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Advertisement call characteristics of a Taiwanese green treefrog *Rhacophorus prasinatus*

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Abstract. Variations in parameters of three types of notes were analyzed in Taiwanese treefrog, *Rhacophorus prasinatus*. In contrast to the previous knowledge, the type B notes are shown to be well pulsed. Frequency parameters show variation, and are not correlated to temperature. Note duration is predicted to be shortened, and note repetition rate to increase under higher temperatures. From the advertisement call characteristics, *R. prasinatus* is supposed to bridge the gap between *R. viridis* on the one hand, and *R. owstoni* on *R. moltrechti* on the other.

Key words. Vocal repertoire, advertisement call, temperature.

Introduction

Among green treefrogs occurring in Taiwan, *Rhacophorus prasinatus* (Mou, Risch & Lue 1983) is peculiarly big-growing (mean SVL 56 mm in males and 72 mm in females: Chen 1992) as compared with its relatives, and looks very attractive, being emerald green and golden in the body colour. This species has a complicate nomenclatural history, and is better known by its synonym *R. smaragdinus* (Lue & Mou 1983; see Zhao & Adler 1993: 158 for a taxonomic review). Its distribution range is restricted to a limited area of northern Taiwan (Lue et al. 1991). Call characteristics of this species recorded at 27—29 °C have been reported by Chou (1992). As is well known, however, some of the acoustic parameters of anurans vary with changes of the surrounding temperatures (e. g., Nevo & Schneider 1976, Schneider 1977, Zweifel 1968). *Rhacophorus prasinatus* is a prolonged breeder and the temperatures surrounding calling males vary greatly from about 13 to 29 °C (Chen 1992). Thus, Chou's (1992) recordings were made at extremely high temperatures, and additional information is needed to better understand the call characteristics of this species. In this article, we will report on the acoustic characteristics of *R. prasinatus* recorded at temperatures lower than those reported by Chou (1992), and clarify the more detailed structure of some calls. Also, relationships of temperature to call parameters are analyzed in this species.

Materials and methods

Calls of *R. prasinatus* were recorded at Mt. Tatung Shan, Feitsui valley, Taipei Hsien on 12, 14, and 24 December 1991. All calls were recorded in the field with cassette tape recorders (Sony TCD5 & TCD5M) with external microphones (Sony ECM-23F & Audio-technica ATM 53) and analyzed using computer programs, SoundEdit Vers. 2 or SoundEdit Pro (MacroMind-Paracomp, Inc.) by a Macintosh computer. Air temperatures recorded near the calling males, were 18.2 °C, 15.0 °C, and 19.0 °C, on 12, 14, and 24 December 1991, respectively.

In the following description, the term "note" means a pulse group, "note length" the time from the beginning of the first pulse to the end of the last pulse in a note, and "pulse repetition rate" the number of pulses per s. Sample size (n) is indicated as the number of calls or notes analyzed/the number of males recorded, and means are given for the number of calls recorded. For statistic analyses, Wilcoxon rank sum tests were utilized. In order to examine relationships between parameters, analysis-of-covariance (ANCOVA) was performed. The significance level was set at 0.05.

Results

From the field observation of breeding behavior, advertisement, courtship, encounter, release, and distress calls (Duellman & Trueb 1986) were differentiated in the vocal repertoire of male *R. prasinatus* (Chen 1992). Of these, the advertisement call included three types of notes (fig. 1), which assuredly correspond to the types, A, B, and C, of Chou (1992). In the following descriptions, only these three note types are considered.

We could not record type B and C notes at 15.0 °C. In the type A note, some of the temporal and frequency characteristics differed between calls recorded at different temperatures, but differences were insignificant between calls recorded at 18.2 °C and 19.0 °C. Thus, the following descriptions and comparisons are made mainly on calls recorded at 15.0 °C and 18.2 °C.

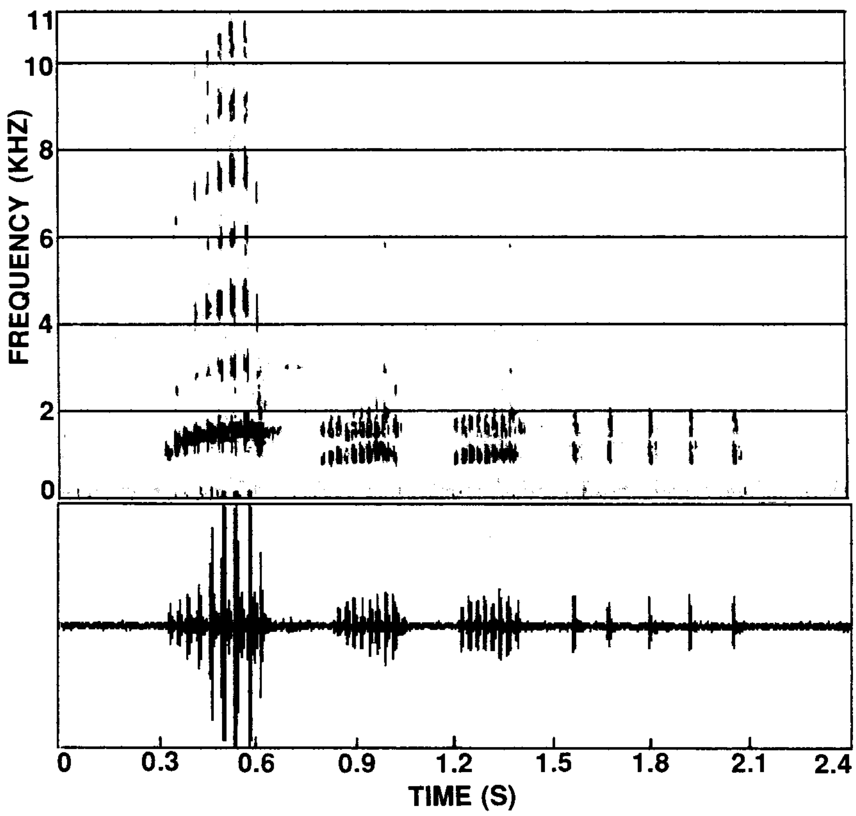

Fig. 1: A sonagram (top) and a sound wave form (bottom) of an advertisement call of *Rhacophorus prasinatus*, including one type A, two type B, and four type C notes. Recorded at 18.2 °C.

The type A note (fig. 2) was well pulsed and included five to 15 pulses (table 1). The note length increased with increasing number of pulses, and at 15.0 °C, the mean length varied from 0.302 s in the note with seven pulses to 0.613 s in the note with 15 pulses. The pulse repetition rate was almost constant, means varying from 23.04 to 24.70. Each pulse, except for the initial and the final one, had clear harmonics, and a clear frequency modulation was seen within a note (fig. 1). The dominant frequency in the mean of the initial pulse was about 1135—1400 Hz, but it increased to about 1500—1600 Hz in the mean of the climax pulse, and rapidly decreased to about 1100—1300 Hz in the final pulse. In the climax pulse, the second dominant frequency was about 4400—4750 Hz, and seven harmonic bands in total were apparent between 0—11 000 Hz (fig. 2). Average harmonic interval, therefore, was about 1550 Hz, and this value corresponded to the fundamental frequency. Thus, the first dominant frequency was the fundamental and the second corresponded to the third harmonic of the spectrogram.

Similar trends were found in the calls recorded at 18 °C, but the note lengths were significantly shorter than in 15.0 °C (table 1; Wilcoxon rank sum tests: $p<0.0001$ in the eight pulsed note; $p<0.0001$ in the nine pulsed note; $p<0.0003$ in the ten pulsed note). The mean note lengths varied from 0.180 s in the note with five pulsed to 0.395 s in the note with 11 pulses. The pulse repetition rates varied from 27.39 to 32.57, and were much larger than in 15.0 °C (Wilcoxon rank sum tests; $p<0.0001$ in the

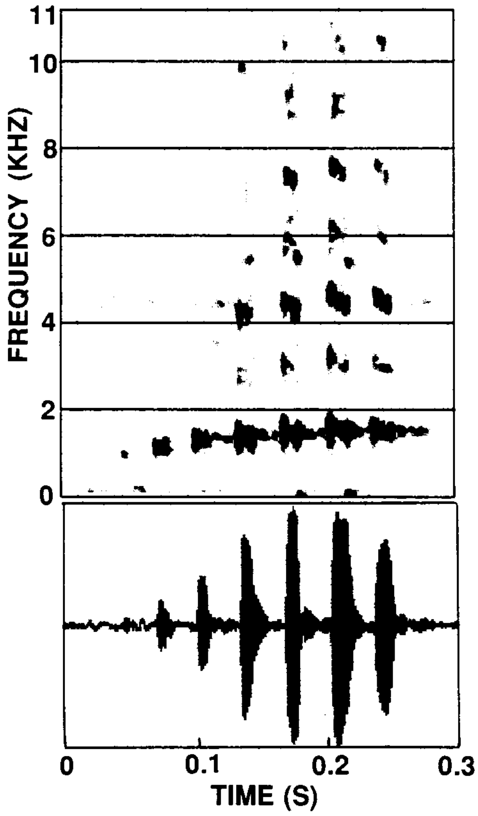

Fig. 2: A sonagram (top) and a sound wave form (bottom) of a type A note of *Rhacophorus prasinatus*. Recorded at 18.2 °C.

Table 1: Characteristics of type A note of *Rhacophorus prasinatus* recorded at 15.0 and 18.2 °C (Mean±1SD, followed by sample size (number of notes/number of males)).

N of pulse	Note length (s)	Pulse repetition rate	Dominant frequency in climax pulse (Hz)
15.0 °C			
7	0.302±0.020 3/2	23.24±1.56 3/2	1500.0±70.7 3/2
8	0.348±0.010 7/4	23.04±0.66 7/4	1557.1±34.5 7/4
9	0.383±0.015 13/5	23.43±0.86 13/5	1584.6±37.6 13/5
10	0.425±0.013 8/4	23.55±0.70 8/4	1556.3±49.6 8/4
11	0.446 2/1	24.70 2/1	1525.0 2/1
13	0.562 2/1	23.13 2/1	1575.0 2/1
14	0.598 1/1	23.40 1/1	1600.0 1/1
15	0.613 1/1	24.49 1/1	1500.0 1/1
18.2 °C			
5	0.180±0.004 3/3	27.82±0.58 3/3	1340.0±52.9 3/3
6	0.219±0.007 8/5	27.39±0.94 8/5	1325.7±64.8 7/5
7	0.235±0.028 16/7	30.38±4.96 16/7	1420.0±154.3 16/7
8	0.273±0.031 26/13	29.86±4.57 26/13	1481.3±95.7 23/13
9	0.314±0.043 16/11	29.38±5.29 16/11	1522.5±63.0 12/11
10	0.332±0.086 12/8	32.57±10.16 12/8	1486.7±51.9 12/8
11	0.395±0.040 9/6	28.11±3.08 9/6	1508.9±27.1 9/6

eight pulsed note; $p<0.0001$ in the nine pulsed note; $p<0.0003$ in the ten pulsed note). Some notes had much larger rates than in others, and these rapid notes were emitted by one individual immediately after another's advertisement call. The mean dominant frequency increased from 938—1027 Hz in the initial pulse to 1325—1522 Hz in the climax pulse, and decreased finally to about 1210—1436 Hz. The dominant frequencies in the climax pulses were significantly lower in calls recorded at 18.2 °C than in 15.0 °C (Wilcoxon rank sum tests: $p=0.019$ in the eight pulsed note; $p=0.005$ in the nine pulsed note; $p=0.020$ in the ten pulsed note).

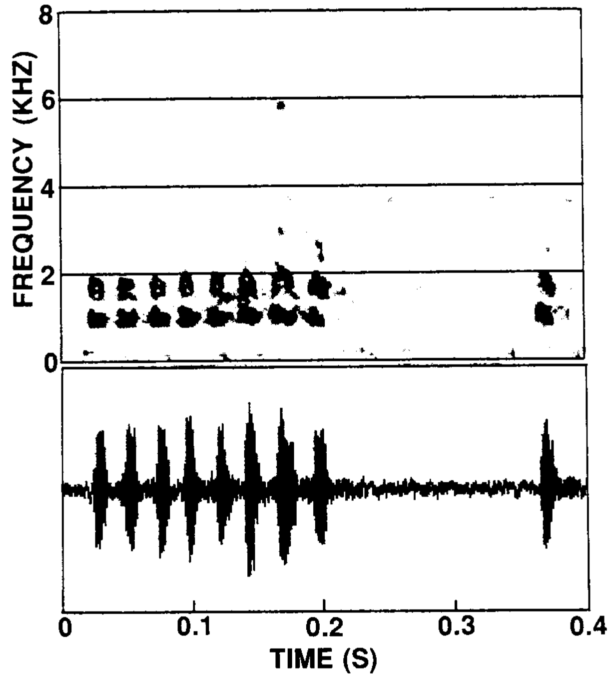

Fig. 3: A sonagram (top) and a sound wave form (bottom) of a part of an advertisement call of *Rhacophorus prasinatus*, showing a type B (eight-pulsed) and a type C notes. Recorded at 18.2 °C.

The type B note (recorded at 18.2 °C) was also pulsed (fig. 3), and the note length varied from 0.014 s in the note with one pulse to 0.340 s in the note with 14 pulses (table 2). When pairs of notes with the same number of pulses were compared, note lengths in the type A notes were always longer than in the type B (Wilcoxon rank sum tests: $p<0.03$), in all the combinations except for the notes with ten pulses. The pulse repetition rate varied from 32.83 to 53.48, but in most cases larger than 40. Some notes with a small pulse repetition rate included pulses with irregular intervals. Like in the note length, the type A notes had larger rates than the type B in all the combinations except for the one with ten pulses (Wilcoxon rank sum tests: $p<0.03$). The dominant frequency varied from about 950 to 1100 Hz, and was much lower than in the type A note (Wilcoxon rank sum tests: $p<0.002$, in all the combinations).

In the type C note (recorded at 18.2 °C), the note length varied from 0.004 s in the note with one pulse to 1.170 s in the note with ten pulses (table 3). The mean pulse repetition rate decreased from 19.31 to 8.54 with the increment of the pulse number. The dominant frequency was similar to that in the type B (fig. 3), and varied from about 950 to 1200 Hz.

As seen in fig. 4, the note duration and the pulse number had positive correlations in all the three note types. Both slopes and positions (table 4) differed among the regression lines (ANCOVA, $p<0.0001$), and from the multiple comparisons among slopes, it was concluded that the slope decreased in the order of type B, type A (15 °C), type A (18.2 °C) and type C. In the type A notes, the calculated slope was

Table 2: Characteristics of type B note of *Rhacophorus prasinatus* recorded at 18.2 °C (Mean±1SD, followed by sample size (number of notes/number of males)).

N of pulse	Note length (s)	Pulse repetition rate	Dominant frequency (Hz)
1	0.014	—	1050
	2/1	—	2/1
2	0.037	53.48	950
	1/1	1/1	1/1
3	0.069±0.006	43.95±4.07	1025.0±50.0
	4/2	4/2	4/2
4	0.085	47.17	1300
	1/1	1/1	1/1
5	0.124±0.012	40.51±3.82	1026.7±40.4
	3/3	3/3	3/3
6	0.189±0.035	32.83±7.23	1004.3±36.0
	7/4	7/4	7/4
7	0.167±0.024	42.47±4.69	1041.0±71.9
	10/5	10/5	10/5
8	0.202±0.037	40.76±6.42	1060.0±63.2
	16/7	16/7	15/7
9	0.224±0.022	40.47±3.84	1073.1±105.3
	15/5	15/5	14/5
10	0.239±0.019	42.16±3.10	1031.1±28.9
	12/9	12/9	9/9
11	0.258±0.008	42.65±1.29	1058.3±49.2
	8/5	8/5	6/5
13	0.317±0.019	41.07±2.47	1100.0±180.3
	3/1	3/1	3/1
14	0.340±0.028	41.38±3.33	1033.3±57.7
	3/1	3/1	3/1

smaller in 18.2 °C than 15 °C, but the position of the regression line was higher in the former, indicating larger pulse repetition rate.

Discussion

Acoustic features of *R. prasinatus* reported here are basically identical to those reported by Chou (1992 as *R. smaragdinus*), but there is at least one great discordance. Chou (1992) reported the note type B to be nonpulsed, but actually it is pulsed as clearly seen in fig. 1. This difference seems to have derived from the difference in the quality of the recording or method of analyses.

As shown in the result, call parameters vary in response to variant temperatures, and this becomes more evident when the present data are compared with those given by Chou (1992). Since Chou (1992) did not give relationships between the number of pulse and other parameters, it is impossible to compare his data directly with ours. However, from his data of pulse repetition rate, some parameters in notes with nine and 11 pulses can be estimated. When these data are considered, it is clear that the

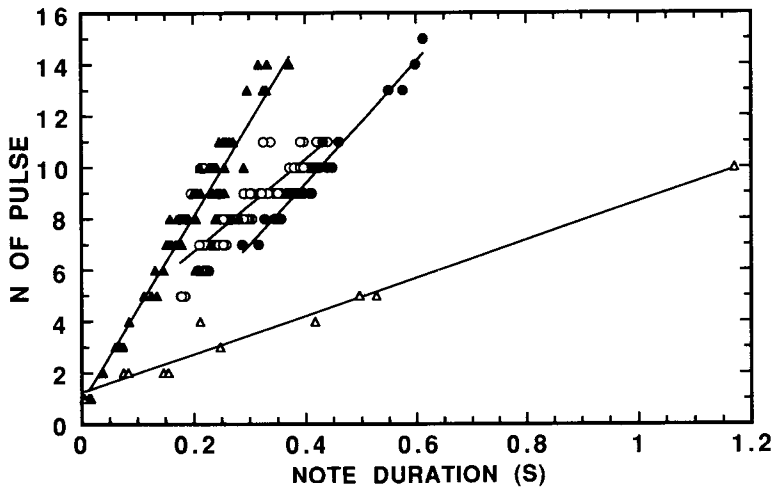

Fig. 4: The relationship between the note duration (in s) and the number of pulse in the three types of notes of *Rhacophorus prasinatus*. Closed circle=note type A at 15.0 °C (Y=23.834X−0.152, r=0.981, n=36 notes/5 males, p<0.0001); open circle=note type A at 18.2 °C (Y=17.932X+3.158, r=0.780, n=89 notes/13 males, p<0.0001); closed triangle=note type B (Y=36.284X+0.846, r=0.922, n=85 notes/9 males, p<0.0001); open triangle=note type C (Y=7.434X+1.249, r=0.984, n=11 notes/8 males, p<0.0001).

note decreases in its duration with the increase of the temperature (fig. 5). The relationships of duration (Y) to temperature (X) are expressed as $Y=0.0136X+0.577$ ($r=-0.990$, $p=0.009$) and $Y=-0.0160X+0.688$ ($r=-0.999$, $p=0.005$) in the notes with nine and 11 pulses, respectively. The regression line for the 11 pulsed note is significantly higher in position than that for the nine pulsed one (ANCOVA:

Table 2: Characteristics of type C note of *Rhacophorus prasinatus* recorded at 18.2 °C (Mean±1SD, followed by sample size (number of notes/number of males)).

N of pulse	Note length (s)	Pulse repetition rate	Dominant frequency (Hz)
1	0.004	—	1200
	1/1	—	1/1
2	0.115±0.042	19.31±7.08	1100.0±204.1
	4/2	4/2	4/2
3	0.247	12.13	1000
	1/1	1/1	1/1
4	0.314	14.26	950
	2/2	2/2	2/2
5	0.511	9.79	1050
	2/1	2/1	2/1
10	1.170	8.54	1100
	1/1	1/1	1/1

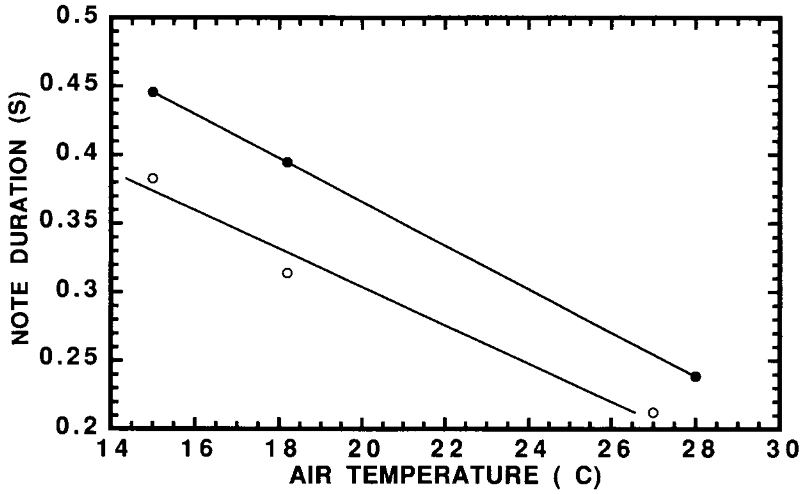

Fig. 5: The relationship between the air temperature (°C) and the note duration (in s) in the type A notes of *Rhacophorus prasinatus*. Data for 27 °C and 28 °C calculated from Chou (1992). Closed circle=note with 11 pulses (Y=−0.016X+0.688, r=−0.999, n=3, p=0.005); open circle=note with nine pulses (Y=−0.014X+0.577, r=−0.990, n=4, p=0.009).

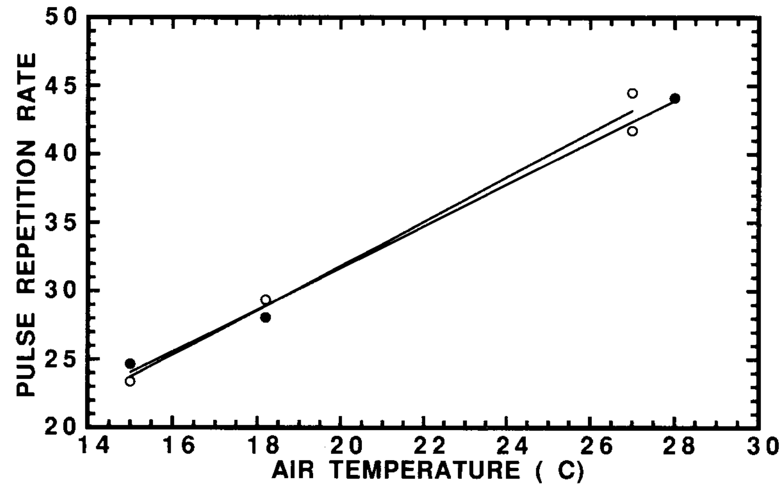

Fig. 6: The relationship between the air temperature (°C) and the pulse repetition rate in the type A notes of *Rhacophorus prasinatus*. Data for 27 °C and 28 °C calculated from Chou (1992). Closed circle=note with 11 pulses (Y=1.529X+1.116, r=0.997, n=3, p=0.047); open circle=note with nine pulses (Y=1.622X−0.581, r=0.993, n=4, p=0.007).

p=0.005), though the slopes did not differ between the two lines (ANCOVA: p> 0.05).

Pulse repetition rate also correlates to the temperature, and the number of pulse per unit time is predicted to increase under higher temperature conditions (fig. 6). The relationships of repetition rate (Y) to temperature (X) in the notes with nine and 11 pulses are expressed as Y=1.6216X−0.581 (r=0.993, p=0.007) and Y=1.5294X+1.116 (r=0.997, p=0.047), respectively. Unlike in the note duration, neither the slope nor position differed in the two regression lines (ANCOVA:

p>0.05), and the combined regression line is expressed as $Y=1.5831X+0.156$ ($r=0.994$, $p<0.0001$). In contrast to these two parameters, frequency parameters (initial, climax, and final ones) are insignificantly correlated to the temperature (ANCOVA: $p>0.05$).

Because of the presence of three different note types, Chou (1992) considered the call of *R. prasinatus* complicated and unique among the rhacophorid frogs of Taiwan, Ryukyu Is., and Japan. However, Chou (1992) himself noted that other Taiwanese species, *R. taipeianus* and *R. moltrechti* also had at least two types of calls. In fact, the vocal repertoire of *R. prasinatus* is not limited to these three types (Chen 1992), and an even more complicated repertoire is found in *R. arboreus* from Japan (Kasuya et al. 1992). Thus, the 'complicated calls' are not unique to *R. prasinatus* among the rhacophorid frogs of these regions.

Chou (1992) emphasized the complexity of the call in *R. prasinatus* and associated this species with *R. appendiculatus* and *R. bimaculatus* (=*R. bipunctatus*) from Thailand, both of which have been reported to have complicated calls (Heyer 1971). Actually, call structures of the latter two species are quite dissimilar to those of *R. prasinatus*, so are their morphologies (Matsui unpublished), and acoustic convergences or close phylogenetic relationships in these species are unlikely.

Instead, *R. prasinatus*seems acoustically related to species from Taiwan and Japan. On the basis of acoustic characteristics, Kuramoto & Utsunomiya (1981) suggested the possibility of splitting species of *Rhacophorus* known from Japan and Taiwan at that time into three groups: 1) *R. taipeianus*, 2) *R. moltrechti* and *R. owstonii*, and 3) *R. arboreus*, *R. schlegelii* and *R. viridis*. The first group is characterized by a very long trill, whereas the second group by clear harmonics and the presence of two phases that differ in pulse repetition rate. The call of the third group is neither very long nor with different phases. The type A note of *R. prasinatus* is similar to the note of *R. viridis* in the temporal and frequency characteristics (see the sonogram in Maeada & Matsui 1989). Therefore, the species would be grouped into the third group if only the type A note is considered. However, in *R. prasinatus* the type B and C notes usually follow the type A note , and this pattern can be well compared to the complex phases seen in frogs of the second group (*R. moltrechti* and *R. owstonii*). Thus, *R. prasinatus* seems to be acoustically intermediate between the second and the third groups.

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Zusammenfassung

Für 3 Ruftypen des Baumfrosches *Rhacophorus prasinatus* von der Insel Taiwan wurde die Varianz verschiedener Strukturparameter analysiert. Im Gegensatz zu früheren Befunden erwiesen sich Rufe des Typs B als deutlich gepulst. Frequenzparameter variieren, aber nicht mit der Temperatur korreliert. Die Dauer der Rufe sinkt und ihre Wiederholungsrate steigt mit zunehmender Temperatur. Die Strukturmerkmale der Werberufe von *R. prasinatus* sind intermediär zu denen von *R. viridis* einerseits und *R. owstoni* andererseits.

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