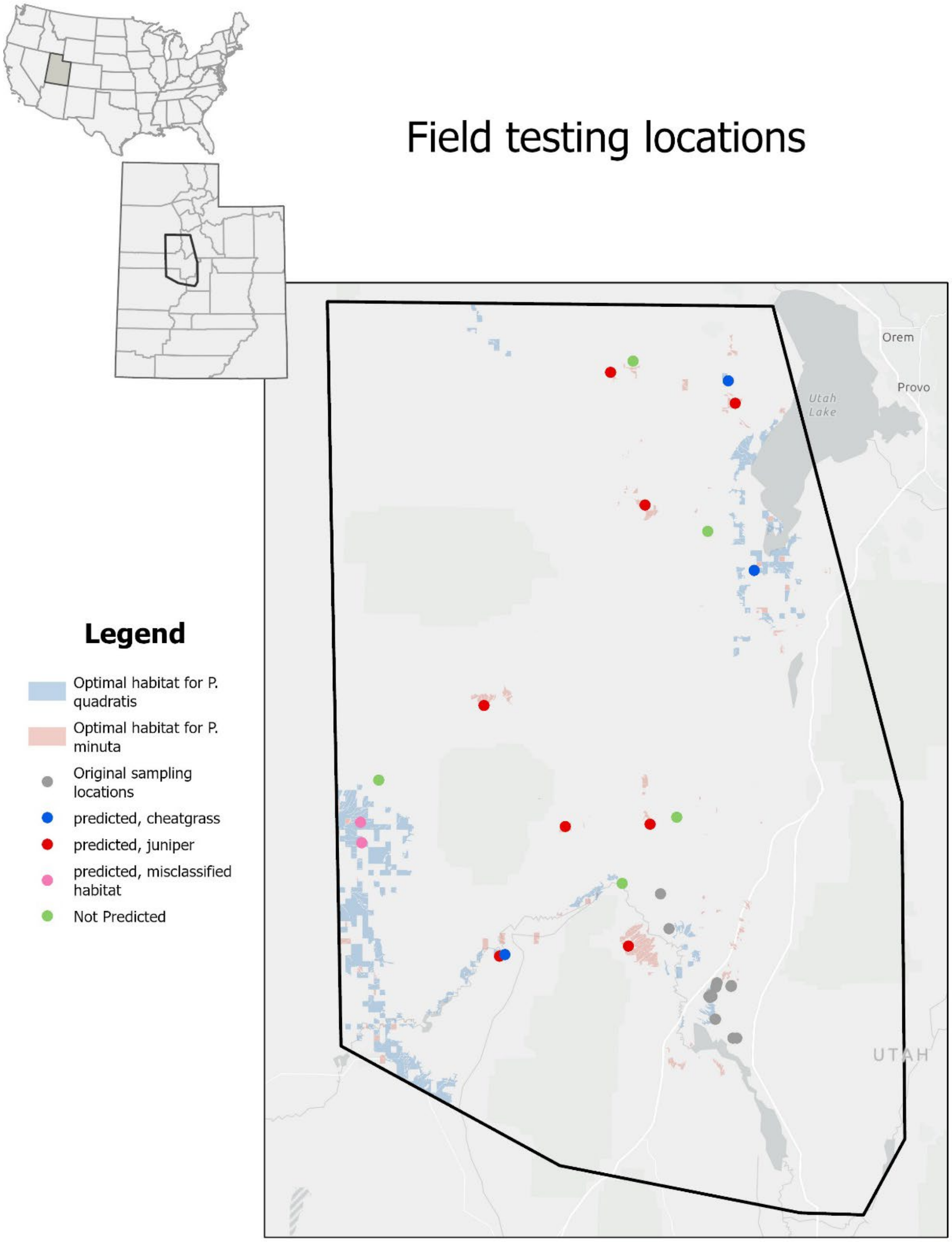
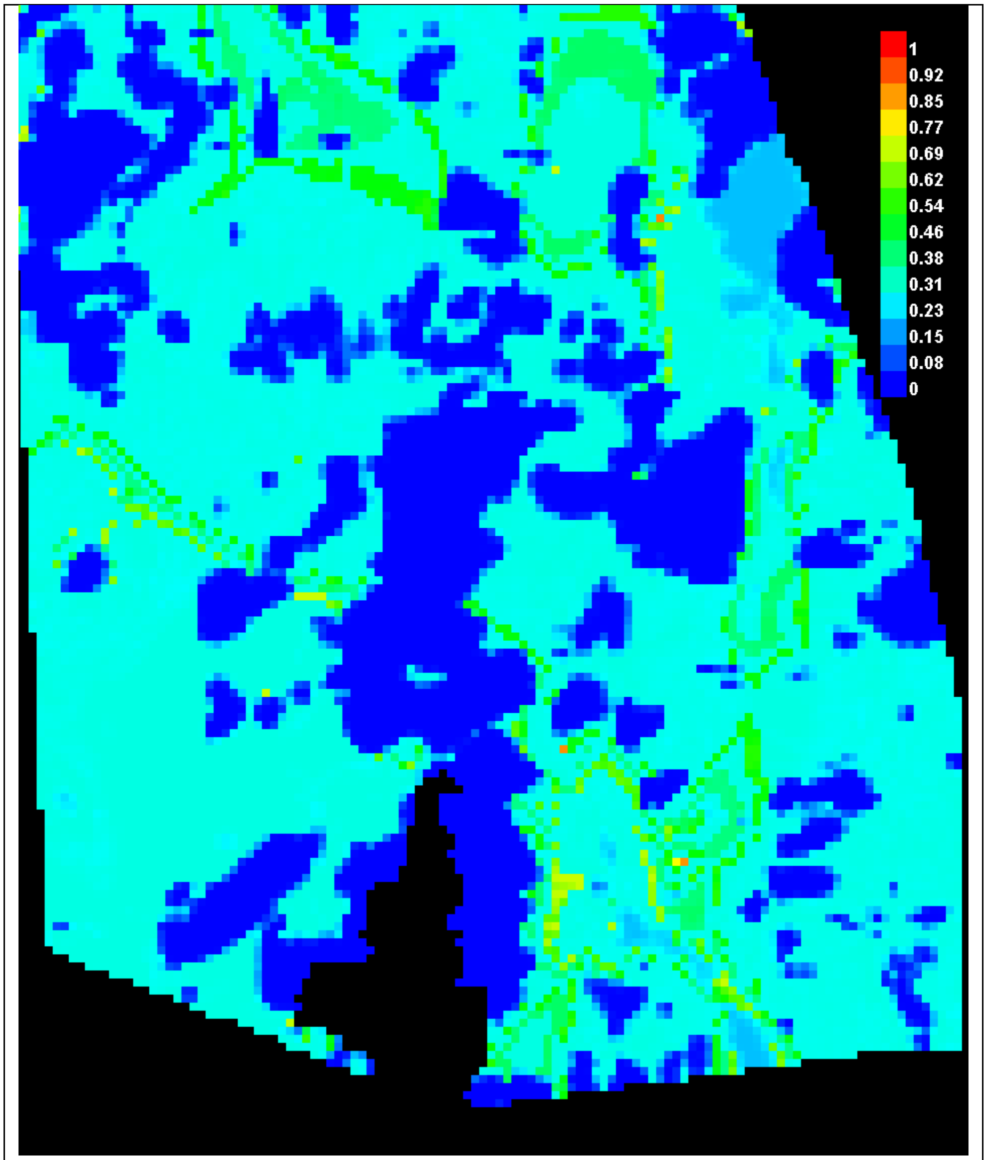


Figure 3.1 Malaise trap sampling locations for field testing of areas of suitable habitat for *Psilochalcis minuta* and *P. quadratis* as predicted by Maxent species distribution models.



a

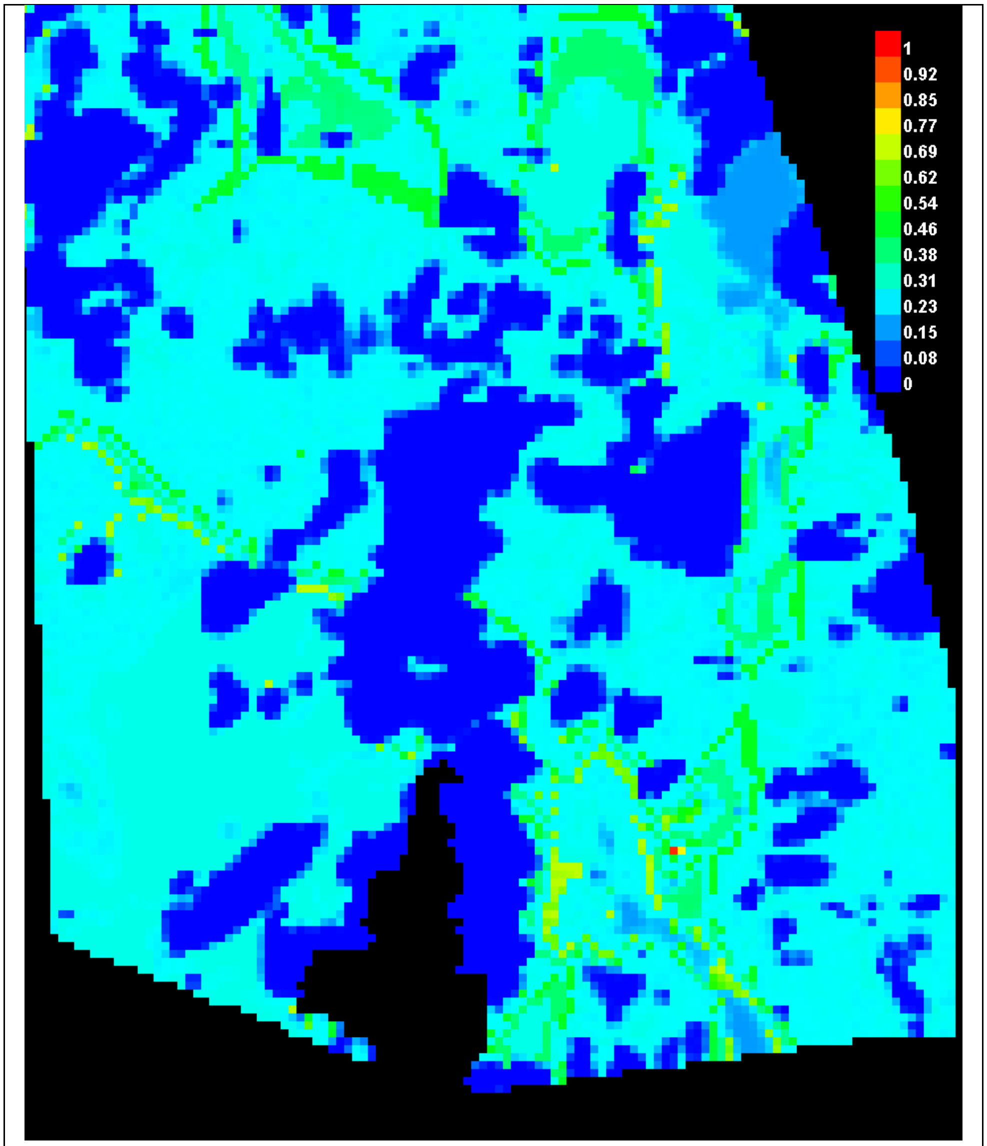
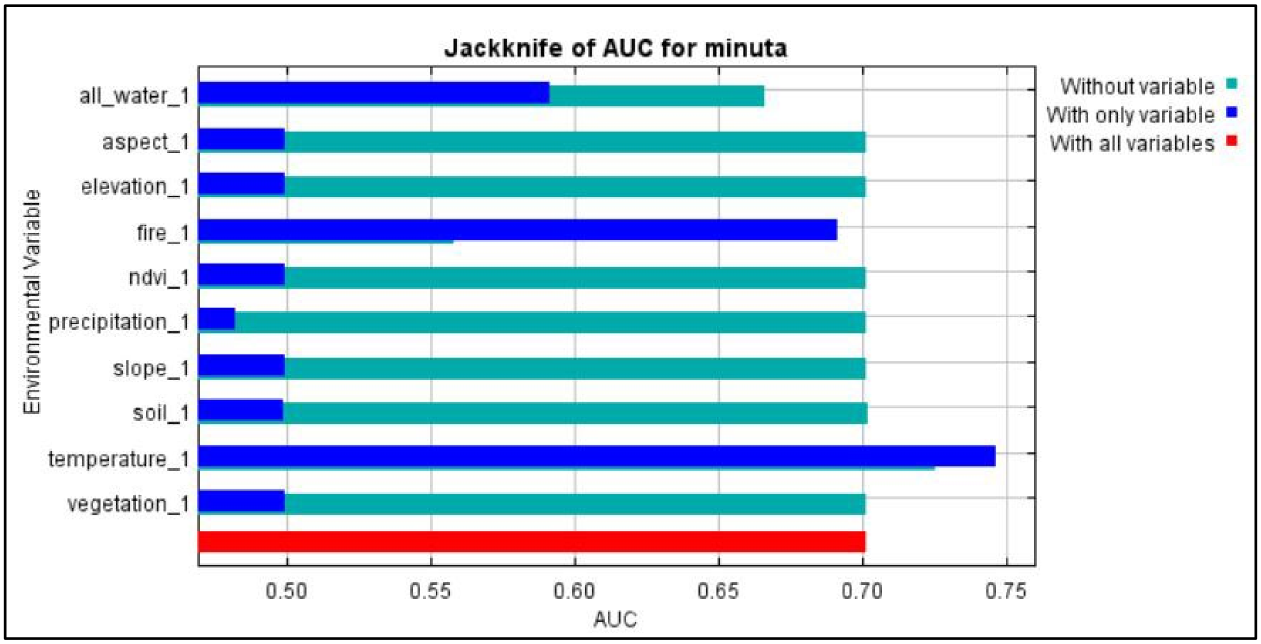
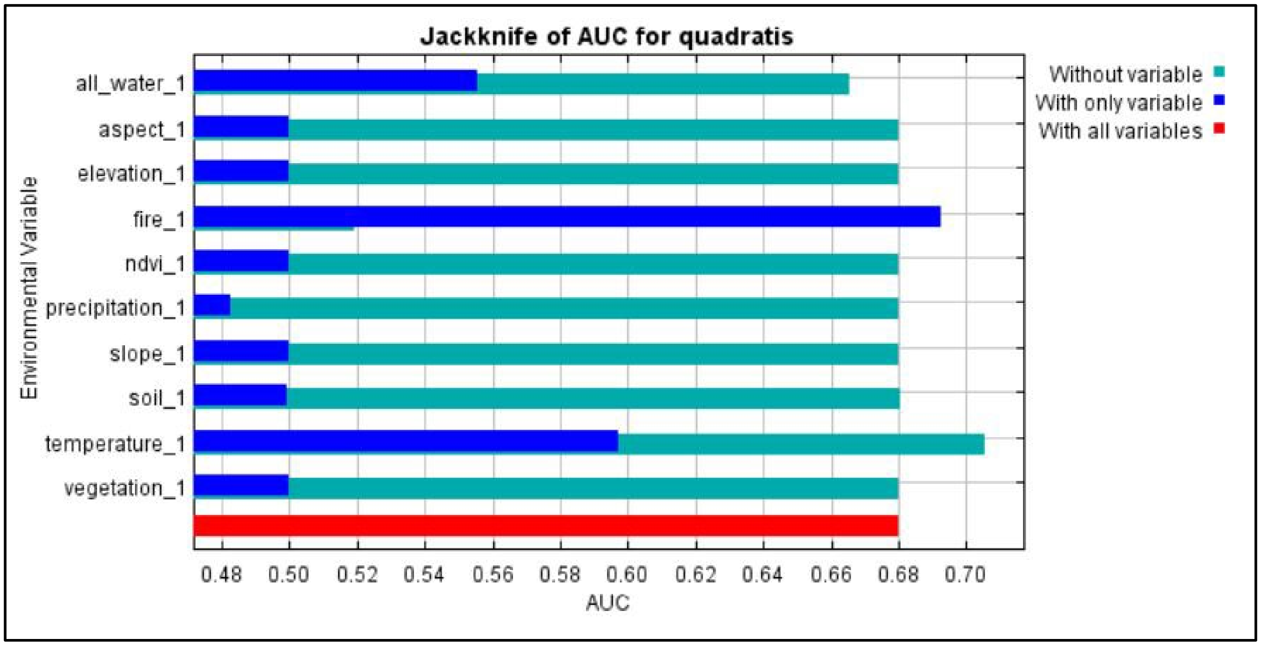


Figure 3.2 Maxent generated maps of areas of potential suitable habitat for a) *Psilochalcis minuta* and b) *Psilochalcis quadratis* within the study area. Areas range from 0 to 1, with 0 (darkest blue) being the lowest and 1 (red) the highest probability of species occurrence.

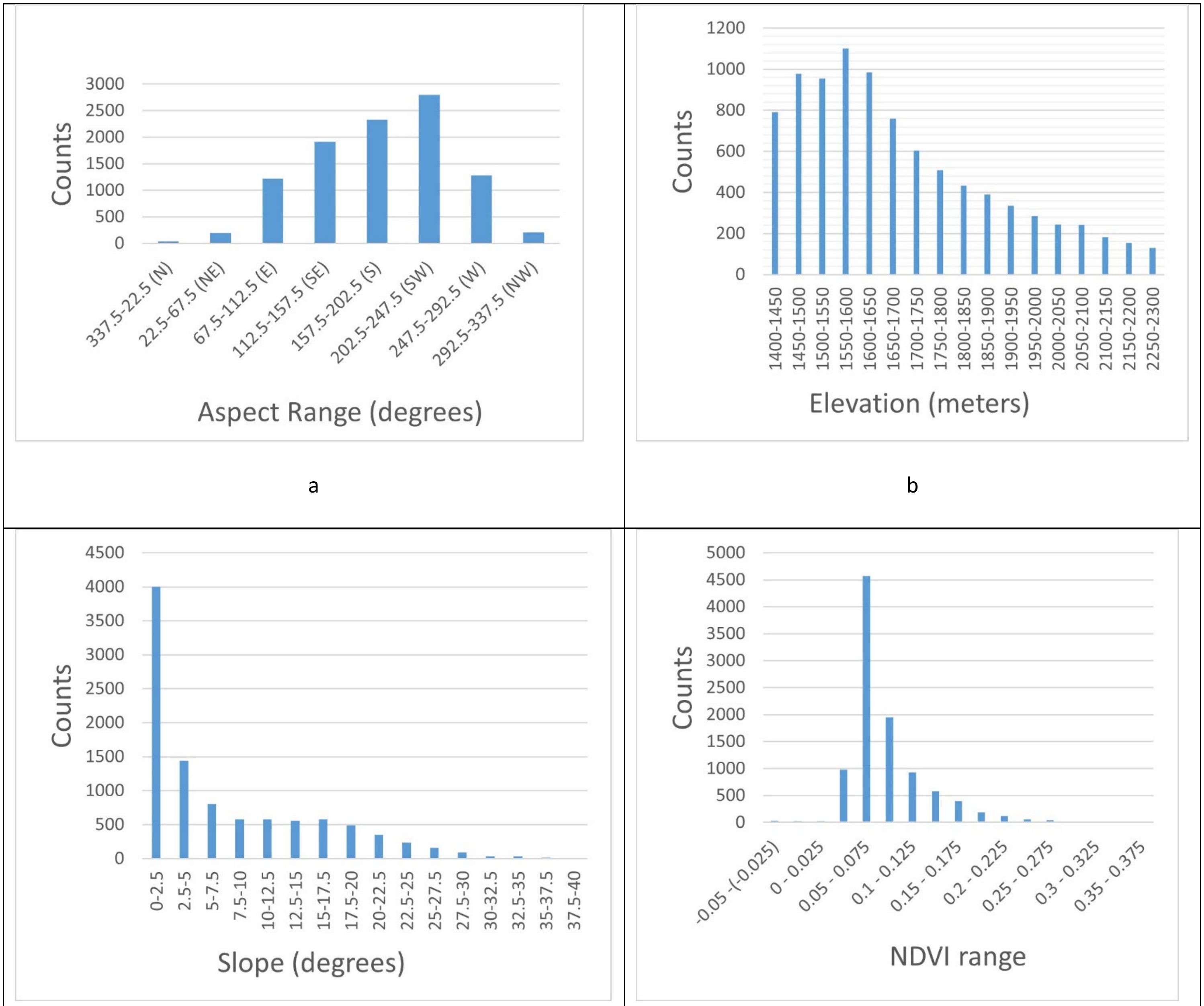


a



b

Figure 3.3 Results of jackknife analyses of area under the receiver operating curve (AUC) for environmental variables used in predicting areas of suitable habitat for a) *Psilochalcis minuta*, and b) *Psilochalcis quadratis*.



a

b

c

d

Figure 3.4 Environmental variable responses for a) aspect, b) elevation, c) slope, and d) NDVI. Graphs created from value range counts from the estimated probability of occurrence in 10,000 data point grid for each *Psilochalcis* species.

TABLES

Table 3.1. Environmental variables selected for construction of *Psilochalc*is species distribution models.

Note: Data sources are EROS = Earth Resources Observation and Science Center, NRCS = National Resource Conservation Service, PRISM = Parameter-elevation Regressions on Independent Slopes Model, SRTM = Shuttle Radar Topography Mission, UGRC = Utah Geospatial Resource Center, USGS = United States Geological Survey, and WSS = Web Soil Survey.

Variable	Data Source
elevation	EROS, SRTM
aspect	generated in ArcGIS
slope	generated in ArcGIS
historic fire disturbance	LANDFIRE
existing vegetation type	LANDFIRE
precipitation	PRISM Climate Group
temperature	PRISM Climate Group
distance to closest water source	UGRC calculated in ArcGIS
ndvi	USGS/EROS
soil composition	WSS/NRCS

Table 3.2. 2021-2022 Malaise trap sampling summary showing occurrence of *P. minuta* and *P. quadratis*.

*Note: Two predicted sites were observed as being primarily composed of greasewood. Initial species distribution models predicted these sites as being potentially suitable for *P. minuta* (orange) and *P. quadratis* (blue) respectively.

Sampling Location Latitude Longitude	**Predicted Habitat**	**Observed habitat**	**# *P. minuta* retrieved**	**# *P. quadratis* retrieved**
40.21209, -111.97083	pinyon/juniper	pinyon/juniper	2	0
39.65849, -112.24926	pinyon/juniper	pinyon/juniper	21	5
39.48876, -112.35678	pinyon/juniper	pinyon/juniper	10	0
40.25033, -112.18350	pinyon/juniper	pinyon/juniper	21	0
40.07829, -112.12203	pinyon/juniper	pinyon/juniper	5	0
39.66354, -112.10690	pinyon/juniper	pinyon/juniper	51	2
39.50412, -112.14085	pinyon/juniper	pinyon/juniper	165	2
39.81450, -112.38919	pinyon/juniper	pinyon/juniper	9	0
39.66003, -112.59415	pinyon/juniper	*greasewood	0	0
40.24126, -111.98340	cheatgrass	cheatgrass	0	1
39.49077, -112.34794	cheatgrass	cheatgrass	0	0
39.59726, -111.56220	cheatgrass	cheatgrass	0	0
39.63317, -112.59161	cheatgrass	*greasewood	0	2
40.26538, -112.14526	no prediction	pinyon/juniper	21	3
40.04515, -112.01527	no prediction	pinyon/juniper & sagebrush	7	1
39.67244, -112.06180	no prediction	mixed shrub & grasses	0	0
39.58563, -112.15250	no prediction	greasewood	5	4
39.71542, -112.56461	no prediction	barren	0	1

Table 3.3. Maxent model performance and features for evaluating two *Psilochalcis* species in central Utah.

Note: P-value is determined by the maximum test sensitivity plus specificity.

Model	P-value	AUC	Standard Deviation	Linear/Quadratic Product	Categorical	Threshold	Hinge
P. minuta	0.02	0.701	0.119	1.000	0.530	1.920	0.500
P. quadratis	0.02	0.680	0.058	1.000	0.530	1.920	0.500

Table 3.4. Environmental variable percent contributions to species distribution models for *Psilochalcis minuta* and *Psilochalcis quadratis.* Bolded numbers indicate high, red moderate, and blue low percent contribution to the model.

Model	Aspect	Elevation	Slope	Soil	Fire	Water	Vegetation	NDVI	Temperature	Precipitation
P. minuta	**40.8**	**13.4**	5.3	**10.1**	**14.3**	0.3	4.1	7.0	4.5	0.3
P. quadratis	**40.3**	**12.6**	6.8	**8.8**	**14.3**	0.2	4.9	7.9	4.0	0.2