

Oecanthus salvii sp. nov. (Orthoptera: Gryllidae: Oecanthinae): A new tree cricket species from Modoc County in northeast California

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Abstract

A new species of *Oecanthus* is described from extreme northeast California. *Oecanthus salvii* sp. nov. is currently known only from Lake Annie in Modoc County, California, and occurs on sagebrush (*Artemisia*) and rabbitbrush (*Ericameria*). It has the narrow tegmina, antennal markings, metanotal gland configuration, and trilling song found in the *Oecanthus nigricornis* species group. Song details and morphology, including the shape of the subgenital plate and copulatory blades, are provided in this paper. This new species has been given the common name of sage tree cricket.

Keywords

Lake Annie, rabbitbrush, sage tree cricket, sagebrush, setae, subgenital plate

Introduction

Oecanthus Serville, 1831 is the only genus of Oecanthinae that occurs in the western U.S. (Cigliano et al. 2020, SINA 2020b). The 19 species of *Oecanthus* reported in the United States are divided into four main groups: *nigricornis*, *niveus*, *rileyi*, and *varicornis* (Walker 1962, 1963, Walker and Collins 2010). These groups can be distinguished by characteristics including song pattern (chirping vs. trilling and continuous vs. intermittent); song pulse or chirp rate at given temperatures; regular vs. irregular pattern of pulses or chirps; coloration of the antennae, head, pronotum, and abdomen; antennal markings on the pedicel and scape; and tegminal width.

Photographs posted on BugGuide (2020) by KS at Lake Annie in Modoc County, California, led to the investigation of this new species (Figs 1, 2). The green coloring, narrow tegmina, and the configuration and shapes of the antennal markings matched the *nigricornis* species group. Three tree crickets in the *nigricornis* species group are known to occur in the western United States: *Oecanthus argentinus* Saussure, 1874, *O. quadripunctatus* Beutenmüller, 1894, and *O. walkeri* Collins & Symes, 2012.

These tree crickets found at Lake Annie had unusual coloring and an unusual upper outer marking on the scape. Photographs taken during two visits by KS in 2017 and 2018 show tree crickets

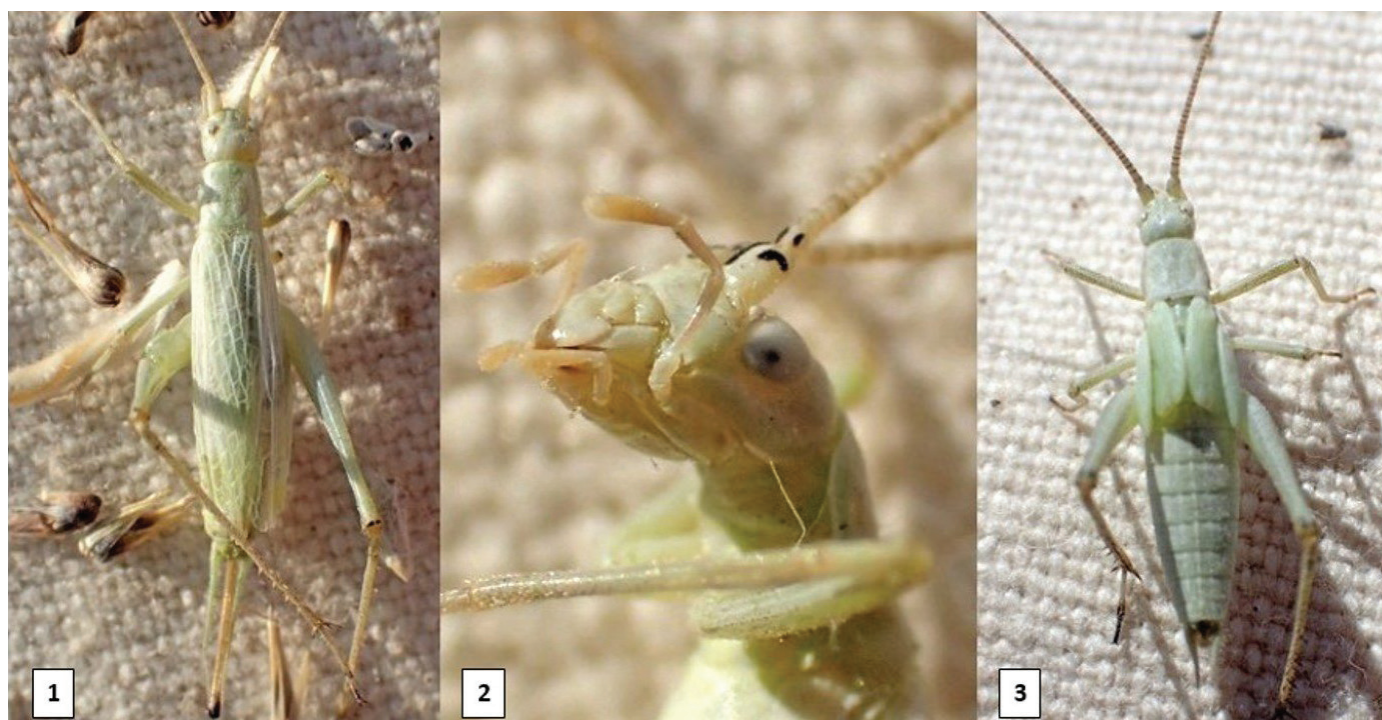
with a milky pale green color. The 2018 male photographed was a 5th stage instar, thus no song recordings were possible (Fig. 3). The upper-outer black mark on the first antennal segment (scape) is in an upward arch shape, and the two marks on the second segment (pedicel) are of medium width and separated by a width greater than either of the marks.

Materials and methods

Collection methods.—Photographs of sweep-netted individuals were taken by KS in July 2017 and July 2018 using an Olympus TG-4 camera in macro mode. A subsequent visit to the area was made by NC in July 2019, and a total of seven individuals were captured with a sweep net: two adult males, two male nymphs, and three female nymphs. Photographs of these seven tree crickets were taken with a Canon S5 IS. The area was not visited at night; thus recordings of captive males were made indoors. The vegetation on the south end of Lake Annie was sweep-netted and tree crickets were collected into hand-held plastic containers. The key from Walker (1967) was used to verify the genus. Specimens were examined for the presence/absence of spines on the hind tibiae.

Acoustics.—Songs were recorded using a Canon S5 IS. Adult males were recorded while singing in captivity at different temperatures, with the thermometer probe placed as close as possible to the tree cricket. The temperature when the tree crickets were singing indoors in captivity was measured using a LaCrosse Technology dual channel digital thermometer. Additional recordings from the Macaulay Library (Cornell Lab 2020) and data from SINA (2020c) were used for the preparation of graphs that compared pulse rate vs. temperature and frequency vs. pulse rate of other species in the *nigricornis* group. DoremiSoft AVI to WAV Converter was used to convert AVI files to WAV files. Raven Lite 2.0 was used to create waveforms for counting the pulses per second and spectrograms to determine dominant frequency. Graphs were created using Excel 2010.

Morphological measurements.—Measurements were made after the specimens were euthanized in 91% ethyl alcohol. The total length



Figs 1–3. Sage tree cricket. 1. Adult female; 2. Antennal markings; and 3. Male 5th instar nymph.

refers to the midline length from the tip of the labrum to the apex of the subgenital plate, not including antennae, tegmina, limbs, or cerci. The tegminal width was measured at the widest section, while the tegmina rested atop the abdomen of the male. Pronotal length was measured along the medial line of the pronotum, and the width was measured at the widest section. The female ovipositor was measured from the base at the distal end of the abdomen to the tip. Photographs and measurements of the ovipositor, cerci, and metanotal gland, as well as counts of the stridulatory teeth, were made using a Canon PowerShot S5 IS in the AV setting in the macro mode through the eyepiece of a My First Lab microscope, model USB, magnification 4 \times .

Genitalia.—Extracted male genitalia were photographed through the eyepiece of a My First Lab microscope at 4 \times using a Canon PowerShot S5 IS in the AV setting in macro mode. The resulting photographs were then cropped and enlarged. Copulatory blades project from the internal genitalia complex and are situated just above the subgenital plate (Fulton 1915). These internal genitalia structures have also been referred to as pseudepiphallus (Chopard 1961, 1969), lophi medians [middle lobes] (Desutter 1987), or main lobe of pseudepiphallus (Zefa et al. 2012).

Comparison with congeneric species.—*O. argentinus* and *O. quadripunctatus* are the only two members of the *nigricornis* species group that are known to occur in northern California. Out of an abundance of caution, we decided to compare our new species with all eight species in the *nigricornis* species group, regardless of distribution range, in order to rule out these tree crickets being a color form of a known species with a range extension or a displaced population. Therefore, the new species was compared with *O. celerinictus* T. Walker, 1963, *O. forbesi* Titus, 1903, *O. laricis* T. Walker, 1963, *O. nigricornis* F. Walker, 1869, *O. pini* Beutenmüller, 1894, and *O. walkeri* Collins & Symes, 2012.

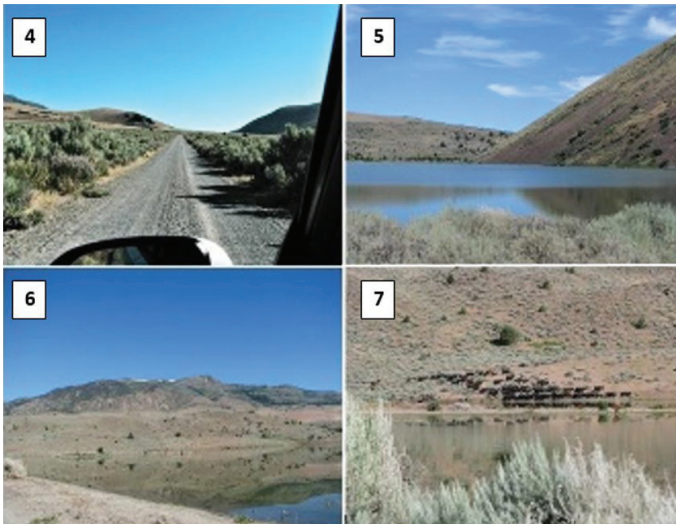
Results

Location.—Lake Annie, in the extreme northeast corner of Modoc County, is located approximately five miles west of Nevada and five miles south of Oregon. The lake lies on the northern end of the Surprise Valley, at the western edge of the Great Basin and just east of the Warner Mountains range. It sits on the western edge of Lake Annie Mountain, a summit with an elevation of 1830 m. The elevation of the lake is 1530 m. Areas searched were no more than 4 m above the level of the lake at the following coordinates: 41°54'24"N, 120°06'31"W.

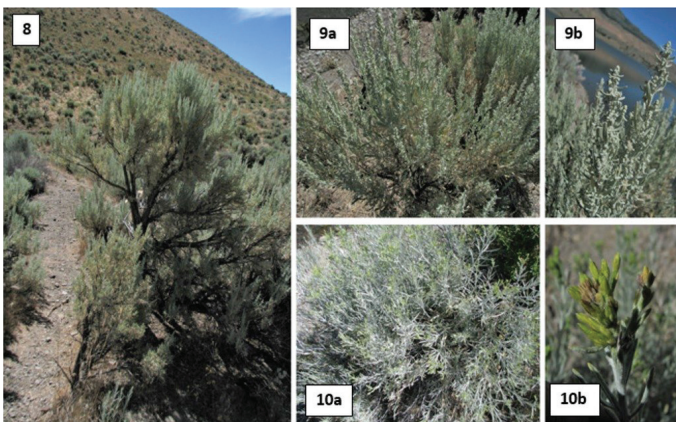
Habitat.—The majority of the area surrounding the lake was dotted with sagebrush (*Artemisia* spp.) and rabbitbrush (*Ericameria* spp.) shrubs that were 1 m tall. Bare ground was common, and the soil was fine and light greyish brown in color (Figs 4–6). A herd of cattle grazing on the surrounding vegetation was not uncommon on the edge of the lake (Fig. 7). Host plants identified in the tree cricket search area included big sagebrush (*Artemisia tridentata* ssp. *tridentata*), mountain sagebrush (*Artemisia tridentata* ssp. *vaseyana*), and rubber rabbitbrush (*Ericameria nauseosa*) (Figs 8–10).

Climate.—According to the University of California Agriculture and Natural Resources (2020), climate variables in 2019 for Cedarville, 22 miles (35 km) south of Lake Annie, were highest temperature (July) 91°F (32.8°C); lowest temperature (December) 15°F (-9.4°C); highest low (July) 58°F (14.4°C); and lowest high (December) 35°F (1.7°C). The total precipitation for 2019 was less than 15 in (381 mm).

Morphology.—These tree crickets at Lake Annie were a pastel, milky-green color and had pale pedicels and scapes, narrow tegmina, and



Figs 4–7. Location of *Oecanthus salvii* sp. nov. discovery. 4. Road to Lake Annie; 5. Eastern edge of lake with foot of Lake Annie Mountain; 6. Western edge of lake; and 7. Cattle drive along western shore.

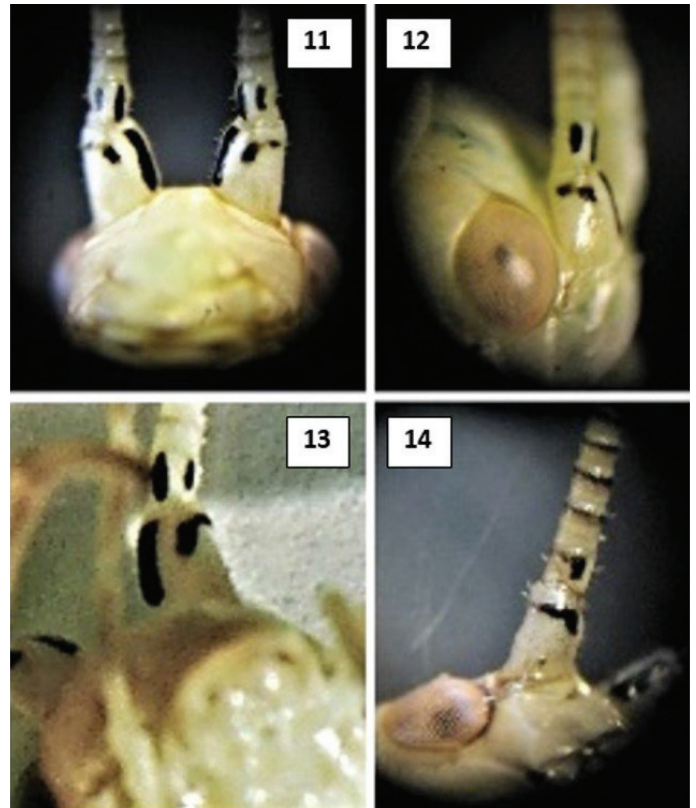


Figs 8–10. Host plants at Lake Annie. 8. Big sagebrush; 9a. Mountain sagebrush; 9b. Mountain sagebrush inflorescences; 10a. Rubber rabbitbrush; 10b. Rubber rabbitbrush inflorescences.

a continuous trilling song. Black antennal markings were visible on the ventral surface of the pedicel and the scape (Figs 11–14), and there were visible greyish brown rings of various degrees of darkness on the pale antennae filaments (Figs 11, 14).

Nymphs of instar stages four and five (Figs 15–17) and adults (Figs 18–20) were encountered on various sagebrush and rabbitbrush plants during July. The 4th stage instar and one 5th stage instar died prior to reaching the next stage. Adults retained a milky-green color and had a white abdomen (Fig. 21). Dark black setae caused a speckling effect on the limbs, especially on the hind limbs (Fig. 22). Black markings were visible on the hind femoral-tibial joints, with a whitish field on the ventral surface (Fig. 23). Two blackish horizontal lines were situated on the tibia just distal to the femoral-tibial joints (Fig. 24).

Song analysis.—Analysis of waveforms confirmed a continuous trilling pattern with a rate of 41 pulses per second at 24.8°C (Fig. 25). Dominant frequency 3.5 kHz at 24.8°C (Fig. 26). The song pulse rate of the sage tree cricket was compared to seven other



Figs 11–14. Antennal markings and dark rings of sage tree cricket.

species (Fig. 27), and the frequency vs. pulse rate was compared to five species (Fig. 28). A recording of two sage tree cricket males in separate netted containers within two feet of each other shows various patterns of synchrony and opposition (Figs 29, 30).

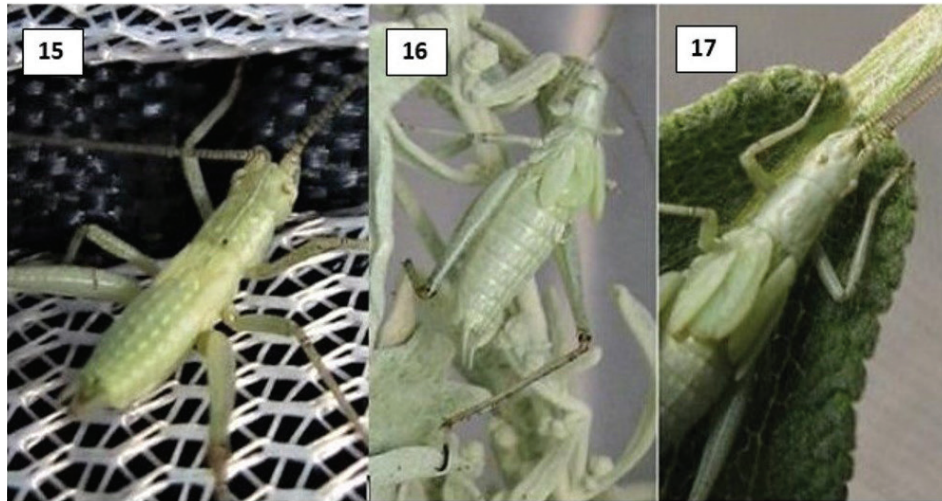
Oecanthus salvii Collins, sp. nov.

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Etymology.—Specific epithet after Lodovico (Ludovico) Salvi, an Italian philosopher and theologian, who included illustrations of a male tree cricket, a female tree cricket, and a stem with oviposition holes, in his article published 270 years ago (Salvi 1750). In *Voices of a Summer Night* (Lioy 1866), Salvi was recognized as being the first person to publish an article about a tree cricket. His 1750 article was published 13 years before the first tree cricket was officially described (*Oecanthus pellucens* Scopoli, 1763). The common name, sage tree cricket, is given because these tree crickets have similar coloration to the sagebrush host plants at Lake Annie.

Type verification.—The genus *Oecanthus* was determined as the specimens had spines on the hind tibiae.

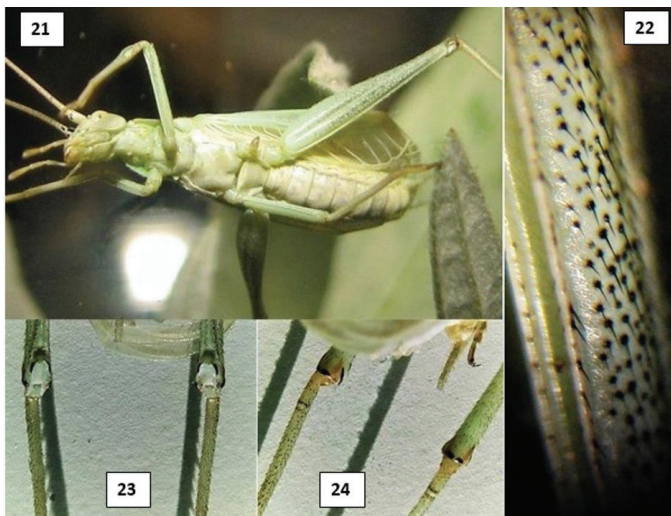
Type-specimen.—Holotype ♂, alcohol vial. Lake Annie, Modoc County, California, USA, 41°54'24"N, 120°06'31"W, elevation ca. 1530 m, arid, sagebrush, N. Collins leg., 25 July 2019. Body length (in mm) 15.4; tegminal length 11.0; tegminal width 5.0; pronotal length 2.2; distal pronotal width 2.0; hind femur length 8.0; cerci 5.4. Four antennal markings per side with two vertical black antennal markings on the pedicel, and one each vertical and horizontal black mark on the scape. Deposited at California Academy of Sciences (CAS).



Figs 15–17. Nymphs. 15. 4th instar; 16, 17. 5th instar.



Figs 18–20. Sage tree cricket. 18. Adult male; 19. Adult female; 20. Raised tegmina of male preparing to sing.

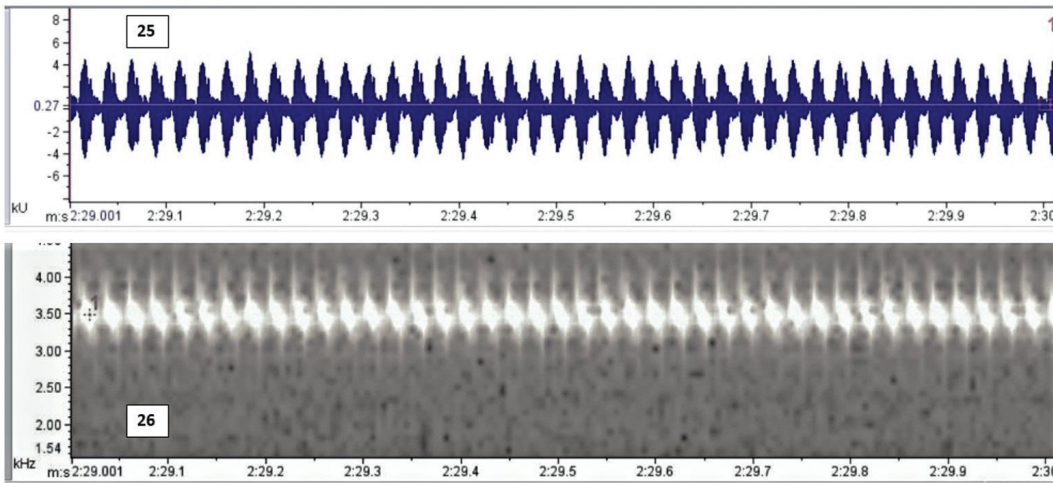


Figs 21–24. Adult sage tree cricket male abdomen, limb setae coloring, and hind femoral-tibial joints. 21. Creamy white ventral abdomen; 22. Dark black setae on limbs; 23. Ventral view of joints; and 24. Dorsal view of joints and two horizontal black lines on tibiae.

Paratypes.—3 ♂ and 1 ♀. Located in same area as holotype, 24–25 July 2019. 1 ♂ and 1 ♀ deposited at CAS, 1 ♂ Academy of Natural Sciences of Philadelphia, and 1 ♂ Florida State Collection of Arthropods. Two nymphs retained by NC for possible future DNA analysis.

Description.—Face creamy white to faint yellowish. Pedicel with two unequal-sized vertical lines, and scape with one vertical black line medially and one horizontal arched or right-angled black mark near the top of the segment. Remainder of antennae segments tan with darker brown or grey rings. Eye color whitish to dark cream. Palpi translucent pale tan. Pronotum light green. Tympanal membrane on fore tibiae whitish. Wing color of both sexes pale greenish. Ventral abdomen whitish or pale tan. Tibiae and femora translucent pale green with black setae. Cerci straight and pale green.

Male ($N=4$).—Hind wings do not extend beyond distal edge of tegmina; cerci do extend beyond the tegmina. Metanotal gland with bilateral horizontal structures with tiny bristles situated midline in the triangular-shaped gland opening as in Fig. 51. Copulatory blades slender with a deep notch between them as in Fig. 41. Subgenital plate with pointed distal tip as in Fig. 43.



Figs 25, 26. One-second trilling of male sage tree cricket at 24.8°C. 25. 41 pulses per second; 26. Dominant frequency 3.5 kHz.

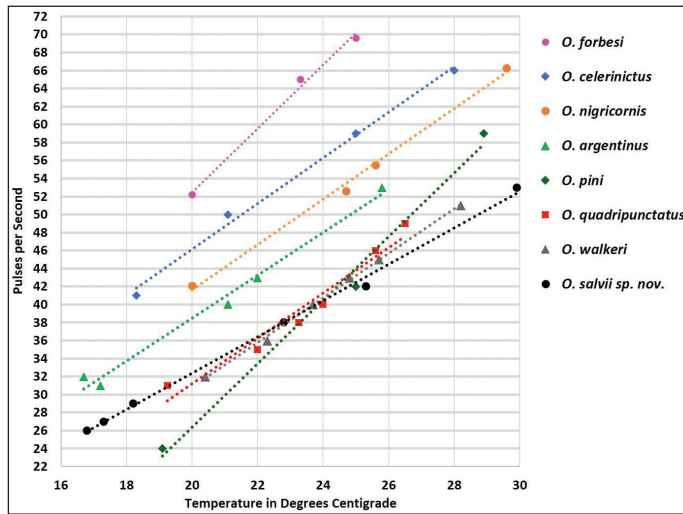


Fig. 27. Song pulse rates of *Oecanthus salvii* sp. nov., *O. forbesi*, *O. celerinictus*, *O. nigricornis*, *O. argentinus*, *O. quadripunctatus*, *O. walkeri*, and *O. pini* (data in Suppl. materials 1, 2).

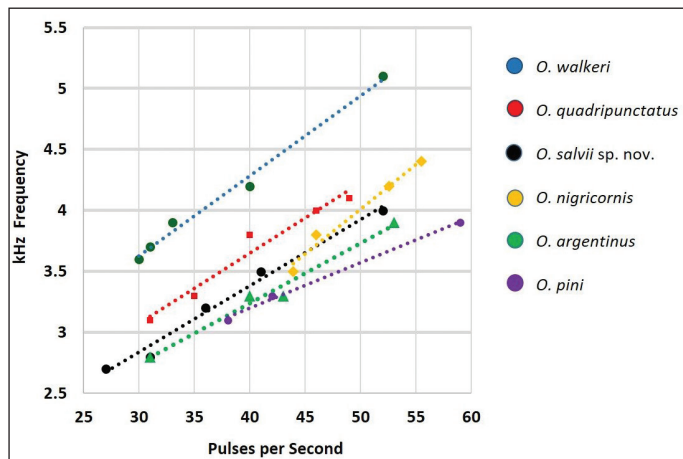


Fig. 28. Dominant frequency vs. pulses per second of *Oecanthus salvii* sp. nov. compared to other members of the *nigricornis* species group: *O. walkeri*, *O. quadripunctatus*, *O. nigricornis*, *O. argentinus*, and *O. pini* (data in Suppl. materials 1,2).

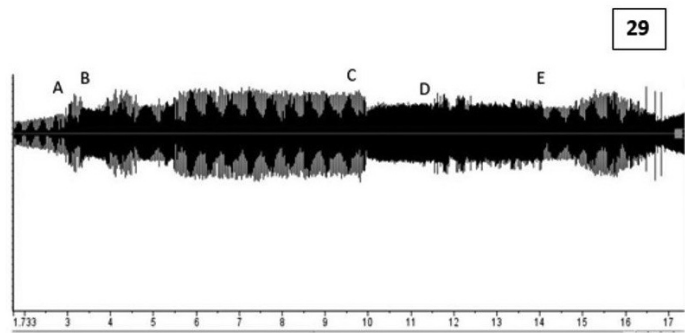


Fig. 29. Seventeen-second waveform of two male sage tree crickets at 17.3°C. Areas of interest shown in Fig. 30a–e.

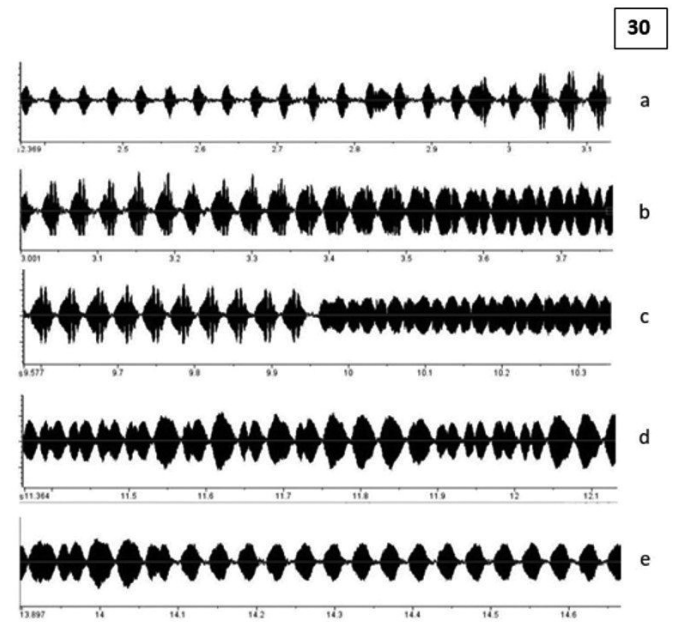


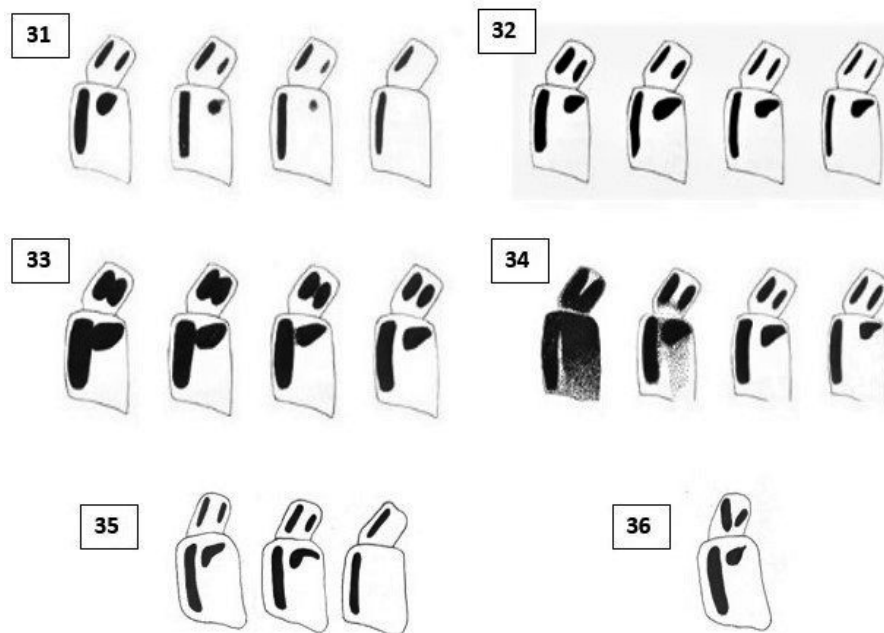
Fig. 30. Waveform sections from Fig. 29. a. Single male then joined by another male; b. The same two males in imperfect synchrony evolving into opposition; c. The same two males in near synchrony, pausing, then in opposition; d. The same two males in various degrees of synchrony; e. The same two males achieving synchrony.

Measurements (in mm).—Body length 15.4–16.8; tegminal length 11.0–11.5; tegminal width 5.0–5.5; pronotal length 2.2–2.6; distal pronotal width 2.0–2.2; hind femur length 8.0–9.0; cerci 5.2–5.6; stridulatory file 0.8 (N=2). Right tegminal stridulatory teeth 50–51 (N=2).

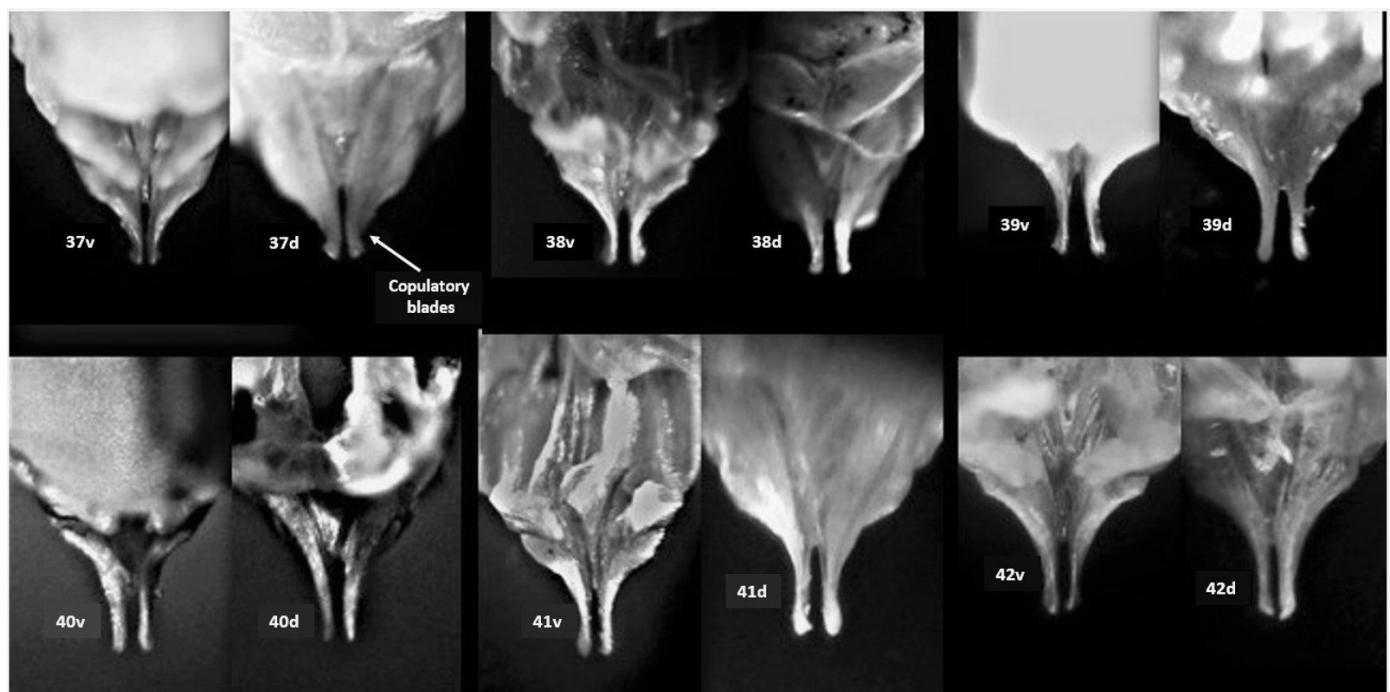
Female (N=1).—Latticed vein pattern on translucent greenish wings. The tip of the ovipositor extends to the tips of the cerci.

Measurements (in mm).—Body length 17.0; pronotal length 2.3, distal pronotal width 2.0; hind femur length 9.0; cerci 5.2; ovipositor length 5.5.

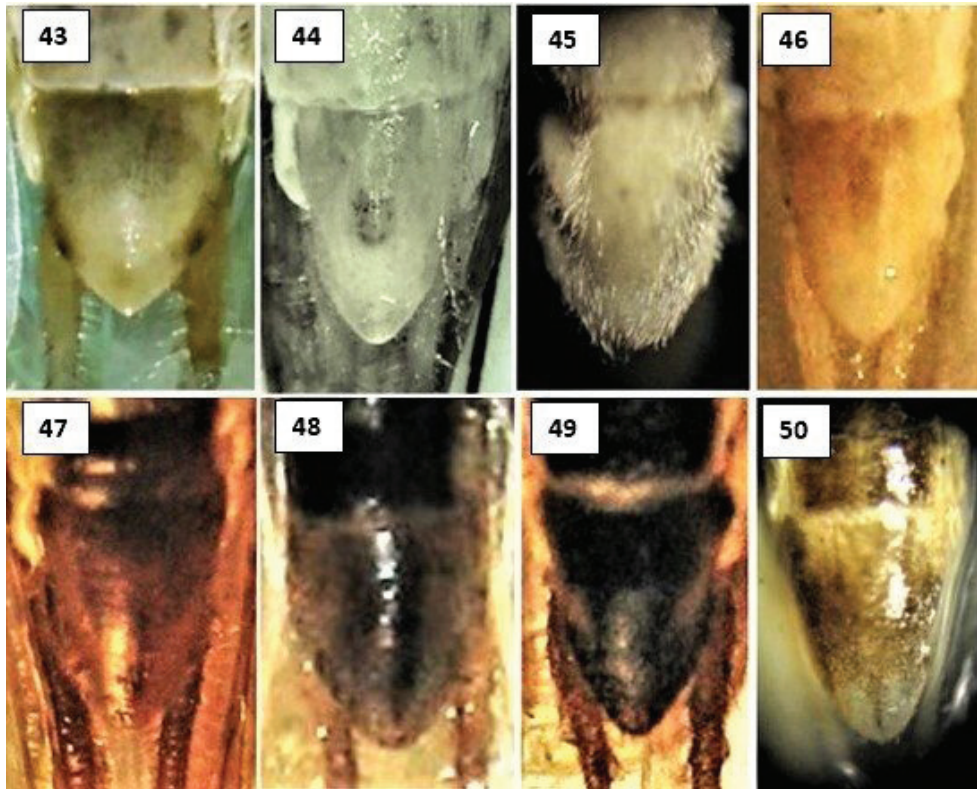
Behavior.—The Lake Annie area was not explored after dark when it is expected these tree crickets would be singing in the wild. No singing was detected during the daytime by either KS on two occasions or by NC on two consecutive days. In captivity, males did



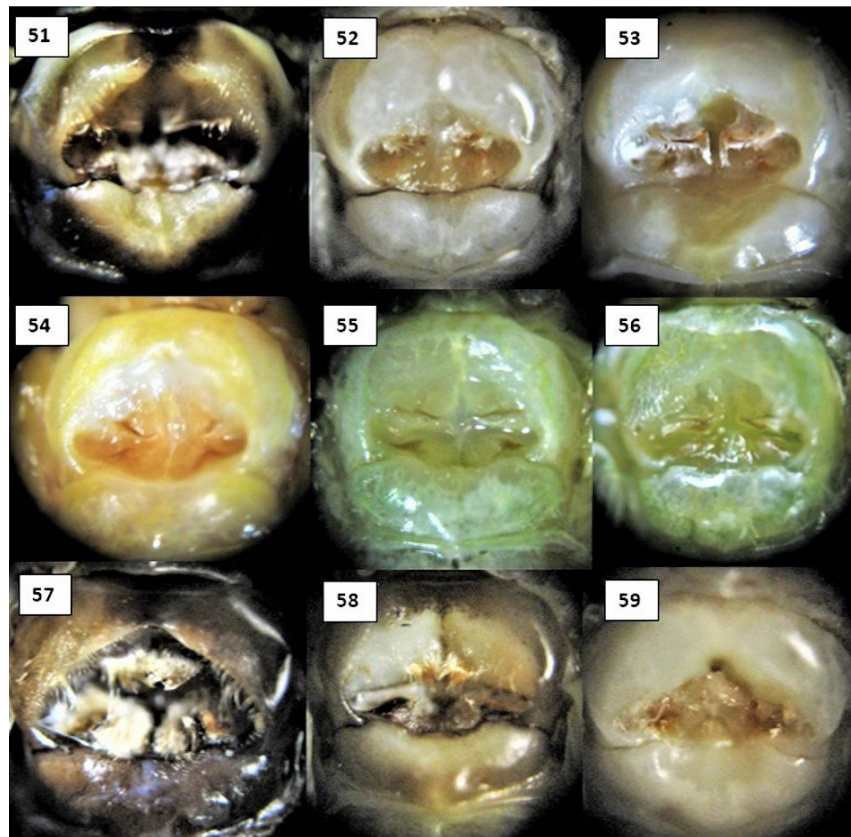
Figs 31–36. Drawings showing variations of antennal markings. 31. *Oecanthus quadripunctatus*; 32. *O. celerinictus*; 33. *O. argentinus*; 34. *O. nigricornis/O. forbesi*; 35. *O. pini*; and 36. *O. walkeri*.



Figs 37–42. Shapes of copulatory blades in (v)-ventral and (d)-dorsal views. 37. *Oecanthus walkeri*; 38. *O. nigricornis*; 39. *O. quadripunctatus*; 40. *O. argentinus*; 41. *O. salvii* sp. nov.; and 42. *O. celerinictus*.



Figs 43–50. Male subgenital plates. 43. *Oecanthus salvii* sp. nov.; 44. *O. walkeri*; 45. *O. celerinictus*; 46. *O. quadripunctatus*; 47. *O. pini*; 48. *O. nigricornis*; 49. *O. forbesi*; and 50. *O. argentinus*.



Figs 51–59. Metanotal glands comparisons. 51. *Oecanthus nigricornis*; 52. *O. argentinus*; 53. *O. celerinictus*; 54. *O. forbesi*; 55. *O. salvii* sp. nov.; 56. *O. quadripunctatus*; 57. *O. laricis*; 58. *O. pini*; and 59. *O. walkeri*.

not start singing until dusk or later. The color of sage tree crickets allows them to blend remarkably well with the rabbitbrush and sage shrubs they inhabit. Shrubs were intensely visually scoured by NC, but no tree crickets were detected. Only with the use of sweep netting were tree crickets found by both KS and NC.

Discussion

We describe a new species of *Oecanthus* that falls into the *nigricornis* species group. While *O. salvii* sp. nov. has some degree of song and morphological similarities to the eight known members of the *nigricornis* group, each of those species also has characters that do not match. The characters most unique for *O. salvii* sp. nov. are an upper outer mark on the scape in the shape of a horizontal arch or right angle, and a distinct pointed tip on the male's subgenital plate.

Comparisons.—The ten known members of the *rileyi*, *niveus*, and *varicornis* species groups in the United States can be ruled out because of having different song types, tegminal widths, antennal markings, or antennal coloring. The eight members of the *nigricornis* species group have many similarities to each other. Table 1 shows our results for comparing eleven of the characters presented in this paper for *O. salvii* sp. nov. to the eight known species in the *nigricornis* group. We were able to rule out *O. salvii* sp. nov. as displaced *O. laricis* or *O. pini* because they are conifer dwellers with a rust or dark brown head. *Oecanthus walkeri* was ruled out as it has two thick markings on the pedicel in the shape of a 'v' that touch or nearly touch at the bottom, and the frequency vs. pulse rate results are too high. *Oecanthus celerinictus* and *O. forbesi* do not match as they have pulse rates over 55 pulses per second at 25.0°C, whereas *O. salvii* sp. nov. has a rate below 45.

Although *O. nigricornis* is considered an eastern US species, there are two photographs on BugGuide of females from California which cannot be ruled out as *O. nigricornis/forbesi*: images 561469 and 325581 (BugGuide 2020). While the frequency of the male's song of *O. nigricornis* is essentially identical to that of *O. salvii* sp. nov., the song rate, metanotal gland, and subgenital plate do not match.

Oecanthus argentinus has seven matching or similar characters to *O. salvii* sp. nov., but it is ruled out as a match as it has two thick pedicel markings that are separated by less than one width of one of the markings, and the male has a longer subgenital plate with no point at the tip.

Oecanthus quadripunctatus is a match or similar to *O. salvii* sp. nov. in six categories. It does not, however, match in the categories of the antennal markings, horizontal black lines on the limbs, and dark black setae on the limbs.

We compared the antennal markings to drawings of *O. quadripunctatus* (Fig. 31), *O. celerinictus* (Fig. 32), *O. argentinus* (Fig. 33), and *O. nigricornis/forbesi* (Fig. 34), from the Singing Insects of North America website (SINA 2020a). We also provide examples of the antennal markings of *O. pini* (Fig. 35) and *O. walkeri* (Fig. 36). The upper outer marking on the first antennal segment of *O. pini* varies, including some individuals with no upper outer mark and some individuals with arched upper outer marks similar to that of *O. salvii* sp. nov. (Figs 11–14).

The copulatory blades of five members of the *nigricornis* species group were compared to those of *O. salvii* sp. nov. (Figs 37–42). We could see no major differences in the sizes or shapes of the blades and the notch between them. We also compared the distal tip of the subgenital plate of *O. salvii* sp. nov. to seven other species (Figs 43–50). The plate of *O. salvii* sp. nov. tapers to a distinct point, which the other species lack. The metanotal glands for members of the *nigricornis* species group are quite similar (Figs 51–59). The prominent feature of the gland of *O. salvii* sp. nov. is the near meeting of the horizontal tapered structures projecting from the lateral sides of the cavity.

Oecanthus walkeri has not been documented west of Arizona, and the markings on the pedicel do not match that of *O. salvii* sp. nov. Despite the close match of the upper outer mark on the scape of *O. pini*, that species and *O. laricis* have not been documented west of the Continental Divide and are both conifer dwellers.

Oecanthus quadripunctatus and *O. argentinus* have several similarities to *O. salvii* sp. nov., and both occur in northern California. However, both have character differences to *O. salvii* sp. nov. *O. quadripunctatus* does not have dark black setae

Table 1. Comparisons of *Oecanthus salvii* sp. nov. characters to the eight members of the *nigricornis* species group. M: Match; S: Similar; P: Possible; D: Different; N: Not included; I: Intermittently matches; U: Undetermined.

Characters of <i>O. salvii</i> sp. nov.	<i>O. quadripunctatus</i>	<i>O. argentinus</i>	<i>O. walkeri</i>	<i>O. celerinictus</i>	<i>O. nigricornis</i>	<i>O. forbesi</i>	<i>O. pini</i>	<i>O. laricis</i>
Pulses per second – 41 pulses per second at 24.8°C.	M	S	M	D	D	D	M	N
Metanotal gland – Horizontal tapered structures projecting from the lateral sides of the cavity and nearly touching at the center.	M	D	D	S	S	S	S	D
Distribution – California or western region states.	M	M	D	D	U	U	D	D
Black setae – Numerous present on pale green limbs.	D	M	D	D	D	D	D	D
Limb lines – Two parallel horizontal lines present on pale green tibiae.	D	I	D	M	I	I	D	D
Subgenital plate – Roundish shape that tapers to a distinct pointed tip.	D	D	S	D	D	D	D	N
Antennal markings – Pedicel: Two vertical black lines separated by more than width of one of the lines. Scape: Upper outer mark in shape of upright arch or right angle.	D	D	D	S	S	S	I	D
Frequency – 3.5 kHz at 24.8°C.	S	S	D	N	M	N	S	N
Copulatory blades – Long and slender with deep round-topped notch between them.	S	S	S	S	S	N	N	N
Coloring – Pale green with white abdomen.	S	S	S	S	D	D	D	D
Host plants – Sagebrush, rabbitbrush.	P	P	P	N	N	D	D	D

on the limbs or horizontal black lines on the limbs, and the subgenital plate of the male of *O. argentinus* is rounded at the distal end. Additionally, *O. quadripunctatus* has no or a mostly round upper outer antennal marking on the scape, and *O. argentinus* has two thick lines on the pedicel that are positioned more closely to each other.

Further study of this new species is needed to determine its potential range beyond Modoc County and whether it dwells on plants other than sagebrush and rabbitbrush. More in-depth investigation of this species' life cycle and singing/mating behavior is also needed. The remote location makes investigating this species more challenging.

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We are grateful to Iowa State University's Department of Entomology for maintaining BugGuide.net, a website that allows scientists and the general public to post photographs of insects from the continental United States and Canada. Kevin McKereghan was tremendously helpful to NC during her field work. We appreciate Thomas J. Walker, Professor Emeritus, University of Florida, for the wealth of knowledge he generously shares. Dr. Walker has long been a proponent of the open access of articles and recordings that were of immense assistance in our investigation of this new species. An Orthoptera Species File grant for "Oecanthines of high interest in the United States" provided financial support for NC's field trip. The Orthopterists' Society provided free publication of this paper. We thank Holger Braun, Zhu Qing He, and Klaus-Gerhard Heller for their constructive suggestions on improving this manuscript.

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Supplementary material 1

Author: Nancy Collins, Ken R. Schneider

Data type: Number of pulses per second vs. temperature in Centigrade

Explanation note: Resources used for creating the figure showing the number of pulses per second vs. temperature in Centigrade of several species in the *nigricornis* group.

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Link: <https://doi.org/10.3897/jor.29.50400.suppl1>

Supplementary material 2

Author: Nancy Collins, Ken R. Schneider

Data type: Song frequency vs. pulses per second

Explanation note: Resources used for creating a graph showing frequency vs. pulses per second of several species in the *nigricornis* group.

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