DOI: 10.4081/nhs.2024.778
Submitted: 19 April 2024
Accepted:28 October 2024

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

Holiness Warjri[1], Jayaditya Purkayastha[2], Madhurima Das[1*]

[1]Assam Don Bosco University, Tapesia Gardens, Kamarkuchi, Sonapur, Tepesia, Assam 782402, India

[2]Help Earth, Raghunath Choudhury Path, Lachitnagar, Guwahati, Assam 781007, India

* Corresponding author: madhurima.das@dbuniversity.ac.in

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*, the 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 in understanding 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 km^2 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 savannas, 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 (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 15:00h to 23:00h. 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 looked into, 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%) and preserved in 10% formaldehyde solution and are deposited in the Assam Don Bosco University. Morphometric 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 15:00h 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 Kohler *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. 2 and 3.

Family Hylidae

***Hyla annectans* (Jerdon 1870)**

(Indian Snout Frog: Fig. 2A)

Adult male SVL is 40.10 mm (n=1). We analyzed 16 advertisement calls. The calls were recorded between 16:00 to 18:30 hours on July 2023 in Langtor (25.535060° N, 91.583314° E). The ambient air temperature was 19 ºC−22 ºC 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 1 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 call of *Hyla annectans* from Mawsynram (25.29745°N, 91.58512°E, 1424 m asl.), Megahalaya. The study only recorded three parameters, number of pulses, call duration, and dominant frequency. The result of Shangpliang *et al*. (2023) mostly matches to our result except for the number pulses mentioned as 19–20 versus 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 analyzed 9 advertisement calls. The calls were recorded between 18:25 to 21:00 hours on August 2023 in Wahlong Byrong (25.193216° N, 91.720320° E). The ambient air temperature was 23ºC− 27ºC 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). 20 advertisement calls were analyzed. The calls were recorded from ponds and large streams in Langtor (25.535060° N, 91.583314° E) between 15:20 to 20:45 hours in June and July 2023. The ambient air temperature was 18 ºC−23 ºC 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 analyzed 20 advertisement calls. The calls were recorded between 18:00 to 23:00 hours in June, July, and August 2023 in Williamnagar (25.531390° N, 90.592003° E). The ambient air temperature was 23ºC−28ºC and the relative humidity was 96%−99%. The calls were heard from swampy areas and small grasslands.

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 analyzed 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 to 23:00 hours in May, and June 2023 in Wahlong Byrong (25.193216° N, 91.720320° E) The ambient air temperature was 22ºC−25ºC 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 analyzed 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 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 variance is 0.08.

Note: Kanamadi *et al*. (2002) reported the call characteristics of *Kaloula pulchra* in Dharwad (15º27'N, 75º05'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 analyzed. The calls were recorded between 18:00 to 21:00 hours in August 2023. The ambient air temperature was 22ºC−27ºC and the relative humidity was 95%−99%.

Advertisement calls

(Fig. 8, Tab. 2)

The typical advertisement call has 29 calls per minute, 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 and 5 stress calls. The calls were recorded between 16:00 to 23:00 hours in June, and July 2023. The ambient air temperature was 18ºC−23ºC 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 the average duration of the note is 0.03 s, the mean inter-note interval is 0.32 s. In 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 *Raorchestes shillongensis* in Malki forest (25°33'45" N, 91°53'19" 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 dominant 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 and 5 stress calls. The calls were recorded between 17:30 to 23:00 hours in May, June, and July 2023 in Langtor (25.535060° N, 91.583314° E). The ambient air temperature was 19ºC−26ºC and the relative humidity was 92%−98%. The calls were heard mainly from the paddy field and marshy areas.

Advertisement calls

(Fig. 10, Tab. 2)

The advertisement calls we analyzed 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 & 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 and 5 stress calls. The calls were recorded between 17:50 to 23:00 hours in July 2023. The ambient air temperature was 22ºC− 27ºC 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 & 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 & Shahrudin (2022), the dominant frequency was 1.10 kHz, which is lower than the 2.29 kHz frequency observed in our findings. Additionally, Ong & Shahrudin (2022) recorded an average 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.

DISCUSSION

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. Bioacoustic 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 temporal 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 mating strategies, habitat preferences, and physiological constraints (Hödl, 1977). For example, species inhabiting open grasslands, such as *Hyla 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 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 bioacoustic 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.

Acknowledgments

We thank the Principal Chief Conservator of Forests, Wildlife and Chief Wildlife Warden, Meghalaya (Permit No. O.O. No. 79 and O.O. No. 28) for permitting us to study. This work was financially supported by the Joint CSIR-UGC fellowship [CSIR-HRDG Ref. No.: Nov/06/2020(i)EU-V] to Holiness Warjri (HW). We also thank the Department of Zoology, Assam Don Bosco University, for supporting us during the study. HW would also like to thank her lab mates.

REFERENCES

Bee M.A. & Swanson E.M., 2007 – Auditory masking of Anuran advertisement calls by road traffic noise. Animal Behaviour, 74(6): 1765-1776. https://doi.org/10.1016/j.anbehav.2007.03.019.

Bee M.A., Cook J.M., Love E.K., O'Bryan L.R., Pettitt B.A., Schrode K. & Velez A., 2010 – Assessing acoustic signal variability and the potential for sexual selection and social recognition in boreal chorus frogs (*Pseudacris maculata*). Ethology, 116(6): 564-576. https://doi.org/10.1111/j.1439-0310.2010.01773.x.

Boruah, B., Raj, P., Dutta, S.K. & Das, A., 2018. Redescription and geographic distribution of *Raorchestes shillongensis* (Anura: Rhacophoridae) from Meghalaya, northeast India. Phyllomedusa: Journal of Herpetology, 17(1), pp.3-20.

Grosjean S. & Dubois A., 2011 – Description of the advertisement calls of nine species of *Fejervarya* Bolkay, 1915 and *Minervarya* Dubois, Ohler & Biju, 2001 from China, India and Nepal. Alytes, 27(4), pp.117-141.

Heyer R., Donnelly M.A., Foster M. & Mcdiarmid R., 2014 – Measuring and monitoring biological diversity: standard methods for amphibians. Smithsonian Institution.

Hödl W., 1977 – Call differences and calling site segregation in Anuran species from Central Amazonian floating meadows. Oecologia, 28: 351-363. https://doi.org/10.1007/BF00345990.

Kanamadi, R.D., Kadadevaru, G.G. & Schneider, H., 2002. Advertisement call and breeding period of the frog, *Kaloula pulchra* (Microhylidae). Herpetological Review, 33(1), p.19.

Köhler J., Jansen M., Rodriguez A., Kok P.J., Toledo L.F., Emmrich M., Glaw F., Haddad C.F., Roedel M.O. & Vences M., 2017 – The use of bioacoustics in Anuran taxonomy: theory, terminology, methods, and recommendations for best practice. Zootaxa, 4251(1):1-124.

Lambert M.R.K., 1984 – Amphibians and reptiles. In: Sahara Desert. Key environments. Cloudsley-Thompson J.L (eds.). Pergamon Press, London, 205–227.

Meghalaya State Climate Change Action Plan. 2017 – Meghalaya State Climate Change Action Plan. http://moef.gov.in/wp-content/uploads/2017/09/Meghalaya.pdf.

Padial J.M. & De la Riva I., 2009 – Integrative taxonomy reveals cryptic Amazonian species of *Pristimantis* (Anura: Strabomantidae). Zoological Journal of the Linnean Society, 155(1): 97-122. https://doi.org/10.1111/j.1096-3642.2008.00424.x.

Ong, D. & Shahrudin, S., 2022. Advertisement calls of *Limnonectes macrognathus* (Anura: Dicroglossidae) and *Leptobrachium smithi* (Anura: Megophryidae), native frog species from Langkawi, Kedah, Peninsular Malaysia. Bioacoustics, 31(1), pp.81-91.

Prasad V.K., Gautam K.B. & Gupta S.K., 2020 – Identification of Anuran species diversity of the Panna Tiger Reserve, Central India, using an integrated approach. Zootaxa, 4851(3): 450-476.

Roy D. & Elepfandt A., 1993 – Bioacoustic analysis of frog calls from northeast India. Journal of Biosciences, 18:381-393.

Roy P. S. & Tomar S., 2001 – Landscape cover dynamics pattern in Meghalaya. International Journal of Remote Sensing, 22(18): 3813-3825.

Shangpliang P.W., Nongkynrih S.J. & Hooroo R.N.,2023- First comprehensive study on the breeding activity of *Hyla annectans* Jerdon, 1870 in pristine water bodies of Meghalaya, Northeast India, 16: 305-310.

Sun J.W. & Narins P.M., 2005 – Anthropogenic sounds differentially affect amphibian call rate. Biological conservation, 121(3): 419-427. https://doi.org/10.1016/j.biocon.2004.05.017.

Thomas A., Suyesh R., Biju S.D. & Bee M.A., 2014 – Vocal behavior of the elusive purple frog of India (*Nasikabatrachus sahyadrensis*), a fossorial species endemic to the Western Ghats. PloS one, 9(2): 84809. https://doi.org/10.1371/journal.pone.0084809.

Tripathi O. P. & Tripathi R. S., 2010 – Community composition, structure and management of subtropical vegetation of forests in Meghalaya State, northeast India. International Journal of Biodiversity Science, Ecosystem Services & Management, 6(3-4): 157-163.

Valetti J.A., Salas N.E. & Martino A.L., 2013 – Bioacoustic of the advertisement call of *Ceratophrys cranwelli* (Anura: Ceratophryidae). Revista de Biología Tropical, 61(1): 273-280.

Fig. 1 – Amphibian habitats mentioned in the text: A, C - Rocky streams, B, D – Woodland, E, F - Marshy areas. / Habitat degli anfibi citati nel testo: A, C – Ruscelli con rocce, B, D - Aree boscose, E, F – Aree palustri.

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.*

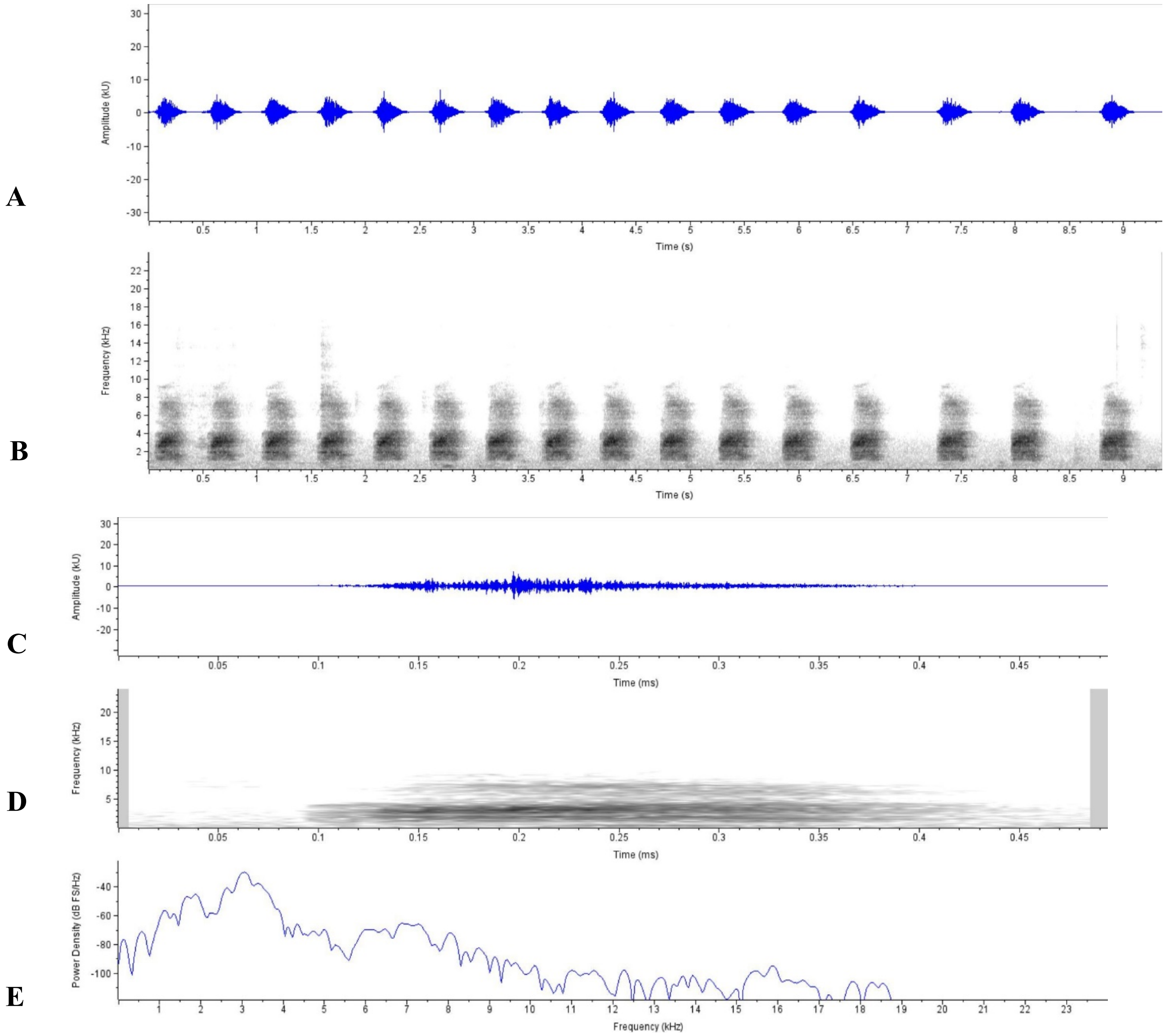

Fig. 3 – Advertisement calls of *Hyla annectans.* A, B: oscillogram, and spectrogram of few calls; C, D: oscillogram, and spectrogram of one note; E: Power spectrum (Window type-Blackman, 3dB Filter Bandwith-150 Hz). / Richiami di *Hyla annectans*. A, B: oscillogramma e spettrogramma di alcuni richiami;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

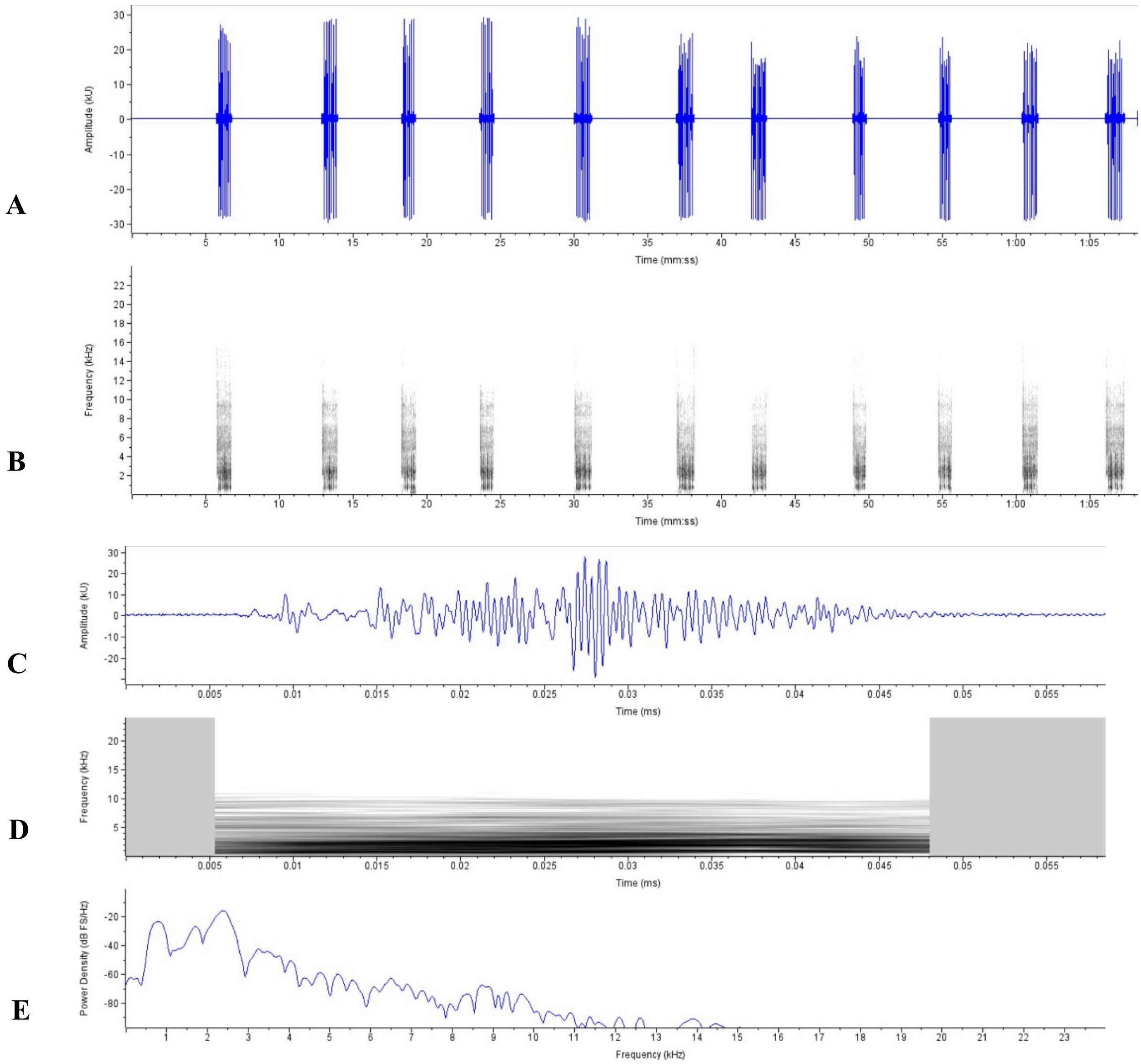

Fig. 4 – Advertisement calls of *Hylarana leptoglossa.* A, B: oscillogram, and spectrogram of few calls; C, D: oscillogram, and spectrogram of one note; E: Power spectrum (Window type-Blackman, 3dB Filter Bandwith-150 Hz). / Richiami di *Hylarana leptoglossa*. A, B: oscillogramma e spettrogramma di alcuni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

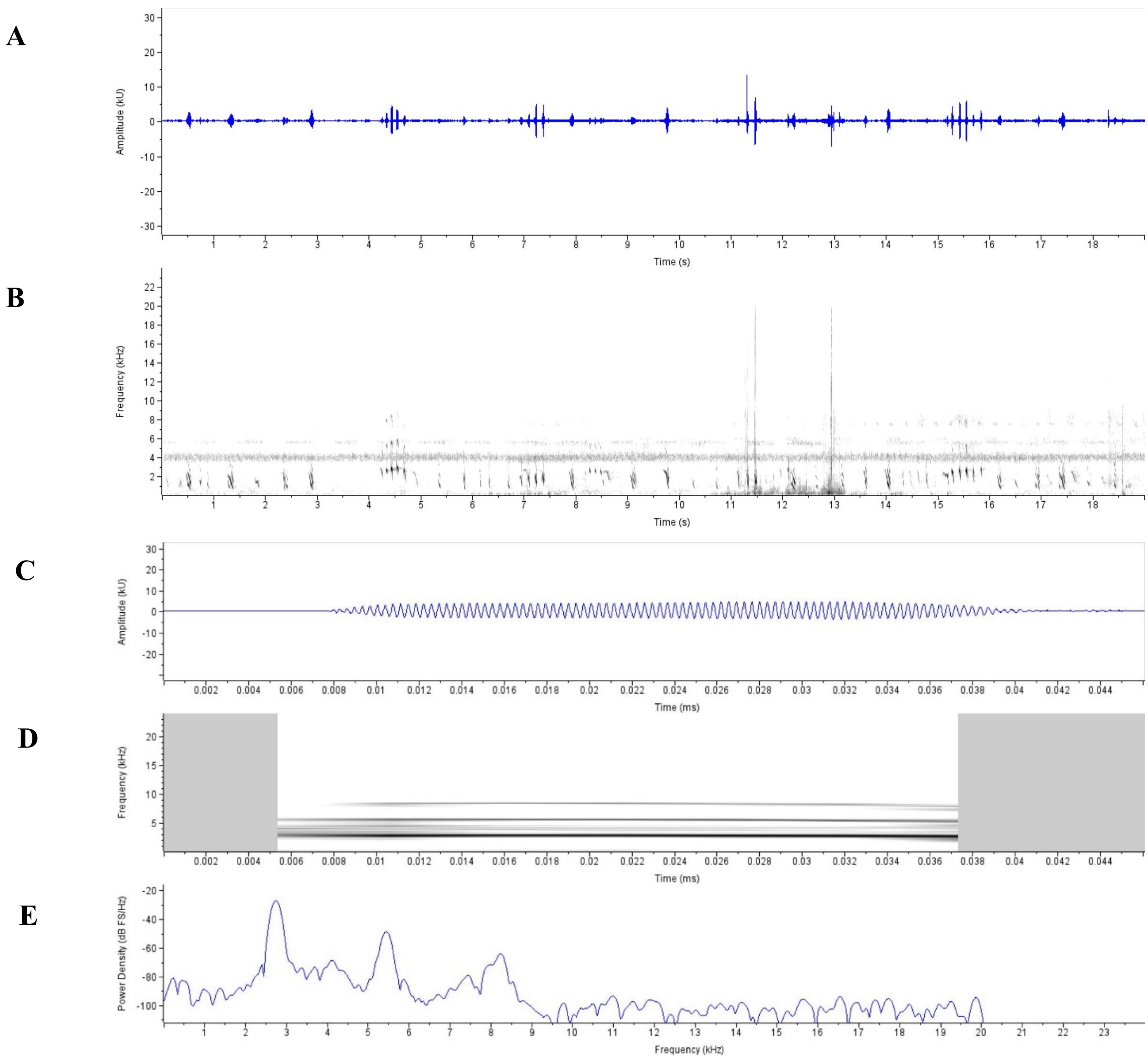

Fig. 5 – Advertisement calls of *Clinotarsus alticola.* A, B: oscillogram, and spectrogram of few calls; C, D: oscillogram, and spectrogram of one note; E: Power spectrum (Window type-Blackman, 3dB Filter Bandwith-150 Hz). / Richiami di *Clinotarsus alticola*. A, B: oscillogramma e spettrogramma di alcuni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

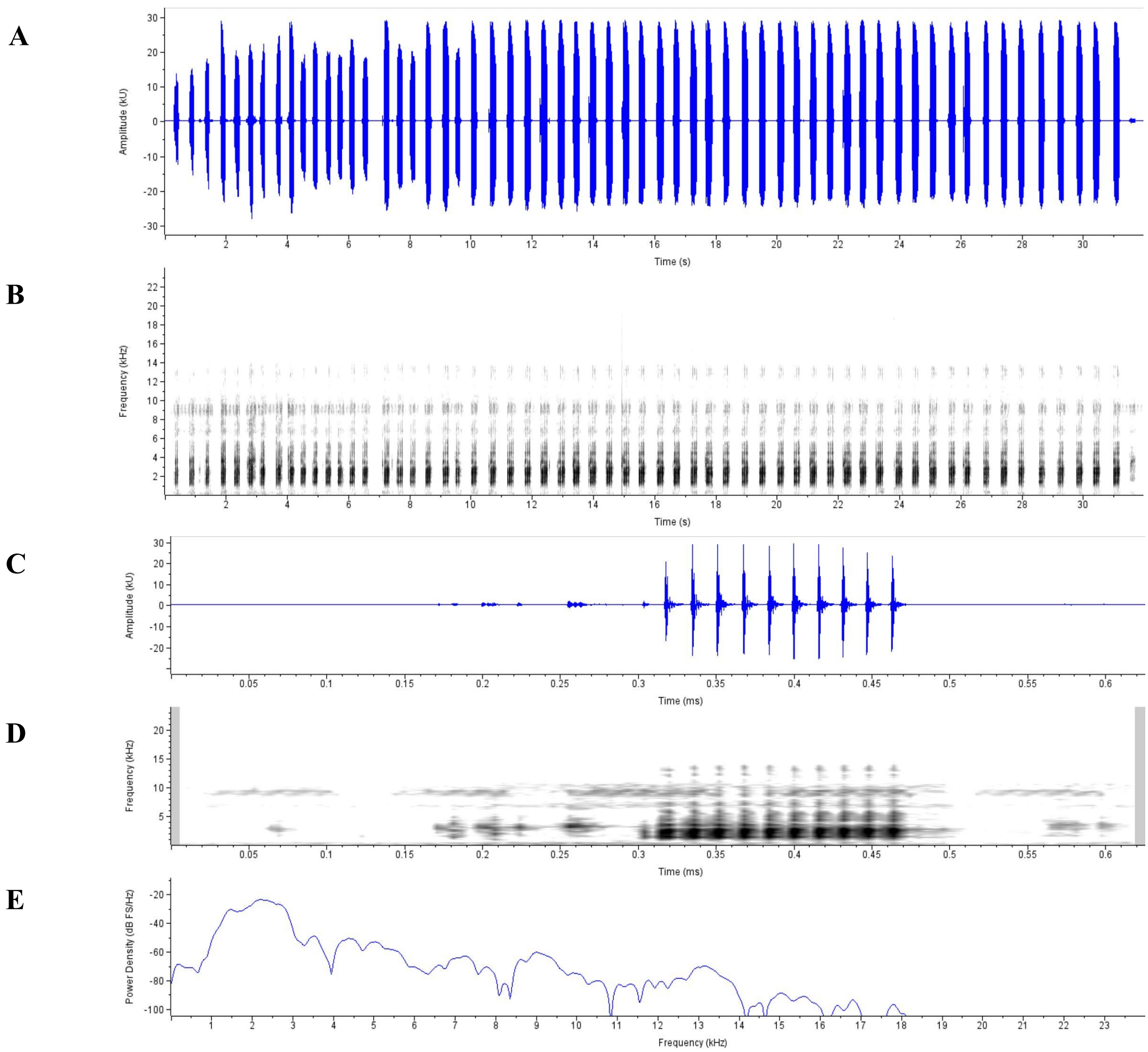

Fig. 6 – Advertisement calls of *Microhyla mymensinghensis.* A, B: oscillogram, and spectrogram of few calls; C, D: oscillogram, and spectrogram of one note; E: Power spectrum (Window type-Blackman, 3dB Filter Bandwith-150 Hz). / Richiami di *Microhyla mymensinghensis*. A, B: oscillogramma e spettrogramma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

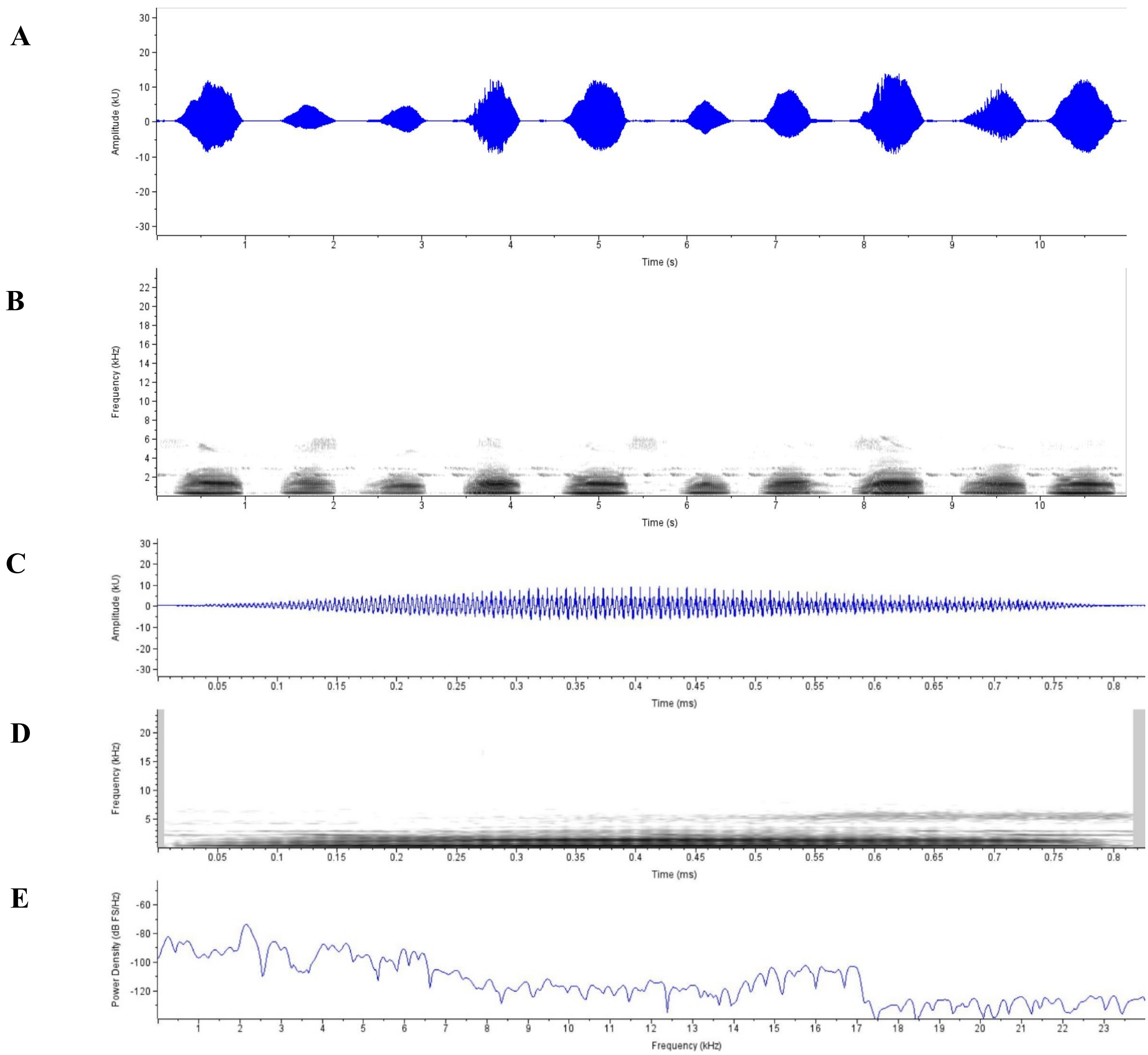

Fig. 7 – Advertisement calls of *Kaloula pulchra.* A, B: oscillogram, and spectrogram of few calls; C, D: oscillogram, and spectrogram of one note; E: Power spectrum (Window type-Blackman, 3dB Filter Bandwith-150 Hz). / Richiami di *Kaloula pulchra*. A, B: oscillogramma e spettrogramma di alcuni richiami;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

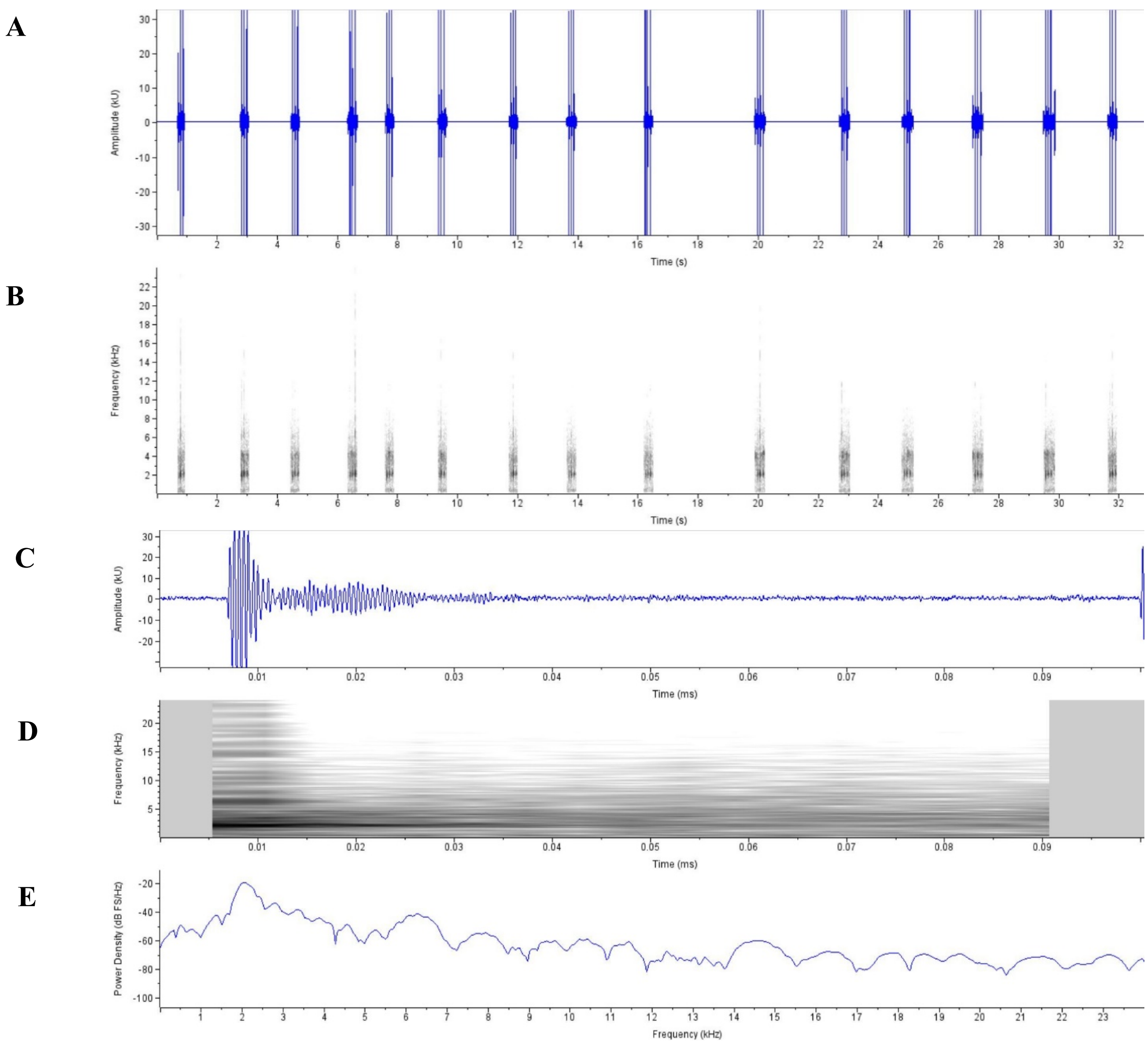

Fig. 8 – Advertisement calls of *Rhacophorus bipunctatus.* A, B: oscillogram, and spectrogram of few calls; C, D: oscillogram, and spectrogram of one note; E: Power spectrum (Window type-Blackman, 3dB Filter Bandwith-150 Hz). / Richiami di *Rhacophorus bipunctatus*. A, B: oscillogramma e spettrogramma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

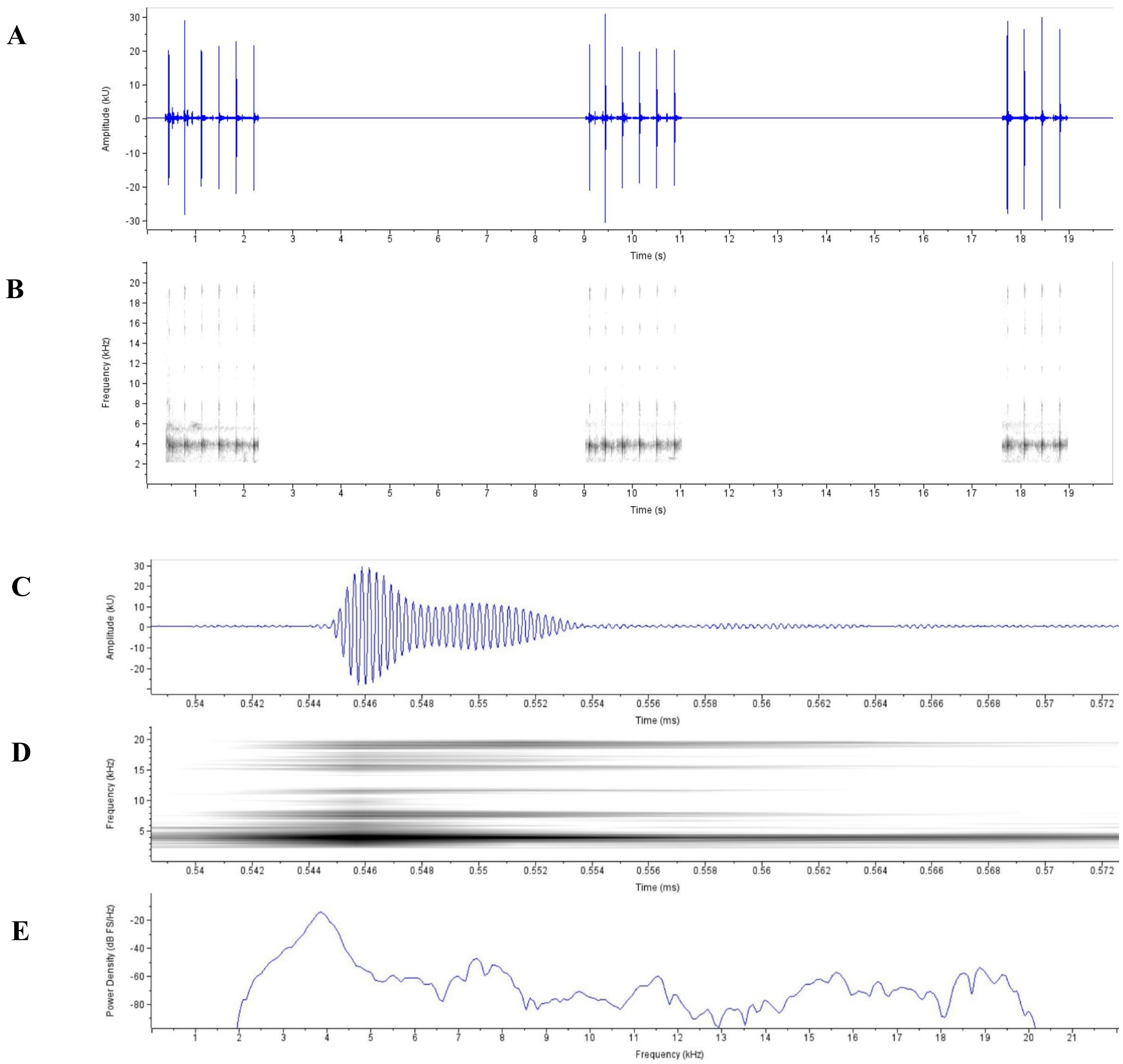

Fig. 9 – Advertisement calls of *Raorchestes shillongensis.* A, B: oscillogram, and spectrogram of few calls; C, D: oscillogram, and spectrogram of one note; E: Power spectrum (Window type-Blackman, 3dB Filter Bandwith-150 Hz). / Richiami di *Raorchestes shillongensis*. A, B: oscillogramma e spettrogramma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

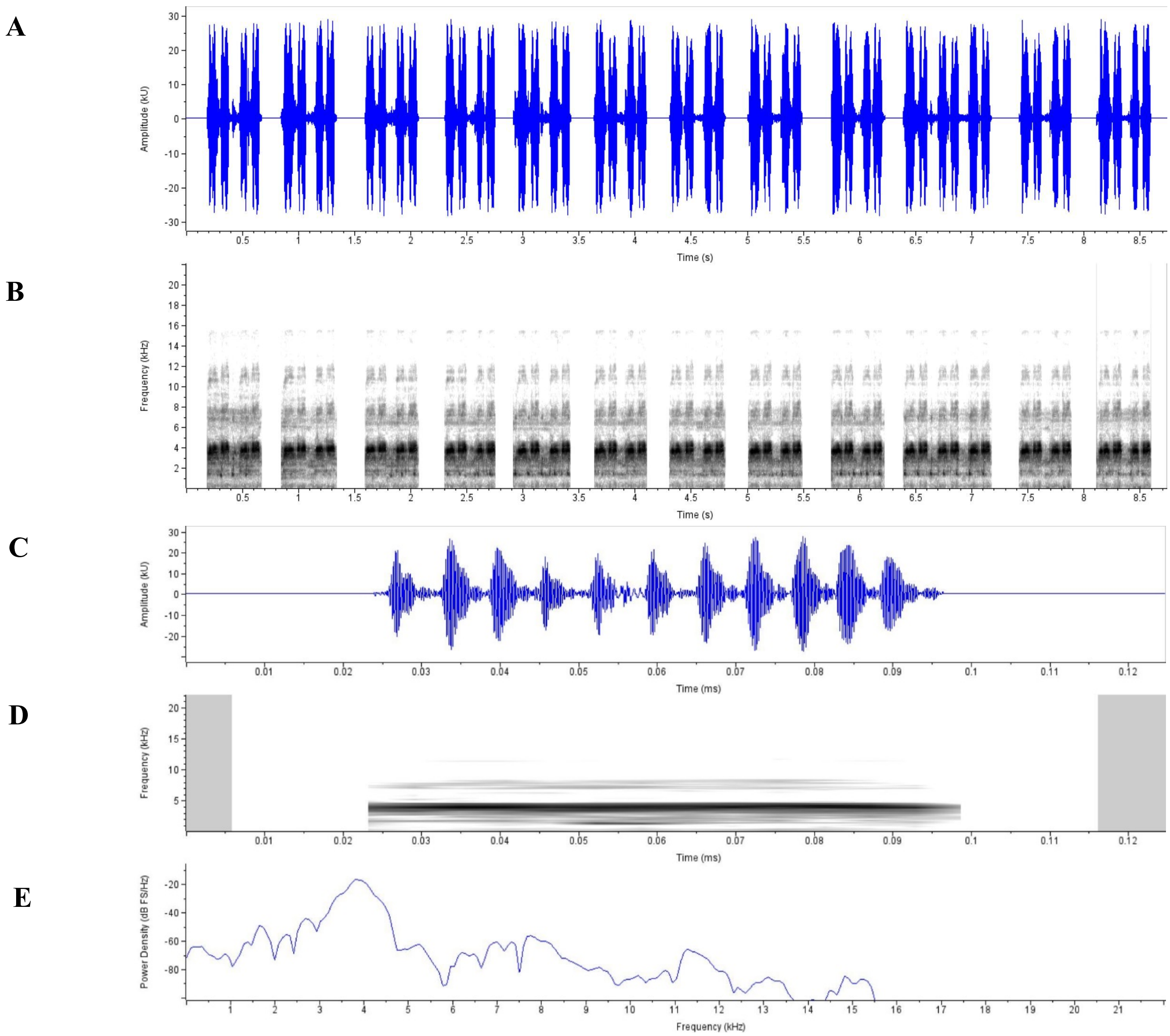

Fig. 10 – Advertisement calls of *Minervarya pierrei.* A, B: oscillogram, and spectrogram of few calls; C, D: oscillogram, and spectrogram of one note; E: Power spectrum (Window type-Blackman, 3dB Filter Bandwith-150 Hz). / Richiami di *Minervarya pierrei*. A, B: oscillogramma e spettrogramma di alcuni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

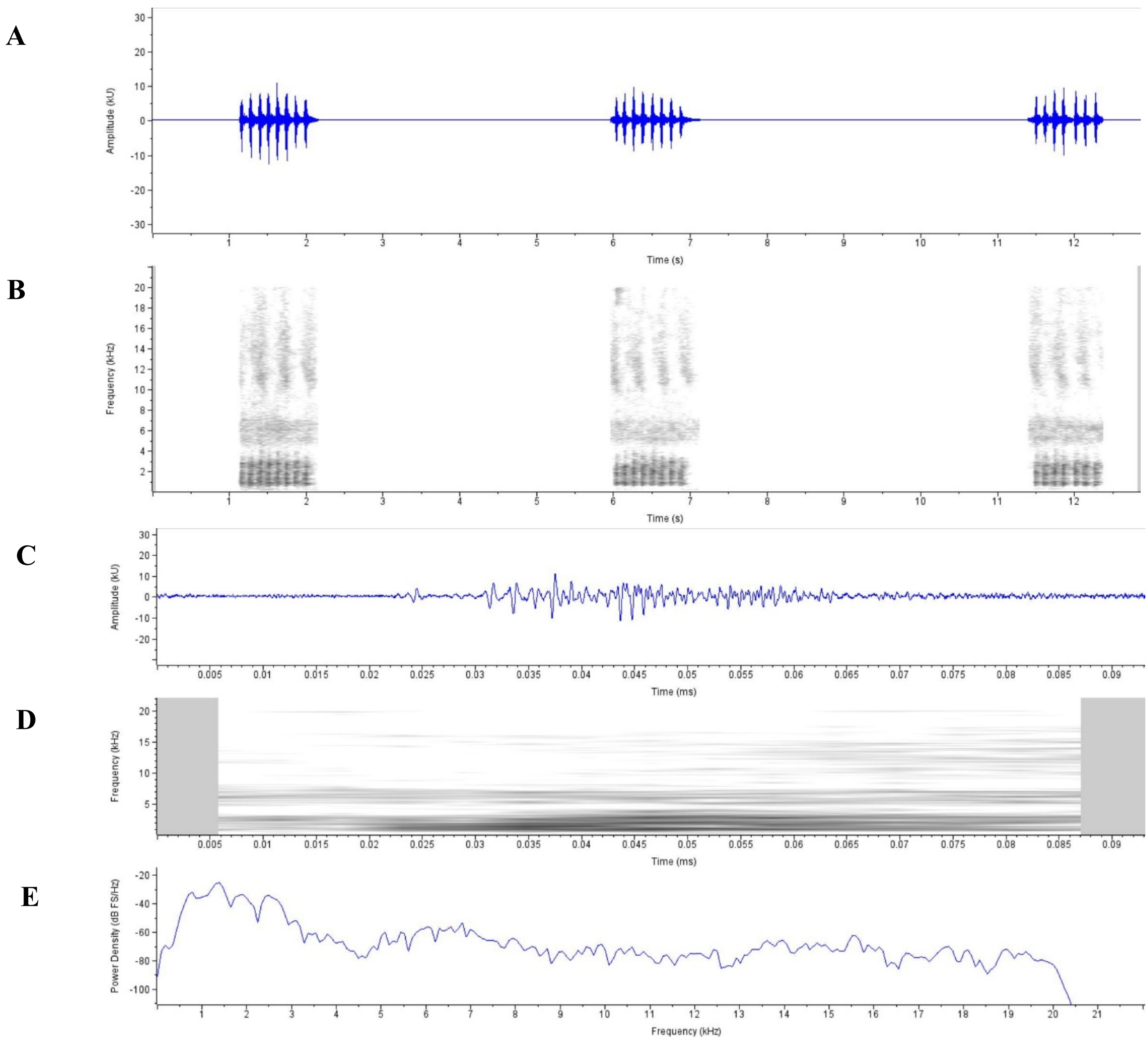

Fig. 11 – Advertisement calls of *Leptobrachium smithi.* A, B: oscillogram, and spectrogram of few calls; C, D: oscillogram, and spectrogram of one note; E: Power spectrum (Window type-Blackman, 3dB Filter Bandwith-150 Hz). / Richiami di *Leptobrachium smithi*. A, B: oscillogramma e spettrogramma di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

Tab. 1 – Definitions of the bioacustic 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.e., k - 1).
Dominant frequency (Hz)	The peak frequency of a call or note, or the frequency with the greatest amount of sound energy.

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

Species	Call Properties												
										Frequency (kHz)			
	Number of calls/minute	Call Duration (s) (±S.D)	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)	Dominant (±S.D)	Minimum	Maximum	Coefficient of Variance
Hyla annectans	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
Hylarana leptoglossa	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
Clinotarsus alticola	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
Microhyla mymensinghensis	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
Kaloula pulchra	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
Rhacophorus bipunctatus	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
Raorchestes shillongensis	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
Minervarya pierrei	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
Leptobrachium smithi	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

* No distinct pulse; ** Since only one pulse per call or no distinct pulse, the pulse rate cannot be determined.