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Feature Identification in a Cicada Song

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Abstract

My encounter with the song of a single cicada hidden in an ornamental cherry tree motivated me to study the cicada's song. In this article, the state of knowledge about cicadas is reviewed, and the cicada song is analyzed. The article is based on the Voix 033 - Voix 040 raw cicada song samples acquired by means of the application Enregistreur Vocal installed on a Galaxy S20 FE 5G phone. The sample analysis has been performed by means of the program Audacity 3.7.8. The waveform diagrams, the spectrograms, and the Fourier analysis of the samples are presented and commented on. The Audacity instructions used in the analysis are included in the article. The recorded raw cicada song samples Voix 033 - Voix 040 are available on request.

Keywords

Cicada, Song, Samples, Galaxy S20, Audacity

1. Introduction

Cicada (**Figure 1**) and cicada's songs accompanied my entire sojourn in Verona (IT) during June and July 2026. During the evenings, while enjoying the sunset, I tried many times to record samples of cicada songs in order to identify their features. Unfortunately, all my recording attempts were unsuccessful. This was because, although clearly audible to my ears, the songs came from rather far away, and my recording device was unable to capture them. Moreover, the noise caused by vehicle circulation and human voices coming from the nearby animated road contributed to confusing the cicada songs. I was a little disappointed by this situation but determined to solve this recording problem in some way. The solution arrived, quite unexpectedly, on 25th July 2026, a day on which, coming home after shopping in a supermarket, I arrived near a three-meter-high ornamental cherry tree on the border of a silent road, hiding a single singing cicada of unknown species. The situation was now ideal, and it became possible for me to record eight

samples of its song from a distance of approximately 1.5 meters. This sample collection stimulated me to collect information about cicadas and to begin the writing of the present article. But which song features are possible to identify in the song of this hidden cicada?

(a) (b)

Figure 1. Cicadas: (a) shed exoskeleton or exuvia of a cicada nymph, on the thorax back the longitudinal slit from which the adult emerged; (b) cicada *Lyristes plebejus*.

2. Background

The cicadas belong to the superfamily Cicadoidea, actually comprising two families: Cicadidae and Tettigarctidae [1]. The Cicadidae comprise about three thousand species worldwide, while the Tettigarctidae comprise only two species spread over Australia. Cicadidae produce loud sounds through the vibration of paired chitinous membranous exoskeletal structures for communication with other cicadas and many individuals. Tettigarctidae use vibrational signals transmitted through the material they stand on for these communications. Cicada nymphs of both families often spend several years underground, moving through the terrain and absorbing root xylem sap. They emerge to undergo a final moult, producing a winged adult. All adult Mesozoic fossils belong to the Tettigarctidae family, because of their forewing venation, while Cicadoidea adult fossils are largely represented by wing fragments, which permitted the identification of fifty-five genera. Up to now, there is no clear evidence determining the divergence time between the Cicadidae and Tettigarctidae families [1].

The evolution of a long life cycle combined with perfect synchronicity allows Magicicada species to escape predators [2]. Periodical cicadas have the longest juvenile development. Their nymphs feed underground on root xylem fluids for 13 or 17 years. From the end of April to the beginning of June of the emersion year, the nymphs start from the terrain, go upwards, and eclose into adults, which remain active for about 4 - 6 weeks. Within the first two weeks, adults aggregate in chorus centers where males sing and mate. After mating, females leave the chorus center for oviposition. Females lay eggs in small tree twigs about 9 - 16 days after

they emerge as adults. They place 20 - 30 eggs in each V-shaped egg nest they cut into small tree branches. After about 6 - 8 weeks, nymphs fall down to the terrain, enter the soil and begin feeding on rootlets. As they grow, they move deeper below the soil, feeding on larger roots. The density of emerging cicadas ranges from approximately 30,000 to more than 3.5 million per hectare. The periodical emergence cicada brood cycles of 13 or 17 years are still a source of debate. Adults and nymphs have similar digestive organs and feed on root xylem fluids containing amino acids, raw minerals, and water. A sex ratio of about 50/50 is observed at the adults' emersion, although differences may occur. The species manifest different, distinctive chorus songs. The mass emergence of the Magicicada species enhances predator satiation, but introduces competition for resources. Populations of periodical cicadas have been destroyed by habitat perturbation and/or destruction. The only synchronized natural enemy of Magicicada species is the fungus Massospora cicadina. Future studies of periodical cicadas are needed to determine what triggers the mass emergence, the effects of nymphal competition, the details of mating behaviour, the differential predation on the sexes, and the effects of periodical cicada damage to host plants [2].

The ecological interactions between predatory mammals and insect prey have often been overlooked and remain relatively unknown [3]. Therefore, studying these interactions and their ecological consequences advances understanding of food chains. Cicadas largely populate warm and temperate forests and are seasonally abundant for vertebrate and invertebrate predators because of their high nutritional value and reduced defensive capabilities. Annual cicadas emerge from the ground every year, and periodical cicadas live in the state of nymph in the ground and emerge after a growing period of several years (Magicicada species, 13 or 17 years). As a consequence, the behaviour of their predators—mammals and insectivorous birds—turns towards a cicada diet. Five methods for confirming cicada consumption by mammals can be used: excrement analysis, stomach analysis, direct observation, remains analysis, and stable isotopes. The author identified fifty-six mammalian species belonging to ten orders as cicada consumers, sixteen cicada species consumed by mammals, and five types of cicada mammal hunting strategies for both nymphal and adult stages: (a) underground predation by underground mammals, such as moles, (b) digging by mammals, such as bears and foxes, (c) ground predation during cicada emergence, (d) arboreal predation of adult cicadas on trees at night by arboreal predators, such as flying foxes and primates, (e) aerial predation of flying cicadas by bats and birds. Many cicada consumers, including fungi, birds, and mammals, adopt a cicada diet and increase their population density at the time of cicada emergence. The overlap between cicada emergence and the mammalian breeding season may be important for breeding success. Cicadas frequently emerge in anthropogenic environments, such as urban parks, orchards, and plantation forests [3].

Periodical cicadas (Magicicada spp.) of the eastern United States are interesting because of their synchronized mass emergence, and a "brood" is defined as the

localized event of a synchronized mass emergence [4]. Broods are normally separated in space and time, but their distribution is largely parapatric, *i.e.*, provided with contact zones. Cicadas emerging outside the mass emergences are called stragglers. However, most stragglers do not survive predation and other causes (Allee effect), so that the coexistence of two broods in the same geographic area becomes impossible. Periodicity probably developed during the ice ages and appears to be linked to predator avoidance. Through mathematical model simulations, predation can be identified as a mechanism maintaining separation among broods notwithstanding the presence of stragglers. Periodical cicadas do not defend themselves against predators, and the brood's massive population allows for a relevant part of it to survive predation (predator satiation strategy, also called predator swamping) [4].

In summer, cicadas are a common species in park forests and natural reserves of Guangzhou (CN) [5]. Thus, three song collection points were placed in each of four different areas. The loud and long transmission distance of cicada songs interfere significantly with bird songs. After analyzing the collected cicada songs, it has been found that their frequency distribution is complex and ranges from 2 kHz to 16 kHz. Some cicadas have a clear syllable structure which overlaps with the frequency of the bird songs. Therefore, cicada songs may mislead bird song monitoring. A twenty-hour dataset of bird songs and an eighteen-hour dataset of cicada songs were built. Then, a learning model was used to remove cicada songs from bird songs. The end-to-end developed deep learning model, CicadaNet, eliminated most of the cicada songs and introduced small bird song distortion [5].

About two hundred twenty cicada species live in China [6]. However, in Ningling (Henan Province, CN), the wild cicada population has declined by approximately 80% in the past decade. This decline has made evident the necessity of urgent ecological action. Although cicadas sometimes harm host plants, they perform important ecological roles, for example, recycling nutrients, soil aeration, serving as a food source for various animals, and supplying carcass fertilization for the soil. However, climate change, inundations, urbanization, anthropogenic activities, and overharvesting have reduced cicada populations. The collection of Cryptotympana atrata, a delicate northern Chinese food, by applying glue on tree trunks, has devastating effects on cicada and other insect populations. Global monitoring and efforts are necessary for mitigating cicada decline [6].

Sap-feeding hemipterans usually establish symbiosis with heritable symbionts to supplement their unbalanced diet [7]. Interesting cases of symbiosis in insects are found in the Auchenorrhyncha suborder of the Hemiptera order, which includes cicadas. Most Auchenorrhynchan insects have developed specialized organs and cells for hosting symbionts. In the cicada species associated with Sulcia and Hodgkinia symbionts, Sulcia's symbionts produce eight vital amino acids, whereas Hodgkinia's symbionts produce two vital amino acids and vitamins. Some cicada species lacking Hodgkinia symbionts host, in their place, yeast-like fungi symbionts (YLS). The YLS genome synthesizes practically all vital amino

acids and other nutrients lacking due to the absence of the Hodgkinia symbionts. Cicadas acquire symbionts from the environment in each generation, and evolve mechanisms to ensure transovarian transmission of certain symbionts to mature oocytes, which form a symbiont sphere in each egg [7].

The most well-known periodical cicadas are the seven Magicicada species emerging every 13 or 17 years in North America, the Chremistica ribhoi emerging every four years in northeast India, and the Raiateana knowlesi emerging every eight years in the Fiji Islands [8]. The Magicicada species share a common ancestor that lived approximately 3.9 Mya. The two life cycle cicadas show only limited genomics and appear linked with the Abricta cicada genera present in Australia, Guatemala, Mauritius, and the Afrotropics of sub-Saharan Africa. Magicicada males establish large groups and sing together. These species manifest courtship sequences, including specific songs and behaviours. Males alternate short flights with calling song. In the coupling progression, males emit different mating songs and stop calling once they begin copulation. Copulation may last several hours. Magicicada females indicate readiness for coupling by means of short wing flicks synchronized with the male song. The males also produce acoustical sounds to discourage potential coupling rivals. Magicicada nymphs from all seven species can be infected by pathogenic fungi. Cicadas emerging as few individuals and/or off-cycle as stragglers usually do not survive for coupling. The Magicicada transition from nymph to adult is age-based with no reference to size. The meaning of the cycles of 13 or 17 years and the presence of stragglers are yet a source of debate [8].

Excretion elimination from cicadas (Cicadidae) living in the Peruvian Amazon and in Singapore has been overlooked and poorly explored [9]. These cicadas, weighing about two grams, form continuous fluid excretion jets through an orifice of approximately 350 μm in diameter. These jets range from approximately 160 to 500 μm in diameter, have durations from approximately 80 to 560 ms, average speeds from approximately 0.6 to 3.16 m/s, and a total volume approximately from 6 to 574 μL. The cicadas seem to use jetting instead of droplet excretion because of the xylem sap they eat, which is diluted and under negative pressure. In addition, fluid jets facilitate expelling larger volumes of excretions rapidly, allowing them to process larger volumes of root xylem sap. The ecosystem impact of the cicada fluid excretion during their mass emersions is largely unknown [9].

In the province of Jaén (Andalusia, ES) during the spring of 2022 and 2023, Cicada barbara appeared to be in close relation with the olive trees [10]. Although it has been considered a parasite of little importance, recently, an increase in cicada populations has been recorded in the olive groves, as well as an increase in the damage they caused. Nymphs and adults feed on xylem sap. However, the nymphs at the end of their cycle in the terrain increase their xylem sap consumption and seriously affect the growth of the plants and trees. On the contrary, adults feed on the olive sap from smooth bark branches. The increase in cicada populations could be related to the development of new practices in soil management,

which would be triggering a substantial increase in the development of juvenile cicada stages. However, the real damage to woody plants comes from the damage caused by female cicadas. They cause oviposition damage by means of their ovipositor, which causes cracks that perturb the bark where the eggs are deposited. These cracks cause many terminal branches to die together with the fruits present on them. Control of Cicada barbara is based mainly on nocturnal application of pyrethroid insecticides from July to August, *i.e.*, during the oviposition period [10].

Cicadas present structured wings for flapping, and owls present a feather morphology which allows them to enhance flight characteristics and stealth [11]. Consequently, engineers are developing 3D-SC propellers based on said features, which provide noise propeller reduction and an increase in aerodynamic efficiency [11].

The genus Vagitanus actually comprises seven cicada species from Mainland Southeast Asia, Southern China, and the Ryukyu Islands [12]. However, further specimens collected at light in central Vietnamese mountainous forests at altitudes higher than 1,000 m during the period from June to August permitted the identification of a new species, Vagitanus venetus. This name comes from the Latin term for the deep green coloration. Vagitanus venetus is described as predominantly dark green and brown, but with green fading to an ochraceous yellow during storage [12].

Recent studies suggest a widely distributed and marked reduction in terrestrial European insects [13]. Long-term monitoring studies revealed sharp reduction trends in insect abundance and diversification, with regional losses, over the past few decades, of more than 75% of the total flying insect biomass. The reduction has been attributed to various anthropic causes such as agricultural enhancement, increasing pesticide use, natural habitat disappearance, light and noise pollution, and climate change. Passive acoustic monitoring (PAM) appears to be a method to improve our comprehension of this reduction. PAM provides a tool for monitoring insect populations by capturing emitted sounds, such as, in the case of cicadas, the timbalizations. The development of cicada Deep Learning (DL) algorithms relies on existing datasets of European cicada songs that can be downloaded from online libraries. The developed ECOSoundSet (European Cicadidae and Orthoptera Sound dataSet) comprises 10,653 audio files concerning two hundred orthopteran and twenty-four cicada species of North, Central, and temperate Western Europe. It corresponds to 204 hours of recording, to 129 Gb in size, and is an important source for DL algorithm training for acoustic identification and classification of cicada species [13].

Preferably, the monitoring of insect population changes and the distributions of species can be performed by means of automatic acoustic detection and classification methods because of their possible application to large environments and their minimal invasiveness [14]. Thus, the developed dataset InsectSet459 from three available database sources comprises acoustic data of 459 insect species, in-

cluding 149 Cicada species. It can be used for instructing DL algorithms. The geographic coverage of this dataset is concentrated towards Europe and North America, so tropical regions are underrepresented notwithstanding their higher insect biodiversity. In a competition experiment, two different DL classifiers, trained with the same dataset, both attained 57% F1-score, rising to more than 80% in the case of the most common insect species. In future works, it is expected and recommended to include in the dataset ultrasound components present in many insect songs [14].

3. Materials and Methods

The cicada song samples have been acquired using the Enregistreur Vocal application set to Standard, installed on a Galaxy S20 FE 5G portable phone. The song sample analysis has been performed using Audacity 3.7.8 (Compilation Date: Jun 11 2026; 64 bits; Compiler: MSVC 19.44.35227.00; Central Libraries: wxWidgets: 3.1.3 (Audacity); PortAudio (Reading and Recording audio): v19; libsoxr (Sample rate conversion): Active).

The following terminology has been adopted:

syllable (S) = each pulse of sound in the cicada's song;

inter-syllable interval (ISI) = silent period between two consecutive Ss.

The song came from an unknown species of cicada, hidden in a three-meter-high ornamental cherry tree (**Figure 2**) located in an urban space (45˚26'22.21"N, 11˚01'51.12"E, height 69 m) in the eastern periphery of Verona (IT). The estimated song recording distance was approximately 1.5 meters.

(a) (b)

Figure 2. Three meters high ornamental cherry tree on the border of a silent road, hiding a single singing cicada of unknown species—(a) panoramic vision, (b) detailed vision.

4. Results

In total, eight raw song samples: Voix 033 - Voix 040, have been obtained as shown in Table 1.

Table 1. Cicada raw song samples.

Sample	Date	UT	Lenght	Size (Kb)	Type	Sequences
Voix 033	2026/7/25	9:15	00:00:21.9	381	M4A	N/A
Voix 034	2026/7/25	9:16	00:00:21.4	373	M4A	N/A
Voix 035	2026/7/25	9:16	00:00:23.4	405	M4A	N/A
Voix 036	2026/7/25	9:17	00:00:21.7	379	M4A	N/A
Voix 037	2026/7/25	9:17	00:00:21.4	374	M4A	N/A
Voix 038	2026/7/25	9:18	00:00:22.4	389	M4A	N/A
Voix 039	2026/7/25	9:18	00:00:38.0	639	M4A	N/A
Voix 040	2026/7/25	9:19	00:00:22.3	387	M4A	N/A
		Average	00:00:24.06			

5. Discussion

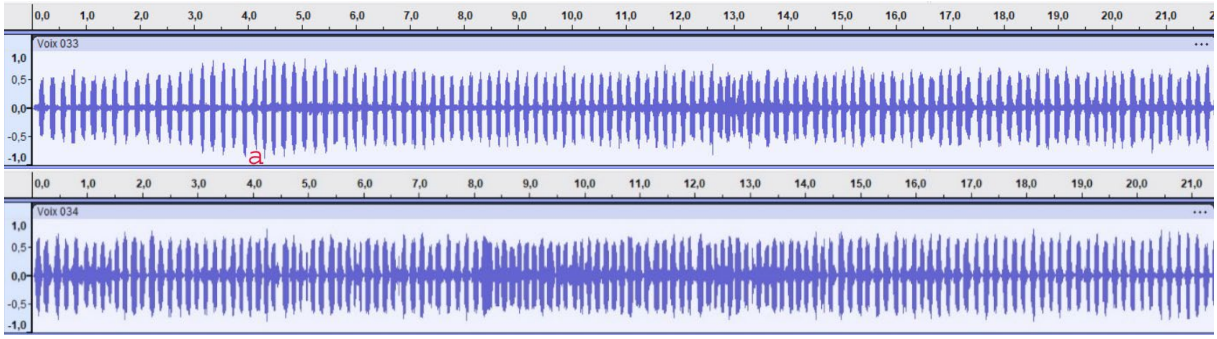
5.1. Waveform Diagrams

The normalized waveform diagram of each raw sample (Figure 3, Figure 4) has been obtained by the instruction set: Audacity → File → insert the Voix sample.

The relatively quiet sound environment (wind, traffic, bells, people) suggested not applying the background noise elimination process of Audacity to the raw samples Voix 033 - Voix 040, in order to not reduce the syllable amplitudes.

The normalized waveform diagrams highlight that:

- the hidden cicada enhanced the tone of the song Ss for 4.199 sec in correspondence with the noise caused by the passage of a car (Figure 3, Voix 033(a)), so as to maintain a uniform audible tone height in the environment;
- a prolonged S of 0.499 sec (Figure 3, Voix 035(a)) was emitted for unknown reasons;
- a prolonged S of 0.724 sec (Figure 4, Voix 039(b)) was emitted for unknown reasons;



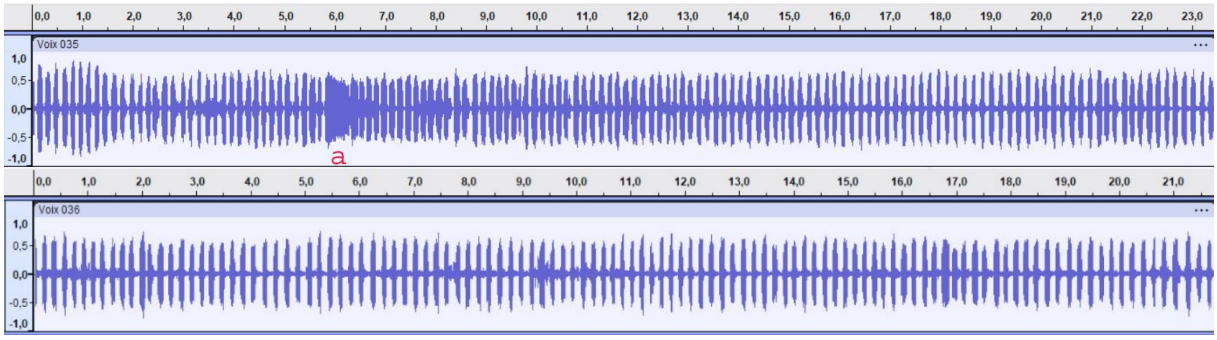


Figure 3. S and ISI in the normalized waveform diagrams of the raw samples Voix 033 - Voix 036; a: features described in the text.

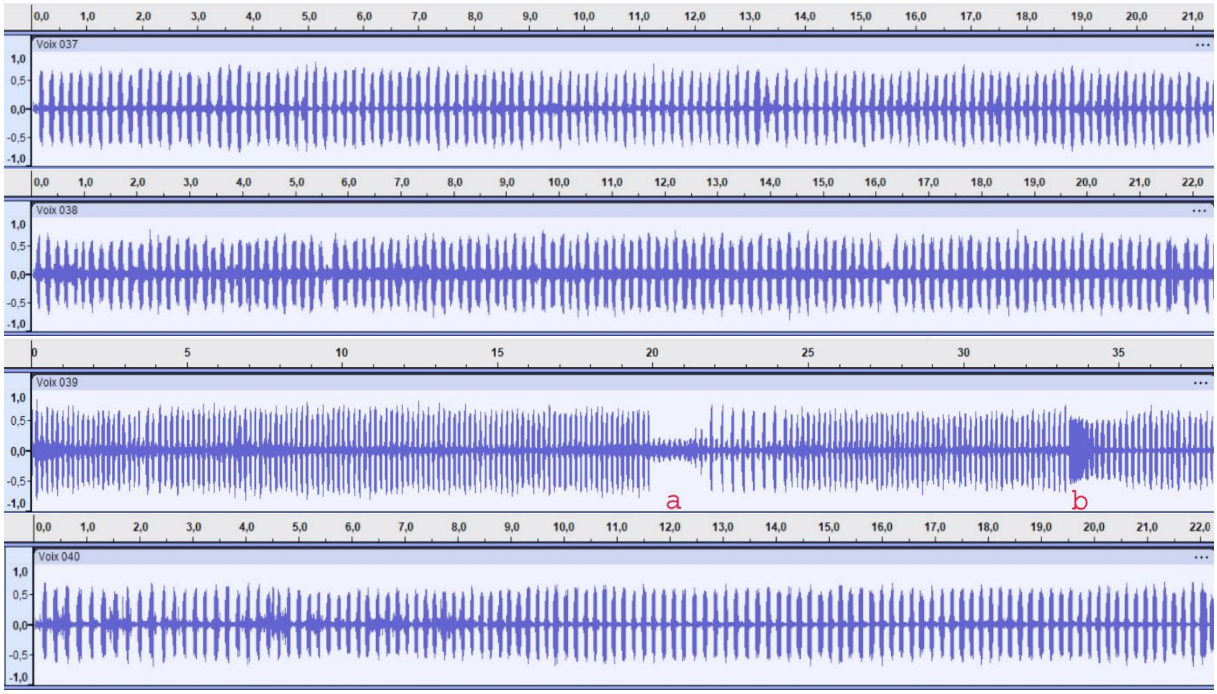


Figure 4. S and ISI in the normalized waveform diagrams of the raw samples Voix 037 - Voix 040; a, b: features described in the text.

- the emitted Ss are approximately four to six per second;
- the Ss duration is approximately 0.1 sec;
- the ISIs duration is approximately 0.06 sec.

5.2. S and ISI Details

To allow the appreciation of the fine details of S and ISI, the initial portion of each normalized waveform diagram of the raw samples Voix 033 - Voix 040 has been enlarged (Figure 5, Figure 6) by means of the instruction set: Audacity → File → insert the Voix sample → 5 times Zoom avant.

Figure 5, Figure 6 highlight that Ss present similarities in length and tone height and are normally composed of a dozen or more sound spikes of variable height, and sounds still appear in the ISIs.

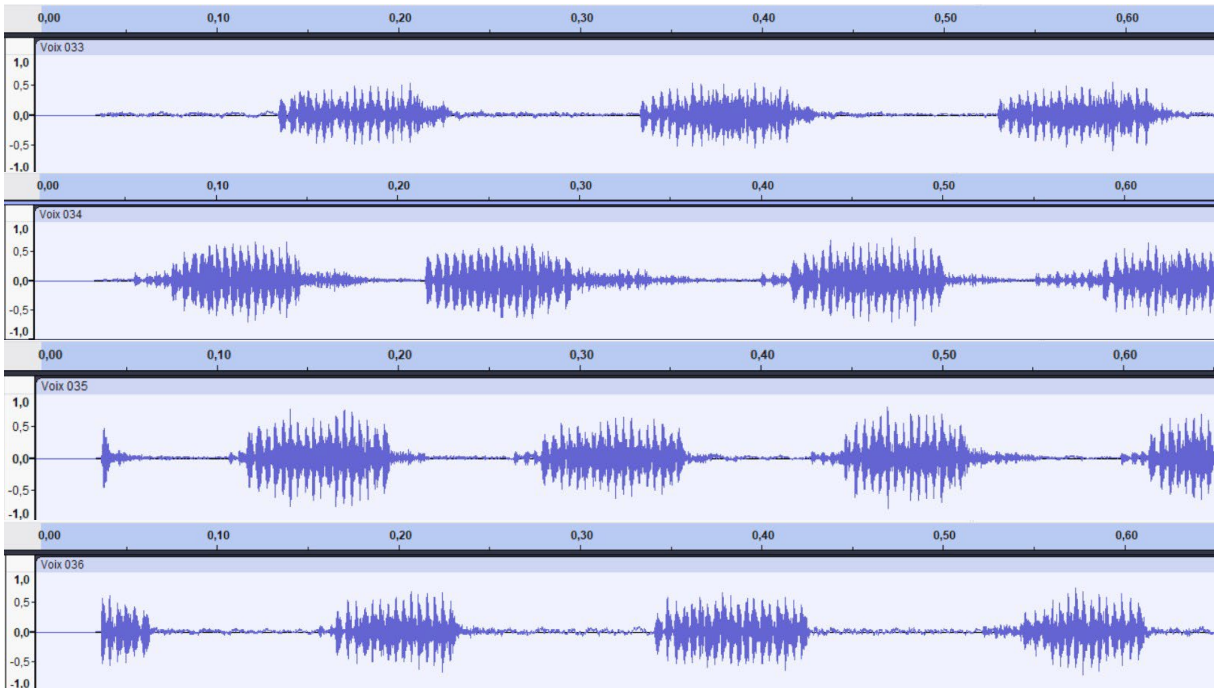


Figure 5. S and ISI in the enlarged normalized waveform diagrams of the raw samples Voix 033 - Voix 036.

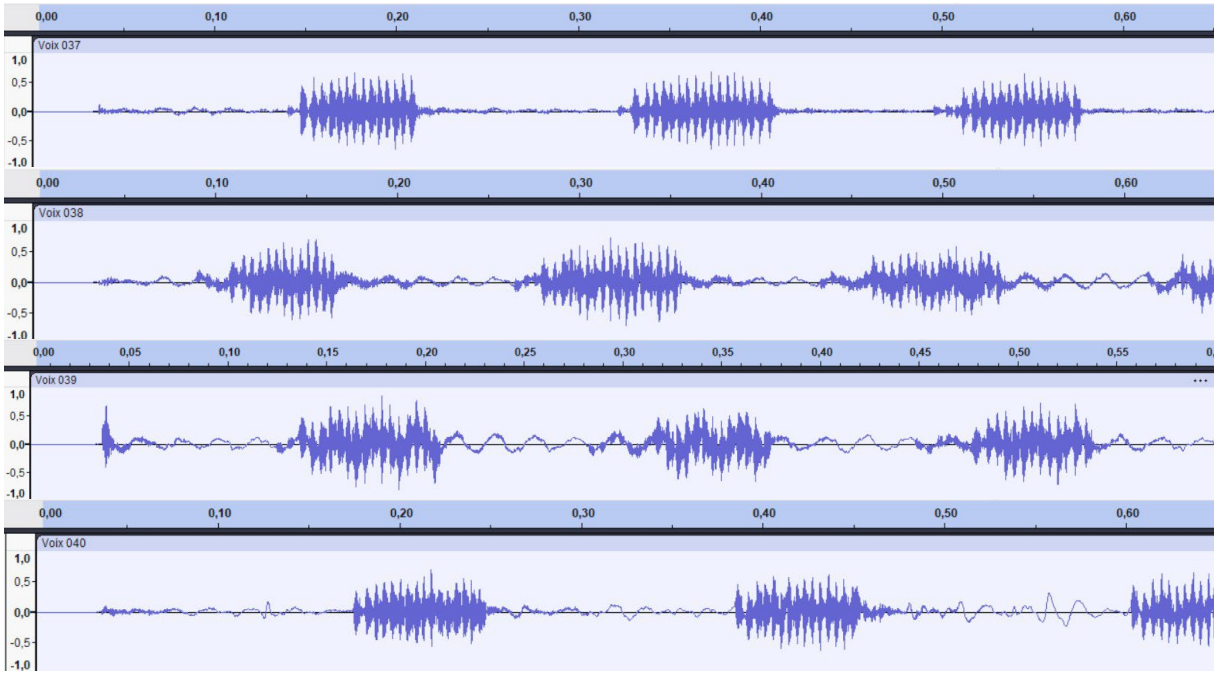


Figure 6. S and ISI in the enlarged normalized waveform diagrams of the raw samples Voix 037 - Voix 040.

5.3. Spectrograms

The spectrogram or sonogram of each enlarged normalized waveform diagram of the raw samples Voix 033 - Voix 040 (**Figure 7**, **Figure 8**) has been obtained by the instruction set: Audacity → File → insert the sample → select the track menu next to the name → select Spectrogram.

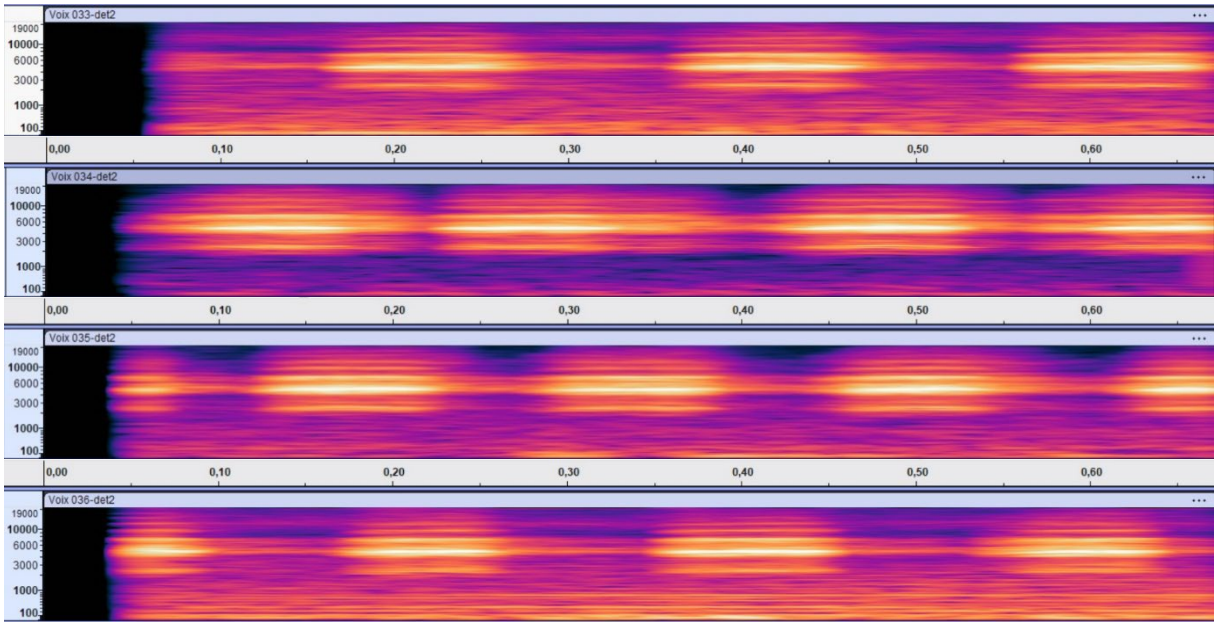


Figure 7. Spectrograms of the enlarged normalized waveform diagrams of the raw samples Voix 033 - Voix 036.

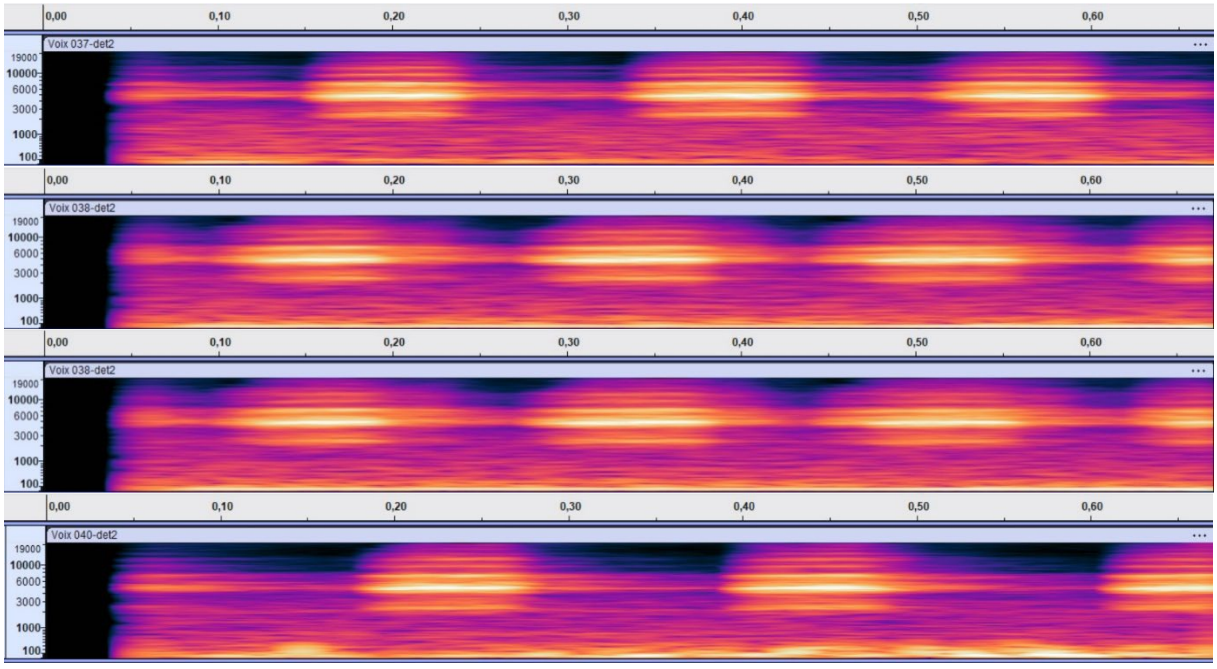


Figure 8. Spectrograms of the enlarged normalized waveform diagrams of the raw samples Voix 037 - Voix 040.

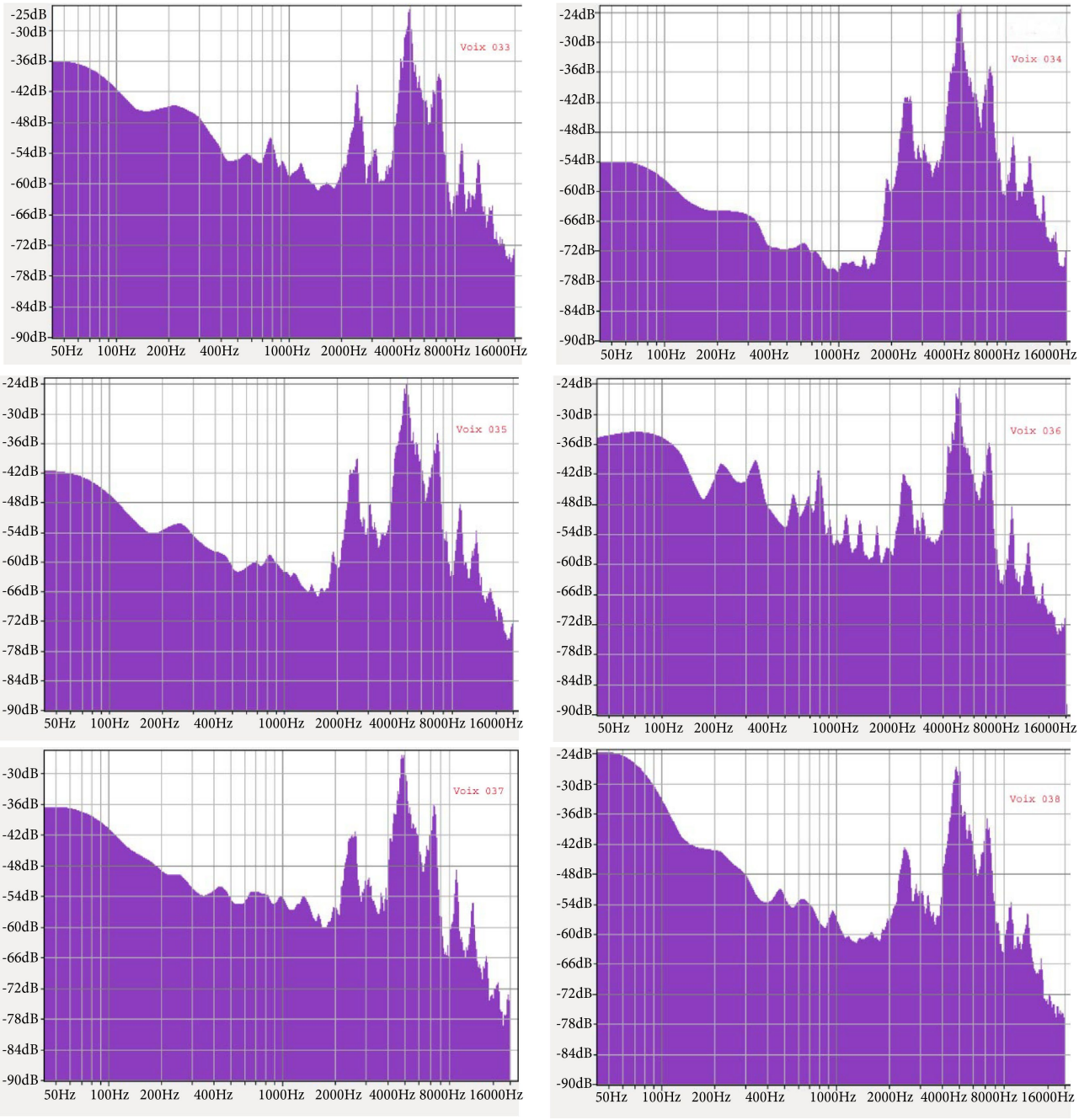
In each spectrogram, the lighter color represents the higher emitted acoustic energy. Most of the energy in an S is emitted approximately between 4 - 5 kHz. Weaker harmonics are present at the higher frequencies of approximately 6.0, 9.0, and 10.0 kHz. Weaker harmonics are present at the lower frequencies of approximately 3.5 and 3.0 kHz, and many other lower frequencies.

Each S shows a region of quick growth in the emitted acoustic energy, a region of relatively stable emitted acoustic energy, and a region of gradual reduction of

the emitted acoustic energy. In the ISIs, the energy emission level is reduced but not absent, probably because of continuous background emission.

5.4. Fourier Analysis

The Fourier analysis of each enlarged normalized waveform diagram of the raw samples Voix 033 - Voix 040 (Figure 9) has been obtained using the instruction set: Audacity → File → insert the sample → Select All → select Analyse → select Trace Spectrum. The Fourier analysis parameters were: Algorithm: Spectre, Taille: 1024, Bartlett window, Logarithmic frequence.



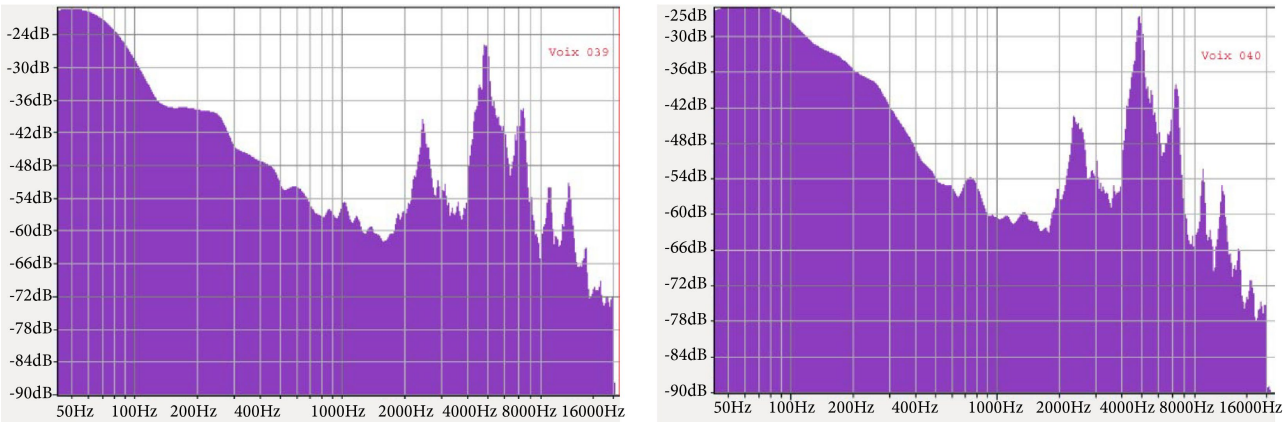


Figure 9. Fourier diagrams of the enlarged diagrams of the Voix 033 - Voix 040.

The Fourier diagrams show a principal peak of the emitted acoustic energy of approximately −24 dB in the frequency range of approximately 4.5 - 7.0 kHz, corresponding to the principal frequency range. At frequencies higher than 7.0 kHz, the emitted energy decreases, showing minor acoustic energy peaks corresponding to possible higher harmonics. At frequencies lower than 4.5 kHz, the emitted energy decreases, showing a secondary peak of the emitted acoustic energy of approximately −42 dB in the frequency range of approximately 2.0 - 4.0 kHz, corresponding to a secondary frequency range. In the frequency range of 1.0 - 2.0 kHz, the emitted acoustic energy is approximately −60 dB, −75 dB. The acoustic energy at frequencies lower than 1.0 kHz is probably due to environmental noise and/or recording device noise. It is reminded that the human ear has a theoretical sensitivity from ~20 Hz up to ~20 kHz, with maximum sensitivity between ~2 kHz and ~5 kHz and peak sensitivity around ~3 and ~4 kHz. For this reason, the principal and secondary peaks of the cicada's song are clearly heard.

6. Conclusions

This article is devoted to the implementation of a sensor package comprising the Enregistreur Vocal application installed on a Galaxy S20 FE 5G portable phone and Audacity 3.7.8 for characterizing the cicada song. From this point of view, it appears to be in line with the scope of the Journal of Sensor Technology.

Notwithstanding that the Ss in the song of the hidden cicada seem similar in length and tone height, the enlarged normalized waveform diagrams have shown marked variations in their structure. The spectrograms permitted the separation of Ss and ISIs, the determination of the Ss harmonics, and the presence of a continuous background emission in the ISIs. The Fourier analysis diagrams permitted the identification of the principal, secondary, and higher harmonics of the Ss of the cicada song.

The hope is that this article will stimulate further research concerning cicadas and cicada song. The recorded raw cicada song samples Voix 033 - Voix 040 are available on request.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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