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# Bioacoustics of Tettigoniidae (Insecta, Orthoptera) Distributed in Hakkari (Eastern Anatolia) Province

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## ABSTRACT

In this study, the male calling songs of sixteen species belonging to the Tettigoniidae family distributed in Hakkari were recorded in the field studies and bioacoustic analyses were performed. The bioacoustic analysis of two genera (*Kurdia* and *Novadrymadusa*) documented first time with present study and in total six species (*Bradyporus (Callimenus) latipes, Isophya hakkarica, Kurdia uvarovi, Novadrymadusa karabagi, Psorodonotus hakkari*, and *Squamiana supericola*) were presented first time. The bioacoustic analyses of seven species (*Conocephalus (Anisoptera) fuscus, Pezodrymadusa indivisa, Polysarcus zacharovi, Tettigonia armeniaca, Tettigonia caudata, Tettigonia viridissima*, and *Uvarovistia satunini*) were examined for the first time from Hakkari populations. In addition, in this study, the bioacoustic analyses of three species (*Apholidoptera kurda, Saga hakkarica*, and *Uvarovistia zebra*) distributed in Hakkari were re-evaluated in this study on new individuals. As a result of the findings, it has been determined that the male calling song of sixteen species belonging to the Tettigoniidae family are species-specific, have a simple calling song type, and morphological species hypotheses are also supported by bioacoustic data (male calling song).

*Keywords*: Anatolia, crickets, calling song, species hypothesis.

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## INTRODUCTION

Communication in organisms can be visual, auditory, sensory or physical (contact), and communication types are generally grouped within ethological characters. Bioacoustics is a discipline of ethology that deals with sound production, song behaviour and analysis in organisms. In order Orthoptera, the family Tettigoniidae is one of the families that use acoustic communication effectively, and the male calling song is used for individuals to recognize each other, determine location, and to select the female for mate (Heller, 1988; Robinson & Hall, 2002; Heller, 2006). Since acoustic communication is the main mechanism in species belonging to the family Tettigoniidae, song characters are very important in understanding whether sexual isolation has occurred and determining the species (Heller, 2006). In most of tettigoniids, males produce calling sounds, but territorial and protest (=disturbance etc.) sounds (as pre-copulatory sounds) in some taxa (for example, *Phaneroptera*) are also known (Korsunovskaya, 2008).

In recent bioacoustic studies in Anatolia, it has been determined that the male calling song is species-specific in many taxa or species groups (Sevgili, 2004; Taylan, 2005; Sevgili, Demirsoy, & Durmuş, 2011; Şirin, Taylan, & Mol, 2014; Şirin, Taylan, Sevgili, & Mol, 2019; Taylan, Mol, Sevgili, & Şirin, 2019). Hakkari province, which is the study area, is at the south-eastern tip of the Anatolia and has borders with Iran and Iraq. Despite its high mountains and valleys, rugged topography, and high biodiversity potential, it has been one of the less-studied areas of Anatolia (Taylan, Şirin, Sevgili, & Yeşilyurt, 2021). The Orthoptera (Insecta) order is represented by a total of 741 species/subspecies in Turkey (Ünal, 2011a).

In their study on the Orthoptera fauna of Hakkari province, Taylan et al. (2021) identified 25 tettigoniid species which some of endemic or sub-endemic species for Hakkari province or Anatolia. These species are: *Isophya hakkarica* Karabağ, 1962; *Kurdia uvarovi* Karabağ, 1975; *Polysarcus zacharovi* (Stshelkanovtzev, 1910); *Phaneroptera* (*Erdemia*) *hackeri* Harz, 1988; *Anadrymadusa* (*Anadrymadusa*) *modestalis* Koçak & Kemal, 2010; *Novadrymadusa karabagi* Demirsoy, Salman & Sevgili, 2002; *Phytodrymadusa hakkarica* Karabağ, 1956; *Uvarovistia zebra* (Uvarov, 1916); *Uvarovistia satunini* (Uvarov, 1934); *Apholidoptera kurda* (Uvarov, 1916); *Apholidoptera pietschmanni* (Ebner, 1912); *Incertana persica* (Uvarov, 1917); *Platycleis intermedia* (Serville, 1838); *Saga hakkarica* Şirin & Taylan, 2019; *Squamiana supericola* (Ünal, 2018); *Psorodonotus hakkari* Kaya, Korkmaz & Çıplak, 2013; *Medecticus assimilis* (Fieber, 1858); *Tettigonia armeniaca* Tarbinsky, 1940 and *Tettigonia caudata* (Charpentier, 1845). All of these species were described as morpho-species and bioacoustic data on the species are very limited (Şirin et al, 2014; Şirin et al, 2019; Taylan et al, 2019).

In this context, we aimed to (i) test the morpho-species hypotheses of the species endemic to the region and Anatolia with bioacoustic data, and (ii) contribute to a better knowledge of bioacoustic data of Anatolian tettigoniids.

## MATERIAL AND METHODS

### Study area

Hakkari province (Fig. 1) is located in the southeast of the Eastern Anatolia Region, between 42° 10' and 44° 50' east longitudes and 36° 57' and 37° 48' north latitudes, and is adjacent to Iran in the east and Iraq in the south. Hakkari has a border with the internal borders of the country, the Başkale, Gürpınar, and Çatak districts of the Van province in the north, and the Beytüşşebap and Uludere districts of the Şırnak province in the western border. Hakkari city center and its surroundings are covered with mountains at different elevations and slopes. 86% of Hakkari is mountainous, 2.4% is lowland, 2.8% is the plateau, 7.5% is rough terrain and 1% is valleys (HÇŞM, 2011). Within the provincial borders of Hakkari, there are more than ten elevations over 3500 m, and the vegetation is generally East Anatolian mountain steppe, East Anatolian high mountain meadow, East Anatolian oak forest and partly wooded steppe (Gökmen, 1962; Atalay, 1983). The map of the study area was created by using the ArcGIS 10.2 (Arc Map Elevation) program.

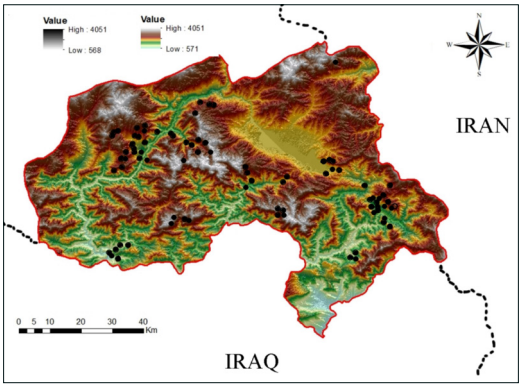


Figure 1. The map of studied area in Hakkari Provinces in this research (*black points indicate the studied localities, the map is derived from Taylan et al, 2021)

### Collections, identification, and conservation of specimens

Within the scope of the study, 16 tettigoniid species were examined and male calling songs were recorded during the field studies carried out between 2020 and 2021. Considering the biological characteristics of the tettigoniids, individuals were caught with a standard sweep net at suitable localities and the coordinates of the collection points were taken with the help of a GPS unit. Male individuals (at least 2-3 individuals) were caught with the help of a sweep net for bioacoustic studies from different points in the areas and they were brought to the room/laboratory alive by taking them into special cages. After the male calling song recordings of the collected tettigoniid individuals, species identifications were made using the related literature, with the help of a LEICA S8 APO model stereo microscope with a digital camera connected imaging feature. After bioacoustic and morphological examinations, tettigoniid specimens were deposited in tubes containing 96% ethyl alcohol, in a deep freezer at -20 °C, in the Zoology Museum (Hakkari) at Hakkari University Biological Diversity Application and Research Centre.

## Song recording and bioacoustic analyses

In tettigoniids, the male calling song is produced by rubbing the stridulatory file teeth on the back of the left wing against the inner edge of the other wing (Heller, 1988). The calling songs were recorded either in the field or in the laboratory under room conditions. Song recordings were made with a high-quality condenser microphone (frequency response flat up to 20 kHz) capable of digital sound recording and with the TASCAM-DR 100 device (a recorder using audio technical) that can record from 44.1 kHz to 48 kHz. In this system, the song records of individuals were recorded on the memory card, or the data were transferred by directly connecting to the computer with a USB connection cable. The bioacoustic data transferred to the computer were analysed with the GoldWave and Cool Edit 96 programs as well as the Labview 7 program. On the other hand, Turbolab 4.0 (Stemmer AG) program was used to prepare and print out the oscillograms. All means of bioacoustic characters are given with standard deviation (±).

## Bioacoustic terminology

The bioacoustic terminology used in the calling song description of Orthoptera species includes differences according to the taxa studied and researchers (Heller, 1988; Ragge & Reynolds, 1998; Kolics et al, 2008; Şirin et al, 2014) although there were some standardization terminology studies for insect (Baker & Chesmore, 2020). The absence of standardized terminology for the song description of taxa belonging to the Orthoptera order causes some difficulties in definitions (Robinson & Hall, 2002). This is due to the difference in the structural features of the wing movements, which constitute the basic calling song type in the Orthoptera order. For this reason, the terminologies in Heller (1988), Ragge & Reynolds (1998), Taylan (2005), Heller (2006), Sevgili et al, (2011), Şirin et al, (2014), Şirin et al, (2019), Taylan et al, (2019) and Baker & Chesmore (2020) provided for the bioacoustic analysis and comparison of calling songs. Therefore, a synthesis of bioacoustic terminology was used in the study (Fig. 2). *Calling song*, song produced by an isolated male; phrase, a first-order assemblage of syllables; *syllable*, the song produced by one opening-closing movement cycle of the tegmina; *syllable interval*, time from end of last impulse to beginning of first impulse of the next syllable; *pulse*, an indivisible and most basic unit of stridulatory song that generated during the opening or closing movement of the wing.

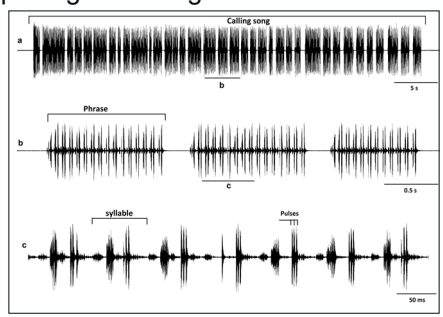


Figure 2. Bioacoustic terminology for studied tettigoniids. *Tettigonia viridissima:* a) calling song, b) three phrases, c) seven syllables.

## RESULTS

The bioacoustic analysis of two genera (*Kurdia* and *Novadrymadusa*) documented first time with present study and in total six species (*Bradyporus latipes*, *Isophya hakkarica*, *Kurdia uvarovi*, *Novadrymadusa karabagi*, *Psorodonotus hakkari,* and *Squamiana supericola*) were presented for the first time in this study. However the bioacoustic analysis of seven species (*Conocephalus fuscus*, *Pezodrymadusa indivisa*, *Polysarcus zacharovi*, *Tettigonia armeniaca*, *Tettigonia caudata*, *Tettigonia viridissima* and *Uvarovistia satunini*) were examined the first time from Hakkari populations. Additionally, the bioacoustic analyses of three species (*Apholidoptera kurda*, *Saga hakkarica* and *Uvarovistia zebra*) distributed in Hakkari were re-evaluated with using new individuals.

Among the examined sixteen tettigoniid species, the distribution, localities, song descriptions, and bioacoustic data of six tettigoniid species collected in the field studies in Hakkari province were presented for the first time in this study and also bioacoustic data of *Polysarcus zacharovi* (which has a different song structure compared with previous data) are presented.

### Bioacoustics

### Subfamily: Tettigoniinae Krauss, 1902

### Genus: *Novadrymadusa* Demirsoy, Salman & Sevgili, 2002

### *Novadrymadusa karabagi* Demirsoy, Salman & Sevgili, 2002

Distribution: The *N. karabagi* is an Anatolian endemic species and is distributed in Hakkari and Şırnak provinces (Demirsoy, Salman, & Sevgili, 2002; Ünal, 2018; Taylan et al, 2021).

Song recording: Male individuals of the species were collected from Hakkari Cilo-Sat Mountains National Park, Kırıkdağ, Cennet-Cehennem valley, Sipilhane location, 37°31.538´ N, 43°58.877´ E, 2570 m, 07.08.2021 (legs. M.S. Taylan & C. Avcı), and song recordings were taken from three males at room conditions (26.5 °C) (song recording: M.S. Taylan & C. Avcı).

Song description: Six song recordings of three males were examined. The male calling song consists of phrases consisting of polysyllabic sequences (Fig. 3a). The duration of the polysyllabic series varies between 8-78 s (28 ± 11.25) and includes 10-11 syllables in 100 ms (Fig. 3b). Bioacoustic analyses showed that syllables consist of two parts. The first part begins with a short, low-amplitude pulse-like structure (6-9 ms (8.15 ± 0.85 ms)) and continues with a longer and higher (21-25 ms (22.25 ± 2.11 ms)) amplitude unit. The second part is similar to the last unit of the first part of syllable and its duration varies between 22-27 ms (24.62 ± 2.48 ms). While syllable duration was 78–138 ms (102.15 ± 7.22 ms) (Fig. 3c), it was determined that there was a 22–78 ms (35.41 ± 7.25 ms) interval between syllables.

**Genus: *Psorodonotus* Brunner von Wattenwyl, 1861**

***Psorodonotus hakkari* Kaya, Korkmaz & Çıplak, 2013**

Distribution: *P. hakkari* is endemic species to Hakkari province (Kaya, Korkmaz, & Çıplak, 2013; Taylan et al, 2021).

Song recording: Male individuals of the species were collected from Hakkari, Berçelan Plateau, 37°42.502´ N, 43°43.907´ E, 2930 m, 04.07.2021 (legs. M.S. Taylan & C. Avcı) and song recordings were taken from three males at room conditions (27°C) (song recording: M.S. Taylan).

Song description: Six song recordings were examined from three males. The male calling song consists of a sequence of regularly repeated syllables (Fig. 4a), with an interval of 320–495 ms (404 ± 28.25 ms) between syllables. The syllable duration varies between 78-102 ms (90.23 ± 7.65 ms) (Fig. 4b). As a result of oscillographic analysis, it was seen that each syllable consisted of 5 elements (Fig. 4c). The first and second elements are short and low amplitude pulses. The third element has a longer and higher amplitude (16-22 ms (19.14 ± 3.11 ms)) and contains 9-12 distinguishable pulses. The fourth elements are also short and of low amplitude, similar to the first and second elements. The last element (5th) is the longest and highest amplitude part, it contains 13-17 visible pulses and its duration varies between 24-31 ms (28 ± 3.72 ms).

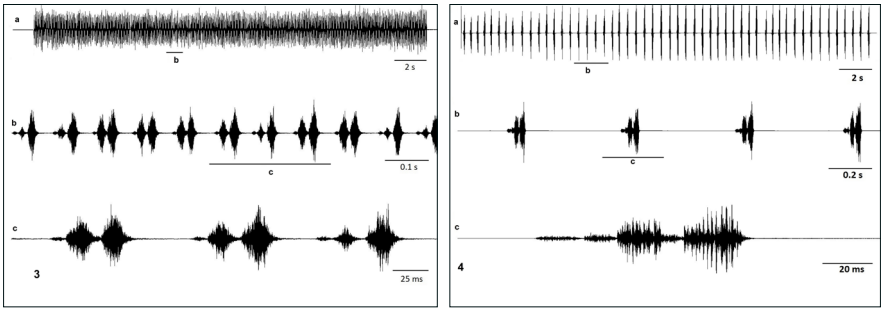


Figure 3-4. 3) Male calling song of *Novadrymadusa karabagi* Demirsoy, Salman & Sevgili, 2002. a) polysyllabic sequence, b) number of syllable in 100 ms, c) three complete syllables; 4) Male calling song of *Psorodonotus hakkari* Kaya, Korkmaz & Çıplak, 2013. a) regularly repeated syllable sequences, b) four complete syllables, c) a complete syllable.

**Genus: *Squamiana* Zeuner, 1941**

***Squamiana supericola* (Ünal, 2018)**

Distribution: *S. supericola* (Ünal, 2018) is an endemic species to Şırnak and Hakkari provinces (Ünal, 2018; Taylan et al, 2021).

Song recording: Male individuals of the species were collected from Hakkari, Berçelan Plateau, 37°40.380´ N, 43°43.622´ E, 2840 m, 08.VII.2021 (legs. M.S. Taylan & C. Avcı), and song recordings were taken from two males at room conditions (27 °C) (song recording: M.S. Taylan & C. Avcı).

Song description: Four song recordings were examined from two males. The male calling song consists of regularly repeated phrases that including of polysyllabic

sequences (Fig. 5a). The phrase is almost crescendo (Fig. 5b), and the syllables at the beginning of the phrase have low amplitude and continue until 1/2-1/3 of the phrase. Then the phrase continues and ends with high amplitude syllables. The duration of the polysyllabic sequence varies between 2.40-6.27 s (3.26 ± 1.23 s), with a gap of 0.25-1.78 s (0.51 ± 0.22 s). The syllables in the first part phrase cannot be distinguished and contain 8-11 (9.15 ± 0.81) pulses. Syllables in the second half of the phrase can be distinguished and its duration varies between 14-18 ms (16.4 ± 1.48 ms). The number of syllables in 100 ms is 6-8 (7.14 ± 0.65) (Fig. 5c).

**Subfamily: Bradyporinae Burmeister, 1838**

**Genus: *Bradyporus* Charpentier, 1825**

***Bradyporus* (*Callimenus*) *latipes* (Stål, 1875)**

Distribution: *B. latipes* (Stål, 1875) is distributed in Eastern Anatolia (Malatya, Bitlis, Kars, Elazığ, Şırnak, and Hakkari) (Ünal, 2011b; Ünal, 2017; Taylan et al, 2021).

Song recording: Male individuals of the species were collected from, Hakkari, Mergabutan Ski Centre, 37°34.877´ N, 43°40.795´ E, 2480 m, 06.08.2021, (legs. M.S. Taylan & C. Avcı) and song recordings were taken from three males at room conditions (27 °C) (song recording: M.S. Taylan & C. Avcı).

Song description: Eight song recordings of three males were examined. The male calling song consists of polysyllabic sequences (Fig. 6a) and the duration of the polysyllabic sequences varies between 6.120–78.540 s (65.320 ± 12.05 s). The syllable duration varies between 58-119 ms (62.15 ± 14.25 ms), and the number of words in 100 ms is 2. Oscillographic analyses show that the syllables are composed of two elements, one which has a high amplitude (42-51 ms ± 2.14 ms), and the other has a low amplitude (19-30 ms ± 3.01 ms) (Fig. 6b, 6c). It is determined that there is a gap of 7–14 ms (10.08 ± 2.45 ms) between syllables.

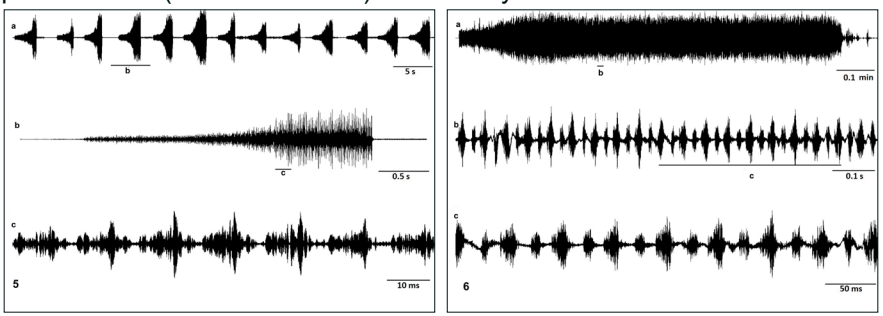


Figure 5-6. 5) Male calling song of *Squamiana supericola* (Ünal, 2018). a) regularly repeated phrases, b) a complete phrase, c) syllable numbers in 100 ms; 6) Male calling song of *Bradyporus* (*Callimenus*) *latipes* (Stål, 1875). a) polysyllabic sequences, b) syllables in 1s, c) eight complete syllables.

**Subfamily: Phaneropterinae Burmeister, 1838**

**Genus: *Isophya* Brunner von Wattenwyl, 1878**

***Isophya hakkarica* Karabağ, 1962**

Distribution: The *I. hakkarica* Karabağ, 1962 is a sub-endemic species to Anatolia and show distribution in Hakkari and Iraq (Karabağ, 1962; Taylan et al, 2021).

Song recording: Male individuals of the species were collected from Hakkari, Berçelan Plateau, 37°40.387´ N, 43°43.636´ E, 2835 m, 08.08.2021 (legs. M.S. Taylan & C. Avcı) and song recordings were taken from three males at room conditions (27 °C) (song recording: M.S. Taylan & C. Avcı).

Song description: Six song recordings of three males were examined. The male calling song consists of an irregular phrase consisting of 2 or 3 syllables of irregular duration and its duration varies between 6-12 s (11.15 ± 3.4 s) (Fig. 7a). The phrase usually consists of two different syllables types (Fig. 7a). First syllable is short-high amplitude and the second syllable long-low-amplitude. The short and high amplitude syllable has a duration of 242-302 ms (297.38 ± 29.15 ms) and has a reverse-crescendo pattern (Fig. 7b). The duration of long and low-amplitude syllable varies between 1.224-1.255 s (1.238 ± 0.18 s), and the first 5-7 structural elements can be distinguished (Fig. 7c).

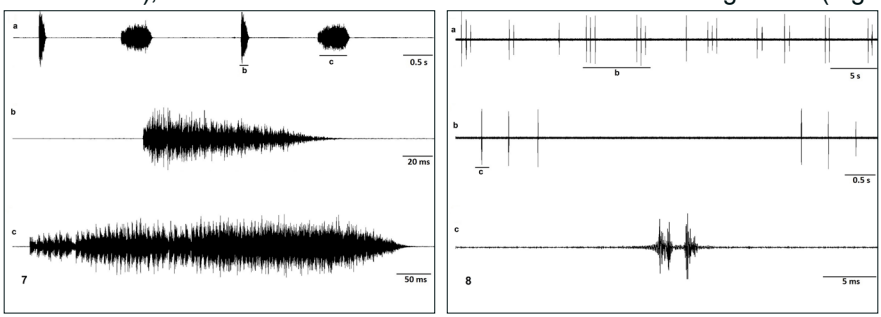


Figure 7-8. 7) Male calling song of *Isophya hakkarica* Karabağ, 1962. a) complete song, b) short and high amplitude syllable, c) long and low amplitude syllable; 8) Male calling song of *Kurdia uvarovi* Karabağ, 1975. a) complete song (variable syllable groups), b) two different triple syllable groups, c) a complete syllable and pulses.

## Genus: *Kurdia* Uvarov, 1916

### *Kurdia uvarovi* Karabağ, 1975

Distribution: *K. uvarovi* is an endemic species to Anatolia and distributed only in Hakkari province (Karabağ, 1975; Taylan et al, 2021).

Song recording: Male individuals of the species were collected from Hakkari, Yüksekova-Şemdinli road, Haruna valley, 37°21.685´ N, 44°32.264´ E, 1690 m, 17.06.2002 (leg. H. Sevgili) and song recordings were taken from two males in the field (22 °C) (song recording: H. Sevgili).

Song description: Four song recordings of two males were examined. The male calling song consists of regular 2 or 3 (rarely single) syllable groups (Fig. 8a). There is a gap of 2.240-4.760 s (3.214 ± 0.742 s) between syllable groups and 412-495 ms (460.25 ± 42.40 ms) between syllables (Fig. 8b). Oscillographic analyses show that syllables are composed of 2 or 3 high amplitude short pulses (Fig. 8c). The syllable duration varies between 3-6 ms (4.72 ± 1.06 ms).

**Genus: *Polysarcus* Fieber, 1853**

***Polysarcus zacharovi* (Stshelkanovtzev, 1910)**

Distribution: The species *P. zacharovi* is distributed in Caucasia, Transcaucasia, and Eastern Anatolia (Karabağ, 1958; Ünal, 2010; Sevgili et al, 2012; Taylan et al, 2021).

Song recording: Male individuals of the species were collected from Hakkari, Berçelan plateau, 37°40.392´ N, 43°43.642´ E, 2840 m, 14.08.2021 (legs. M.S. Taylan & C. Avcı) and song recordings were taken from two males in laboratory conditions (27 °C) (song recording: M.S. Taylan).

Song description: Three song recordings of two males were examined. The song consists of isolated single syllables (Fig. 9a). There is a gap of 0.802-7.75 s (3.915 ± 2.35 s) between syllables (Fig. 9b). Oscillographic analyses show that syllables are usually composed of one element (Fig. 9c). The syllable duration ranged from 64 to 73 ms (70.12 ± 2.42 ms). Rarely, there is a short, low-amplitude pulse at the beginning of the syllable, lasting 4-6 ms (5.25 ± 0.85 ms). This element contains a gap of 5-7 ms with the main song.

The remaining nine species of tettigoniids examined in Hakkari province (*Apholidoptera kurda* (Fig. 10), *Conocephalus* (*Anisoptera*) *fuscus* (Fig. 11), *Pezodrymadusa indivisa* (Fig. 12), *Saga hakkarica* (Fig. 13), *Tettigonia armeniaca* (Fig. 14), *Tettigonia caudata* (Fig. 15), *Tettigonia viridissima* (Fig. 16), *Uvarovistia satunini* (Fig. 17), and *Uvarovistia zebra* (Fig. 18), mainly show similar patterns with previous studies (Heller, 1988; Heller, 2006; Grzywacz, Heller, Warchałowska-Śliwa, Karamysheva, & Chobanov, 2017; Şirin et al, 2014, 2019; Taylan et al, 2019). For these reason, song descriptions of these species were not presented again. The comparisons of song descriptions of these nine species with previous studies' song data are given in the next section.

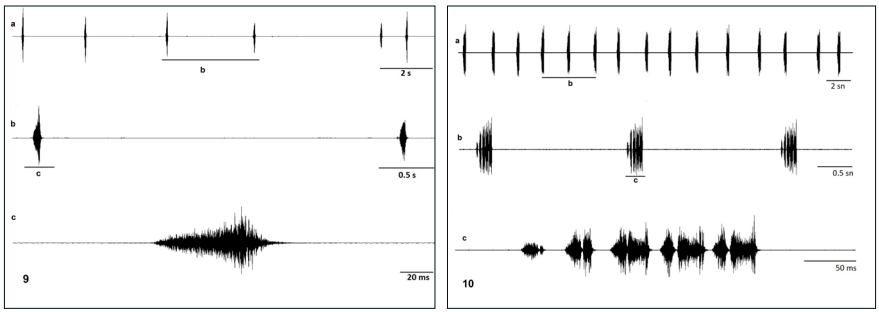


Figure 9-10. 9) Male calling song of *Polysarcus zacharovi* (Stshelkanovtzev, 1910). a) complete song (repeated syllables), b) two complete syllables, c) a complete syllable; 10) Male calling song of *Apholidoptera kurda* (Uvarov, 1916). a) complete song (regularly repated phrases), b) three complete phrases, c) a complete phrase and its syllables and elements

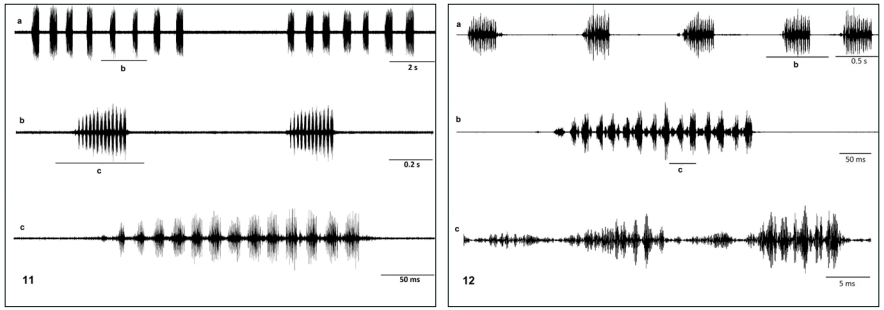


Figure 11-12. 11) Male calling song of *Conocephalus* (*Anisoptera*) *fuscus* (Fabricius, 1793). a) syllable sequences, b) two complete syllables, c) a complete syllable sequence; 12) Male calling song of *Pezodrymadusa indivisa* Karabağ, 1961. a) phrase sequences, b) a complete phrase, c) two complete syllables.

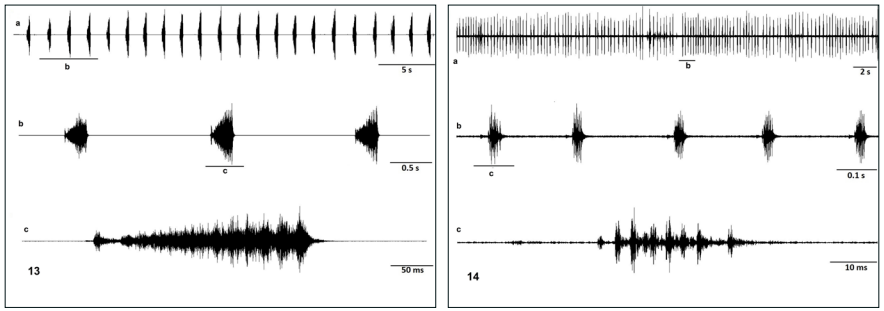


Figure 13-14. 13) Male calling song of *Saga hakkarica* Sirin & Taylan, 2019. a) complete song (regularly repeated phrases), b) three complete phrases, c) a complete phrase and syllables; 14) Male calling song of *Tettigonia armeniaca* Tarbinsky, 1940. a) repeated syllable series, b) five complete syllables, c) a complete syllable.

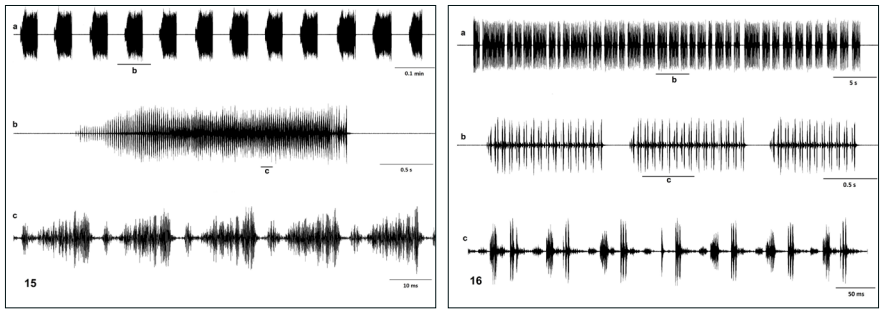


Figure 15-16. 15) Male calling song of *Tettigonia caudata* (Charpentier, 1845). a) polysyllabic sequences, b) a complete plysyllabic sequence, c) number of syllables in 100 ms; 16) Male calling song of *Tettigonia viridissima* (Linnaeus, 1758). a) calling song (polysyllabic phrase sequences), b) three complete phrases, c) seven complete syllables.

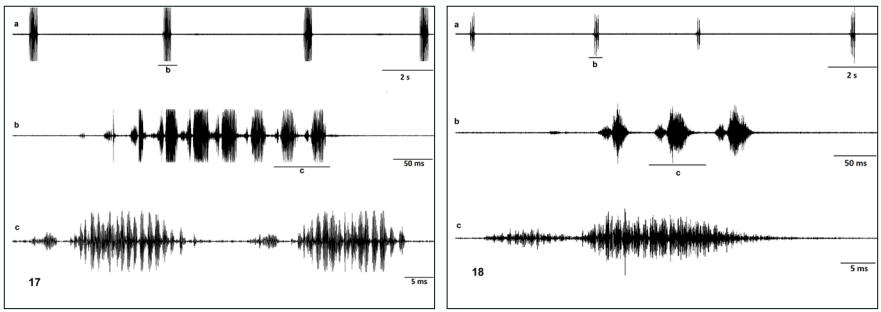


Figure 17-18. 17) Male calling song of *Uvarovistia satunini* (Uvarov, 1916). a) repeated syllables groups, b) a complete syllable group (octal), c) two complete syllables; 18) Male calling song of *Uvarovistia zebra* (Uvarov, 1916). a) repeated syllables groups, b) a complete syllable group (octal), c) a complete syllable and elements.

## CONCLUSIONS AND DISCUSSION

In this paper, the bioacoustic evaluation of the male calling songs of sixteen species of Tettigoniidae family belonging to five subfamilies (ten species of Tettigoniinae, three species of Phaneropterinae and one species of each of Bradyporinae, Conocephalinae and Saginae subfamilies) distributed in Hakkari province was carried out. Among the sixteen tettigoniid species distributed in Hakkari, six of them are Anatolian endemic (*Saga hakkarica*, *Psorodonotus hakkari*, *Novadrymadusa karabagi*, *Pezodrymadusa indivisa*, *Squamiana supericola*, and *Kurdia uvarovi*), seven are sub-endemic or have restricted distribution to Anatolia (*Apholidoptera kurda*, *Bradyporus* (*Callimenus*) *latipes*, *Isophya hakkarica*, *Polysarcus zacharovi*, *Tettigonia armeniaca*, *Uvarovistia zebra* and *Uvarovistia satunini*) and three (*Conocephalus* (*Anisoptera*) *fuscus*, *Tettigonia caudata*, and *Tettigonia viridissima*) have a relative widespread distribution (Taylan et al, 2019; Sirin et al, 2019; Taylan et al, 2021).

Bioacoustic data of six species (*Bradyporus* (*Callimenus*) *latipes*, *Isophya hakkarica*, *Kurdia uvarovi*, *Novadrymadusa karabagi*, *Psorodonotus hakkari*, and *Squamiana supericola*) were presented for the first time in this study. Additionally, eight species (*Conocephalus fuscus*, *Pezodrymadusa indivisa*, *Polysarcus zacharovi*, *Tettigonia armeniaca*, *Tettigonia caudata*, *Tettigonia viridissima* and *Uvarovistia satunini*) were examined the first time from Hakkari province. On the other hand, male calling song analyses of three other tettigoniid species (*Apholidoptera kurda*, *Saga hakkarica*, and *Uvarovistia zebra*) distributed in Hakkari were re-evaluated in this study.

The genus *Bradyporus* Charpentier, 1825, is represented by 11 species in Anatolia (Ünal, 2011a; Cigliano et al, 2022). Among these species, song descriptions of *B*. (*Callimenus*) *avanos* Ünal, 2011, *B*. (*Callimenus*) *dilalatus* (Stål, 1875), *B*. (*Bradyporus*) *dasypus* (Illiger, 1800), *B*. (*Callimenus*) *toros* Ünal, 2011, and *B*. (*Callimenus*) *conophallus* Ünal, 2011 were given in previous studies (Heller, 1988; Şirin et al, 2014; Taylan et al, 2019). However, interspecies bioacoustic comparisons only have been examined by Taylan et al, (2019) and they noted that *B*. *avanos*, *B. toros*, and

*B. conophallus* have species-specific calling song characters, with differences in syllable period. According to bioacoustic analysis of *B. latipes*, it was determined that the species produced a simple calling song, similar to other species belonging to the genus *Bradyporus* in general song structure but differed from other species in terms of syllable duration and number of syllables/100 ms. *B. latipes* has a longer calling song structure than other species in terms of syllable duration. In species *B. latipes*, the syllable duration varies between 58-119 ms, while the number of syllables/100 ms is 2. When these values are compared with *B. avanos* (syllable duration: 21-28, syllables number in 100 ms: 4), *B. toros* (syllable duration: 16-19, syllable number in 100 ms: 6-7), and *B. conophallus* species (syllable duration: 11-16, syllables number in 100 ms: 7-8), we identified that *B. latipes* produces species-specific songs.

The genus *Isophya* Brunner von Wattenwyl, 1878, is represented by 45 species/subspecies in Turkey (Sevgili, 2004; Ünal, 2011a; Cigliano et al, 2022). Sevgili (2004), divided the genus *Isophya* into six species groups in a morphological and bioacoustics-based comprehensive study of the Anatolian members of the genus. Sevgili (2004), performed a bioacoustic analysis of *I. hakkarica*, (a species which was examined in the present work), and placed it together with *I. schneideri* Brunner von Wattenwyl, 1878, *I. acrita* (as sp.n) and *I. acuminata* Brunner von Wattenwyl, 1878, species in the *schneideri*-subgroup of the *rectipennis*-species group. However, Ünal (2010) examined *I. hakkarica*, together with *I. schneideri*, *I. sikorai* Ramme, 1951, *I. karabaghi* Uvarov, 1940, *I. cania* Karabag, 1975 and *I. thracica* Karabag, 1962, species within the *schneideri*-species group in a morphological-based study. On the other hand, *I. iraca* Maran, 1977, which is geographically closest to *I. hakkarica*, was noted as a synonym of *I. hakkarica* in Taylan et al, (2021). Zhantiev, Korsunovskaya & Benediktov, (2017) examined some *Isophya* species in Eastern Europe, the Caucasus, and surrounding countries and in their bioacoustics-based study, the male calling song description of *I. schneideri* from the *schneideri*-species group was presented. When the bioacoustics of *I. hakkarica* is compared with *I. schneideri*, it is seen that both species have similar song pattern and the calling song of both species have simple calling song structure consisting of two syllables of different duration and type. However, while the short and high amplitude first syllable duration in *I. hakkarica* ranged between 242 and 302 ms (297.38 ± 29.15 ms), this duration was 239.3 ms in *I. schneideri* species. The second syllable, which is long and has low amplitude, has duration of 1.224-1.255 s (1.238 ± 0.18 s) in *I. hakkarica*, while ranged between 600-1100 ms in *I. schneideri*. Therefore, although the general song pattern of these two species is similar, it has been determined that the syllables differ in terms of duration.

The genus *Kurdia* Uvarov, 1916, belongs to the Phaneropterinae subfamily and Barbitistini tribe and is represented by two species in the world. Among these species, *Kurdia nesterovi* Uvarov, 1916, is very restricted to North Iraq, while *Kurdia uvarovi* Karabağ, 1975 is endemic to Hakkari province in Anatolia (Karabağ, 1975; Taylan et al, 2021). Since the male calling song of the *Kurdia nesterovi* was not defined, the male calling song of the *Kurdia uvarovi* could not be compared within the genus. However, the male calling song of *Kurdia uvarovi* consists of regularly spaced double or triple

(rarely single) isolated syllable groups. On the other hand, the song structure of this species shows similarity to some species of the *Leptophyes* Fieber, 1853 (especially *L. sicula*) and *Isophya* (especially *I. brunneri* Retowski, 1888) genera in the tribe Barbitistini (Kleukers, Odé, & Fontana, 2010; Zhantiev et al, 2017).

*Novadrymadusa* Demirsoy, Salman & Sevgili, 2002, genus belongs to the subfamily Tettigoniinae and tribe of Drymadusini, and is distributed only in Iran and Anatolia (Ramme, 1939; Demirsoy et al, 2002). One of the species belonging to the genus, *Novadrymadusa kurda* (Uvarov, 1930), has not yet been studied bioacoustically. The other species of the genus, *Novadrymadusa karabagi* is endemic to Hakkari and Şırnak provinces in Anatolia. Since the other species of the genus could not be examined bioacoustically, an intra-genus evaluation could not be presented here. However, bioacoustic analyses show that *Novadrymadusa karabagi* has a simple calling song structure and the male calling song consists of phrases consisting of the polysyllabic sequences. It has been determined that the duration of the polysyllabic sequence varies between 8-78 s (28 ± 11.25 s) and 10-11 syllables are produced in 100 ms. Furthermore, it is structurally similar to *Lithodusa helverseni* Heller, 2009, which calling song structure and descriptions are known in the same tribe (Heller, & Korsunovskaya, 2009).

The genus *Psorodonotus* Brunner von Wattenwyl, 1861 is known with 13 species from Anatolia and 10 of these species are endemic or sub-endemic to Anatolia (Ünal, 2011a; Taylan et al, 2019; Cigliano et al, 2022). In previous studies, it has been noted that species within the genus (*P. caucasicus* (Fischer von Waldheim, 1846), *P. suphani* Taylan & Şirin, 2014, *P. davisi* Karabag, 1957, *P. ebneri* Karabag, 1952, and *P. rugulosus* Karabag, 1952) have species-specific calling song structures (Şirin et al, 2014, Taylan et al, 2019). The male calling song of the *P. hakkari* Kaya, Korkmaz & Çıplak, 2013, consists of regularly spaced syllables, with an interval of 320–495 ms (404 ± 28.25 ms) between syllables. The syllable duration varies between 78-102 ms (90.23 ± 7.65 ms). As a result of oscillographic analysis, it was seen that each syllable consisted of five elements (short + short + high + short + high) and with this structure, it is similar to the *P. davisi*. However, it is also distinguished from this species and other species in the genus in terms of duration (Şirin et al, 2014; Taylan et al, 2019).

There are nine species belonging to the genus *Squamiana* Zeuner, 1941, and among these species, the calling song description of *S. kurmana* (Ramme, 1951) has been obtained by Taylan et al, (2019). The calling song of the *S. supericola* (Ünal, 2018) species was given in this study and differences were determined in terms of structure and duration with *S. kurmana* species (Taylan et al, 2019). In *S. supericola*, the male calling song is in a crescendo structure, consisting of polysyllabic sequences, pulses in syllables cannot be distinguished, and the number of syllables in 100 ms was determined as 6-8 (7.14 ± 0.65). On the other hand, in *S. kurmana*, the male calling song consists of regular phrases. The syllable structure consists of two distinguishable parts and the calling song contains only one syllable in 100 ms (Taylan et al, 2019). In this context, it is observed that the male calling song has a simple song structure and is species-specific within the genus.

Furthermore, although calling song descriptions were noted before, the male calling song of the *Conocephalus* (*Anisoptera*) *fuscus*, *Pezodrymadusa indivisa*, *Polysarcus zacharovi*, *Tettigonia armeniaca, Tettigonia caudata*, *Tettigonia viridissima* and *Uvarovistia satunini* species, which were recorded for the first time in Hakkari province, were examined oscillographically and it was observed that Hakkari populations of these species (except *Polysarcus zacharovi* species) were similar to the populations given from other provinces in terms of calling song structure and characters of male calling song.

The genus *Polysarcus* Fieber, 1853, generally produces a complex song and it was previously given from the *P. zigana* Ünal & Chobanov, 2013, and the Erzurum population of the *P. zacharovi* species (Heller, 1988; Korsunovskaya, 2008; Taylan et al, 2019). However, in our study, distinct bioacoustic differences were detected between the Hakkari population of *P. zacharovi* and other populations. Hakkari population of *P. zacharovi* species does not produce complex calling song but produces simple song structures. The male calling song in this population consists of isolated syllables, and oscillographic analyses show that a syllable is usually composed of one element. On the other hand, when the male calling song recording of Jafari et al, (2015), the *P. denticauda* (Charpentier, 1825) species from Iran is examined, it is seen that this song is not complex, but consists of polysyllabic sequences. Therefore, the male call song of the Iranian population of this species is more similar to the song structure of the Hakkari population of the *P. zacharovi*. Taylan et al, (2021) noted some morphological differences between Hakkari population and the type of P*. zacharovi*. To clarify the taxonomic status of the Hakkari population, a phylogenetic evaluation is required in which the Erzurum population of *P. zacharovi*, Iran population of *P. denticauda* species and Giresun population of *P. zigana* species will be considered together. However, it should not be ignored that (i) the difference in the male calling song of the Hakkari population of *P. zacharovi* may also be due to the inability to record the complete calling song, (ii) or the signal given in the article may be a signal of protest, which is also emitted by katydids of the genus *Polysarcus* (Korsunovskaya, 2008: Zhantiev & Korsunovskaya, 2015) or (iii) this population belongs to a new species. However, it was observed that all three calling songs recorded from single males at different times had a simple song structure.

Additionally, when the current bioacoustic data of *Apholidoptera kurda*, *Saga hakkarica*, and *Uvarovistia zebra* species whose Hakkari population male calling songs were re-evaluated, it was discovered that they were similar to the original song description (Şirin et al, 2019; Taylan et al, 2019). Otherwise, a shorter phrase duration (253 ms) was noted in the phrase duration of the current population of *Saga hakkarica*.

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## CONFLICT OF INTEREST DISCLOSURE

There is no conflict of interest.

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