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[COMMUNICATION]

Vocal Repertoire of the Japanese Treefrog, *Rhacophorus arboreus* (Anura: Rhacophoridae)

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ABSTRACT—The vocal repertoire of males and females of the treefrog, *Rhacophorus arboreus* was described with audiospectrogram and oscillogram. The repertoire of males included the advertisement call, the courtship call, four types of aggressive calls and compound calls. The repertoire of females included three types of release calls.

INTRODUCTION

Acoustic communication is one of the well documented features in the mating of anuran amphibians [1]. Male anurans use different kinds of calls in response to particular situations [1–3]. Description of the vocal repertoire is one of the prerequisites to study the mating behavior and acoustic communication in anurans. The vocal repertoire in the foam-making rhacophorid frogs has not been described. The advertisement call has been described in several species [4, 5] and Coe [6] reported the change in *Chiromantis* male calls occurred in response to the approach of females.

In the present paper, we describe the physical properties of vocalizations, their functions and the situations where they were emitted in the Japanese treefrog, *Rhacophorus arboreus*.

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MATERIALS AND METHODS

The observations were made from May to July, in 1984 and 1985 at the Hyoutan pond in Iwamuro, Niigata, Japan (altitude about 180 m) [7]. Frogs were individually marked with colored waist bands. Observations were made with a 6V battery head lamp that appeared not to disturb the behavior of frogs.

Vocal activities of frogs were recorded with SONY TC-D5M tape-recorder and SONY ECM Z-300 microphone. Metal cassette tapes were used as the recording media. All the recordings were made when the ambient temperature was from 18 to 23°C. Soundspectrogram analysis was performed on MacReacorder Sound analyzing system and Kay 7800 Digital Sonagraph.

RESULTS AND DISCUSSION

We were able to distinguish the following nine types of vocalizations. They were typical ones and intermediates between call types were not described in this study except the variation in the advertisement call in the section of the compound call. Of the nine types, six were produced by males and three by females. We followed the classification of vocalizations by Wells (cited in [3]) except for compound calls. In this classification, vocalizations were classifed by their function as other terminologies of anuran vocalizations. In statistical analysis of calls, the sample size was the number of individuals. We presented mean ± SD

for physical features of calls. The statistical test used was Mann-Whitney *U*-test if not otherwise mentioned. Figure 1 shows audiospectrograms (sonograms) and oscillograms of these calls.

Advertisement call (*A, hereafter*)

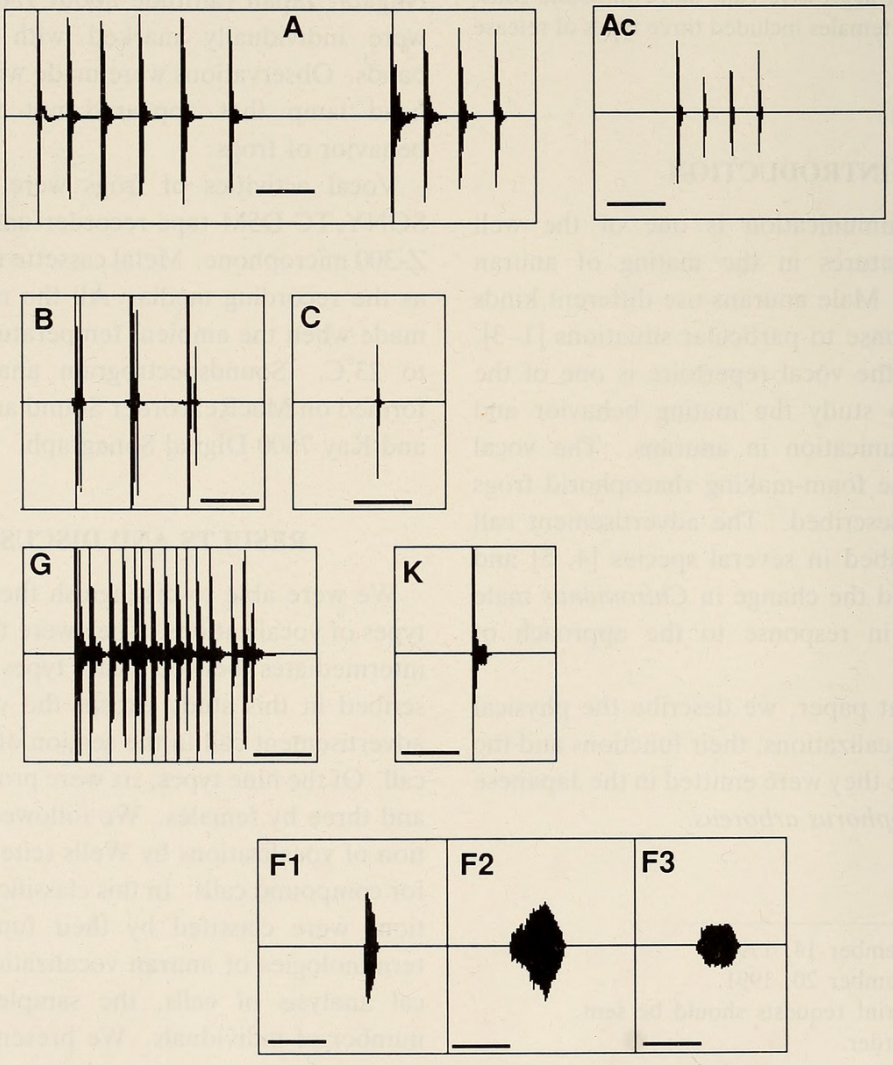
This call is a rattle that consists of 2 to 6 notes. The harmonics were not clear. The dominant frequency ranged from 900 to 1900 Hz. This call sometimes has a preceding and/or a following weak notes (Fig. 2). The spectral feature of this weak additional note was different from notes of A. The spectrum of this additional note was near the pure tone and had a sharp peak at about 900 Hz

Courtship call (*Ac, hereafter*).

This call was emitted by males when females were near (within about 50 cm from males). The temporal structure of Ac was similar to A except a shorter interval between notes. The spectral feature of individual notes was similar to A. The interval between notes in a call was significantly shorter in Ac (39.6 ± 4.2 ms, n=10) than in A (61.5 ± 6.4 ms, n=26) ($z=4.6$, $P<0.001$).

Aggressive calls

multi-note aggressive call (*B, hereafter*): This call is also a rattle consisting of several notes similar to A. The dominant frequency was similar to A. But, B had a flatter spectrum than A. As shown in Figure 1, the temporal feature of B was similar to A except that a note of B often had two pulses. The duration of a whole note of this call (29.10 ± 5.9ms, n=14) was significantly longer than A ($z=3.52$, $P<0.001$) though the duration of the major pulse (20.72 ± 2.6 ms, n=14) was not significantly longer than that of A (21.2 ± 7.0 ms, n



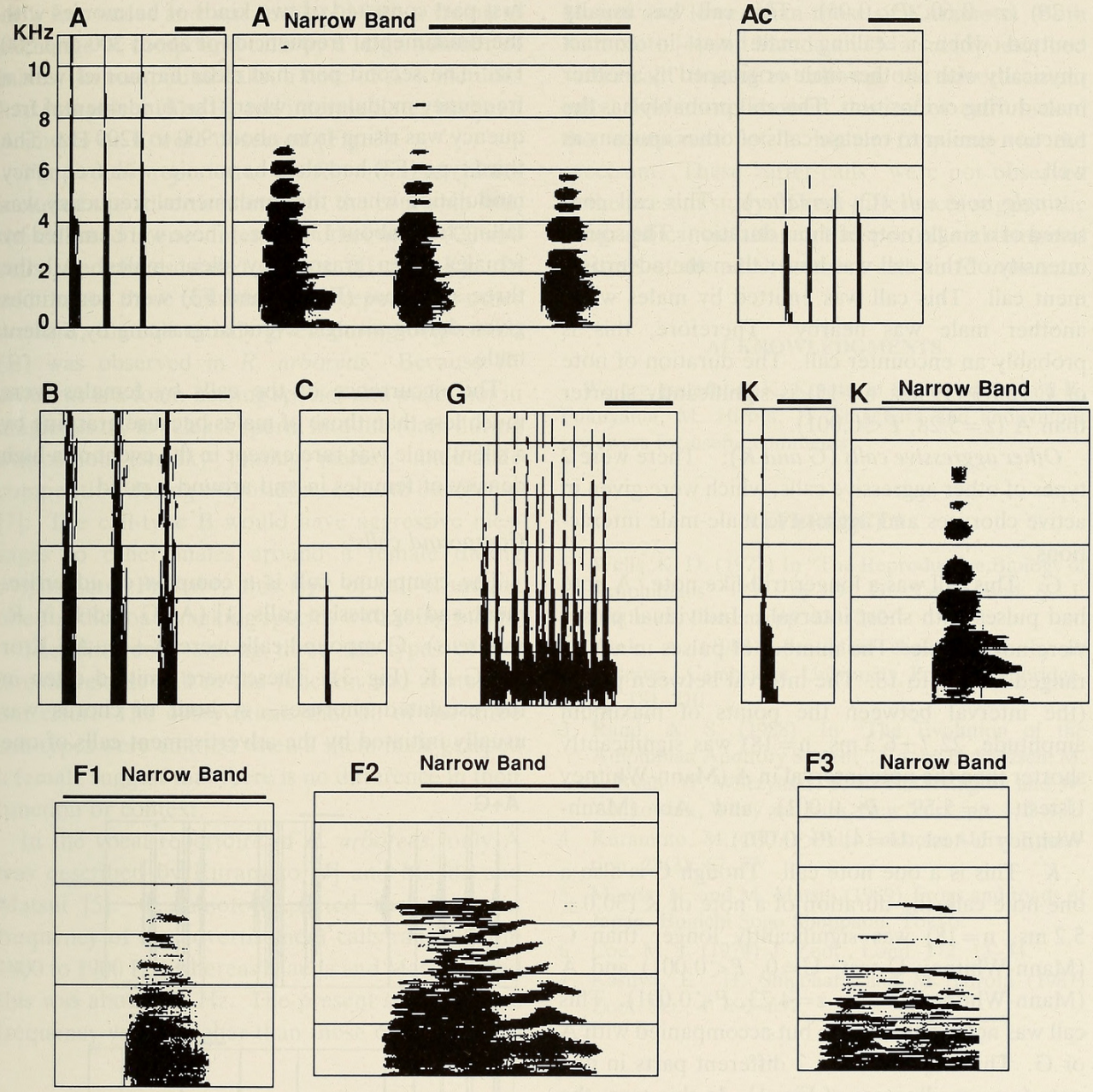


FIG. 1. Oscillographs (p. 470) and sonograms (p. 471) of vocalizations.
horizontal bar shows 0.1 s. For sonograms, the grids of 2 KHz interval were also shown. Oscillograms and sonograms were made by MacRecorder and Sound Edit. Sonogram setting was transform size = 64 (frequency resolution was 344 Hz) if not mentioned, and transform size = 512 (frequency resolution was 43 Hz) if shown as "narrow band".
A: advertiserment call, B: multi-note aggressive call, Ac: courtship call, C: one note call (encounter call), G and K: aggressive call, F1, F2 and F3: female release call.

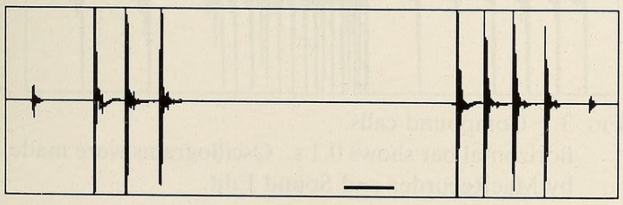


FIG. 2. Weak note which preceded and/or followed advertisement call.
horizontal bar shows 0.1 s. Left: additional note preceding an advertisement call, and right: following an advertisement call. Oscillograms were made by MacRecorder and Sound Edit.

=26) ($z=0.60$, $P>0.05$). This call was usually emitted when a calling male was in contact physically with another male or grasped by another male during oviposition. This call probably has the function similar to release calls of other anurans as well.

single note call (*C, hereafter*): This call consisted of a single note of short duration. The sound intensity of this call was lower than the advertisement call. This call was emitted by males when another male was nearby. Therefore, this is probably an encounter call. The duration of note of C (6.8 ± 0.9 ms, $n=15$) is significantly shorter than A ($z=5.28$, $P<0.001$).

Other aggressive calls (*G and K*): There were 2 types of other aggressive calls, which were given in active choruses and aggressive male-male interactions.

G This call was a longer trill-like note. A note had pulses with short intervals. Individual pulses were not audible. The number of pulses in a note ranged from 5 to 18. The interval between pulses (the interval between the points of maximum amplitude, 22.7 ± 6.3 ms, $n=18$) was significantly shorter than the note interval in A (Mann-Whitney U-test, $z=5.59$, $P<0.001$) and Ac (Mann-Whitney U-test, $U=4$, $P<0.001$).

K This is a one note call. Though C is also a one note call, the duration of a note of K (30.0 ± 5.2 ms, $n=18$) was significantly longer than C (Mann-Whitney U-test, $U=0$, $P<0.001$) and A (Mann-Whitney U-test, $z=4.23$, $P<0.001$). This call was not emitted alone but accompanied with A or G. This call often has 2 different parts in one note (see, oscillogram of Fig. 1). In this case, the first part with the larger amplitude had the spectral feature similar to A, and the second part with the small amplitude had the clear harmonics (fundamental frequency was about 700Hz).

Female release calls (*F*)

These calls had different temporal and spectral features from the vocalizations by males. These calls included three types of vocalizations (Fig. 1). The first one (F1) had harmonics with a weak frequency modulation (the freqeuncy was falling). The fundamental frequency was about 1100 Hz. The second one (F2) had two parts in a note. The first part consisted of two kinds of harmonics with the fundamental frequencies of about 300 and 500 Hz. The second part had clear harmonics with a freqeuncy modulation where the fundamental frequency was rising from about 900 to 1200 Hz. The third type (F3) had clear harmonics with frequency modulation where the fundamental frequency was falling from about 1300 Hz. These were emitted by females when grasped by silent males. All the three sub-types (F1, F2 and F3) were sometimes given during a single event of grasping by a silent male.

The occurrence of the calls by females were much less than those of males because grasping by a silent male was rare except in the event of a high density of females in and around a pond.

Compound calls

The compound call is a complex of advertisement and aggressive calls [1] (A, G and K in *R. arboreus*). Compound calls were A+G, A+K or A+G+K (Fig. 3). These were emitted often in the escalated choruses. A bout of chorus was usually initiated by the advertisement calls of one

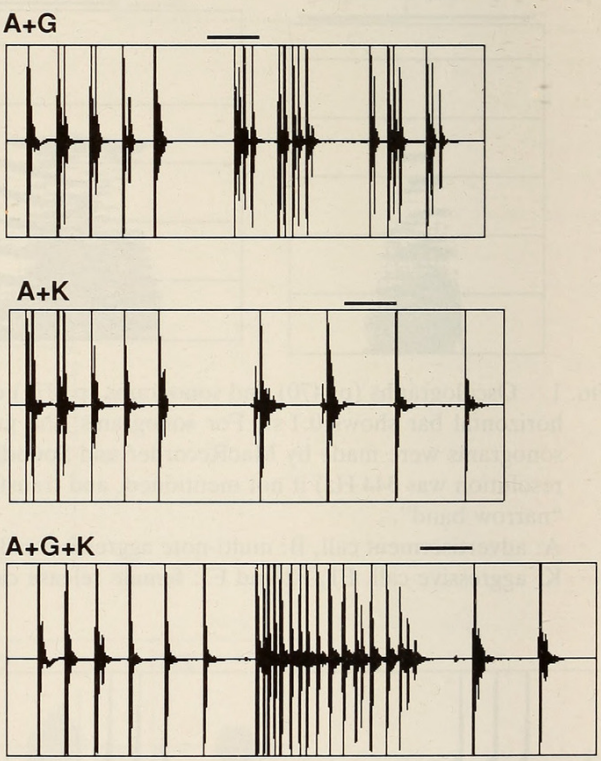


FIG. 3. Compound calls.
horizontal bar shows 0.1 s. Oscillograms were made by MacRecorder and Sound Edit.

or a few males and was escalated into a frequent exchange of compound calls by a large number of males. In compound calls, a note of A sometimes had two pulses (like B) and intermediates between A and G or K were observed (Fig. 3).

The vocal repertoire of *R. arboreus* males included the advertisement call, the courtship call, the call used in encounter with other males (C) and calls used in escalated chorus (G and K). In addition to these calls that were reported in other anurans, the call usually given during oviposition (B) was observed in *R. arboreus*. Because *R. arboreus* is a foam-nesting species and males not in amplexus try to release sperm into the foam during oviposition (sneaky joining males), male-male competition during oviposition seems to be intense [7]. The call-type B would have aggressive messages to other males around a female during oviposition. Probably this type of call is unique one for the foam-making species with joing males.

The difference among three sub-types of the female release call in the function and context is not clear. The observations that all of the three sub-types were emitted when a silent male grasped a female suggest that there is no difference in their function or context.

In the vocal repertoire of *R. arboreus*, only A was described by Kuramoto [4] and Maeda and Matsui [5]. Kuramoto reported the dominant frequency of the advertisement calls ranged from 1800 to 1900 Hz, whereas Maeda and Matsui noted this was about 800 Hz. The present study reports frequency values higher than those of Maeda and Matsui and lower than those of Kuramoto. Both Kuramoto [4] and Maeda and Matsui [5] described "after call" that often followed the advertisement calls. Kuramoto showed this "after call" lacked the component of a higher frequency in the spectrum. These "after-calls" were not observed in the present study. These differences suggest the geographical variation in the spectral and temporal features of the advertisement calls in *R. arboreus*.

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