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Annual temperature data for two Malagasy sites of high anuran diversity

ABSTRACT

We present microclimatic temperature data for two Malagasy rainforest sites with high amphibian diversity. Our data show that daily, monthly and annual temperature ranges in these microhabitats are relatively narrow and, as expected, temperatures are much more buffered in streams than in the leaf litter. A successful ex-situ conservation of many species may require adaptation to the reported thermal conditions. Because many Madagascan amphibians seem to be restricted to certain elevations and hence climatic conditions, global warming could endanger stenothermic amphibian species adapted to these narrow climatic envelopes, which highlights the need for more detailed monitoring, and for an assessment of temperature tolerances and preferences.

Key words: amphibians, ex-situ conservation, Madagascar, temperature variation, ecology.

INTRODUCTION

Species' fundamental ecological niches are determined by both biological and physical environmental conditions. Among those conditions, microclimatic data are critical to understand species activity rhythms and annual phenology, especially in ectothermic vertebrates like amphibians. Large-scale global warming has already been related to amphibian declines in Neotropical areas (Pounds et al., 2006). If this turns out to be a global phenomenon, microclimatic data and long-term comparative studies on amphibian declines in other tropical areas of the world are urgently needed. Although temperature and rainfall data are available from the global network of meteorological stations and can be interpolated to develop climate surfaces (Hijmans et al., 2005), those data usually do not reflect actual microclimatic conditions for most amphibian habitats.

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Despite the recent technological advances in field temperature recordings (i.e. miniaturized data loggers), few studies report their use in this group of vertebrates, being normally employed for a short period of time (Kusano et al., 2006). Long-term data-logging of temperature in local amphibian microhabitats will not only provide the dynamics and range of microclimatic conditions where species live, but can also be of great interest in developing protocols for captive breeding of endangered species.

For Madagascar, temperature data are available from many meteorological stations, and data on general Madagascan climate zones have been published (e.g., Donque, 1975), yet to our knowledge no data exists about annual temperatures in microhabitats relevant for anurans, such as leaf litter or small streams. Therefore, annual temperature curves from leaf litter and streams in Madagascar can be helpful to fill in these gaps, and provide preliminary data on these microhabitats critical for both adult and larval stages of amphibians.

Current studies suggest that highest values of amphibian diversity in Madagascar are concentrated in the primary rainforests of the central-east and south-east (Lees et al., 1999; Andreone et al., 2005; own, unpublished data). Microclimatic data for the above mentioned localities are especially interesting in the context of ex situ conservation because they are applicable to captive breeding of multiple species, especially those that live mainly on the forest floor or in streams. Here we present data about microhabitat temperatures gathered during 2006-2007 at two sites of high amphibian species diversity in Madagascar: Andasibe and Ranomafana.

METHODS

In total, five data loggers (ibutton DS1921G-F5, Dallas Technologies) were set for one year (2006-2007) in Andasibe and Ranomafana. These data loggers can record temperature data from -40°C to 85°C at 0.5°C precision, and can record data in different time periods. We set them up to record data every 4 hours, providing three measurements during the night and three during the day. In Andasibe, one data logger was placed in the vicinities of the "Station forestiére" in the leaf litter on a slope, about 200 m from the nearest stream. In Ranomafana, we placed each two data loggers at two localities, Sahamalaotra and Talatakely. Both these sites are located in Ranomafana National Park. At each site, one data logger was set in the water of a permanent stream and the second one in the leaf litter (2-5 cm underground) near the stream (Tab. I). All loggers were placed in primary rainforest under a closed canopy. At all three sites, diverse amphibian communities occur, which mostly comprise stream-breeding species of *Boophis* and *Mantidactylus*, but also various leaf-litter dwelling cophyline microhylids (*Stumpffia* and *Plethodontohyla*) and mantellids (*Gephyromantis*, Glaw & Vences, 2007). In general, from both the Ranomafana and Andasibe areas, high amphibian diversities of about 100 species occurring within a few square kilometers have been recorded.

Locality		Data acquisition time	Coordinates
Andasibe	"Station forestière", leaf litter under *Ravenala* palm	03/25/2006 - 2/24/2007	Altitude = 939m S = 18°56.169' E = 48°24.734'
Sahamalaotra	Leaf litter	02/25/2006 - 02/22/2007	Altitude = 846m S =21°14.282' E =47°23.753'
	Submerged in small stream	02/25/2006 - 02/22/2007	Altitude = 846m S =21°14.282' E =47°23.753'
Talatakely	Leaf litter	03/01/2006 - 02/24/2007	Altitude = 846m S =21°15.8' E =47°25.8'
	Submerged in small stream	03/01/2006 - 02/24/2007	Altitude = 846m S =21°15.8' E =47°25.8'

Tab. I. Locality information, data acquisition time and coordinates of the sampled sites.

RESULTS AND DISCUSSION

Our data show the typical temperature patterns for a tropical climate, with relatively small temperature ranges and only two seasons during the year. In figures 1, 2 and 3, a temperature curves typical for Malagasy rainforests can be observed; mean annual temperatures in the leaf litter range between 15.8°C (Sahamalaotra leaf litter) and 17.2°C (Andasibe leaf litter). Mean annual temperatures in the two sampled streams were 16.0°C and 16.9°C (Tab. II). In the dry season from April to September, temperatures are lower than their annual mean in all sampled localities, and in the rainy season (October to March) the mean temperatures increase (see Tab. II).

Comparison of the annual temperatures in water and leaf litter shows that temperatures in the streams are generally more constant than leaf litter temperatures. In Sahamalaotra, the annual leaf litter temperatures shift between +2.0°C (rainy season) and -1.9°C (dry season) compared to annual means; the water temperature shifts only between +1.0°C (rainy season) and -1.0°C (dry season). In Talatakely, the annual leaf litter temperature shifts between +1.3°C (rainy season) and -1.3°C (dry season) compared to annual mean; the water temperature shifts only between +0.7°C (rainy season) and -0.6°C (dry season). For Andasibe, no data for stream temperatures could be obtained. However, leaf litter temperatures in Andasibe were the highest among the three sampled localities. Information on temperature fluctuations between daytime and night can be seen in Tab. III (and are visualized in Fig. 4). Characteristically, the mean temperature shifts between daytime and night are small (≤0.2°C) in rainy and dry season, respectively. Also, temperature differences between rainy and dry season are generally smaller in streams than in the leaf litter at daytime and at night.

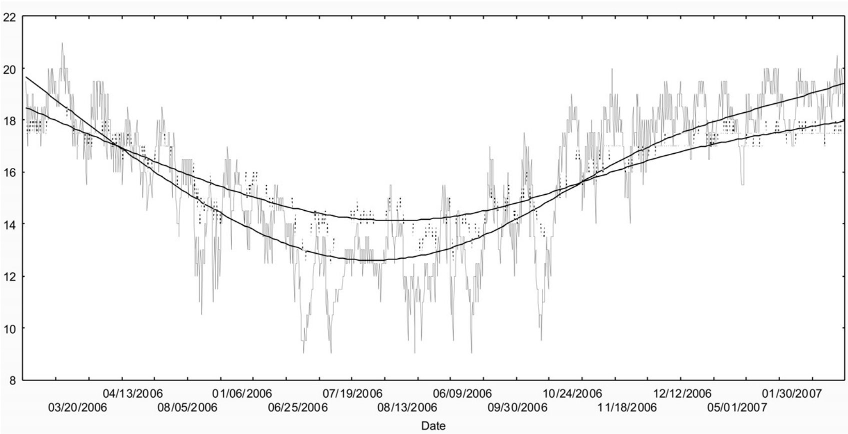

Fig. 1. Annual temperature curves for stream and leaf litter data in Sahamalaotra. Leaf litter temperature is indicated by a continuous line, stream temperatures are indicated by a broken line. Line fit: Distance weighted least-squares.

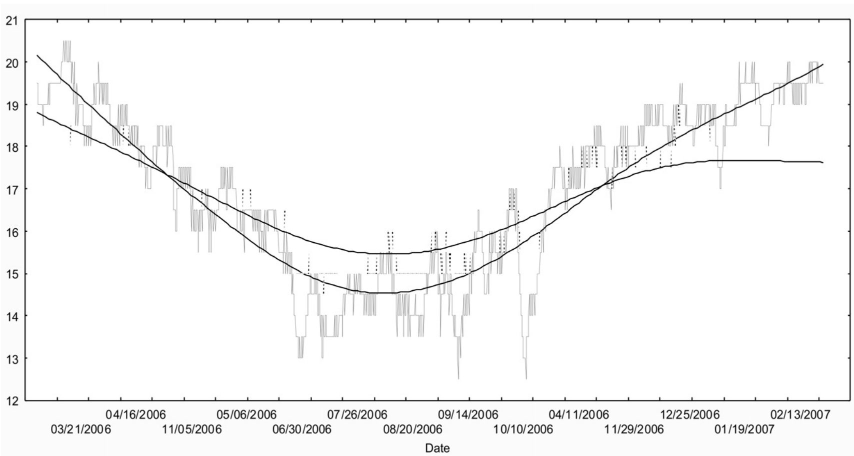

Fig. 2. Annual temperature curves for stream and leaf litter data in Talatakely. Leaf litter temperature is indicated by a continuous line, stream temperatures are indicated by a broken line. Line fit: Distance weighted least-squares.

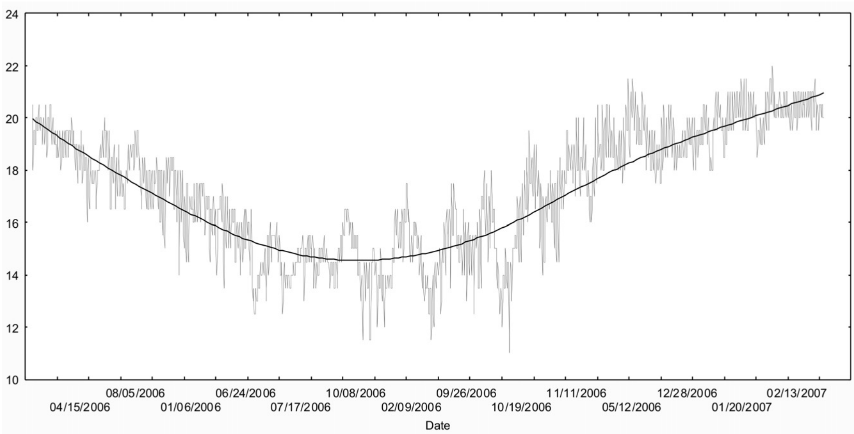

Fig. 3. Annual temperature curves for temperature data for the leaf litter in Andasibe. Line fit: Distance weighted least-squares.

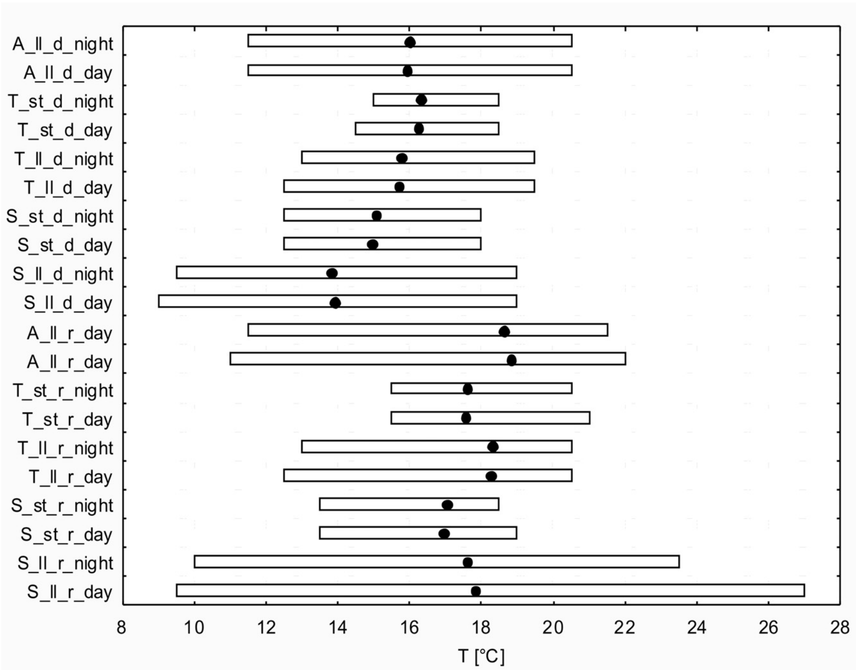

Fig. 4. Mean temperatures at day and night time, and their minimal and maximal values. Values are shown for dry and rainy season separately. A = Andasibe, T = Talatakely, S = Sahamalaotra, st = stream, ll = leaf litter, r = rainy season, d = dry season.

Whole period	T [°C]	Dry season	T [°C]	Rainy season	T [°C]
Sahamalaotra leaf litter					
mean	15.8	mean	13.9	mean	17.7
sd	2.8	sd	2.0	sd	1.9
max	27.0	max	19.0	max	27.0
min	9.0	min	9.0	min	9.5
Sahamalaotra stream					
mean	16.0	mean	15.0	mean	17.0
sd	1.5	sd	1.2	sd	1.0
max	19.0	max	18.0	max	19.0
min	12.5	min	12.5	min	13.5
Talatakely leaf litter					
mean	17.0	mean	15.7	mean	18.3
sd	2.0	sd	1.6	sd	1.4
max	20.5	max	19.5	max	20.5
min	12.5	min	12.5	min	12.5
Talatakely stream					
mean	16.9	mean	16.3	mean	17.6
sd	1.2	sd	1.1	sd	0.7
max	19.0	max	18.5	max	19.0
min	14.5	min	14.5	min	15.5
Andasibe leaf litter					
mean	17.2	mean	16	mean	18.6
sd	2.3	sd	1.9	sd	1.9
max	22.5	max	20.5	max	22.5
min	11.0	min	11.5	min	11.0

Tab. II. Summary statistics of the obtained temperature data for all sites. The arithmetic mean, standard deviation, minimal and maximal values are given for (a) the whole sampling period, (b) the dry season (04/01/2006 - 10/01/2006) and (c) the rainy season (10/02/2006 - begin of sampling in February / March, see Tab. I).

Our data indicate that natural microclimatic conditions for a large number of Malagasy frog species involve relatively low minimum temperatures around 9-11°C (Tab. III), and that temperature changes are much more buffered in streams. Adjusting tank temperatures as well as water temperatures (for tadpole rearing) to the observed conditions may at least in some cases be a premise for successful captive breeding (e.g., in the context of ex-situ conservation) of these frogs. Furthermore, our data suggest that the temperature range in the sampled microhabitats is relatively narrow, both on a daily, monthly and annual scale. This may be relevant to the potential decline of amphibian species under future global warming scenarios, as these narrow climatic envelopes could be largely affected by a global increase in temperature (Williams et al., 2007). Climate change has naturally occurred over millions of years, and most Malagasy species of amphibians have a strong genetic differentiation and hence an old age (Köhler et al., 2005), and therefore must have survived past climate shifts. However, under the present conditions of largely fragmented and destroyed forests in Madagascar, species may not always be able to adequately respond to such shifts by moving into habitats at different elevations. Therefore, long-term monitoring efforts should also include measurements of other environmental parameters like humidity or temperatures at various heights above the ground which are relevant to anurans, to understand possible changes in these parameters.

Rainy season	**T [°C]**	**Dry season**	**T [°C]**		**T [°C]**
Sahamalaotra stream					
mean day	16.9	mean day	14.9	Δ mean day r/d	2.0
sd day	1.0	sd day	1.2	Δ sd day r/d	0.2
max day	19.0	max day	18.0	Δ max day r/d	1.0
min day	13.5	min day	12.5	Δ min day r/d	1.0
mean night	17.0	mean night	15.1	Δ mean night r/d	2.0
sd night	1.0	sd night	1.2	Δ sd night r/d	0.2
max night	18.5	max night	18.0	Δ max night r/d	0.5
min night	13.5	min night	12.5	Δ min night r/d	1.0
Δ mean day/night	0.1	Δ mean day/night	0.1		
Δ sd day/night	0.0	Δ sd day/night	0.0		
Δ max day/night	0.5	Δ max day/night	0.0		
Δ min day/night	0.0	Δ min day/night	0.0		
Sahamalaotra leaf litter					
mean day	17.8	mean day	13.9	Δ mean day r/d	3.9
sd day	1.9	sd day	2.1	Δ sd day r/d	0.2
max day	27.0	max day	19.0	Δ max day r/d	8.0
min day	9.5	min day	9.0	Δ min day r/d	0.5
mean night	17.6	mean night	13.8	Δ mean night r/d	3.8
sd night	1.9	sd night	2.0	Δ sd night r/d	0.2
max night	23.5	max night	19.0	Δ max night r/d	4.5
min night	10.0	min night	9.5	Δ min night r/d	0.5

Δ mean day/night	0.2	Δ mean day/night	0.1		
Δ sd day/night	0.0	Δ sd day/night	0.1		
Δ max day/night	3.5	Δ max day/night	0.0		
Δ min day/night	0.5	Δ min day/night	0.5		
Talatakely stream					
mean day	17.5	mean day	16.0	Δ mean day r/d	1.3
sd day	0.7	sd day	1.1	Δ sd day r/d	0.4
max day	21.0	max day	18.5	Δ max day r/d	2.5
min day	15.5	min day	14.5	Δ min day r/d	1.0
mean night	17.6	mean night	16.3	Δ mean night r/d	1.3
sd night	0.7	sd night	1.1	Δ sd night r/d	0.4
max night	20.5	max night	18.5	Δ max night r/d	2.0
min night	15.5	min night	15.0	Δ min night r/d	0.5
Δ mean day/night	0.1	Δ mean day/night	0.1		
Δ sd day/night	0.0	Δ sd day/night	0.0		
Δ max day/night	0.5	Δ max day/night	0.0		
Δ min day/night	0.0	Δ min day/night	0.5		
Talatakely leaf litter					
mean day	18.3	mean day	15.7	Δ mean day r/d	2.6
sd day	1.4	sd day	1.6	Δ sd day r/d	0.2
max day	20.5	max day	19.5	Δ max day r/d	1.0
min day	12.5	min day	12.5	Δ min day r/d	0.0
mean night	18.3	mean night	15.8	Δ mean night r/d	2.5
sd night	1.4	sd night	1.6	Δ sd night r/d	0.2
max night	20.5	max night	19.5	Δ max night r/d	1.0
min night	13.0	min night	13.0	Δ min night r/d	0.0
Δ mean day/night	0.0	Δ mean day/night	0.0		
Δ sd day/night	0.0	Δ sd day/night	0.0		
Δ max day/night	0.0	Δ max day/night	0.0		
Δ min day/night	0.5	Δ min day/night	0.5		
Andasibe leaf litter					
mean day	18.8	mean day	15.9	Δ mean day r/d	2.9
sd day	1.9	sd day	1.9	Δ sd day r/d	0.0
max day	22.5	max day	20.5	Δ max day r/d	1.5
min day	11.0	min day	11.5	Δ min day r/d	0.5
mean night	18.6	mean night	16	Δ mean night r/d	2.6
sd night	1.9	sd night	1.9	Δ sd night r/d	0.0
max night	21.5	max night	20.5	Δ max night r/d	1.0
min night	11.5	min night	11.5	Δ min night r/d	
Δ mean day/night	0.2	Δ mean day/night	0.1		
Δ sd day/night	0.1	Δ sd day/night	0.0		
Δ max day/night	0.5	Δ max day/night	0.0		
Δ min day/night	0.5	Δ min day/night	0.0		

Tab. III. - Daily temperature ranges and the absolute differences between day/night and rainy/dry season values (in °C, indicated by Δ). See Figure 4.

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RÉSUMÉ

Température annuelle pour deux sites malgaches sur une grande diversité d'anuran.

Nous présentons des données de températures microclimatiques de deux sites malgaches de forêts pluvieuses avec une grande diversité d'amphibiens. Nos données montrent que les gammes de températures, quotidiennes, mensuelles et annuelles dans ces micro habitats sont relativement proches, et comme on pouvait l'attendre, les variations de température sont bien plus marquées dans les rivières que entre les litières de feuilles. Une conservation ex-situ réussie pour de nombreuses espèces nécessite une adaptation à ces conditions thermiques rapportées. En effet, beaucoup d'amphibiens malgaches semblent être limités par certaines altitudes et donc par les conditions climatiques. Le réchauffement global pourrait mettre en danger les espèces d'amphibiens sténo thermiques adaptés dans ces étroites enveloppes climatiques, ce qui souligne le besoin de plus de détails de suivi.

Mots clés: Amphibiens, Conservation, Écologie, Madagascar, variation de température.

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