

An insight into the bioacoustics of some anurans of Meghalaya, India (Amphibia: Anura)

Holiness Warjri¹, Jayaditya Purkayastha², Madhurima Das^{1*}

Abstract - This paper presents an analysis of the temporal and spectral acoustic variables of nine anuran species across six families living in Meghalaya. The species accounted for in the study include the Jerdon's tree frog *Hyla annectans*, Long-tongued Forest Frog *Hylarana leptoglossa*, Northern Pointed-Snout Frog *Clinotarsus alticola*, Mymensingh Chorus Frog *Microhyla mymensinghensis*, Beautiful Painted Frog *Kaloula pulchra*, Double-spotted Oranged Webbed Tree Frog *Rhacophorus bipunctatus*, Shillong Bush Frog *Raorchestes shillongensis*, Pierrei Cricket Frog *Minervarya pierrei*, and Smith's Litter Toad *Leptobrachium smithi*. For four out of nine species (*Hylarana leptoglossa*, *Clinotarsus alticola*, *Microhyla mymensinghensis*, and *Rhacophorus bipunctatus*), this is the first account of their calls; the remnant five recordings add considerable knowledge to the species' acoustic variability. This study opens up potential benefits for taxonomy, ecology, and conservation.

Key words: conservation, frog, Khasi Hills, taxonomy.

Riassunto - Un contributo sulla bioacustica di alcuni anuri di Meghalaya, India (Amphibia: Anura).

Questo lavoro presenta un'analisi delle variabili acustiche temporali e spettrali di nove specie di anuri di sei famiglie residenti in Meghalaya. Le specie prese in considerazione nello studio includono *Hyla annectans*, *Hylarana leptoglossa*, *Clinotarsus alticola*, *Microhyla mymensinghensis*, *Kaloula pulchra*, *Rhacophorus bipunctatus*, *Raorchestes shillongensis*, *Minervarya pierrei* e *Leptobrachium smithi*. Per quattro delle nove specie (*Hylarana leptoglossa*, *Clinotarsus alticola*, *Microhyla mymensinghensis* e *Rhacophorus bipunctatus*) si tratta della prima registrazione dei richiami: le cinque registrazioni rimanenti aggiungono notevoli conoscenze sulla variabilità acustica delle specie. Questo studio fornisce potenziali vantaggi per la tassonomia, l'ecologia e la conservazione.

Parole chiave: conservazione, rana, Khasi Hills, tassonomia.

INTRODUCTION

The study of anuran amphibians is made possible in large part by the use of bioacoustics (Thomas *et al.*, 2014). Given the importance of acoustic in the breeding of most anurans (Valetti *et al.*, 2013), assessing the acoustic signals helps understand their social behavior and reproduction (Bee *et al.*, 2010). In addition to the morphological and molecular data, acoustic data are increasingly used in the taxonomy of anuran amphibians (Roy & Elepfandt, 1993; Padial & De la Riva, 2009; Köhler *et al.*, 2017). Anuran species identification can be made through auditory analysis since the anuran mating calls are species-specific and serve to entice females of the same species (Hödl, 1977). Bioacoustics also helps in the study of ecology and conservation biology as acoustic data can be utilized as a non-intrusive approach for population surveys (Roy & Elepfandt, 1993; Thomas *et al.*, 2014). Understanding the anuran acoustics will help to assess the harmful effects of the anthropogenic noise that will affect the anuran reproduction and therefore their population (Sun & Narins, 2005; Bee & Swanson, 2007). Therefore, the use of bioacoustics is of primary importance in the development of conservation actions.

This study aims to provide the acoustical and statistical analysis of the calls of nine anurans of Meghalaya.

MATERIALS AND METHODS

Study site

Meghalaya (25.631388 N, 91.872499 E), having an area of 22,429 km², is a part of the Indo-Myanmar Biodiversity hotspot. The state's diverse physiological characteristics give rise to a range of climates, from the near tropical to the temperate to the alpine, which enhances species diversity (Meghalaya State Climate Change Action Plan, 2017). Meghalaya experiences pre-monsoon from April to May and monsoon from June to October. Throughout the year, the state receives abundant rainfall due to the Southwest monsoon. The average yearly precipitation is 1150 cm, and the average minimum and maximum temperatures are 5 °C and 33 °C, respectively (Tripathi *et al.*, 2010). The vegetation consists of subtropical broadleaved hill forests, tropical moist deciduous forests, tropical wet evergreen forests, grasslands and savannahs, and subtropical pine forests (Roy & Tomar, 2001).

The study was done in four locations namely, Langtor (25.535060 N, 91.583314 E, 1740 m asl), Wahlong Byrong

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(25.193216 N, 91.720320 E, 380 m asl), Shillong (25.572676 N, 91.887979 E, 1520 m asl) and Williamnagar (25.531390 N, 90.592003 E, 280 m asl). Most of the call and breeding activities take place during the pre-monsoon season.

Field survey

The study was conducted from July 2022 to October 2023 using randomized walks (Lambert, 1984) and visual encounter surveys (Heyer *et al.*, 2014) on different sites during the evening from around 15:00 h to 23:00 h. An

average of eight man hours was invested during each survey and a total of 42 surveys were undertaken during the study period. Various ecosystems were investigated, including woods, rocky streams, marshy places, and temporary ponds (Fig. 1). By paying attention to the male frogs' calls, the frogs were located and recorded. The samples were either hand-picked or net-captured. The frogs were photo-documented using Canon EOS M50 Mark II. Collected frogs were euthanized using lignocaine (2%), preserved in a 10% formaldehyde solution, and deposited in the Assam Don Bosco University. Mor-



Fig. 1 – Amphibian habitats mentioned in the text: A,B) rocky streams; C,D) woodland; E,F) marshy areas. / Habitat degli anfibii citati nel testo: A,B) ruscelli con rocce; C,D) aree boschive; E,F) aree palustri.

phometric measurements were done using a Mitutoyo vernier calliper. The location was determined by Garmin eTrex 10x GPS. Geographical coordinates, elevation, date, time, and temperature are among the variables that were noted during on-site data collecting.

Bioacoustics recording and analyses

The calls were recorded in real-time using BOYA BY-DMR7 unidirectional handheld microphones (WAV format, 24-bit) and SONY ICD-PX470 Stereo digital voice recorders (mp3 format, 256 kbps) between 15:00 h and 23:00 h. The distance between the recording equipment and the calling males was kept between 30 and 50 cm, and the recording levels were adjusted before each recording (Prasad *et al.* 2020).

The acoustic properties of the nine species were analysed using Raven Pro 1.6. For calls, we analysed the temporal variables like the number of notes per call, note duration, duration of the silent interval between notes, call duration, duration of the silent intervals between the calls, call repetition rate, pulses per call, and pulse rate. The spectral variables include the dominant frequency. The definitions of acoustic properties were taken following Köhler *et al.* (2017) and Thomas *et al.* (2014) (Tab. 1). Descriptive statistics like mean, standard deviation, range, and coefficient of variance were computed using Microsoft Excel 2010.

RESULTS

In this study, calls from nine species of anurans belonging to six families were recorded and used for bioacoustics analysis and the database spectrogram, waveforms, and power spectrum were generated. The sampling habitats and the anuran species accounted for in the study are shown in Figs. 1 and 2.

Family Hylidae

Hyla annectans (Jerdon 1870)

(Indian Snout Frog: Fig. 2A)

Adult male SVL is 40.10 mm (n=1). We analysed 16 advertisement calls. The calls were recorded between 16:00 h to 18:30 h on July 2023 in Langtor (25.535060 N, 91.583314 E). The ambient air temperature was 19-22 °C and the relative humidity was 94-98%. Calling males produced calls on the grassland near the forest.

Advertisement calls

(Fig. 3, Tab. 2)

A typical advertisement call has 46 calls per minute and a mean call duration of 0.30 ± 0.02 s, a mean inter-call interval of 0.29 s, and an average call repetition rate of 3.42 calls/m. There is only one note per call and the mean duration of the note is 0.30 s, the mean inter-note interval is 0.29 s. There are an average of 42.56 pulses per call and a mean pulse rate of 254.18 pulses/s. The mean dominant frequency of the call is 3.05 ± 0.09 kHz (3.00-3.38 kHz) and the coefficient of variance is 0.003.

Note: Shangpliang *et al.* (2023) reported a call of *H. annectans* from Mawsynram (25.29745 N, 91.58512 E, 1424 m asl.), Meghalaya. The study only recorded three parameters, number of pulses, call duration, and dominant frequency. The result of Shangpliang *et al.* (2023) mostly matches our result except for the number of pulses mentioned as 19-20 vs. 38-48 in this study.

Family Ranidae

Hylarana leptoglossa (Cope 1868)

(Long-tongued Forest Frog: Fig. 2B)

Adult male SVL is 49 mm (n=1). We analysed 9 advertisement calls. The calls were recorded between 18:25 h to 21:00 h on August 2023 in Wahlong Byrong (25.193216 N, 91.720320 E). The ambient air temperature was 23-27 °C

Tab. 1 – Definitions of the bioacoustic parameters used. / Definizione dei parametri bioacustici utilizzati.

Acoustic parameters	Descriptions
Calls	A vocalization pattern made by frogs, a distinctive noise. A period of silence separated the two calls.
Call duration (s)	The time span between a call's first pulse and last pulse offset.
Inter-call interval (s)	The time span between two consecutive calls, calculated from the end of the first call to the start of the next.
Note	A call's primary component. It can be further split into pulses.
Note duration (s)	The time span between the notes in a call, calculated from the start to the end of the note.
Call repetition rate (calls/min)	Calls made during a specific time period. It can be calculated as the reciprocal of the call period.
Inter-note interval(s)	The time span between two consecutive notes.
Pulse	A single uninterrupted wave train that has been physically segregated in time by a considerable amplitude reduction.
Pulses per call (k)	The number of pulses in a call, expressed in k.
Pulse rate (pulses/s)	The time between the first and last pulse's onset is divided by the number of pulses per call (k) minus 1 (<i>i.e.</i> , $k - 1$).
Dominant frequency (Hz)	The peak frequency of a call or note, or the frequency with the greatest amount of sound energy.

and the relative humidity was 95-99%. The calls were heard from small muddy ponds and marshy areas.

Advertisement calls (Fig. 4, Tab. 2)

The advertisement call we worked with has 9 calls per minute and a mean call duration of 0.87 ± 0.74 s, a mean inter-call interval of 5.19 s, and an average call repetition rate of 1.18 calls/m. The average number of notes per call is 7.00 and the average duration of the note is 0.05 s, the mean inter-note interval is 0.08 s. There are an average of 7 pulses per call and a mean pulse rate of 6.41 pulses/s. The mean dominant frequency of the call is 2.23 ± 0.22 kHz (1.97-2.63 kHz) and the coefficient of variance is 0.01.

Note: this is the first description of the calls of this species. No other records have been found in the literature or in sound repositories.

Clinotarsus alticola (Boulenger 1882)

(Northern Pointed-Snout Frog: Fig. 2C)

Adult male SVL is 35.79 mm (n=2). A total of 20 advertisement calls were analysed. The calls were recorded from ponds and large streams in Langtor (25.535060 N, 91.583314 E) between 15:20 h to 20:45 h in June and July 2023. The ambient air temperature was 18-23 °C and the relative humidity was 95-99%.

Advertisement calls (Fig. 5, Tab. 2)

The advertisement call has 55 calls per minute and a mean call duration of 0.19 ± 0.19 s, a mean inter-call interval of 0.67 s, and an average call repetition rate of 5.05 calls/m. The call we worked with has a 1.95 average number of notes per call and the average duration of the note is 0.06 s, the mean inter-note interval is 0.59 s. There are an average of 4.05 pulses per call and a mean pulse rate of 22.52 pulses/s. The mean dominant frequency of the call is 1.50 ± 0.53 kHz (0.94-2.72 kHz) and the coefficient of variance is 0.04.

Note: this is the first description of the calls of this species. No other records have been found in the literature or in sound repositories.

Family Microhylidae

Microhyla mymensinghensis Hasan, Islam, Kuramoto, Kurabayashi & Sumida 2014

(Mymensingh Chorus Frog: Fig. 2D)

Adult male SVL is 21.23 mm (n=2). We analysed 20 advertisement calls. The calls were recorded between 18:00 h to 23:00 h in June, July, and August 2023 in Williamnagar (25.531390 N, 90.592003 E). The ambient air temperature was 23-28 °C and the relative humidity was 96-99%. The calls were heard from swampy areas and small grasslands.



Fig. 2 – Anurans species for which acoustic analysis was performed. / Specie di anuri per cui è stata eseguita l'analisi acustica. A) *Hyla annectans*; B) *Hylarana leptoglossa*; C) *Clinotarsus alticola*; D) *Microhyla mymensinghensis*; E) *Kaloula pulchra*; F) *Rhacophorus bipunctatus*; G) *Raorchestes shillongensis*; H) *Minervarya pierrei*; I) *Leptobrachium smithi*.

Advertisement calls (Fig. 6, Tab. 2)

The advertisement call we worked with has 70 calls per minute, a mean call duration of 0.22 ± 0.02 s, a mean inter-call interval of 0.32 s, and an average call repetition rate of 4.69 calls/m. The average number of notes per call is 12.55 and the average duration of the note is 0.01 s, the mean inter-note interval is 0.01 s. The call we analysed has an average of 12.55 pulses per call and a mean pulse rate of 61.8 pulses/s. The mean dominant frequency of the call is 2.25 ± 0.04 kHz (2.16-2.34 kHz) and the coefficient of variance is 0.001.

Note: this is the first description of the calls of this species. No other records have been found in the literature or in sound repositories.

Kaloula pulchra Gray 1831

(Beautiful Painted Frog: Fig. 2E)

Adult male SVL is 65.64 mm (n=2). We recorded 20 advertisement calls. The calls were recorded between 18:00 h to 23:00 h in May, and June 2023 in Wahlong Byrong (25.193216 N, 91.720320 E). The ambient air temperature was 22-25 °C and the relative humidity was 95-97%. The calls were heard from temporary ponds and soaked pits for areca nut fermentation.

Advertisement calls

(Fig. 7, Tab. 2)

The advertisement call we analysed has 40 calls per minute, a mean call duration of 0.65 ± 0.12 s, a mean inter-call interval of 0.49 s, and an average call repetition rate of 1.61

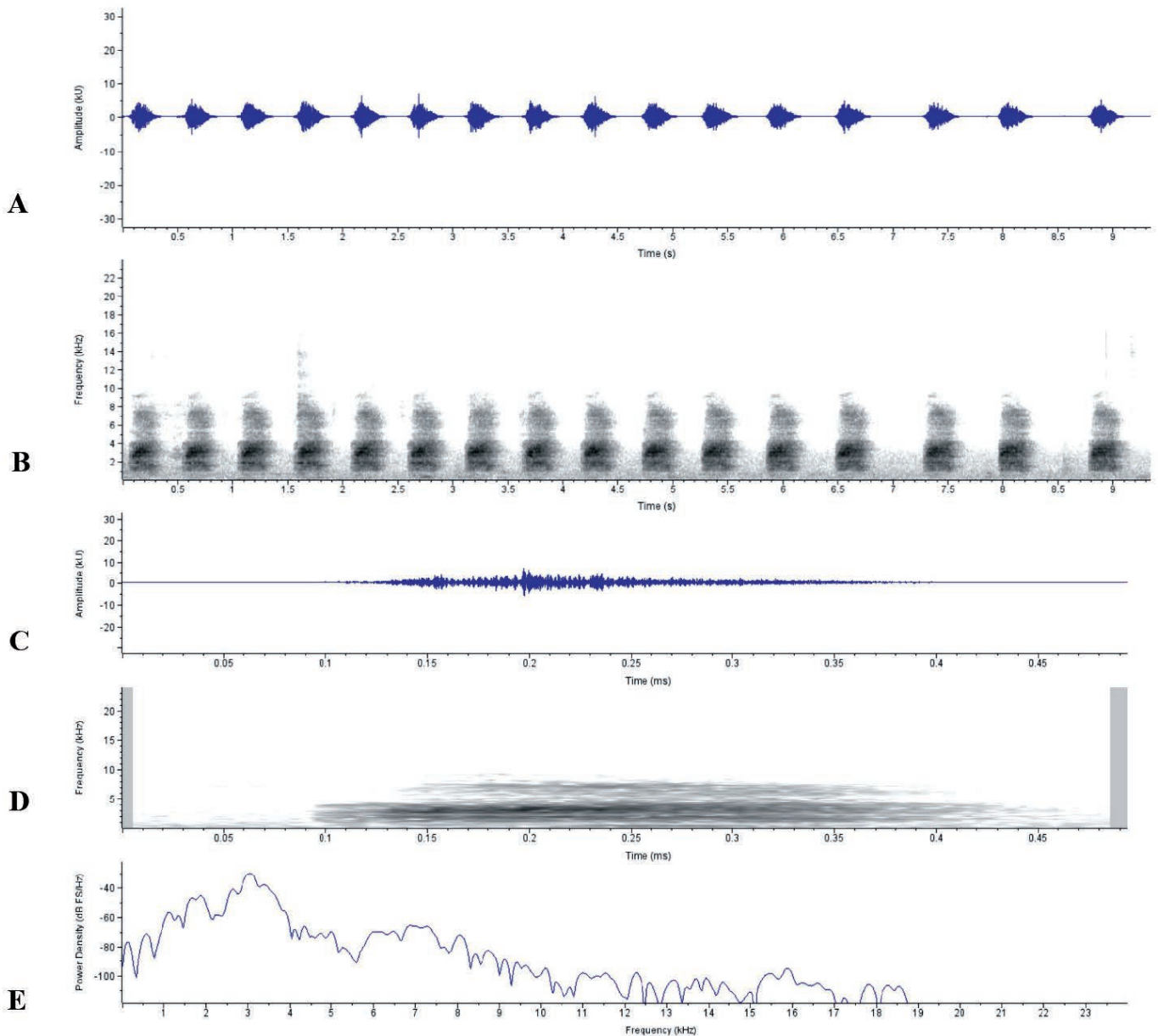


Fig. 3 – Advertisement calls of *Hyla annectans*. A,B) oscillogram, and spectrogram of few calls; C,D) oscillogram, and spectrogram of one note; E) power spectrum (Window type-Blackman, 3dB Filter Bandwidth-150 Hz). / Richiami di *Hyla annectans*. A,B) oscillogramma e spettrogramma di alcuni richiami; C,D) oscillogramma e spettrogramma di una nota; E) spettro di potenza (Window type-Blackman, 3dB Filter Bandwidth-150 Hz).

calls/m. The average number of notes per call is 1.00 with an average duration of the note of 0.65 s and a mean inter-note interval of 0.49 s. There is an average of 1 pulse per call and since only one pulse per call, the pulse rate cannot be determined. The mean dominant frequency of the call is 0.56 ± 0.44 kHz (0.28-1.31 kHz) and the coefficient of variation is 0.08.

Note: Kanamadi *et al.* (2002) reported the call characteristics of *Kaloula pulchra* in Dharwad (15.4500 N, 75.0833 E), taking into account several parameters, including the dominant frequency. They recorded a dominant frequency of 0.70 kHz, which is slightly higher than the 0.56 kHz observed in our findings.

Family Rhacophoridae

Rhacophorus bipunctatus Ahl 1927

(Double-spotted Oranged Webbed Tree Frog: Fig. 2F)

Adult male SVL is 40.29 mm (n=2). From the trees in the hilly forest areas in Wahlong Byrong (25.193216 N, 91.720320 E), advertisement calls were recorded and 10 were analysed. The calls were recorded between 18:00 h to 21:00 h in August 2023. The ambient air temperature was 22-27 °C and the relative humidity was 95-99%.

Advertisement calls

(Fig. 8, Tab. 2)

The typical advertisement call has 29 calls per minute,

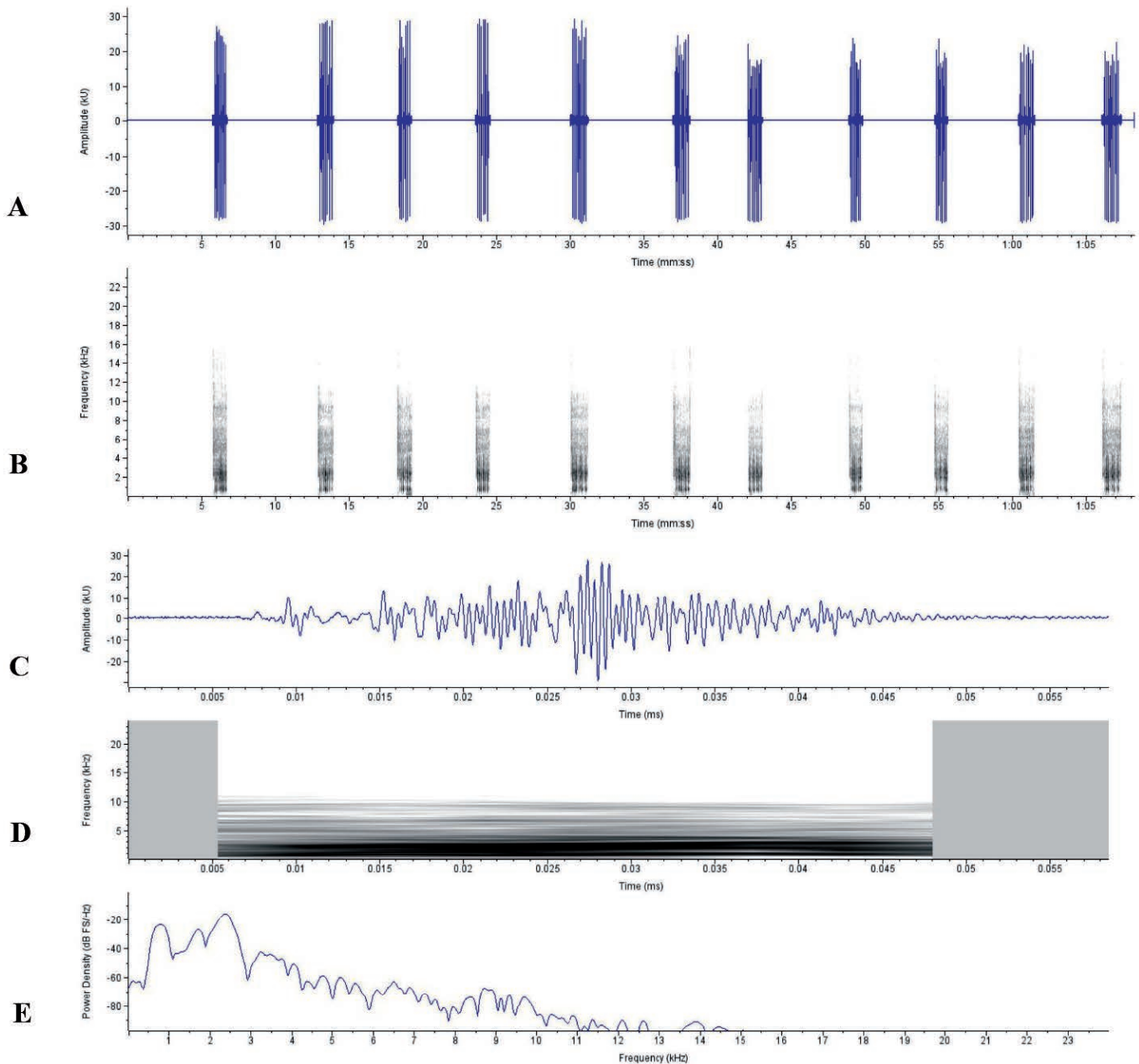


Fig. 4 – Advertisement calls of *Hylarana leptoglossa*. A,B) oscillogram, and spectrogram of few calls; C,D) oscillogram, and spectrogram of one note; E) power spectrum (Window type-Blackman, 3dB Filter Bandwidth-150 Hz). / Richiami di *Hylarana leptoglossa*. A,B) oscillogramma e spettrogramma di alcuni richiami; C,D) oscillogramma e spettrogramma di una nota; E) spettro di potenza (Window type-Blackman, 3dB Filter Bandwidth-150 Hz).

a mean call duration of 0.29 ± 0.05 s, a mean inter-call interval of 1.86 s, and an average call repetition rate of 3.51 calls/m. The average number of notes per call is 3.00. The average duration of the note is 0.06 s, and the mean inter-note interval is 0.03 s. There is no distinct pulse per call and therefore, the pulse rate cannot be determined. The mean dominant frequency of the call is 2.08 ± 0.04 kHz (2.03-2.16 kHz) and the coefficient of variance is 0.001.

Note: this is the first description of the calls of this species. No other records have been found in the literature or in sound repositories.

***Raorchestes shillongensis* (Pillai & Chanda 1973)**
(Shillong Bush Frog: Fig. 2G)

Adult male SVL is 22.43 mm (n=3). From the small bushes in and around human settlements in Shillong (25.572676 N, 91.887979 E) advertisement calls were heard. We analyzed 10 advertisement calls. The calls were recorded between 16:00 h to 23:00 h in June, and July 2023. The ambient air temperature was 18-23 °C and the relative humidity was 90-99%.

Advertisement calls

(Fig. 9, Tab. 2)

The advertisement call has 9 calls per minute and a mean call duration of 1.15 ± 0.40 s, a mean inter-call interval of 5.72 s, and an average call repetition rate of 0.96 calls/m. The average number of notes per call is 4.40 and

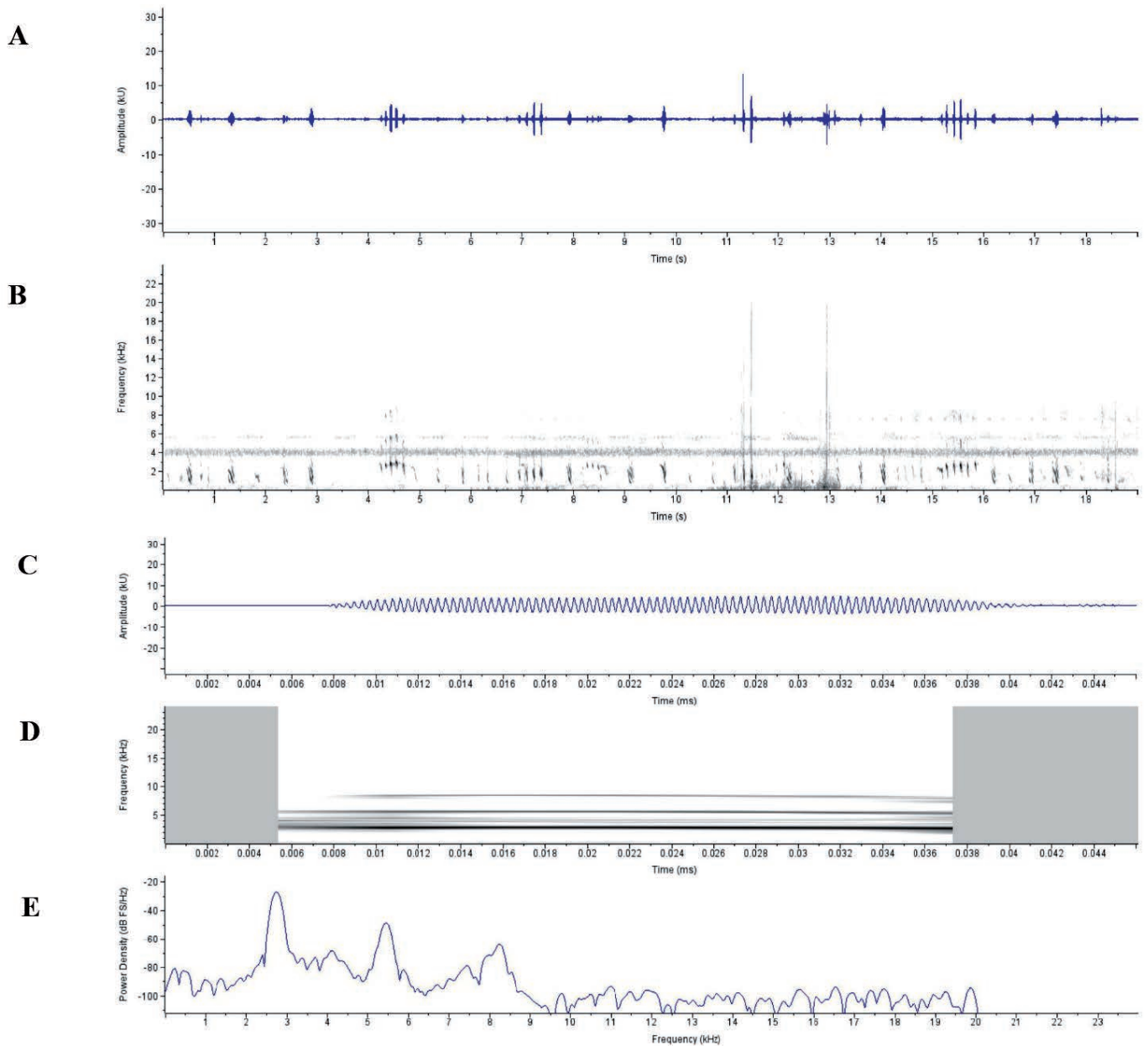


Fig. 5 – Advertisement calls of *Clinotarsus alticola*. A,B) oscillogram, and spectrogram of few calls; C,D) oscillogram, and spectrogram of one note; E) power spectrum (Window type-Blackman, 3dB Filter Bandwidth-150 Hz). / Richiami di *Clinotarsus alticola*. A,B) oscillogramma e spettrogramma di alcuni richiami; C,D) oscillogramma e spettrogramma di una nota; E) spettro di potenza (Window type-Blackman, 3dB Filter Bandwidth-150 Hz).

the average duration of the note is 0.03 s, the mean inter-note interval is 0.32 s. This call that we worked with has no distinct pulse per call and therefore, the pulse rate cannot be determined. The mean dominant frequency of the call is 3.87 ± 0.03 kHz (3.79-3.88 kHz) and the coefficient of variance is 0.007.

Note: Boruah *et al.* (2018) reported the call characteristics of *R. shillongensis* in Malki forest (25.562479 N, 91.888606 E), including a call duration of 22.62 seconds, which is significantly longer than the 1.15 seconds observed in our study. Additionally, they reported a dom-

inant frequency of 3.62 kHz, which is slightly lower than 3.87 kHz, the value we recorded in our findings.

Family Dicroglossidae
***Minervarya pierrei* (Dubois 1975)**
 (Pierre's Cricket Frog: Fig. 2H)

Adult male SVL is 41.47 mm (n=4). We measured 10 advertisement calls. The calls were recorded between 17:30 h to 23:00 h in May, June, and July 2023 in Langtor (25.535060 N, 91.583314 E). The ambient air temperature was 19-26 °C and the relative humidity was 92-98%. The

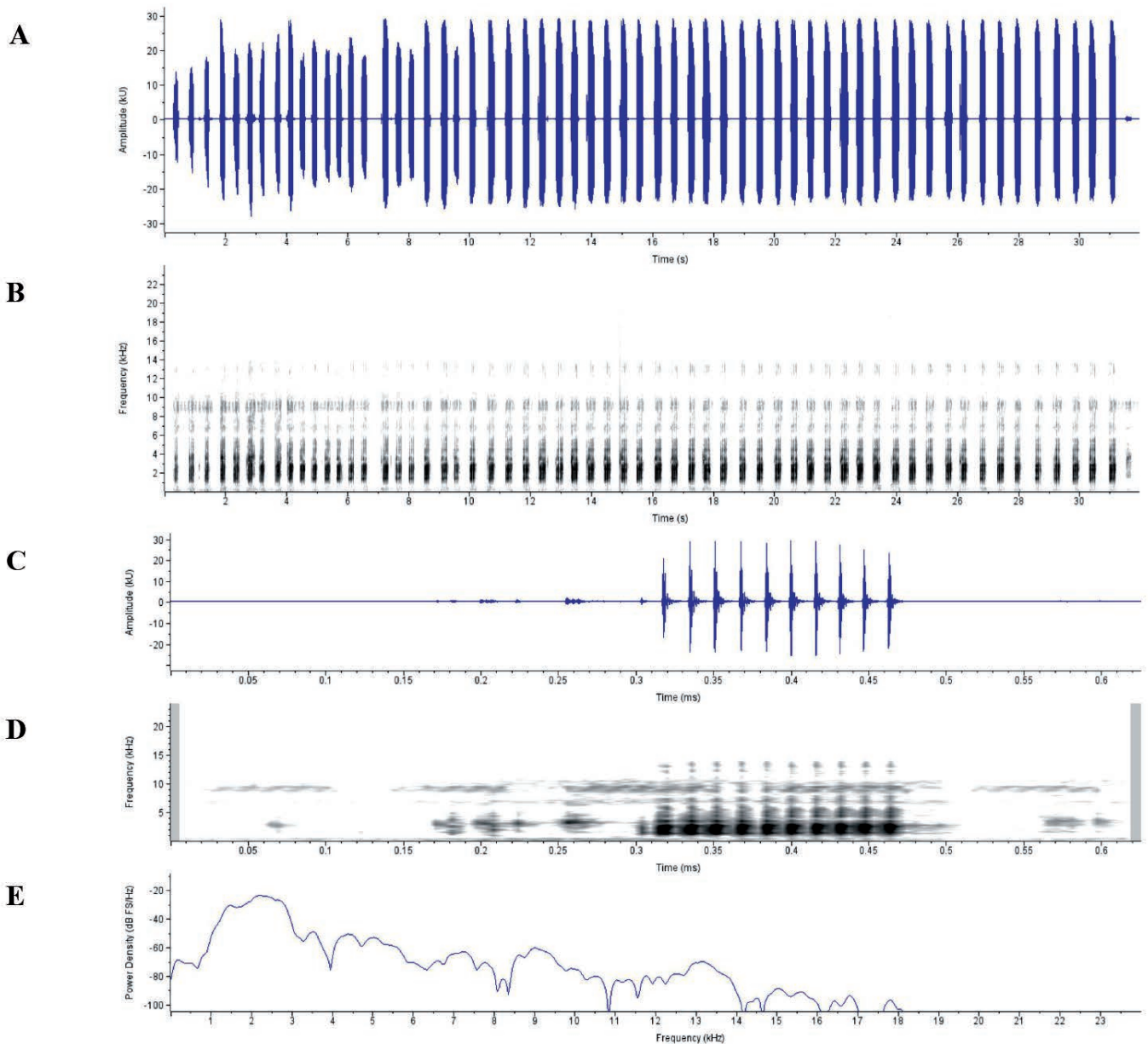


Fig. 6 – Advertisement calls of *Microhyla mymensinghensis*. A,B) oscillogram, and spectrogram of few calls; C,D) oscillogram, and spectrogram of one note; E) power spectrum (Window type-Blackman, 3dB Filter Bandwidth-150 Hz). / Richiami di *Microhyla mymensinghensis*. A,B) oscillogramma e spettrogramma di alcuni richiami; C,D) oscillogramma e spettrogramma di una nota; E) spettro di potenza (Window type-Blackman, 3dB Filter Bandwidth-150 Hz).

calls were heard mainly from the paddy field and marshy areas.

Advertisement calls (Fig. 10, Tab. 2)

The advertisement calls we analysed have 56 calls per minute and a mean call duration of 0.53 ± 0.09 s, a mean inter-call interval of 0.20 s, and an average call repetition rate of 1.94 calls/m. The average number of notes per call is 2.10 and the average duration of the note is 0.22 s, the mean inter-note interval is 0.08 s. There are an average of 44.70 pulses per call and a mean pulse rate of 93.02 pulses/s. The mean dominant frequency of the call is 3.63 ± 0.05 kHz (3.53-3.70 kHz) and the coefficient of variance is 0.001.

Note: Grosjean and Dubois (2011) reported the call characteristics of *Fejervarya pierrei* (= *M. pierrei*), including an inter-note interval duration of 0.092 s. However, in our study, we observed a slightly shorter inter-note interval of 0.08 s, which does not align with their findings.

Leptobrachium smithi Matsui, Nabhitabhata & Panha 1999

(Smith's Litter Frog, Fig. 2I)

Adult male SVL is 52.26 mm (n=2). Below the dead leaves on the forest floors in Wahlong Byrong (25.193216 N, 91.720320 E), advertisement calls were heard. We measured 5 advertisement calls. The calls were recorded between 17:50 to 23:00 hours in July 2023. The ambient

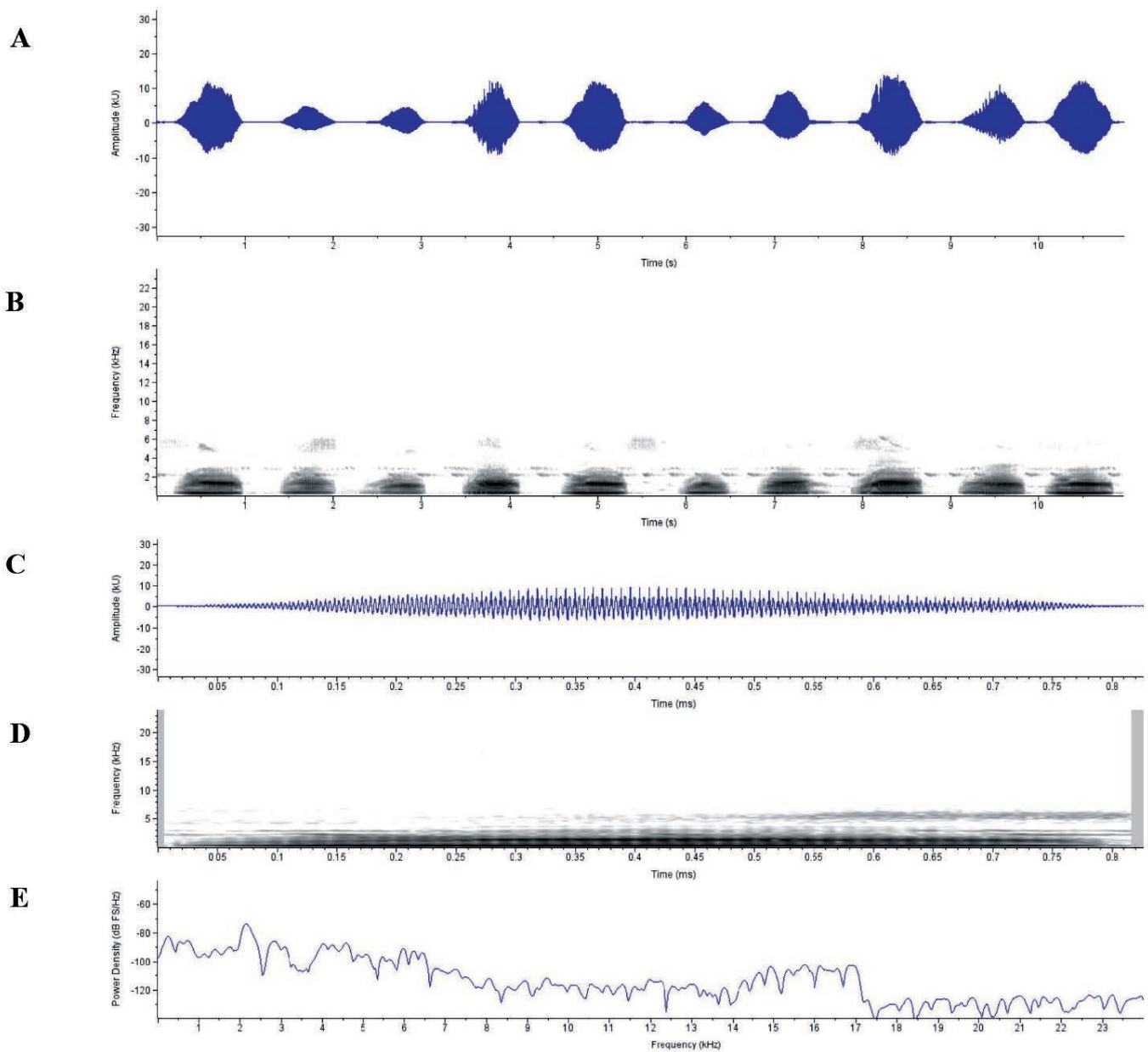


Fig. 7 – Advertisement calls of *Kaloula pulchra*. A,B) oscillogram, and spectrogram of few calls; C,D) oscillogram, and spectrogram of one note; E) power spectrum (Window type-Blackman, 3dB Filter Bandwidth-150 Hz). / Richiami di *Kaloula pulchra*. A,B) oscillogramma e spettrogramma di alcuni richiami; C,D) oscillogramma e spettrogramma di una nota; E) spettro di potenza (Window type-Blackman, 3dB Filter Bandwidth-150 Hz).

air temperature was 22-27 °C and the relative humidity was 92-99%.

Advertisement calls

(Fig. 11, Tab. 2)

The advertisement call has 10 calls per minute and a mean call duration of 0.88 ± 0.08 s, a mean inter-call interval of 3.95 s, and an average call repetition rate of 1.15 calls/m. The average number of notes per call is 7.40 and the average duration of the note is 0.06 s, the mean inter-note interval is 0.05 s. The call we worked with has no distinct pulse per call and therefore, the pulse rate cannot be determined. The mean dominant frequency of the call is

2.29 ± 0.34 kHz (1.98-2.67 kHz) and the coefficient of variance is 0.02.

Note: Ong and Shahrudin (2022) reported the call characteristics of *L. smithi* in Langkawi Island, Malaysia (6.3500 N, 99.8000 E) focusing on parameters such as dominant frequency and the number of notes per call. According to Ong and Shahrudin (2022), the dominant frequency was 1.10 kHz, which is lower than the 2.29 kHz frequency observed in our findings. Additionally, Ong and Shahrudin (2022) recorded an average of one note per call, significantly fewer than the 7.40 notes per call we observed. These discrepancies indicate that the two sets of findings are not aligned.

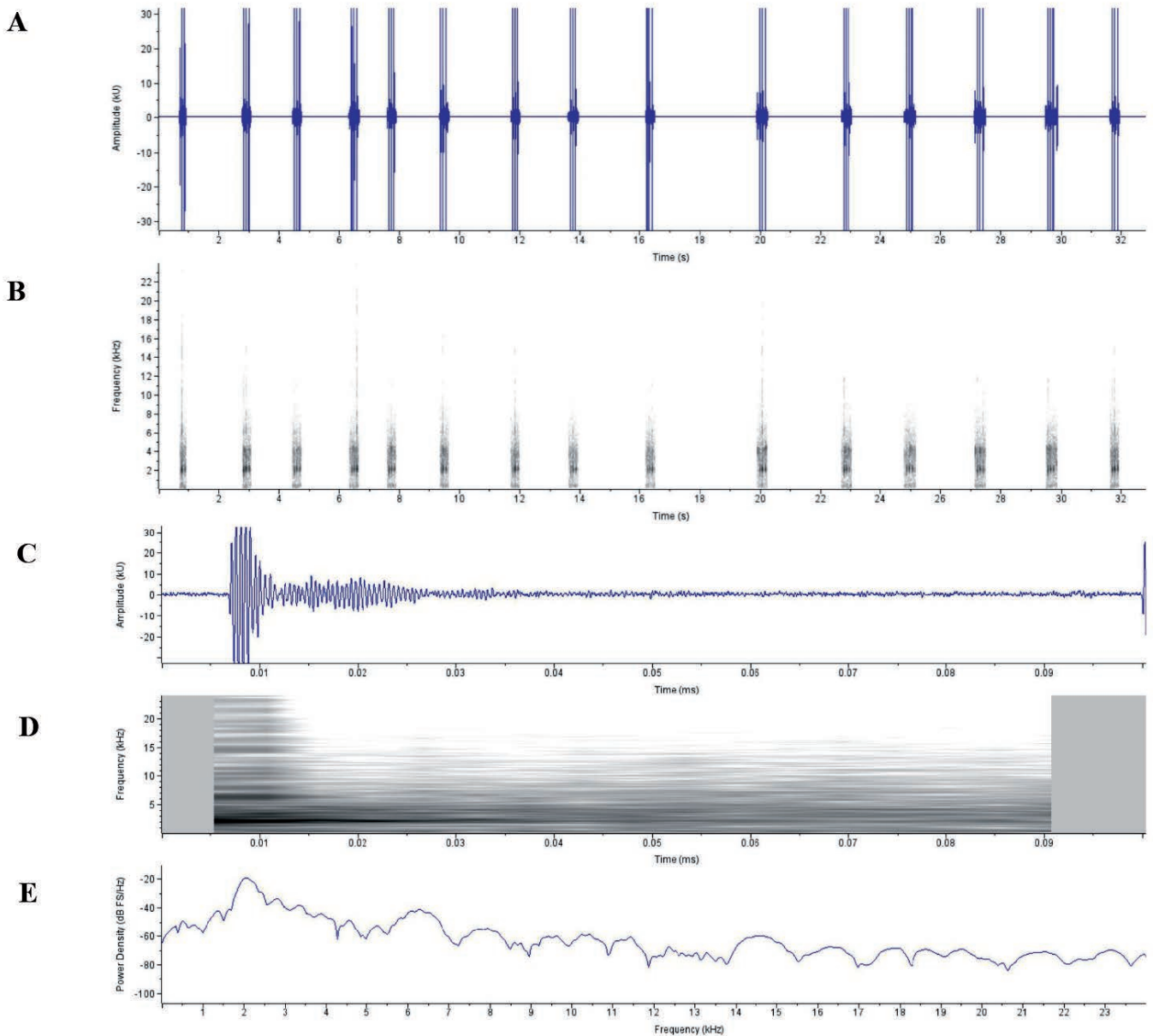


Fig. 8 – Advertisement calls of *Rhacophorus bipunctatus*. A,B) oscillogram, and spectrogram of few calls; C,D) oscillogram, and spectrogram of one note; E) power spectrum (Window type-Blackman, 3dB Filter Bandwidth-150 Hz). / Richiami di *Rhacophorus bipunctatus*. A,B) oscillogramma e spettrogramma di alcuni richiami; C,D) oscillogramma e spettrogramma di una nota; E: spettro di potenza (Window type-Blackman, 3dB Filter Bandwidth-150 Hz).

DISCUSSION AND CONCLUSIONS

The study conducted on nine species of anurans in Meghalaya provides valuable insights into their acoustic behaviour, contributing significantly to the understanding of their ecology, taxonomy, and conservation. Bioacoustics analysis has emerged as a powerful tool in studying anuran amphibians due to the species-specific nature of their calls and their importance in social behaviour, reproduction, and ecological interactions (Thomas *et al.*, 2014; Bee *et al.*, 2010). In this study, we conducted detailed analyses of the calls of nine anuran species from six families, shedding light on their acoustic properties and behavioural patterns.

The acoustic properties of anuran calls, including tem-

poral and spectral variables, serve as crucial indicators for species identification and classification (Roy & Elepfandt, 1993; Padial & De la Riva, 2009). Our findings reveal significant variations in call characteristics among the studied species, highlighting the uniqueness of each species' acoustic signature. For instance, *H. annectans* exhibited a relatively high call repetition rate and pulse rate compared to other species, with a dominant frequency of around 3 kHz. Conversely, species like *K. pulchra* displayed lower call repetition rates and pulse rates, accompanied by lower dominant frequencies.

The observed differences in call properties can be attributed to various factors, including species-specific mat-

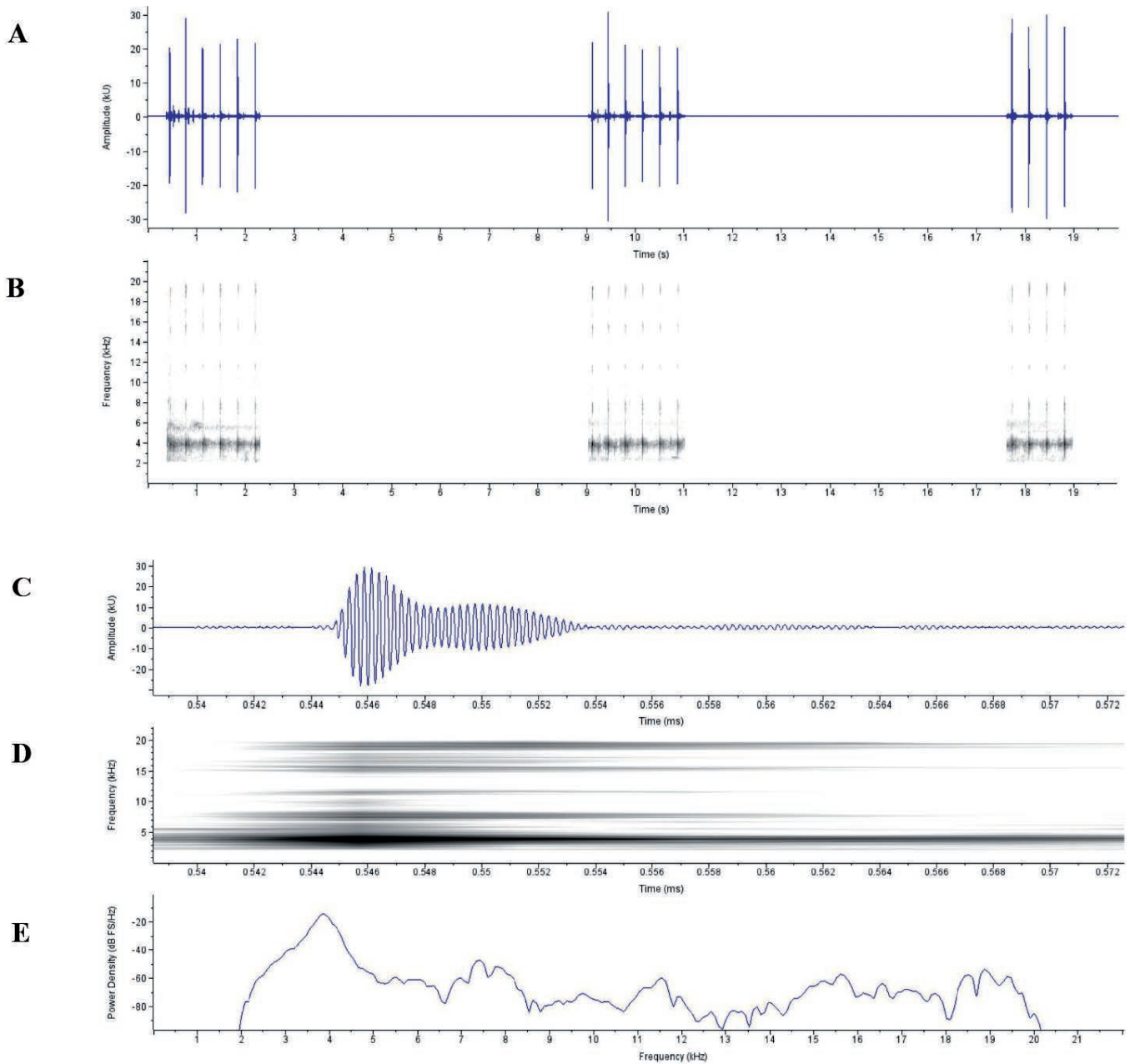


Fig. 9 – Advertisement calls of *Raorchestes shillongensis*. A,B) oscillogram, and spectrogram of few calls; C,D) oscillogram, and spectrogram of one note; E) power spectrum (Window type-Blackman, 3dB Filter Bandwidth-150 Hz). / Richiami di *Raorchestes shillongensis*. A,B) oscillogramma e spettrogramma di alcuni richiami; C,D) oscillogramma e spettrogramma di una nota; E) spettro di potenza (Window type-Blackman, 3dB Filter Bandwidth-150 Hz).

ing strategies, habitat preferences, and physiological constraints (Hödl, 1977). For example, species inhabiting open grasslands, such as *H. annectans*, may utilize high-frequency calls with rapid repetition rates to maximize communication efficiency in open environments with limited acoustic interference. On the other hand, species like *R. shillongensis*, found in densely vegetated areas, may rely on lower frequency calls with longer durations to enhance signal transmission through dense vegetation (Sun & Narins, 2005).

Beyond species identification and ecological insights,

our study has implications for conservation and management strategies. Anurans are particularly vulnerable to anthropogenic disturbances, including habitat loss, pollution, and noise pollution (Bee & Swanson, 2007). Anthropogenic noise can disrupt anuran communication networks, leading to decreased reproductive success and population declines (Sun & Narins, 2005). By providing baseline data on anuran acoustic behaviour, our study lays the groundwork for assessing the impacts of anthropogenic noise on local frog populations in Meghalaya.

In conclusion, our study underscores the importance of

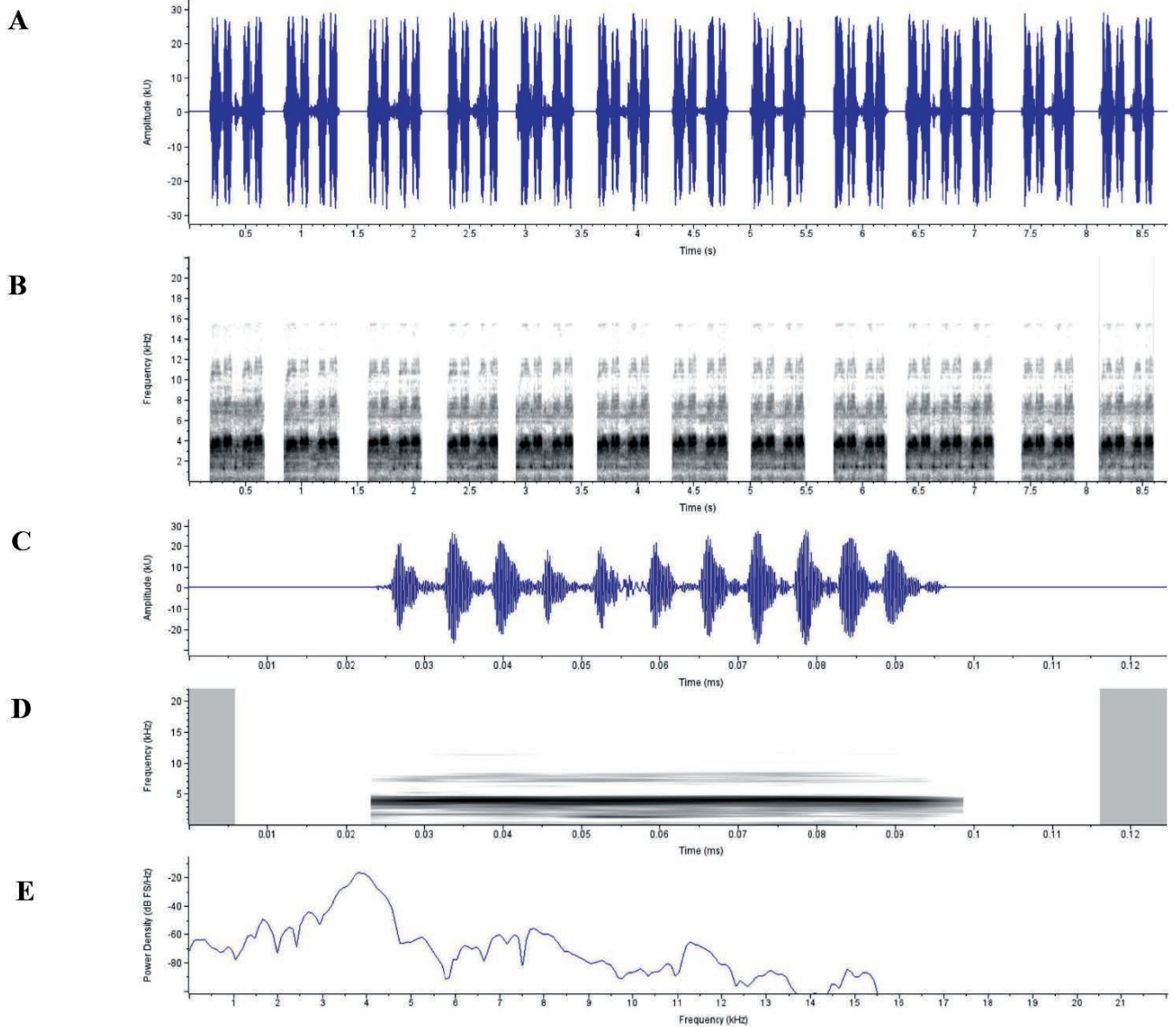


Fig. 10 – Advertisement calls of *Minervarya pierrei*. A,B) oscillogram, and spectrogram of few calls; C,D) oscillogram, and spectrogram of one note; E) power spectrum (Window type-Blackman, 3dB Filter Bandwidth-150 Hz). / Richiami di *Minervarya pierrei*. A,B) oscillogramma e spettrogramma di alcuni richiami; C,D) oscillogramma e spettrogramma di una nota; E) spettro di potenza (Window type-Blackman, 3dB Filter Bandwidth-150 Hz).

bioacoustics in understanding the ecology, taxonomy, and conservation of anuran amphibians. Through detailed analyses of call properties, we have elucidated the acoustic diversity among nine anuran species in Meghalaya, revealing species-specific adaptations to their environments. Moving forward, integrating bioacoustics monitoring into conservation efforts can aid in the assessment of anthropogenic impacts on anuran populations and inform targeted conservation interventions to mitigate threats and preserve biodiversity.

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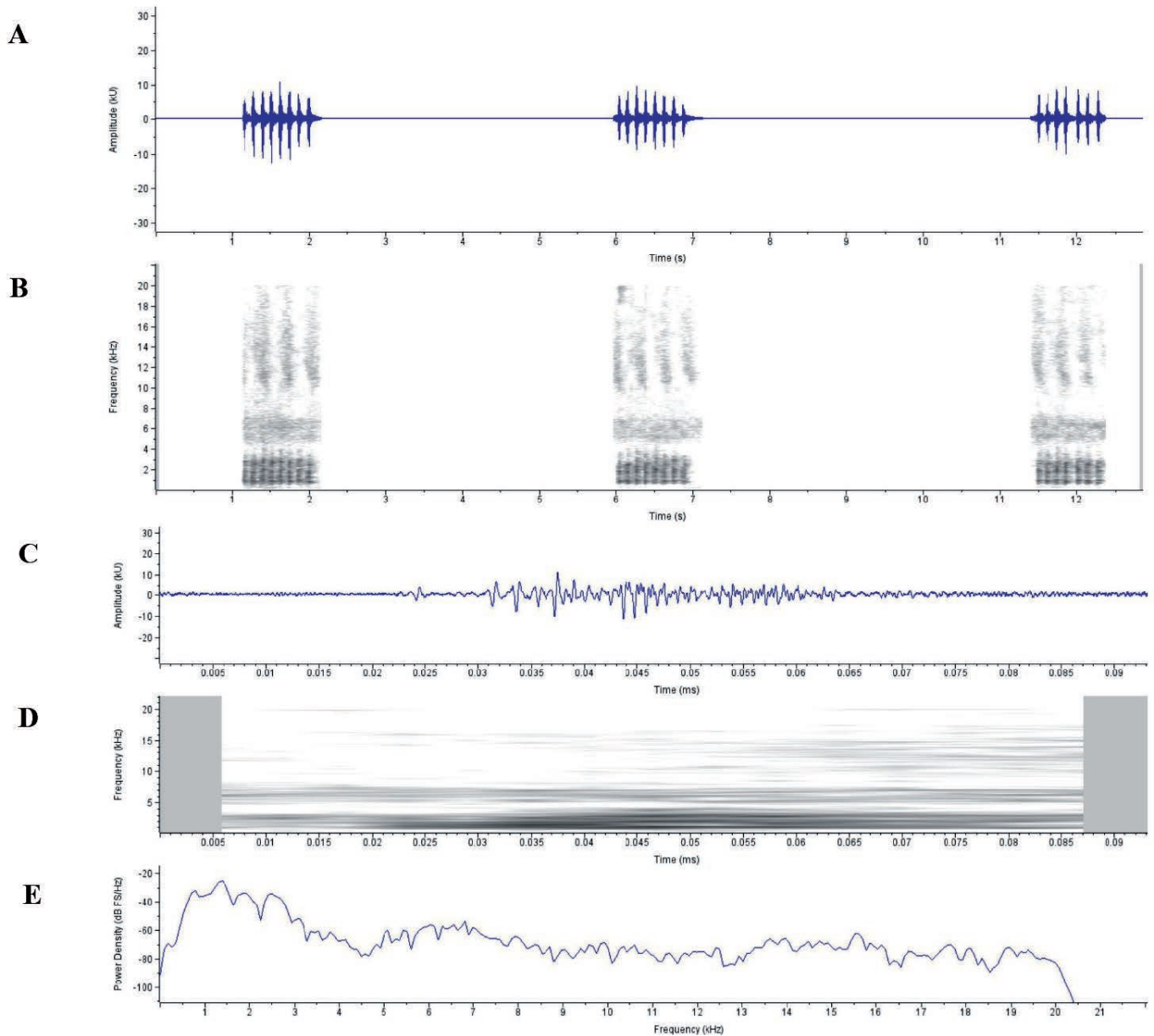


Fig. 11 – Advertisement calls of *Leptobranchium smithi*. A,B) oscillogram, and spectrogram of few calls; C,D) oscillogram, and spectrogram of one note; E) power spectrum (Window type-Blackman, 3dB Filter Bandwidth-150 Hz). / Richiami di *Leptobranchium smithi*. A,B) oscillogramma e spettrogramma di alcuni richiami; C,D) oscillogramma e spettrogramma di una nota; E) spettro di potenza (Window type-Blackman, 3dB Filter Bandwidth-150 Hz).

Tab. 2 – Acoustic properties of the studied species. / Proprietà acustiche delle specie studiate.

Species	Call properties										Coefficient of Variance
	Number of calls/minute	Call duration (s) (±SD)	Inter-call interval (s)	Number of notes per call	Note duration (s)	Call repetition rate (calls/min)	Inter-note interval (s)	Pulses per call (k)	Pulse rate (pulses/s) (±SD)	Frequency (kHz) Minimum Maximum	
<i>Hyla annectans</i>	46	0.30(0.02)	0.29	1.00	0.30	3.42	0.29	42.56	254.18	3.05 (0.09) 3.00 3.38	0.003
<i>Hylarana leptoglossa</i>	9	0.87(0.74)	5.19	7.00	0.05	1.18	0.08	7.00	6.41	2.23 (0.22) 1.97 2.63	0.01
<i>Clinotarsus alticola</i>	55	0.19(0.19)	0.67	1.95	0.06	5.05	0.59	4.05	22.52	1.50 (0.53) 0.94 2.72	0.04
<i>Microhyla mymensinghensis</i>	70	0.22(0.02)	0.32	12.55	0.01	4.69	0.01	12.55	61.89	2.25 (0.04) 2.16 2.34	0.001
<i>Kaloula pulchra</i>	40	0.65(0.12)	0.49	1.00	0.65	1.61	0.49	1.00	**	0.56 (0.44) 0.28 1.31	0.08
<i>Rhacophorus bipunctatus</i>	29	0.29(0.05)	1.86	3.00	0.06	3.51	0.03	*	**	2.08 (0.04) 2.03 2.16	0.001
<i>Raorchestes shillongensis</i>	9	1.15(0.40)	5.72	4.40	0.03	0.96	0.32	*	**	3.87 (0.03) 3.79 3.88	0.0007
<i>Minervarya pierrei</i>	56	0.53(0.09)	0.20	2.10	0.22	1.94	0.08	44.70	93.02	3.63 (0.05) 3.53 3.70	0.001
<i>Leptobranchium smithi</i>	10	0.88(0.08)	3.95	7.40	0.06	1.15	0.05	*	**	2.29 (0.34) 1.98 2.67	0.02

SD, standard deviation; *no distinct pulse; **since only one pulse per call or no distinct pulse, the pulse rate cannot be determined.

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