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Air temperature changes in a burrow of Chinese pangolin, *Manis pentadactyla*, in winter

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Abstract. We determined burrow temperature variation for the Chinese pangolin in winter over a study period from 1 December 2009 to 28 February 2010, at Luofushan Nature Reserve, China. Our results show that the air temperature inside the burrow was stable with only a slight fluctuation, the diurnal variation amplitude was merely 0.0-0.5 °C (SD = 0.08 ± 0.09 °C, n = 90), and winter temperature fluctuated between 17.8-21.0 °C. On the contrary, air temperature outside the burrow fluctuated dramatically, the diurnal variation amplitude ranging from 0.7-20.0 °C (SD = 4.99 ± 3.47 °C, n = 90); the seasonal temperature fluctuated between 4.6-38.3 °C. In winter, the average temperature inside the burrow was 18.96 °C (SD = 0.91, n = 90), and significantly higher than the average temperature outside the burrow ($p < 0.01$), which was 15.16 °C (SD = 3.85, n = 90). No significant relationship was found between the temperatures inside and outside the burrow, and the temperature changes outside the burrow had almost no significant influence on thermal conditions inside the burrow. It was therefore proposed that the most optimum ambient temperature for Chinese pangolins in winter was in the range of 18-21 °C.

Key words: subterranean mammal, adaptation, wintering, micro-environment, Luofushan Natural Reserve

Introduction

The Chinese pangolin (*Manis pentadactyla*) is one of eight extant species of pangolins (*Manis* spp.) in the order of Pholidota (Wilson & Reeder 2005). The eight species of pangolins have multiple similarities in their morphology and natural history, e.g. lack of hair on the body surface, which is covered with armor of imbricate scales, and a diet comprised almost exclusively of ants and termites. As such, they are also called "scaly anteaters".

The extant species of the order Pholidota are considered vulnerable or endangered (Jiang et al. 1997, Wu et al. 2002, Wu et al. 2005a). All species of pangolins are listed in CITES appendix II (www.cites.org) and are listed on the IUCN's (World Conservation Union's) Red List of Endangered Species, with the Chinese pangolin and Malayan pangolin categorized as endangered (www.iucnredlist.org). Knowledge of field ecology is the scientific foundation and basis for endangered species protection, population recovery and artificial rescue. However, data on the ecology of the eight species of pangolin are very rare and details of activity, foraging and habitat are only infrequently reported (Liu & Xu 1981, Jiang 1988, Heath & Coulson 1997, Richer et al. 1997, Swart et al. 1998, Wu et al. 2003, Cai et al. 2004, Wu et al. 2004, Wu et al. 2005b, Lim & Ng 2008). Poor knowledge of the biology of pangolins may be associated with their characteristic features such as timidity, elusiveness, single disperse activity, burrow-dwelling, nocturnal habits, tiny trails, and small body. Thus, it is necessary to collect more data and carry out more field research on these animals, to promote their conservation.

Temperature is one of the most important environmental factors affecting wild animals. Within a certain temperature range, animals can carry out normal physical activity, but exposure to temperatures beyond this range can lead to abnormal physiological activity (Feng et al. 2005). Burrows usually provide a stable micro-climate for animals ensuring they avoid adverse climatic impacts (Reichman & Smith 1990, Nikol'skii & Khutorskoi 2001, Nikol'skii 2002). Burrowing is extremely important in the life history of Chinese pangolin, which it uses to reside in, hide, breed and avoid bad weather and predators. Chinese pangolins spend most of their time in underground

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burrows during the day, and leave their burrows only when foraging or mating at night. It was proposed that Chinese pangolins can not survive without burrows (Liu & Xu 1981, Gu et al. 1983, Jiang 1988, Wu et al. 2005a). Under captive conditions, Chinese pangolins spend 20-22 hours per day sleeping in their burrow (Wang 2000). Previous studies have focused mainly on the burrow structure and habitat selection of Chinese pangolins (Wu et al. 2003, Cai et al. 2004, Wu et al. 2004), but little attention has been paid to the characteristics of temperature changes inside the burrow of Chinese pangolins.

Our research aims are to reveal the temperature variation features in the Chinese pangolin burrow in winter and the influence of temperature changes outside the burrow on temperature inside the burrow. We further discuss the demands and adaptability of the Chinese pangolin to temperature inside the burrow and the maintaining temperature mechanisms of the burrow in order to provide data to inform ex-situ conservation and captive breeding of the species.

Material and Methods

Study area

This study was carried out at Luofushan Nature Reserve (113°57′-114°04′ E, 23°15′-23°22′ N, altitude 31.5-1281.5 m), Guangdong Province, South China. This nature reserve comprises subtropical evergreen broad-leaved forest and is host to rare and endangered animals and plants in the province; the total area of the reserve is 9828 ha (Zhang 1997). The climate is wet and warm monsoon climate characteristic of the south subtropical zone and with a distinct wet-and-dry season. The annual average temperature is 21.5 °C and the annual precipitation is 1800-1900 mm. The average temperature in July, the hottest month, is 28 °C. In contrast, the average temperature in January, the coldest month here, is 12.5 °C. The frost-free period is around 345 days.

Study burrow

On 25 November 2009, a fresh burrow of Chinese pangolin was found at Luofushan Natural Reserve of Guangdong Province, China, and a Chinese pangolin was dwelling in the burrow. Owing to the disturbance of placing the probe (temperature sensor) of temperature recorder into the burrow, the Chinese pangolin left the burrow for a while. We found that the pangolin had returned back to the burrow for dwelling when we visited the burrow on the fifth day after leaving, and it still lived in the burrow for a few days until the end of this study. Whether the pangolin was residing in the burrow could be judged mainly according to the orientation of its footprints around the burrow entrance and whether the entrance was sealed with fresh dirt. If the burrow entrance was sealed with fresh dirt and the orientation of the footprints was toward the interior of the burrow, we could confirm that the pangolin was residing in the burrow. Otherwise the pangolin got out of the burrow. After completing temperature determination, we dissected the burrow and found the burrow was blind, with 1.65 m in depth and 11.5 × 12.0 cm in entrance size. The tunnel first stretched horizontally but in a slightly lower-right direction, then curved slightly and finally slightly extended upwards. The diameter of the tunnel was approximately uniform except at the bottom. The bottom gradually increased in size and reached a maximum diameter of 50 cm, resembling a calabash. The burrow was located at 78.1 m altitude, at the middle or lower slope location (32° of steep slope) on the wide stretch side of a mountain. The burrow with the entrance facing south-east was hard to find, hidden in the flourishing shrub/herb layer of the understory in an evergreen broadleaf forest.

Collection of burrow temperature data

The air temperature inside and outside the burrow was determined with a 24-hour automatic temperature recorder (ZDR-11, Hangzhou Zeda Instruments, Zhejiang, China). The accuracy in the measurements is 0.1 °C. This device consists of two temperature sensors, two data cables, and data acquisition and storage equipment, which can automatically record the synchronous changes of the air temperatures inside and outside the burrow. The initial time, terminal time and time interval for temperature determination can be arbitrarily set, and recorded data were automatically stored. The air temperatures inside and outside the burrow were recorded at an interval of one hour for 24 hours. For the temperature measurements, the two temperature sensors were placed inside and outside the burrow, respectively. Here the air temperature inside the burrow is defined as the air temperature at the enlarged bottom where the animal resides. The air temperature outside the burrow is defined as the air temperature in the shadow at a height of 10 cm from the soil surface at the burrow entrance. The initial time for temperature determination was set at 00:00 on 1 December 2009; and the terminal time was set at 24:00 on 28 February 2010, the total duration of 90 days throughout the winter.

Table 1. The statistics for daily temperature variation amplitude outside the Chinese pangolin burrow in winter (from 1 December 2009 to 28 February 2010).

	Daily variation amplitude (°C)			
	0.7-5.0	5.1-10.0	10.1-15.0	15.1-20.0
Number. of days	58	26	3	3
%	64.4	28.9	3.3	3.3

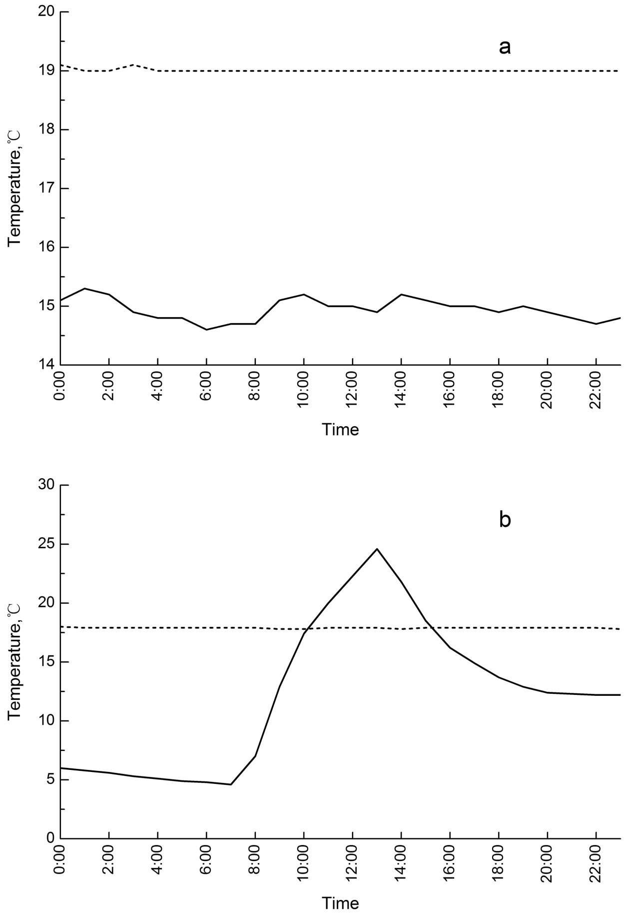

Fig. 1. The temperature change trend inside (the broken line) and outside (the full line) the burrow within 24 hours (a) on 2 January and (b) 20 February 2010.

Results

Daily temperature changes

No obvious change was found in the daily temperature inside the burrow, which almost remained constant or changed very slightly within 24 hours during the day. Daily temperature variation inside the burrow was only 0-0.5 °C (SD = 0.08 ± 0.09 °C, n = 90), most of which (84.5 %) was 0 °C or 0.1 °C.

On the contrary, an obvious change was found in the daily temperature outside the burrow, value range was 0.7-20 °C (SD = 4.99 ± 3.47 °C, n = 90). Outside the burrow, most of daily temperature variation (93.3 %) was in the range of 0.7-10.0 °C and only a small percentage (6.6 %) was above 10.0 °C (Table 1).

The observed maximum (20 °C) and minimum (0.7 °C) daily temperature variation amplitude outside the burrow occurred on 20 February and 2 January 2010, respectively. However, the temperature change amplitude inside the burrow on the same day was only 0.2 °C and 0.1 °C separately. The temperature change trend inside and outside the burrow within 24 hours on 2 January and 20 February 2010 is shown in Fig. 1. The amplitude of diurnal temperature variation outside the burrow was significantly higher than that inside the burrow ($P < 0.01$).

The daily maximum temperature outside the Chinese pangolin burrow usually occurred at 11:00-17:00 (76.5 %) during the day, but mainly at 12:00-14:00 (47.8 %) during the day. The daily minimum temperature outside the Chinese pangolin burrow usually occurred at 05:00-08:00 (52.5 %) during the day and 22:00-01:00 next day (25.4 %).

Winter temperature changes

Outside the Chinese pangolin burrow, the seasonal temperature showed relatively large fluctuations (Fig. 2, Table 2). Outside the burrow, the winter maximum temperature was 38.3 °C, occurring on 27 February 2010; and the winter minimum temperature was 4.6 °C, occurring 20 February 2010. The amplitude of winter temperature variation outside the burrow was 33.7 °C. The monthly average temperature in January (14.35 °C) was relatively low, it was the coldest month within the study period (Table 2). The minimum

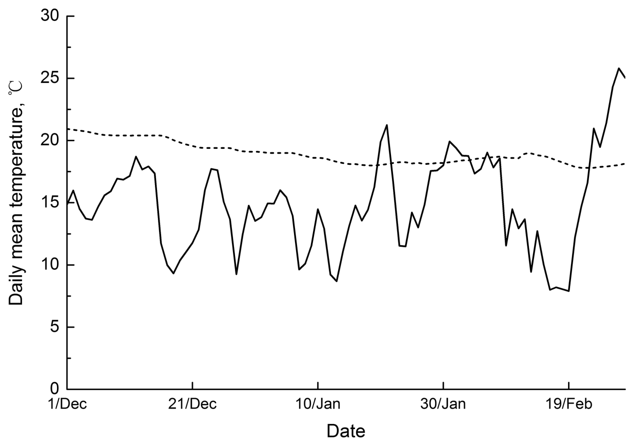

Fig. 2. Temperature seasonal fluctuation outside (the full line) and inside (the broken line) the Chinese pangolin burrow in winter (from 1 December 2009 to 28 February 2010).

Table 2. The temperature variation for Chinese pangolin burrow in winter (from 1 December 2009 to 28 February 2010).

	Inside the burrow			Outside the burrow		
	Dec.	Jan.	Feb.	Dec.	Jan.	Feb.
Monthly temperature change scope (°C)	19.1-21	18-19.2	17.8-19	6.7-21.7	5.2-23.4	4.6-38.3
Monthly temperature variation amplitude (°C)	1.9	1.2	1.2	15	18.2	33.7
Monthly average temperature (°C)	20.02 (n = 31)	18.41 (n = 31)	18.38 (n = 28)	14.47 (n = 31)	14.35 (n = 31)	16.83 (n = 28)
Seasonal average temperature (°C)	18.96 (SD = 0.91, n = 90)			15.16 (SD = 3.85, n = 90)		
Mean of the daily highest temperature (°C)	19.01 (SD = 0.92, n = 90)			18.01 (SD = 5.40, n = 90)		
Mean of the daily lowest temperature (°C)	18.92 (SD = 0.90, n = 90)			13.01 (SD = 4.12, n = 90)		

temperature in January was 5.2 °C, occurring on 13 January. The monthly average temperature outside the burrow in February (16.83 °C) was the highest in winter, higher than the winter average temperature (Table 2). Both the day number of diurnal average temperature outside the burrow was higher than that inside the burrow (10/13 = 76.9 %) and the winter maximum temperature which occurred in February, indicated that the temperature outside the burrow began to rise (Fig. 2, Table 2). However, it is noteworthy that the winter minimum temperature also occurred in February (Fig. 2).

On the contrary, inside the Chinese pangolin burrow, the seasonal temperature, like the daily temperature was very stable with slight fluctuations (Fig. 2, Table 2). The fluctuation range in the seasonal temperature inside the burrow was 17.8-21.0 °C. The amplitude of seasonal temperature variation inside the burrow was 3.2 °C, only one tenth of that outside the burrow. The recorded maximum temperature inside the burrow was 21.0 °C, occurring in 1 December 2009. The recorded minimum temperature inside the burrow was 17.8 °C, occurring in 20-24 February 2010, which remained constant within five days. In winter, average temperature inside the burrow was 18.96 °C, significantly higher than that outside the burrow (15.16 °C, $P < 0.01$). The monthly average temperature in December (20.02 °C), January (18.41 °C) and February (18.38 °C), the maximum daily average temperature (19.01 °C) and the minimum daily average temperature (18.92 °C) inside the burrow were significantly higher than those outside the burrow (Table 2, $P < 0.01$). The recorded data showed that 85.6 % (77 days) daily average temperature inside the burrow was significantly higher than that outside the burrow (Fig. 2, $P < 0.01$). These analyses showed that inside the Chinese pangolin burrow was warmer than outside the burrow in winter.

It is noteworthy that the monthly average temperature in December, January and February inside the burrow decreased month by month (Table 2). The monthly average temperature in December inside the burrow showed the highest value, higher than the seasonal average temperature inside the burrow. The monthly average temperature inside the burrow in January was relatively closer to that in February, but lower than the seasonal average temperature inside the burrow; and moreover, the monthly average temperature inside the burrow in February was relatively lower. These results indicated that the temperature inside the burrow showed a very slight decrease from December to February the following year (Fig. 2) and different from that outside the burrow.

Discussion

The temperature characteristics of the Chinese pangolin burrow in winter have been studied for the first time. Although the temperature data were obtained from only a single burrow, it has provided useful preliminary knowledge about temperature changes of the Chinese pangolin burrow in winter, which will be beneficial for further research. The Chinese pangolin is an endangered species, which has experienced a sharp decline in population. There are very few opportunities to encounter the burrow where the Chinese pangolin is residing. Moreover, it is also very difficult to find a relatively fresh or even old burrow in the field (Wu et al. 2002, Wu et al. 2005a).

Both diurnal and seasonal temperatures inside the burrow were very stable as compared to the temperature outside the burrow. The temperature outside and inside of the burrow were not significantly correlated. Even maximum temperature fluctuation outside the burrow on 20 February 2010 had no effect on the temperature inside the burrow (Fig. 1). This may be related to the burrow structure, heat insulation of soil and buffering capacity of temperature transmission of soil. The temperature of the underground burrow is mainly adjusted by the form of heat transfer. In other words, if the temperature inside the burrow is higher than that outside the burrow, the heat inside the burrow is dissipated outside the burrow by the forms of conduction, convection and radiation of soil and burrow entrance (Reichman & Smith 1990, Nikol'skii & Khutorskoi 2001, Nikol'skii & Savchenko 2002, Nikol'skii 2002).

The Chinese pangolin burrows function well in maintaining a constant temperature. The burrows are usually located in habitats with higher canopy closure and most of their burrow entrances are hidden under the dense shrub/herb layer (Wu et al. 2003) which can efficiently reduce air convection around the burrow entrance. The entrance of the burrow is usually closed with earth when the Chinese pangolin is inside, with only a small gap left (Liu & Xu 1981), which can efficiently prevent air from flowing in and out of the burrow.

The temperature inside the Chinese pangolin burrow in winter had relatively small fluctuations and maintained relatively constant. After 10 years of captive breeding research in Taipei Zoo, it was concluded that the most optimum ambient temperature range for the survival of Chinese pangolin was 18.1-26.9 °C (Yang et al. 2001). The Chinese pangolin showed better adaptation to temperature changes inside the burrow, but poorer adaptation to temperature changes with relatively larger fluctuations outside the burrow. When the ambient temperature was above 33 °C, the Chinese pangolin showed senses of heat stress (Gu et al. 1983, Heath & Vanderlips 1988, Yang et al. 2001). When ambient temperature dropped sharply because of cold air coming, the Chinese pangolin would demonstrate discomfort and then die due to pneumonia caused by a cold which was caused by larger temperature fluctuations outside the burrow (Gu et al. 1983).

Compared with other mammals, the Chinese pangolin has a lower metabolism rate with an average of 3.06 ml $O_2 \times kg^{-1} \times min^{-1}$ (1.5-5.0 ml $O_2 \times kg^{-1} \times min^{-1}$) and a lower body temperature of only 33.5-35 °C (Heath & Hammel 1986, Weber et al. 1986). Due to its limited ability to regulate body temperature, it is very hard for the Chinese pangolin to compensate for the body heat loss caused by sharply decreased ambient temperature by obtaining heat energy from rapid oxidation of nutrients in the body. The morphological and physiological characteristics in the Chinese pangolin are compatible with its burrowing lifestyle, which indicates that the Chinese pangolin can adapt to the relatively stable environment with relatively small changes in temperature inside the burrow, but can not adapt to the environment with relatively larger changes in temperature outside the burrow.

Maintaining Chinese pangolins in captivity is difficult due to a lack of understanding of the burrow structure, the characteristics of habitat surrounding burrows and the properties of temperature change inside natural and artificial burrows. As such current burrow provisions do not meet the needs of the Chinese pangolins thereby resulting in sickness which can lead to death (Gu et al. 1983, Yang et al. 2001). It is therefore important to minimize the effects of temperature fluctuations outside the burrow on the temperature inside the burrow and maintain a relatively constant temperature inside the burrow.

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