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Research Article

POSTNATAL GROWTH AND AGE ESTIMATION IN A TROPICAL INSECTIVOROUS BAT, *HIPPOSIDEROS SPEORIS*

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ABSTRACT

We studied the patterns of postnatal growth in a tropical insectivorous bat, *Hipposideros speoris*, under natural conditions in Tirunelveli, Southern India. The body mass and morphometric growth parameters of length of forearm, fingers, tail, tibia and condylobasal length were measured from ten young bats (5♀ and 5♂s) at 10 days intervals of time starting from neonatal stage to adult. At birth, young *H. speoris* were altricial and their mothers enshrouded them with their palagiopatagium until the pup's age of 20 days. Clumsy flight of young bats observed after 40 days, and they became completely volant with steady flights at 50 days. Pups obtained 90% of mean sizes of length of condylobase, ear and thumb finger of postpartum females at the age of 30 days. This indicates a faster growth compared to the length of forearm that attained 90% of postpartum females only at 50 days. A linear regression equation was derived to predict the age of young *H. speoris* on the basis of length of forearm from 19.9 ± 0.5 mm to 47.8 ± 1.0 mm (1 to 50 days). Of all three models (Logistic, Gompertz and von Bertlanffy), the Logistic and Gompertz models best described the growth patterns of forearm length and body mass, respectively.

Keywords: Age estimation, *Hipposideros speoris*, Growth curve models, Postnatal development.

INTRODUCTION

Postnatal growth in bats not only include general development but also accomplish specialized tasks in their life such as development of flight navigation (Hughes *et al.,* 1995), hearing (Kossl *et al.,* 2003), echolocation (Habersetzer and Marimuthu, 1986; Vater *et al.,* 2003), vocalizations (Zhang *et al.,* 2005; Liu *et al.,* 2007; Jin *et al.,* 2012), and foraging and feeding skills (Raghuram and Marimuthu, 2007). Growth and development of bats have been studied during prenatal and postnatal periods (Kunz and Hood, 2000), under both natural (Kunz and Robson, 1995; Isaac and Marimuthu, 1996; Stern and Kunz, 1998; Hoying and Kunz 1998; Bapista *et al.,* 2000; Cheng and Lee, 2002; Sharifi, 2004; Shi *et al.,* 2008; Lin *et al.,* 2010; Jin *et al.,* 2012; Sharifi and Vaissi, 2013) and captive conditions (Rajan Marimuthu, 1999; Swift, 2001; Elangovan *et al.,* 2003; Sharifi and Akmali, 2006). These studies emphasize measuring of spectrum of growth parameters in bats starting from their newborn stage to age of sexual maturity. Postnatal development and growth rate are particularly important in deriving equations to predict age, which is useful in behavioural, physiological and ecological studies (Kunz and Hood, 2000). In ecological studies it is often necessary to determine the exact age of an animal to establish certain factors, such as growth rate, survival, sexual maturity, development of various behavioural repertoire, periodicity of reproduction and longevity of an animal (Kunz and Hood, 2000).

Previous studies have proved that measurements of length of forearm, body mass and length of total epiphyseal gap were the important variables useful for assessing postnatal growth rates in bats (e.g. Kunz and Robson, 1995;

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Isaac and Marimuthu, 1996; Stern and Kunz, 1998; Cheng and Lee, 2002; Sharifi, 2004; Shi *et al.*, 2008; Lin *et al.*, 2010; Jin *et al.*, 2012; Sharifi and Vaissi, 2013). Patterns of growth and development vary among species and within families of bats (Kunz and Hood, 2000). Generally, members of the Megachiroptera are more advanced than the Microchiroptera at birth (Orr, 1970; Elangovan *et al.*, 2002, 2003). Postnatal growth of bats influenced by environmental factors like temperature, availability of food, litter size and also biological factors such as size at birth, metabolic rate, and foraging success (Tuttle and Stevenson, 1982; Kunz and Stern, 1995; Stern and Kunz, 1998).

Patterns of growth rates have been evaluated using different growth models for both in Microchiroptera (Kunz and Robson, 1995; Isaac and Marimuthu, 1996; Stern and Kunz, 1998; Cheng and Lee, 2002; Sharifi, 2004; Shi *et al.*, 2008; Lin *et al.*, 2010; Jin *et al.*, 2012; Sharifi and Vaissi, 2013) and Megachiroptera (Elangovan *et al.*, 2002, 2003). Although we have adequate information on parturition, mother-young relations, foraging and echolocation ontogeny of Schneider's leaf nosed bat, *Hipposideros speoris* (Habersetzer and Marimuthu, 1986; Marimuthu, 1988; Radhamani *et al.*, 1990; Pavey *et al.*, 2001), knowledge about postnatal growth and age estimation are still scanty. Habersetzer and Marimuthu, (1986) described the general pattern of postnatal growth and ontogeny of sounds in *H. speoris* both in captivity and seminaturalistic condition. Here, we describe patterns of postnatal growth in *H. speoris* under natural conditions from birth to the post-flight period and we derive equations for estimating their ages.

MATERIALS AND METHODS

The study was carried out in a small colony of 30-50 bats roosting in a temple at Cheranmahadevi in Tirunelveli, Southern India (8° 44'N; 77 ° E). We used longitudinal (mark-recapture) sampling methods to assess the postnatal growth of infants from known age (Bapista *et al.*, 2000). Infants were captured with a hand-held collecting net along with mothers from the temple roost. The mother and the young were marked individually and the morphometric measurements were recorded. Infants with fresh umbilical cords attached were assumed to be 1 day old (Kunz and Anthony, 1982). Because newborn young were tiny and delicate, and marking with bands may cause injuries, we used non-toxic coloured paints to mark them.

When the pups were three weeks old, each individual was banded with a plastic collar having a coloured bead for individual identification (Balasingh *et al.*, 1992). The bats did not show any adverse reaction on banding. Body mass and morphometric growth parameters of length of forearm, fingers, tail, tibia, and also condylobasal length were measured from all the marked young bats, at 10 days interval of time. All the morphometric measurements were done using vernier calipers to the nearest 0.1 mm and body mass was measured to the nearest 0.1 g using a spring balance (Avinet Inc., USA). Morphometric data were collected from a total of 10 young ones, five males and five females, starting from neonate stage. We continued to recapture young until they approached 90 % of adult size and till the stage of complete weaning from their mothers.

We combined data for both males and females in all analyses because we found no significant differences between sexes in size at birth or in rates of growth (see Results). We used linear regression analysis, with age as the dependent variable to derive age predictive equations and to estimate the linear changes in the lengths of forearm and body mass. We divided the growth patterns of the lengths of forearm into linear and non-linear periods and the linear changes were used to derive age predictive equation. The best-fit postnatal growth models of the length of forearm and body mass were fitted using three standard non-linear models (Simply Growth, Version 1.7, PISCES conservation Ltd.). These models were Logistic, Gompertz and von Bertalanffy, fitted using mean values across the individuals for length of forearm and body mass, and the growth patterns were compared among the three models (Elangovan *et al.*, 2003; Shi *et al.*, 2008; Lin *et al.*, 2010; Jin *et al.*, 2012; Sharifi and Vaissi, 2013). Goodness of fit was taken inversely related to the sum of squares of the models after checking systematic deviations (Kunz and Robson, 1995; Swift, 2001; Elangovan *et al.*, 2003). Linear regression analyses were performed using SigmaStat for Windows Version 2.03 (SPSS) and age predicting equations at 95% prediction and confidence limits were plotted using SigmaPlot Version 2.0. Data are given as mean ± SD.

RESULTS

At birth, the young ones of both the sexes were altricial. They were naked, and pink in colour, with eyes closed and pinnae folded. The wing membranes were translucent and the umbilical cord found attached. The mean length of umbilical cord was 6.15 ± 0.45 mm (n = 10). The pups positioned themselves firmly on the ventral side of their mothers. The forearm length of neonate ranges from 19.4 to 20.7 mm (n = 10) and their body mass ranges between 2.5 and 3 g (n = 10). The forearm length and body mass of neonate were of 38 % and 22% of the postpartum females respectively (Table 1). At birth, there were no significant differences between sexes for the length of forearm (Chi-square test, $\chi^2 = 0.06$, $df = 4$, $P>0.05$) and body mass ($\chi^2 = 0.20$, $df = 4$, $P>0.05$). Also there was no significant difference between sexes in rates of growth in forearm length (One-way ANOVA, $F = 2.07$, $df = 1, 118$, $P = 0.15$) and body mass ($F = 2.38$, $df = 1, 58$, $P = 0.12$).

The short, fine, soft hairs of pups were distinguishable at about tenth day and thereafter, developed gray fur, which appeared to that of sub-adults. Up to two recapture sessions, when the pups age at 20 days, we observed the mothers enshrouding their young with their plagiopataium. The length of the forearm increased linearly until 30 days, and thereafter it became non-linear (Figure 1a). However, the body mass increased throughout the study period and a linear pattern of growth were observed (Figure 1b). Pups started to roost separately but adjacent to their mothers at the age of 30 days and further, clumsy flight of pups was also observed from this age. By the time of first flight (clumsy flight), the pups attained the forearm length of 40.8 ± 1.0 mm which was 77% of postpartum females. Steady flights of pups were observed at the age of 40 days and the pups preferred to roost away from their mother. However, they visited their mothers periodically to suckle. The pups were completely volant at the age of 50 days. The forearm length of volant pups were 47.8 ± 1.0 mm, that was 90 % of the postpartum females and body mass were 9.4 ± 0.8 g that reaches 74 % of the postpartum females (Table 1). Pups obtained 90% of mean sizes of length of condylobase, ear and thumb finger of post-partum females at the age of 30 days (Table 1). Thus the growth of condylobase, ear and thumb were fast compared to the growth of II, III, IV, V fingers, tail and tibia (Table 1).

A linear regression equation allowed to predict the age of young *H. speoris* on the basis of length of forearm from 19.9 ± 0.5 mm to 40.8 ± 1.0 mm (1 to 30 days) with 95 % confidence and prediction limits (Figure 2). Curves derived from the three models for body mass were similar in shape, since the correlation coefficient of the predicted values for each model was ≥ 0.95. Nevertheless, the Gompertz equation appeared to the most appropriate model on the basis of statistical criteria describing postnatal changes in body mass of *H. speoris* (Figure 1b; Table 2):

$$\text{Body mass}_{(t)} = 10.22e^{-e^{-0.032(t-10.64)}}$$

where ‘e’ is 2.718 and ‘t’ is time in days.

The predicted values for the length of forearm of three non-linear growth models had correlation coefficients ≥ 0.99. Because of these high correlations in the lengths of forearm, it was difficult to distinguish among the three models. However, after deriving an equation based on each model we chose the logistic equation as best-fit growth model to express the postnatal changes in the length of forearm of *H. speoris* (Figure 1a; Table 2):

$$\text{Forearm length}_{(t)} = 52.84[e^{-0.05\,(t-10.74)}+1]^{-1}$$

Coefficients of variation for the estimates of growth parameters were consistently lesser when derived from the logistic growth model (1.50), compared to the von Bertlanfy model (6.91).

Table 1. Morphological measurements and body mass of *Hipposideros speoris* measured from the age of neonate to 50 days (n = 10).

Age (days)	Length of Thumb (mm)	Length of II finger (mm)	Length of III finger (mm)	Length of IV finger (mm)	Length of V finger (mm)	Condylo-basal length (mm)	Length of tail (mm)	Length of ear (mm)	Length of tibia (mm)	Forearm length (mm)	Body mass (g)
Neonate	5.8 ± 0.2 (94.1)	12.71 ± 0.5 (29.6)	23.1 ± 0.5 (33.3)	20.7 ± 0.4 (35.7)	20.5 ± 0.8 (36.0)	15.8 ± 0.3 (81.9)	8.6 ± 0.6 (37.9)	7.0 ± 1.7 (46.9)	10.4 ± 0.2 (45.8)	19.9 ± 0.5 (37.7)	2.8 ± 0.3 (21.6)
10	5.9 ± 0.3 (96.4)	16.6 ± 2.0 (38.6)	28.5 ± 3.0 (41.0)	25.3 ± 2.2 (43.8)	26.2 ± 3.2 (46.0)	16.1 ± 0.3 (83.6)	9.4 ± 0.8 (41.6)	9.4 ± 1.2 (63.0)	11.6 ± 0.9 (51.4)	24.6 ± 1.9 (46.6)	3.5 ± 0.4 (27.1)
20	5.9 ± 0.4 (96.6)	23.18 ± 2.5 (53.9)	37.6 ± 1.1 (54.0)	33.3 ± 0.9 (57.6)	33.8 ± 1.2 (59.3)	17.6 ± 0.7 (91.1)	13.3 ± 1.5 (58.7)	12.2 ± 1.7 (81.6)	15.4 ± 1.1 (68.1)	33.3 ± 1.0 (96.0)	4.6 ± 0.4 (35.7)
30	6.0 ± 0.4 (97.7)	29 ± 1.6 (67.4)	47.8 ± 3.06 (68.8)	41.8 ± 2.0 (72.2)	42.9 ± 2.1 (75.2)	18.5 ± 0.6 (95.8)	17.2 ± 0.5 (78.9)	13.5 ± 1.5 (90.3)	18.1 ± 0.8 (79.9)	40.8 ± 1.0 (77.3)	5.9 ± 0.5 (46.3)
40	6.0 ± 0.3 (98.3)	33.12 ± 1.8 (77.0)	55.3 ± 2.3 (79.6)	46.4 ± 1.9 (80.4)	47.3 ± 1.7 (82.85)	19.0 ± 0.9 (98.4)	17.3 ± 1.1 (76.5)	13.5 ± 1.7 (90.7)	18.8 ± 0.6 (83.0)	44.8 ± 1.3 (84.7)	6.8 ± 0.5 (53.3)
50	6.1 ± 0.6 (99.1)	35.94 ± 0.9 (83.6)	60.7 ± 1.0 (87.3)	50.9 ± 0.8 (88.1)	51.2 ± 0.7 (89.7)	19.0 ± 0.8 (98.4)	19.6 ± 1.3 (86.6)	14.9 ± 2.5 (99.8)	19.8 ± 0.5 (87.2)	47.8 ± 1.0 (90.4)	7.8 ± 0.4 (73.7)
Adult	6.2 ± 0.5	42.97 ± 0.7	69.52 ± 1.7	57.8 ± 1.3	57.0 ± 1.1	19.3 ± 0.9	22.6 ± 1.4	14.9 ± 3.1	22.7 ± 0.8	52.8 ± 0.8	10.9 ± 1.2

Measurements from post-partum females (n = 10) were indicated in the last row for comparison.

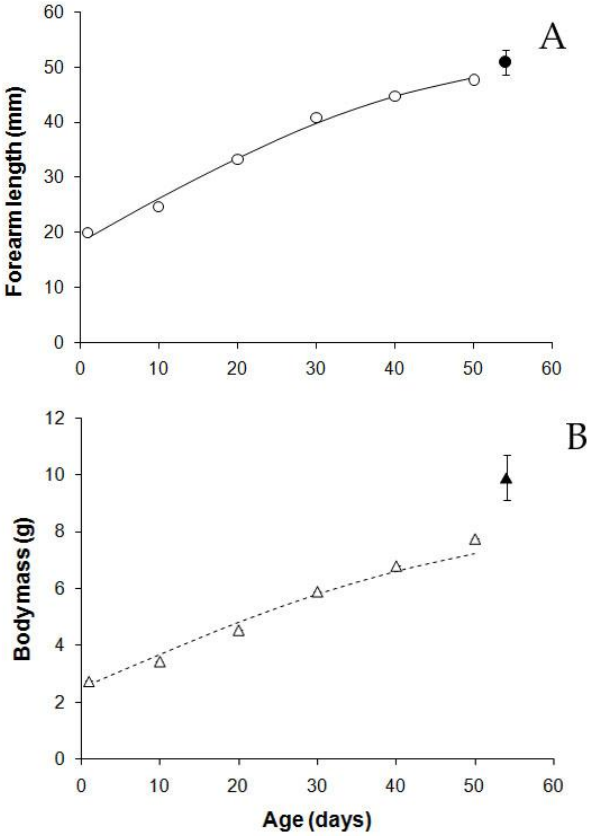

Figure 1. Empirical growth curves for A) length of forearm (n = 60; from day 1 to 50) and B) body mass (n = 60; from day 1 to 50) of free ranging *Hipposideros speoris*. Open circles represents the mean values from 10 bats for forearm length (mm) and solid line indicate the non-linear growth curve of logistic model for forearm length. Open triangles represents the mean values from 10 bats for body mass (g) and dashed line indicate the non-linear growth curve of Gompertz model for body mass. Solid circles in A and solid triangles in B indicate the mean values from 10 adult bats for forearm length (mm) and body mass (g) respectively.

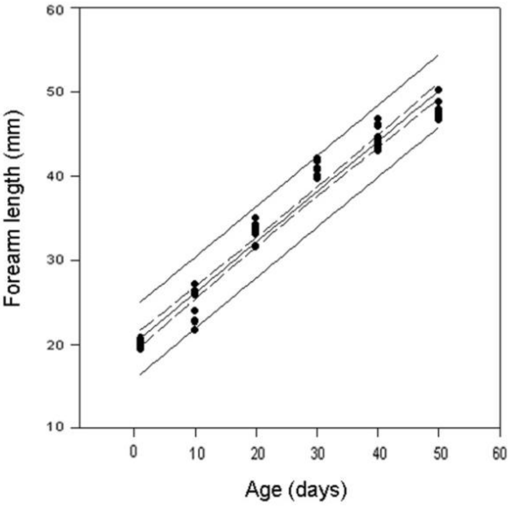

Figure 2. Regression line estimating the age of free ranging *Hipposideros speoris* from the values of length of forearm from neonates to 50 days. The predictive equation is valid for length of forearm ranging from 19.9 ± 0.5 mm to 40.8 ± 1.0 mm (30 days). Narrow (dashed lines) and wide bands (solid lines) indicate 95% confidence and prediction intervals respectively; n = 60, r^2 = 0.97, P < 0.001, age = – 31.87 + (1.62 x length of forearm).

Table 2. Growth parameters of *Hipposideros speoris*, derived from the logistic, Gompertz and von Bertalanffy nonlinear growth models. A- asymptotic size of length of forearm (mm) or body mass (g); K - growth rate constant; I - inflection point; T_0 - time when length of forearm or body mass is 0; CV - coefficient of variation.

Growth model	Parameter	Body mass versus age						
		SE	CV (%)	Sum of Squares model	Estimate	SE	CV (%)	Sum of Squares model
Logistic	A	0.793	1.50		10.432	1.516	14.53	
	K	0.002	3.45	6291.87	0.053	0.010	18.87	190.23
	I	0.603	5.61		23.31	6.510	27.92	
Gompertz	A	1.183	1.89		10.223	1.099	10.75	
	K	0.062	200	6295.51	0.032	0.052	162.5	189.22
	I	38.829	654.56		10.64	37.24	350.00	
von Bertlanffy	A	4.853	6.917		33.89	53.29	157.24	
	K	0.001	5.88	6296.54	0.0045	0.008	177.77	190.03
	T_0				-14.374			

DISCUSSION

The body mass of young bats at birth in general vary from 20% to 40% of a female's post-partum body mass (Kurta and Kunz, 1987; Hayssen and Kunz, 1996). At birth, *H. speoris* in the present study represents 22% of the average body mass of their mother's mass. These values were in close agreement within the range reported for other Hipposiderids, *H. larvatus* (Lin *et al.*, 2010), *H. terasensis* (Cheng and Lee, 2002) and also the other members of microbats (Jin *et al.,* 2012; Sharifi and Vaissi, 2013). However, this is not always consistent for all bat species and with a few exceptions, for example a relative body mass as low as 16% has been reported for its sympatric species *Pipistrellus mimus* (Isaac and Marimuthu, 1996). As like other microchiropterans, the juveniles of *H. speoris* began to fly steadily when they have attained the 74% of adult body mass and 90% of adult skeletal size and dimension (Kunz and Stern, 1995). The postnatal growth of length of condylobase in *H. speoris* was more advanced than fingers indicate that the development of skull is likely to be achieved faster than the development of wings.

H. speoris showed a basic trend of a linear growth of forearm as well as body mass during preflight periods of young ones. However the body mass of the young achieved an asymptote when the postnatal growth rate tends to zero as observed in other microchiropteran species (Isaac and Marimuthu, 1996; Shi *et al.,* 2008; Sharifi and Vaissi, 2013). The reason for lesser asymptotic mass of young bats than adult was due to the reasons because of lack of accretionary growth after the first year (Kunz and Stern, 1995). The values of the lengths of forearm increased during the linear phases of growth in preflight period and hence, it can be used as a reliable parameter for deriving equations in estimating the age of *H. speoris*. The postnatal growth based on three models from our study showed that the logistic and Gompertz models best described the growth patterns of length of forearm and body mass of *H. speoris*.

Bapista *et al.* (2000) compared the longitudinal and cross-sectional sampling to predict the age of free-ranging bats. They argued that longitudinal sampling method is more reliable than cross-sectional, i.e. grab sampling. Our study provides the data on longitudinal sampling in *H. speoris* and can be reliable to predict of age of young bats that may be used in the physiological, behavioral and ecological studies. Many studies showed variations in the postnatal growth of young bats between bats reared in captivity and natural condition. Habersetzer and Marimuthu, (1986) studied the postnatal growth of *H. speoris* and observed a slower rate of growth in bats reared in outdoor enclosure (seminaturalistic condition) than compared to bats from natural caves. However, in case of fruit bats, there were no significant changes in the post natal growth pattern between captivity and wild conditions (Elangovan *et al.*, 2002, 2003). The most important critical parameter is the temperature constraints of roost that directly influence the post natal growth of bats (Hoying and Kunz, 1998). Generally, warm temperature in the roost enhances the growth, whereas cold temperatures suppress the growth of bats (Kunz and Hood, 2000). *H. speoris* roosts in both caves as well as unused buildings with high fidelity. The temperature inside the caves in south India (e.g. Keelakuyilkudi, Madurai) are basically constant around 28°C although the year (Habersetzer and Marimuthu, 1986), whereas in man-made buildings it is highly variable (ranges 30°C to 36°C).

CONCLUSION

The present report invites further studies on comparison of bats roosting in caves *vs* bats roosting in buildings at these tropical regions.

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