

Novel Behaviors of Southeast Asian Rhacophorid Frogs (Anura, Rhacophoridae) with an Updated Anuran Species List for Danum Valley, Sabah, Malaysian Borneo

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ABSTRACT.— Land-use change and the predicted impacts of climate change are major threats to the biodiversity of Southeast Asia. Judging their impacts requires baseline biodiversity data and an understanding of the behavior of resident species in order to effectively manage that diversity. Here, we present an updated anuran species list for Danum Valley Field Center from the results of a nine-week survey expedition. We employed nocturnal stream searches as the basis of sampling and include data gathered from opportunistic encounters. We documented 47 anuran species, including one new locality record. In addition, we recorded a single species of caecilian (Gymnophiona). During this survey period we also documented aggressive territoriality in *Rhacophorus appendiculatus*, the manipulation of leaves to surround eggs by *Rhacophorus pardalis*, and predation of an adult *Rhacophorus dulitensis* by *Polypedates otitophus*. These observations and their implications are discussed.

KEY WORDS: Amphibians, *Rhacophorus*, *Polypedates*, reproduction, predation, diet, call recording

INTRODUCTION

Southeast Asia is comprised of four biodiversity hotspots (Myers et al., 2000), and currently faces one of the highest rates of deforestation on the planet (FAO, 2006). The threats associated with climate change are likely to further disrupt the few remaining intact lowland rainforests in the region, and increase biodiversity loss. One of the biggest challenges to mitigating the effects of land use and climate change in the region is the relative paucity of data on basic ecology and ethology. In order to effectively preserve biodiversity, it is

necessary to quantify that diversity, and understand the behaviors and ecologies governing distribution and abundance. One of the most threatened groups of organisms is the Anura.

Frogs have the highest percentage of species at risk of extinction of any vertebrate group (IUCN, 2010), and in SE Asia they are threatened by habitat loss and risks associated with climate change. Ecological and behavioral data from remaining primary forest sites are important for establishing baselines against which future changes can be measured. One of the few remaining lowland forested areas on

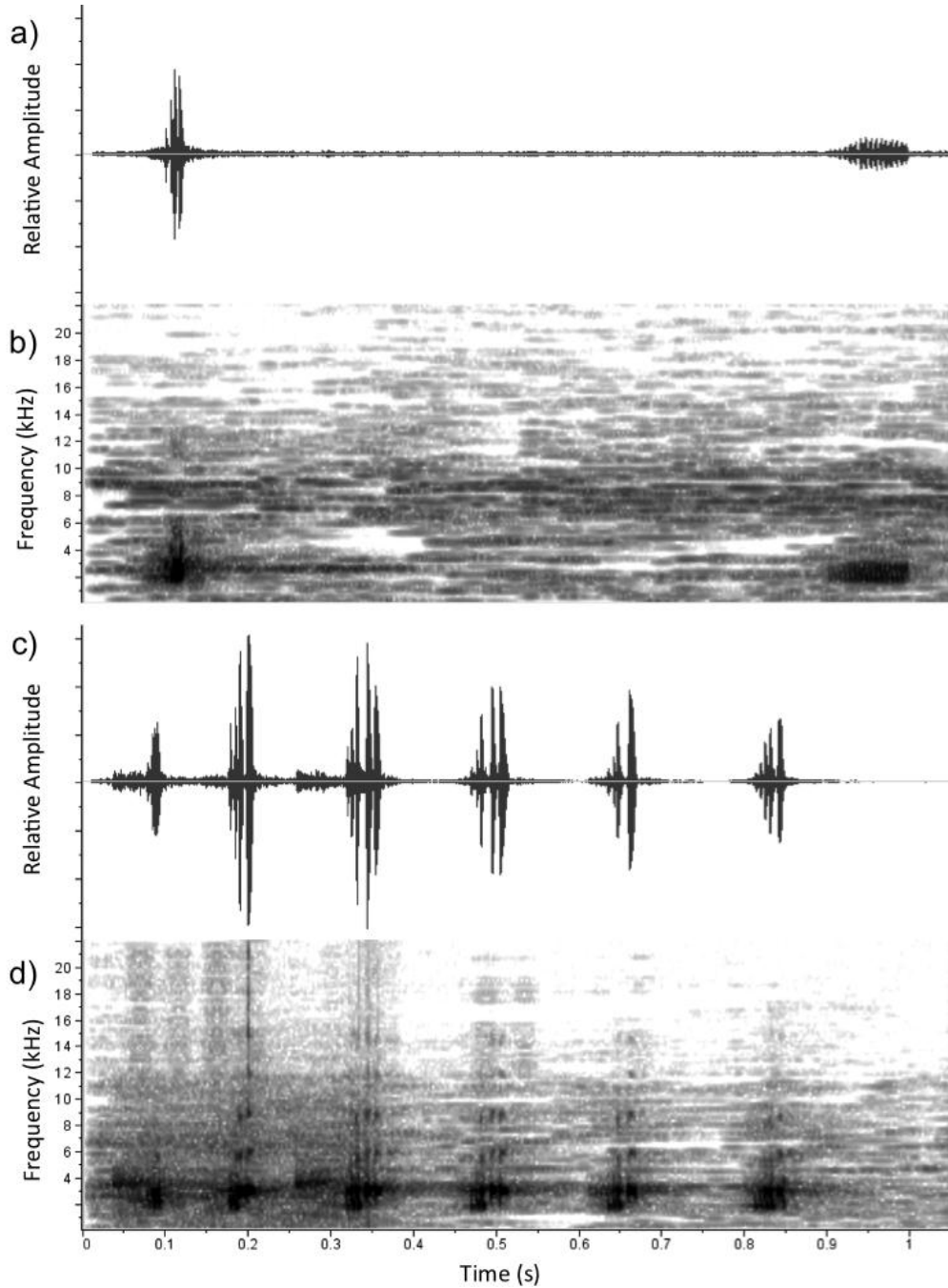


FIGURE 1. Oscillograms and spectrograms of (a, b) "normal" and (c, d) "territorial" calls of *Rhacophorus appendiculatus*. Calls are from the same individual (voucher specimen SP27078, Sabah Parks Museum). Temperature during recordings, 24–25 °C.

Borneo is Danum Valley Field Center. The anuran fauna of Danum Valley has been surveyed since the mid-1980s, with studies on acoustic communities (Preininger et al. 2007), behavior (Preininger et al., 2009), ecomorphology (Emerson, 1991), and changes in abundance and diversity through time (Inger et al., 1987; Inger and Voris, 1993; Voris and Inger, 1995). Aside from largely unpublished student projects, few studies have reported on unique behavior of resident anurans, and an updated list of anuran species has not been available in the literature for nearly 20 years. Here, we report three previously undescribed behaviors of rhacophorid frogs, along with an updated species list for the site.

MATERIALS AND METHODS

Study area.— Danum Valley Field Center (5° 01' 43" N 117° 45' 5" E) is located in the Lahad Datu district of Sabah, Malaysia. It comprises 438 km² of primary lowland dipterocarp rainforest between 180 – 900 m asl, with an annual rainfall of 2825 mm. There is no distinct seasonality.

Field methods.— For nocturnal surveys, we established 600 m transects on four streams: Cabin, W6S5, Kalison, and Palum Tambun. Each transect was surveyed once per week, with some surveys abandoned for logistical reasons, resulting in seven, eight, seven, and six surveys on each stream, respectively. Surveys commenced at approximately 18:30 h and lasted approximately 3 h, following Inger and Voris (1993), for a total of 74 to 83.5 man hours on each stream (Table 1).

Forest plots were conducted along two 1 km transects in minimally disturbed forest (Danum Valley Field Center transects W0 and S5). Each transect was an established trail: the West Trail, and the South 5 Trail.

Plot placement each day was determined randomly, and plots were laid parallel to the trail, at a distance of 5 m from the trail. Plots were either 5 x 5 m (n = 45), following methods used by Inger and Voris at this site (pers. comm., unpublished data) or 7.6 x 7.6 m (n = 58), following methods used at other sites in the region (Inger and Colwell, 1977). The total number of man hours spent on forest plot searches was 156.81.

Opportunistic behavioral observations were made wherever frogs were found calling or breeding. All behaviors described below were observed in a pond (approximately 7 m in diameter) located along the main road, near the entrance to Danum Valley Field Center (180 m asl).

RESULTS AND DISCUSSION

Anuran species diversity.— Fifty species have been reported from Danum Valley Field Center, with 45 in published species lists (Inger et al., 1987; Inger and Voris, 1993; Preininger et al., 2007; Voris and Inger, 1995), and an additional five in museum records (*Phrynoides asper*, *Microhyla berdmorei*, *M. maculifera*, *Odorrana hosii*, and *Theloderma horridum*). During nocturnal stream surveys, diurnal plot surveys, and opportunistic encounters conducted between 15 October and 16 December 2011, we recorded 47 species, one of which (*Rhacophorus harrissoni*,) is a new locality record (Table 1). Prior studies and museum records documented five species that were not recorded during our research (*Kalophrynus heterochirus*, *Microhyla maculifera*, *Occidozyga laevis*, *Rana luctuosa*, and *Theloderma horridum*). These five species are known to, or likely, breed in temporary pools (*K. heterochirus*, *M. maculifera*, *O. laevis*, and *R. luctuosa*) or in tree holes (*T. horridum*), which were not

TABLE 1. Anuran species by family encountered at Danum Valley, Sabah 15 October – 16 December 2010. Species in bold text represent those not previously documented, and underlined species represent those previously documented but not detected during the current study. Detection methods are forest plots (FP), opportunistic encounter (OE), and stream survey (SS). Number in parentheses below each stream indicates total number of man hours spent searching.

Species	Detection Method						Broad habitat type
	FP	OE	SS				
			Cabin (74.53)	P. Tambun (79.13)	S. Kalison (83.13)	W6S5 (83.45)	
Bufonidae							
<i>Ansonia spinulifer</i>			x		x	x	Stream
<i>Ingerophrynus divergens</i>			x		x	x	Stream
<i>Pedostibes hosii</i>			x	x	x		Stream
<i>Phrynoidis asper</i>			x				Stream
<i>Phrynoidis juxtasper</i>			x	x	x	x	Stream
Megophryidae							
<i>Leptobrachella parvus</i>			x				Stream
<i>Leptobrachium abbotti</i>		x				x	Forest
<i>Leptotalax gracilis</i>	x		x	x	x	x	Forest, Stream
<i>Megophrys nasuta</i>		x					Forest
Microhylidae							
<i>Calluella smithi</i>		x					Forest
<i>Chaperina fusca</i>	x		x	x		x	Forest, Stream
<i>Kalophrynus heterochirus</i>		n/a					n/a
<i>Kalophrynus pleurostigma</i>		x					Forest
<i>Metaphrynella sundana</i>		x			x		Forest
<i>Microhyla berdmorei</i>				x			Stream, Forest
<i>Microhyla borneensis</i>		x					Forest
<i>Microhyla maculifera</i>		n/a					n/a
Ranidae							
<i>Fejervarya limnocharis</i>		x					Grassland
<i>Hylarana erythraea</i>							Stream
<i>Hylarana picturata</i>			x	x	x	x	Stream
<i>Hylarana raniceps</i>			x	x	x	x	Stream
<i>Ingerana baluensis</i>			x		x		Stream
<i>Limnonectes finchi</i>		x				x	Forest, Stream
<i>Limnonectes ingeri</i>			x				Stream
<i>Limnonectes kuhlii</i>		x	x	x	x	x	Forest, Stream
<i>Limnonectes leporinus</i>			x	x	x	x	Stream
<i>Limnonectes palavanensis</i>	x	x					Forest
<i>Meristogenys orphnocnemis</i>			x	x	x	x	Stream
<i>Occidozyga baluensis</i>		x			x		Pond
<i>Occidozyga laevis</i>		n/a					n/a
<i>Odorrana hosii</i>			x	x		x	Stream
<i>Rana luctuosa</i>		n/a					n/a
<i>Rana nicobariensis</i>		x					Pond
<i>Staurois latopalmaris</i>			x	x	x		Stream
<i>Staurois natator</i>			x	x	x	x	Stream

TABLE 1. Continued

Rhacophoridae						
<i>Nyctixalus pictus</i>						Forest
<i>Philautus</i> sp. (likely <i>disgregus</i>)	x					Forest
<i>Philautus hosii</i>				x		Stream
<i>Polypedates leucomystax</i>		x				Pond
<i>Polypedates macrotis</i>		x				Pond
<i>Polypedates ottilophus</i>		x				Pond, Stream
<i>Rhacophorus appendiculatus</i>		x				Forest, Pond
<i>Rhacophorus dulitensis</i>		x				Pond
<i>Rhacophorus gauni</i>			x	x	x	Stream
<i>Rhacophorus harrissoni</i>			x		x	Stream
<i>Rhacophorus kajau</i>		x				Forest, Stream
<i>Rhacophorus nigropalmatus</i>		x				Forest
<i>Rhacophorus pardalis</i>		x	x		x	Pond
<i>Rhacophorus rufipes</i>		x				Forest
<i>Thelodermma horridum</i>		n/a				n/a

focal points of our surveys. It is likely that thorough searching of suitable breeding habitats will reveal their continued presence. The new locality record likely represents local colonization and may not indicate that this species was previously absent from the forest at Danum Valley Field Center, but rather that it did not occupy the previously sampled sections of the study streams. The same pattern of colonization has been observed by others conducting repeated sampling of the same streams over a period of years (Inger and Voris, 1993; Voris and Inger, 1995). Inger and Voris report several species that were seen in only one of the three study years, so it is not surprising that our surveys (conducted on the same streams) revealed a new locality record.

In addition to anurans, a single species of caecilian (Amphibia: Gymnophiona) was detected. The positive identity of this species will require expert assessment but it appears most similar to *Caudocaecilia nigroflava* in its pattern and maximum size (651 mm snout vent length). Voucher specimens of anurans and Gymnophiona were deposited in the Sabah Parks museum with museum tag numbers SP27065-99.

***Rhacophorus appendiculatus* territoriality.**— During routine call recording, we played back the call of *R. appendiculatus* (Fig. 1A, B, “normal” calls) to the recorded male to determine the response to close-proximity (within 2 m) conspecific calling. The male exhibited a unique suite of call types (Fig. 1C, D, “territorial” calls) that appeared to function as territorial calls only, as they were different from the call types previously recorded. Notably, when the male responded to the recording, he called simultaneously with the recording so that calls of the two males overlapped, instead of forming a call and response. In almost all instances, the male oriented himself towards the playback video camera (Sanyo xacti camcorder, model VPC-E2) and after some minutes, jumped onto the video camera while still making what we term territorial calls. We repeated this with three different males, and each time our playback elicited the same orienting response and positive phonotaxis to the video camera (males jumping on the video camera). It is likely that if the playback device had been another frog, there would have been competitive behavior between individuals but we were unable to test this. Similar behavior has

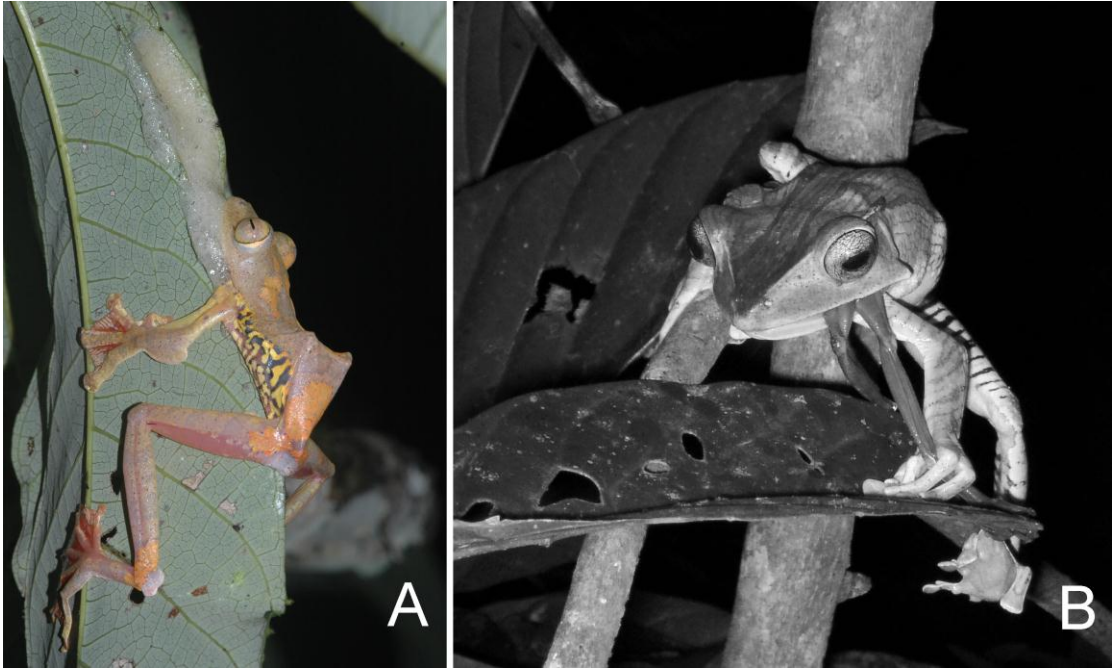


FIGURE 2. **A.** *Rhacophorus pardalis* constructing leaf nest around foam egg mass. **B.** *Polypedates otilophus* consuming *Rhacophorus dulitensis*.

been observed in South American poison-arrow frogs (Dendrobatidae) with distinct call response, phonotaxis, and conflict (Narins et al., 2003). It is highly probable that ‘normal’ calls of *R. appendiculatus* subserve male-female interactions while ‘territorial’ calls are used during male-male, territorial interactions. We believe this to be the first documentation of such behavior in Southeast Asian anurans, certainly the first documentation for this species, and further study is needed to confirm the role these calls play in reproductive fitness.

***Rhacophorus pardalis* nest construction.**—

On three occasions, we observed female *Rhacophorus pardalis* laying eggs, and subsequently manipulating leaves to cover the foam nest. In each case, the female laid her eggs on a single leaf and after the male departed, used her front and hind limbs to

pull an adjacent leaf towards the egg mass or folded over the leaf on which her eggs were placed, to form a cover for the foam nest. The female then positioned herself in a way that allowed her to press the two leaves together around the eggs (Fig. 2A), which appeared to ‘glue’ the leaves or leaf blades to the egg mass. Each time, the female sat near the bottom or top of the clutch with her front and hind feet splayed to press the leaves, or halves of the single leaf, together for approximately 30 minutes, then shifted her position to the top or bottom end, again pressing the leaves together for an additional 30 minutes. We believe this is the first report of such behavior in *Rhacophorus pardalis*, and the first report of such behavior in a Southeast Asian member of the family Rhacophoridae. Other reports of this behavior in Rhacophorid frogs come from India, where *R. lateralis*, *R.*

pseudomalabaricus, *R. calcadensis* (Biju 2009), and *R. malabaricus* (Kadadevaru and Kanamadi, 2000) construct leaf nests surrounding the foam nest (Biju, 2009). Other examples of this behavior have been reported for South American *Phyllomedusa* (Pyburn, 1970; Pyburn and Glidwell, 1971; Wogel et al., 2005) and African *Afrixalus* (Backwell and Passmore, 1990). *Rhacophorus lateralis*, *Phyllomedusa*, and *Afrixalus* construct the leaf nest using only single leaves, similar to the *R. pardalis* nest construction with one or two leaves. Nest construction in *Rhacophorus* differs from that of *Phyllomedusa* and *Afrixalus* in that females construct nests singly rather than with the help of the males (Backwell and Passmore, 1990; Pyburn, 1970; Pyburn and Glidwell, 1971; Wogel et al., 2005). *Rhacophorus pardalis* nest construction can be further distinguished from that of *R. lateralis* by the amount of time spent on leaf nest construction. *Rhacophorus lateralis* nest construction takes a maximum of 30 minutes, and is always performed from the top to the bottom of the leaf (Biju, 2009). In contrast, *R. pardalis* were observed to take 45–70 minutes to construct the nest, and at least on one occasion started the nest at the bottom of the clutch. Further studies on nest building behavior in widespread Rhacophoridae will be useful in determining the evolution of reproductive strategies and parental care.

Frog predation by *Polypedates ottilophus*.—On a single occasion, we observed an adult *Polypedates ottilophus* in the process of consuming an adult male *Rhacophorus dulitensis* (Fig. 2B). Upon collection of the *P. ottilophus*, the meal was disgorged. To our knowledge, this is the first documented case of frog predation by a rhacophorid.

CONCLUSION

The novel behaviors and new locality records reported here for Danum Valley highlight the importance of preserving lowland Bornean forests. Currently, much of Southeast Asia is being logged or converted to oil palm plantations (Sodhi et al., 2004; Sodhi et al., 2010), with devastating consequences for ecosystem services and biodiversity in general. Studies are currently under way to determine the effects of conversion of forest to oil palm on biodiversity of amphibians. Continued monitoring of lowland biodiversity is essential as a baseline to judge the impacts of forest fragmentation and potential latitudinal and elevation range shifts, through lowland biotic attrition, predicted under climate change scenarios. It may be possible for many species to behaviorally adapt to land use and climate change, and it is important to document baseline behavioral patterns where possible. We encourage further research on Bornean amphibian ecology, evolution, and behavior in order to more fully understand the region's biodiversity before it is lost.

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