Comparison of anuran acoustic communities of two habitat types in the Danum Valley Conservation Area, Sabah, Malaysia

Doris Preiningr, Markus Böckle & Walter Hödl

Abstract. We compared advertisement calls of frog assemblages in two different habitats, (i) an open area along a dirt road with ponds and secondary vegetation; (ii) a fast flowing stream in primary forest. Eleven frog species were recorded and significant differences in the dominant call frequencies between the two observed frog communities were discovered. Stream-breeding species produce higher frequencies than species occurring in the roadside habitat. Noisy habitats have an influence on dominant frequency and demand acoustic adaptations to increase the signal-to-noise ratio. Selective logging represents a major threat to stream-breeding anurans in Sabah. Pollution of clear water threatens the stream-dependent herpetofauna.

Keywords. Amphibia, Anura, conservation, vocalisation, Malaysia.

Introduction

Selective logging has been the main cause of disturbance to tropical forests in Southeast Asia (Marsh & Greer 1992, Willett et al. 2000). Concession-based timber extraction and plantation establishment result in highly fragmented forests (McMorrow & Talip 2001, Curran et al. 2004) and increase river sediment yields (Douglas et al. 1993). The extent to which biodiversity is altered in selectively logged forest is an important conservation issue. Fragmentation, degradation and conversion of rainforests affect the tropical herpetofauna (Alcala et al. 2004). About half the frog species in Southeast Asia are restricted to riparian habitats and develop in streams (Inger 1969, Zimmermann & Simberloff 1996). Most anuran stream-side communities in Borneo are known to breed in clear, turbulent water and are absent in streams with silt bottoms and lacking riffles and torrents (Inger & Voris 1993). Several anuran community studies have focused on environmental conditions such as vegetation, elevation, rainfall and microhabitat (Inger 1969, Duellman 1978, Inger & Voris 1993, Gillespie et al. 2004). Apart from behavioural and morphological adaptations to the environment, frog assemblages also show acoustic differences. A prime factor separating species within anuran assemblages is vocalization (Duellman & Trueb 1986). Acoustic partitioning through temporal and spectral features minimizes competition and allows conspecific females to recognize individual signalling males (Hödl 1977, Garcia-Rutledge & Narins 2001, Gerhardt & Huber 2002). The dominant frequency of a frog's call is partially constrained by its body size (Kime et al. 2000). Snout-vent length and dominant frequency are negatively correlated (Littlejohn 1977, Duellman & Pyles 1983, Ryan & Brenowitz 1985). Sounds produced by waterfalls and fast-flowing streams contribute to the ambient noise level. Distinct, acoustic habitat properties ("melotops") demand different adaptations on animal vocalizations. In this study, species composition was determined for two habitats within the Danum Valley Conservation Area (DVCA), a fast flowing stream in the primary forest.
and a roadside habitat with secondary vegetation, and spectral and temporal features of the acoustic signals were compared.

Material and methods

Study area

From 10 January to 13 March 2006, we studied frog communities in DVCA, Sabah, Malaysia. DVCA has an area of 43,800 ha of lowland tropical rainforest and is located in the upper catchment area of the Segama River. The Danum Valley Field Centre (DVFC) is located on the western edge of the DVCA (4°57'40" N, 117°48'00" E; all but 9% of the area is below 760 m above sea level) from where a 2.8 km long trail leads south to the Tembaling waterfall. The rainy season in Sabah extends from December to March (Northeast Monsoon) with rainfall peak during February (monthly total 788 mm). Annual precipitation is near 3,000 mm with year-to-year fluctuation of about 100 mm. Mean annual temperature is 26.7°C with mean maximum 30.9°C and mean minimum 22.5°C. Daily temperature fluctuations are noticeably more pronounced than the year-to-year fluctuations. In the period from January to March the highest recorded temperature was 32.5°C and the lowest was 20.3°C; mean relative humidity at the DVFC was 97.0% at 8:00h and 89.7% at 14:00h. Daily rainfall and temperature data from January to March 2006 derived from the Danum Valley weather station, which is maintained by the staff of the Royal Society SE Asia Rain Forest Research Programme.

Sampling methods

We focused on two macrohabitat types. One is pristine, the other disturbed. The Tembaling River within the primary dipterocarp forest at about 900 m elevation is a fast flowing freshwater stream with rapids, waterfalls and no siltation. The selected disturbed habitat was along a dirt road in the DVFC with secondary vegetation, ephemeral roadside pools filling seasonally with water, and varying degrees of human disturbance. In both habitats 1000 m long and y-shaped transects were established and marked with coloured tape. We performed visual and acoustic encounter surveys. The search areas also included adjacent riverbanks or vegetation up to a distance of 3 m to the water- or road-edge. Sampling was performed independent of prevailing weather conditions. Each transect was sampled at least 20 times by two observers during the day and during nocturnal censuses. Repeated controls of the same transect on consecutive days were avoided to ensure independence of samples. To determine all calling species, a 24-hour time period was sampled four times during one month along both transects. After locating a vocalizing male, call recordings were made from distances of 1 to 5 m using directional and surround microphones (Sennheiser Me 66, AKG D 190 E) and DAT- recorders (Sony DAT-Rec. TCD-D8). Microhabitat temperature and humidity were measured with a digital thermohygrometer (Testo 610 GM) before each recording. Frogs were located at their resting sites, and if possible, captured and placed in plastic bags. Snout-vent length and snout-urostyle length were measured using a Wiha calliper (± 0.1 mm). To differentiate between individuals we photographed and compared dorsal colour patterns. All individuals were released after taking their measurements.

Data analysis

We digitized and analysed the recorded calls with the sound-analysis software Raven 1.2.1 at a sampling frequency of 44.1 Hz and with a mono 16 bit PCM Input and a 10 Hz update rate at normal speed. Power spectra, sonograms and oscillograms of one to five advertisement calls were analyzed for each frog and the average dominant frequency, minimum and maximum frequency, call duration, note duration, repetition rate and number of
notes, when applicable were calculated for each individual. Spectrogram views were produced with a Hann-filter with a sample size of 512 and a 3-dB filter bandwidth of 124 Hz. The correlation between body size (SVL) and dominant frequency was calculated with a Spearman non-parametric correlation (p ≤ 0.05). ANOVA (p ≤ 0.05) was used to test for statistical differences, in SVL (mm) and dominant frequency (Hz) of advertisement calls, among frog assemblages in two habitats. The influence of SVL and habitat on the dominant frequency of the frog species was calculated by an ANCOVA (p ≤ 0.05). Since the sample size for some anuran species tested was N = 1, the influence of SVL on dominant frequency was calculated twice: once corrected according to number of individuals and once without correction. All statistical tests were produced with SPSS for Mac 11.0.4.

Results

During the sampling period 20 frog species were found. Eleven frog species were recorded, six along the disturbed area and five within the pristine habitat: Fejervarya nicobariensis (Fig. 1), Fejervarya limnocharis (Fig. 2), Rhacophorus dulitensis (Fig. 3), Polypedates leucomystax (Fig. 4), Polypedates macrotis (Fig. 5), Polypedates otilophus (Fig. 6), and Bufo asper (Fig. 7), Meristogenys orphnocnemis (Fig. 8), Microhyla sp. (Fig. 9), Staurois natator (Fig. 10), Staurois latopalmatus (Fig. 11), respectively. No calls could be recorded for species without frequency data (Tab. 1). A total of 213 calls were analyzed. The dominant call frequencies of the anuran species are not dependent on the SVL of the vocalizing individuals (N = 11; c = -0.555; p ≤ 0.077; r² = 0.30) (Fig. 13). Meristogenys orphnocnemis, a species found in the stream habitat produced the highest calling frequency (7,205.0 Hz). Frog species from the torrent are above the

![Fig. 1. Spectrogram (frequency [kHz]) and waveform (rel. amplitude [kUnit] = proportional to sound pressure of the recording) of the advertisement call and non-collected specimen of Fejervarya nicobariensis. Temperature during recording 25.4 °C.](image1)

![Fig. 2. Spectrogram (frequency [kHz]) and waveform (rel. amplitude [kUnit] = proportional to sound pressure of the recording) of the advertisement call of Fejervarya limnocharis. Temperature during recording 24.6 °C.](image2)

![Fig. 3. Spectrogram (frequency [kHz]) and waveform (rel. amplitude [kUnit] = proportional to sound pressure of the recording) of the advertisement call and non-collected specimen of Rhacophorus dulitensis. Temperature during recording 26.3 °C.](image3)
calculated regression except *Bufo asper* and *Microhyla* sp. All frog species in the roadside habitat are below the calculated regression. The largest frog species was *Polypedates otilophus* with a dominant call frequency of 1,033.6 Hz. No frog species with a dominant call frequency below 1,000 Hz was recorded. Frequencies of advertisement calls of anuran species found in the stream transect are higher than call frequencies recorded of species occurring in the roadside habitat (Fig. 14) ($N = 11; df = 1; F = 7.315, p = 0.024$). Dominant frequency is not dependent on the SVL ($N = 11; df = 1; F = 3.822, p = 0.082$) but the influence of the habitat is significant ($N = 11; df = 1; F = 7.031, p = 0.029$). If the number of analyzed individuals is included, the dependency of the dominant frequency, the influence of SVL ($N = 11; df = 1; F = 0.519, p = 0.049$) and the influence of the habitat ($N = 11; df = 1; F = 11.435, p = 0.010$) become more significant.
Discussion

The comparison of two local frog assemblages in different habitats shows that advertisement calls of frog species living in noisy environments constrain higher frequencies. Fast flowing streams and waterfalls produce low-frequency-dominated noise which may present a selective force for stream-breeding species (HÖDL & AMEZQUITA 2001, FENG et al. 2006, authors’ unpublished data). Environmental constraints should have an effect on the evolution of signals (NARINS & ZELICK 1988). Selection favors signals that minimize the effects of background noise and interfering signals from other species (ENDLER 1993). Riparian frog species are acoustically well adapted to their environment and show
Fig. 12. a) Fejervarya nicobariensis, b) Fejervarya limnocharis, c) Rhacophorus dulitensis, d) Polypedates leucomystax, e) Polypedates macrotis, f) Polypedates otilophus, g) Bufo asper, h) Meristogenys orphanocnemis, i) Microhyla sp., j) Staurois natator, k) Staurois latopalmatus. Photos: M. Böckle, W. Hödl, T. Reis.
Anuran acoustic communities in Sabah, Malaysia

With the exception of *Bufo asper* the mean dominant frequency was above 3.9 kHz for frogs calling in the undisturbed habitat. A possible explanation for the call frequency in *B. asper* could be that it prefers stream banks, with small riffles that produced less background noise. Additionally, dominant frequency is determined by SVL. Larger frogs call with lower frequencies than smaller frogs (LITTLEJOHN 1977, KIME et al. 2000). The sampling size was probably too small to produce the dependency of SVL on dominant frequency. Only weighted data were able to show the influence. All species found in the disturbed roadside habitat call with lower frequencies and less constant noise is emitted by the surrounding environment. This gives rise to the question why a high proportion of species breeds close to fast flowing streams (INGER 1969). ZIMMERMANN & SIMBERLOFF (1996) showed that reproductive mode and developmental habitat are strongly associated with phylogeny. The same limited set of ecological and reproductive traits is shared by ranids, pelobatids and rhacophorids. Environmental conditions and interspecific interactions may have led to adaptations, but local selection on species can not be counted independent when closely related species occur in the same community. Phylogeny was not included in our analysis and a certain bias may result from the fact that two species of the genus *Staurois* are present at the stream habitat. Advertisement calls are important determinants of reproductive success and could have evolved in a common ancestor. However, we were able to record five species of the family of ranids, three at the stream (*Staurois latopalmatus*, *S. natator* and *Meristogenys orphnocnemis*) and two along the roadside (*Fejervarya nicobariensis* and *F. limnocharis*). All three ranid species recorded along the stream produce advertisement calls in which the dominant frequencies are above the calculated linear regression line (Fig. 13). Although morphological and phylogenetic limitations constrain frog vocalizations, selective pressures such as environmental factors have resulted in a diversity of advertisement calls (DUELLMAN & TRUEB 1986). Acoustic partitioning and increasing the signal-to-noise ratio are prerequisites for frogs living along torrents and streams. The influence of the habitat on advertisement calls should emphasize the importance of microhabitat composition on frog assemblages. Most recorded species are threatened by habitat loss (Tab. 1). Deforestation and subsequent siltation of streams and rivers are the major threats to most stream-breeding species in Sabah. Out of twelve species found along the stream, three are clas-
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Fig. 13. Influence of SVL on dominant frequency of the species advertisement call ($y = -55.49x + 5472.71$). Frog species of the stream transect are marked with a square, those from the roadside habitat with a circle.

Fig. 14. Dominant call frequencies of the anuran species from two different habitat types. Species along the stream call with higher frequencies than frog species in the roadside habitat.

specified as “near threatened” according to the IUCN Red List status (Tab. 1). INGER & VORIS (1993) found that a stream with a silt bottom completely lacked all the species known to breed along clear and fast flowing streams. Selective logging changes the water chemistry considerably in nearby streams. Sediment yields of streams are 18 times higher within the next five months in selectively logged areas (DOUGLAS et al. 1992, 1993). The increase in sedimentation levels has a clear effect on larval anurans and on reproduction of several stream-breeding species. Frog assemblages as those found at the Tembaling River show the importance of conservation areas like Danum Valley. On the other hand more microhabitats are created through reduced impact logging which attracts frog species that are normally not found in primary forests (e.g., Polypedates macrois, Fejervarya nico-bariensis and Rhacophorus pardalis) (WONG in press). We believe that disturbed areas such as those around the Danum Valley Field Center and adjacent roads contain suitable ponds and breeding habitats for disturbance-tolerant breeders, but the large destruction
Tab. 1. List of anuran species found including weight, snout-vent length (SVL), dominant call frequency (DF) and IUCN Red List status. Habitat: 1 = stream, 2 = road edge (numbers in parentheses are the absolute number of individuals measured); weight [g]; SVL [mm]; dominant frequency, DF [Hz] (number of individuals/number of analyzed calls); major threat: HL = habitat loss, P = pollution of streams and rivers, ID = infrastructure development, N = none; Red List status according to IUCN et al. (2006).

<table>
<thead>
<tr>
<th>species</th>
<th>habitat</th>
<th>SVL</th>
<th>DF</th>
<th>major threat</th>
<th>IUCN Red List status</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bufo asper</em></td>
<td>1</td>
<td>76.2</td>
<td>1,031.2 (1/9)</td>
<td>HL/P</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Meristogenys orthonocnemis</em></td>
<td>1</td>
<td>30.2</td>
<td>7,205.0 (1/6)</td>
<td>HL/P</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Microhyla sp.</em></td>
<td>1</td>
<td>14.9</td>
<td>3,969.3 (4/25)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><em>Staurois natator</em></td>
<td>1</td>
<td>33.9</td>
<td>4,746.0 (3/19)</td>
<td>HL/ID</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Staurois lanigularis</em></td>
<td>1</td>
<td>47.7</td>
<td>5,149.4 (5/20)</td>
<td>HL/P</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Ansonia longidigita</em></td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>HL/ID</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Ansonia spinulifer</em></td>
<td>1</td>
<td>3.2</td>
<td>-</td>
<td>HL/P</td>
<td>near threatened</td>
</tr>
<tr>
<td><em>Leptobrachium abbotti</em></td>
<td>1</td>
<td>56.5</td>
<td>-</td>
<td>HL/P</td>
<td>near threatened</td>
</tr>
<tr>
<td><em>Limnonectes leporinus</em></td>
<td>1</td>
<td>106.8</td>
<td>-</td>
<td>HL/P</td>
<td>near threatened</td>
</tr>
<tr>
<td><em>Rana picturata</em></td>
<td>1</td>
<td>39.8</td>
<td>-</td>
<td>HL/P</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Pedostibes rugosus</em></td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>HL/P</td>
<td>near threatened</td>
</tr>
<tr>
<td><em>Chaperina fusca</em></td>
<td>1</td>
<td>18.8</td>
<td>-</td>
<td>HL/P</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Chaperina fusca</em></td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>HL/P</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Polypedates leucomystax</em></td>
<td>2</td>
<td>30.0</td>
<td>2,056.7 (4/35)</td>
<td>N</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Polypedates macrois</em></td>
<td>2</td>
<td>57.0</td>
<td>1,388.9 (1/3)</td>
<td>N</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Polypedates otophous</em></td>
<td>2</td>
<td>81.1</td>
<td>1,033.6 (1/2)</td>
<td>HL</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Fejervarya limnocharis</em></td>
<td>2</td>
<td>33.4</td>
<td>1,274.0 (3/3)</td>
<td>-</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Fejervarya nicobariensis</em></td>
<td>2</td>
<td>41.2</td>
<td>3,169.7 (5/44)</td>
<td>HL/N</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Rhacophorus dulieuensis</em></td>
<td>2</td>
<td>46.6</td>
<td>1,868.6 (5/47)</td>
<td>HL</td>
<td>near threatened</td>
</tr>
<tr>
<td><em>Rhacophorus pardalis</em></td>
<td>2</td>
<td>43.5</td>
<td>-</td>
<td>HL/P</td>
<td>least concern</td>
</tr>
<tr>
<td><em>Occidozyga laevis</em></td>
<td>2</td>
<td>31.0</td>
<td>-</td>
<td>N</td>
<td>least concern</td>
</tr>
</tbody>
</table>

and fragmentation of primary forest poses a major threat to the characteristic herpetofauna of Sabah.

Acknowledgements

We thank the Danum Valley Management Committee, the Economic Plauing Unit, the Sabah Wildlife Department and the Universiti of Malaysia Sabah for giving us the opportunity to work in the Danum Valley Conservation Area. Special thanks go to the Royal Society (RS) and GLEN REYNOLDS for their support and commitment to make this project possible. JULIA FELLING and KAROLINE SCHMIDT assisted during our fieldwork and MARKUS GMEINER did the photo editing. We are very thankful for the statistical help of ADOLFO AMÉZQUITA. ANNA WONG acted as our local collaborator. Financial support was given by the University of Vienna (Brief Scientific Stays Abroad) and the DGHT (WILHELM-PETERS-Fonds). The Department of Evolutionary Biology (University of Vienna) provided the necessary field equipment. Last but not least we thank the DVCA and RS staff for keeping our spirits up.

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Manuscript received: 24 August 2006

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