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Density Effect on Postnatal Growth of Laboratory-Bred Yangtze Vole (*Microtus fortis calamorum*)

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ABSTRACT

We performed four morphometric measurements to study the postnatal development of Yangtze vole *Microtus fortis calamorum* from birth through approximately 3 months of age with respect to growth. Vole pups were randomized into litters of 1-2 (LD, low density), 3-5 (MD, medium density), and 6-9 (HD, high density) individuals, and the body weight, body length, tail length, and hind foot length were measured and curve-fitted by using Von Bertalanffy and Logistic equations. Instantaneous growth rates and growth acceleration of Yangtze vole at different densities were calculated. Results showed that at different stages, the growth of the pups was density-dependent, while during the adult age, was independent of the presence of other individuals. The difference of hind foot length (HFL) between groups was not significant from day 21 while the body weight (BW) difference was significant or highly significant from birth to day 79, for body length (BL), it was significant from day 2 to day 86, and for tail length (TL), it was significant from day 4 to day 58, indicating that HFL reaches mature size ahead of BW, BL, and TL.

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Authors' Contribution
QHH and MWZ designed and performed experiments, analyzed data, and wrote the manuscript. CG and XJZ helped with data collection and reviewed the manuscript. BL and YW were the guarantors of this work and take responsibility for the integrity of the data.

Key words
Yangtze vole, *Microtus fortis calamorum*, Postnatal growth, Density effect, Growth curve, Body measurement.

INTRODUCTION

The Yangtze vole *Microtis fortis calamorum* (the vole) is the only known mammal species with natural resistance to schistosomiasis, and is a candidate experimental animal. There are many reports of the immunological characteristics of the vole's innate resistance to *Schistosoma japonicum* infection (Zhu *et al*., 1991; He *et al*., 1999a, b; Li *et al*., 2003). As part of the search for anti-schictosomiasis substances, some researchers have been investigating the mechanisms underlying the anti-schistosome effects observed in the vole and the molecules involved in their natural resistance to *S. japonicum* infection (Liu *et al*., 2001; Jiang *et al*., 2008; Jia *et al*., 2008; Sun *et al*., 2008; Song *et al*., 2009; Gong *et al*., 2010; Hu *et al*., 2010, 2012; Wang *et al*., 2010; Cheng *et al*., 2011; Xiang *et al*., 2012). The vole could also be developed as an experimental animal model of diabetes mellitus and spontaneous ovarian cancer that can be used in a variety of research, such as examination of pathological changes, pathogenesis, drug treatment, and vaccine development (Xiao and Wang, 2008). Other *Microtus* species have also been suggested as candidates for small laboratory animal models of large domestic ruminants (Dieterich and Preston, 1977a, b; Kudo and Oki, 1984; Widayati *et al*., 2003), as they have strong herbivorous features characterized by a complex stomach and possession of cellulolytic bacteria (Kudo and Oki, 1984). *Microtus* species are poly-oestrus, showing postpartum oestrus on the day of parturition, and having little or no delay in implantation due to lactation (Kudo and Oki, 1984). In order to establish a laboratory population, over 100 voles were captured from Dongting Lake beaches in 2009. After 3 years of breeding in the laboratory, the population has become a stable breeding population that can reproduce throughout the year and successfully reach reproductive age under the artificial feeding conditions in the laboratory (Zhang *et al*., 2016). Reproductive characteristics of the vole in the laboratory have been reported by Zhang *et al*. (2016) and in the wild by Wu *et al*. (1996). Laboratory observations on the growth and development of juvenile Yangtze voles have been reported by Wu (1996). Han *et al*. (2014) reported that Yangtze voles display significant density-dependent effect on reproduction in the laboratory. Population density, in general, acts as one of the major variables in the regulation of growth, development, reproduction, and other

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cyclic changes in adaptation (Christian, 1961; 1971). For instance, maternal milk production is an important limiting factor to the offspring growth in the Piute Ground squirrel *Spermophilus mollis* (Rickart, 1986). Density-dependence has a strong relationship with immune function (Nelson *et al*., 1996; Li *et al*., 2003), Reproduction (Christian, 1971; Nakata, 1989; Han *et al*., 2014), and Infanticide behaviors (Korpela *et al*., 2010; Opperbeck *et al*., 2012). To date, it still remains unclear whether the growth and development of young Yangtze voles could be affected by population density.

The main purpose of this study was to examine the effect of population density on the patterns of growth and development in laboratory-reared individuals, which we believe will be an indispensable role for further studies on laboratory breeding or population ecology and to explain population fluctuation of Yangtze vole in the wild habitat.

MATERIALS AND METHODS

Animals and ethics statement

The study was conducted at Key Laboratory of Agro-ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, Chinese Academy of Sciences, and all experimental work was carried out following the rules of Key Laboratory of Agro-ecological Processes in Subtropical Region (2004, No. 50). The Yangtze vole, a small herbivore species occurring on the beaches of Dongting Lake in Hunan Province, China, is one of the important pest species in this region. The Yangtze voles bred in our laboratory were initially captured from the beaches of Dongting Lake in 2009. In China, no ethical approval is needed for sampling/capturing/killing rodent pests. All experiments on animals are approved by the Ethics Committee of Institute of Subtropical Agriculture, Chinese Academy of Sciences. All the voles' disposals were complied with "Manipulative Technique for the Care and Use of Laboratory Animals (Xu, 2007)". Body weight (BW), body length (BL), tail length (TL) and hind foot length (HFL) were measured in accordance with the guidelines of "National Agricultural Industry Standards of Monitoring and Control of Rodent pests in rural areas (NY/T1481-2007)" by Chinese Ministry of Agriculture. The litters tested were offspring of captured voles. Vole sub adults, about 20 days of age, born between February and April 2013 were weaned and used for the experiment. The pups were housed in polypropylene cages (43 × 32 × 19 cm) with a stainless-steel mesh lid, white pine shavings covered the cage bottom; food and water were furnished *ad libitum*. The temperature in the lab was maintained at 20-22°C, with a 12:12- h light/dark cycle. Relative humidity varied from 40-70 percent without controlling.

Density groups

The newborn voles were randomly divided into three density-gradient groups: low-density group (LD) contained 1-2 pups/fetal; medium-density group (MD) contained 3-5 pups/fetal, and high-density group (HD) contained 6-9 pups/fetal, and 19, 33 and 32 individuals in each group, respectively. Data on growth and development of voles were collected for nearly 90 days. Body length (BL), tail length (TL) and hind foot length (HFL) were measured with a ruler (0.1-cm precision), while the body weight (BW) was weighed using an electronic balance (0.1-g precision). Individual observations were recorded from birth to day 90 (daily before day 30 and subsequently at weekly intervals). The homogeneity test for variance was used to check the normality of data distribution. Parametric normally distributed data were compared by ANOVA for the comparisons of BW, BL, TL and HFL among different groups; otherwise, the Kruskall-Wallis of non-parametric multivariate ANOVA was tested for differences.

Growth model

According to previous studies (Hu *et al*., 2003), the Logistic equation ($M_{(t)} = A/[\ 1+ Be^{-kt}]$) and the Von Bertalanffy equation ($M_{(t)} = A\ [\ 1- Be^{-k(t)}]^3$) (Ricker, 1979) were used to describe the postnatal growth of BW, BL,TL and HFL of experimental Yangtze vole. Curve fitting was performed using the SPSS 18.0 statistical software.

The birth date and body size were subjected to the Gauss–Newton algorithm, to calculate the minimum of the residual sum squares, which were used as target functions. Then, all the parameters were computed using successive iterations. When the standard accuracy of convergence reached 0.001 and the residual sum of squares of residuals was less than 10^{-5}, the iterations ended. The fitting degree was determined by the correlation index (coefficient) R^2. The fitting was used to calculate the optimal model parameter values for *A*, *B* and *k*. *M*(*t*) of the model representing the BW (g), BL (mm), TL (mm), and HFL (mm) at the age *t* (d), *A* was the asymptotic size, B and *k* are constants and *k* represents the growth rate constant.

RESULTS

Influence of population density on the growth curve and fitting parameters

The sigmoidal growth models, *i.e.,* Logistic and Von Bertalanffy equations were used to fit the BW, BL, TL, and HFL of different groups (all R^2>0.99, details in Table I). According to the method described previously (Hu *et al*., 2006), the Von Bertalanffy equation was used to describe the increases of the BW, BL, and TL, while the Logistic equation was used to describe the HFL.

The growth parameters of the phenotypic

characteristics of each group are shown in Table I and the growth curves are shown as Figures 1A, 2A, 3A and 4A. The *B* values of the HFL are significantly greater than those of the BW, BL and TL, indicating that the HFL reaches mature size ahead of BW, BL, and TL. Moreover, the *k* value of the TL and HFL in the LD group is more than that in the MD and HD groups, suggesting that TL and HFL in the LD group reach maturity earlier than those in the MD and HD groups.

Analysis of growth curve and growth rate at different densities

Growth rate equations of the phenotypic characteristics

The Von Bertalanffy equation was used to describe the increase in BW, BL, and TL, while the Logistic equation was used to describe the HFL. First derivation of BW, BL, TL and HFL growth equations are worked out, and then get the growth rate equations of BW, BL, TL and FHL, respectively (dW/dt, dL/dt, dTL/dt, dHFL/dt) (Table II). Then, with BWt=f (t), BWt=f(t), TLt=f(t) and HFLt=f(t), two-order derivative are conducted, get the equations of growth acceleration of BW, BL, TL and HFL, they are d^2W/dt^2, d^2L/dt^2, d^2TL/dt^2, d^2HFL/dt^2, respectively (Table III). The growth rate curves and growth acceleration curves are shown as Figures 1B, 2B, 3B and 4B, respectively.

Body weight

Basing on the regressive analysis, the growth curve, growth rates and growth acceleration of BW at different densities is presented in Figure 1. According to the Von Bertalanffy equation of BW (Fig. 1A), the inflection age (t), which means the maximum growth rate, was 13.49 days, 14.00 days and 16.82 days at LD, MD, respectively and HD body weight of the inflection age was 17.17g, 17.40g and 19.11g, respectively. The BW increased gradually when t was lower than age at the inflection point (days), when t was equal to the point age, growth acceleration was zero (Fig. 1B), and after, the growth acceleration was in the negative, the growth rate slowed down, the rate of BW gain was reduced; when nearly at 28 or 29 days, the growth acceleration was the lowest, that increased again, but the value was below zero. Thereafter, BW gradually tended to attain the asymptotic value, while the growth rate and growth acceleration tended to be zero. The maximum daily gain at LD during the life time was 5.757g, and 5.374g and 4.839 g at MD and HD, respectively. The maximum growth rate was around 1.705 g at LD, 1.594 g at MD and 1.431 g at HD, respectively (Fig. 1B).

Table I.- The growth curve parameters of Yangtze vole *Microtus fortis* at different population densities.

Growth Parameter	Density	B	A	k (g/d)	R^2
Body weight	LD	0.729	66.173	0.058	0.996
	MD	0.783	58.729	0.061	0.993
	HD	0.773	64.517	0.050	0.990
Body length	LD	0.364	130.270	0.062	0.997
	MD	0.372	122.369	0.067	0.994
	HD	0.359	127.305	0.054	0.994
Tail length	LD	0.555	60.405	0.073	0.998
	MD	0.553	57.448	0.068	0.997
	HD	0.541	59.824	0.063	0.995
Hind foot length	LD	2.672	23.752	0.182	0.998
	MD	2.912	23.574	0.173	0.999
	HD	2.735	23.299	0.167	0.998

Low-density group (LD), 1–2 pups/fetal; medium-density group (MD), 3–5 pups/fetal; high-density group (HD), 6–9 pups/fetal; A was the asymptotic size, B and k are constants and k represent the growth rate constant, R^2 is the goodness of fit meaning the fitting degree of regression line to observation value.

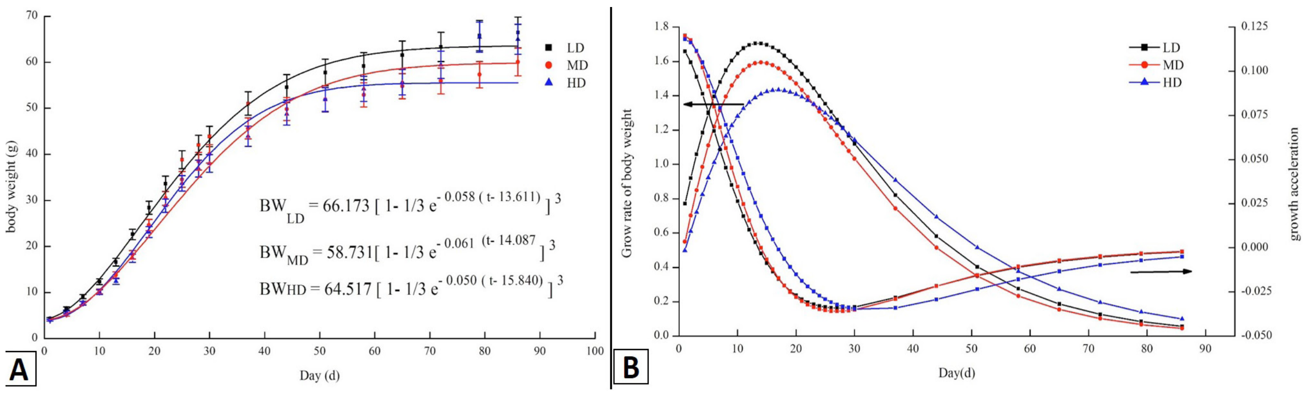

Fig. 1. Growth curve (A), growth rate and growth acceleration (B) of body weight for different density group of Yangtze vole, *Microtus fortis*.

Table II.- The growth rate of Yangtze vole *Microtus fortis* at different population densities.

Growth parameter	Density	Curve equation
Body weight	LD	$dW/dt=8.394(1-0.729\ e^{-0.058\ t})^2\ e^{-0.058\ t}$
	MD	$dW/dt=8.425(1-0.783\ e^{-0.061\ t})^2\ e^{-0.061\ t}$
	HD	$dW/dt=7.481(1-0.773e^{-0.050\ t})^3\ e^{-0.050\ t}$
Body length	LD	$dL/dt=8.820(1-0.364\ e^{-0.062\ t})^2\ e^{-0.062\ t}$
	MD	$dL/dt=9.150(1-0.372e^{-0.067\ t})^2\ e^{-0.067\ t}$
	HD	$dL/dt=7.404(1-0.359e^{-0.054\ t})^2\ e^{-0.054\ t}$
Tail length	LD	$dTL/dt=7.342(1-0.555\ e^{-0.073\ t})^2\ e^{-0.073\ t}$
	MD	$dTL/dt=6.481(1-0.553\ e^{-0.068\ t})^2\ e^{-0.068\ t}$
	HD	$dTL/dt=6.117(1-0.541\ e^{-0.063\ t})^2\ e^{-0.063\ t}$
Hind foot length	LD	$dHFL/dt=3.323e^{-0.182t}/(1+2.672e^{-0.182t})^2$
	MD	$dHFL/dt=4.078e^{-0.173t}/(1+2.912e^{-0.173t})^2$
	HD	$dHFL/dt=3.891e^{-0.167t}/(1+2.735e^{-0.167t})^2$

Low-density group (LD), 1–2 pups/fetal; medium-density group (MD), 3–5 pups/fetal; high-density group (HD), 6–9 pups/fetal; t represents daily time.

Body length

The growth curve, growth rates and growth acceleration of BL at different densities is described (Fig. 2). From Figure 2A, we can learn that there is no inflection age for BL growth rate, one inflection age exists for growth acceleration. The growth rate of BL decreased gradually along with age and tended to attain the asymptotic value, the growth acceleration was the lowest when around 12 or 13 days, that increased again gradually. The maximum daily growth of BL at LD was 12.15cm; and 12.298cm and 10.312cm at MD and HD, respectively. The maximum growth rate located at the birth day, was 3.588, 3.639 and 3.054, at LD, MD and HD, respectively (Fig. 2B).

Tail length

The growth curve, growth rates and growth acceleration of TL at different densities is presented in Figure 3. The inflection age (t) of TL was 6.98d, 7.44d and 7.69d at LD, MD and HD, respectively. Tail length at the inflection age was 18.798 cm, 17.021 cm and 17.726 cm, respectively. TL increased gradually when t was lower than the inflection age, when t was more than age at the inflection point (days), values of growth acceleration were all negative, when t was around 18 or 19 days, the growth acceleration reached the lowest, and increased again. Thereafter, TL gradually tended to be the asymptotic value, while the growth rate and growth acceleration tended to be zero. The maximum daily length of TL at LD was 6.614 cm, and 6.860 cm, 5.653 cm at MD and HD, respectively. The maximum growth rate at LD was 1.954, at MD and HD 1.731, 1.671, respectively (Fig. 3B).

Hind foot length

The growth curve, growth rates and growth acceleration of HFL at different densities is shown in Figure 4. The inflection age (t) of HFL was 5.40d, 6.18d and 6.02d at LD, MD and HD, respectively. Hind foot length at the inflection age was 11.876 cm, 11.613 cm and 11.787 cm, respectively. HFL increased litter by litter when t was less than age at the inflection point (days), and the decreasing speed of HFL-increase followed when t was more than the inflection age; growth acceleration

Table III.- The growth acceleration of Yangtze vole *Microtus fortis* at different population densities.

Growth Parameter	Density	Curve equation
Body weight	LD	$d^2W/dt^2=0.355\ e^{-0.058\ t}\ (1-0.729\ e^{-0.058\ t})\ (2.187\ e^{-0.058\ t}-1)$
	MD	$d^2W/dt^2=0.402\ e^{-0.061\ t}\ (1-0.783\ e^{-0.061\ t})\ (2.349\ e^{-0.061\ t}-1)$
	HD	$d^2W/dt^2=0.289\ e^{-0.050\ t}\ (1-0.773\ e^{-0.050\ t})\ (2.319\ e^{-0.050\ t}-1)$
Body length	LD	$d^2L/dt^2=0.199\ e^{-0.058\ t}\ (1-0.364\ e^{-0.058\ t})\ (1.092\ e^{-0.058\ t}-1)$
	MD	$d^2L/dt^2=0.228\ e^{-0.061\ t}\ (1-0.372\ e^{-0.061\ t})\ (1.116\ e^{-0.061\ t}-1)$
	HD	$d^2L/dt^2=0.143\ e^{-0.050\ t}\ (1-0.359\ e^{-0.050\ t})\ (1.007\ e^{-0.050\ t}-1)$
Tail length	LD	$d^2TL/dt^2=0.297\ e^{-0.058\ t}\ (1-0.555\ e^{-0.058\ t})\ (1.665\ e^{-0.058\ t}-1)$
	MD	$d^2TL/dt^2=0.243\ e^{-0.061\ t}\ (1-0.553\ e^{-0.061\ t})\ (1.659\ e^{-0.061\ t}-1)$
	HD	$d^2TL/dt^2=0.208\ e^{-0.050\ t}\ (1-0.541\ e^{-0.050\ t})\ (1.623\ e^{-0.050\ t}-1)$
Hind foot length	LD	$D^2HFL/dt^2=[0.605e^{-0.182t}(1+2.672e^{-0.182t})-3.232(e^{-0.182t})^2\ ]/(1+2.672e^{-0.182t})^3$
	MD	$D^2HFL/dt^2=[0.705\ e^{-0.173t}(1+2.912e^{-0.173t})-4.109(e^{-0.173t})^2]/(1+2.912e^{-0.173t})^3$
	HD	$D^2HFL/dt^2=[0.650\ e^{-0.167t}(1+2.735e^{-0.167t})-3.554(e^{-0.167t})^2]/(1+2.735e^{-0.167t})^3$

Low-density group (LD), 1–2 pups/fetal; medium-density group (MD), 3–5 pups/fetal; high-density group (HD), 6–9 pups/fetal; t represents daily time.

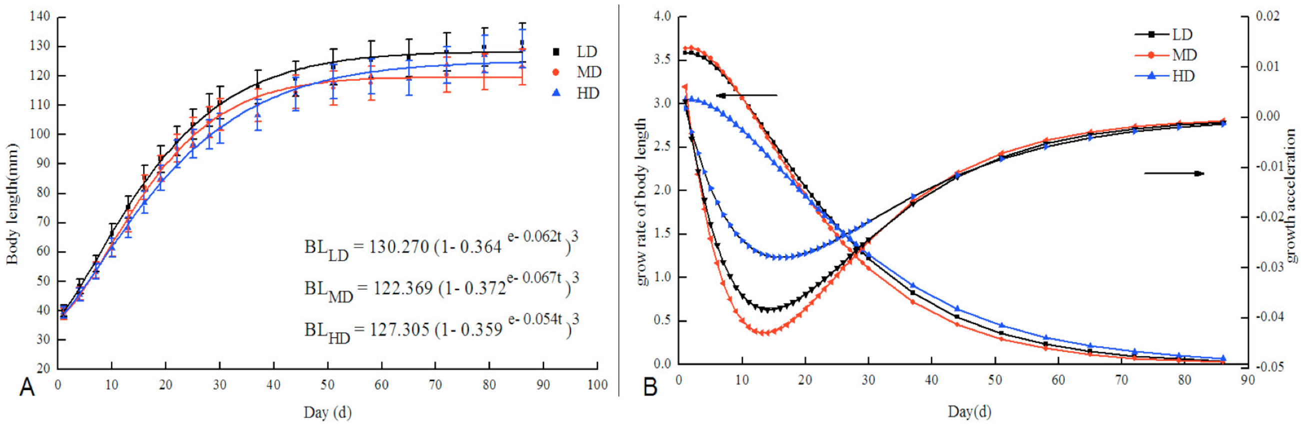

Fig. 2. Growth curve (A), growth rate and growth acceleration (B) of body length for different density group of Yangtze vole *Microtus fortis*.

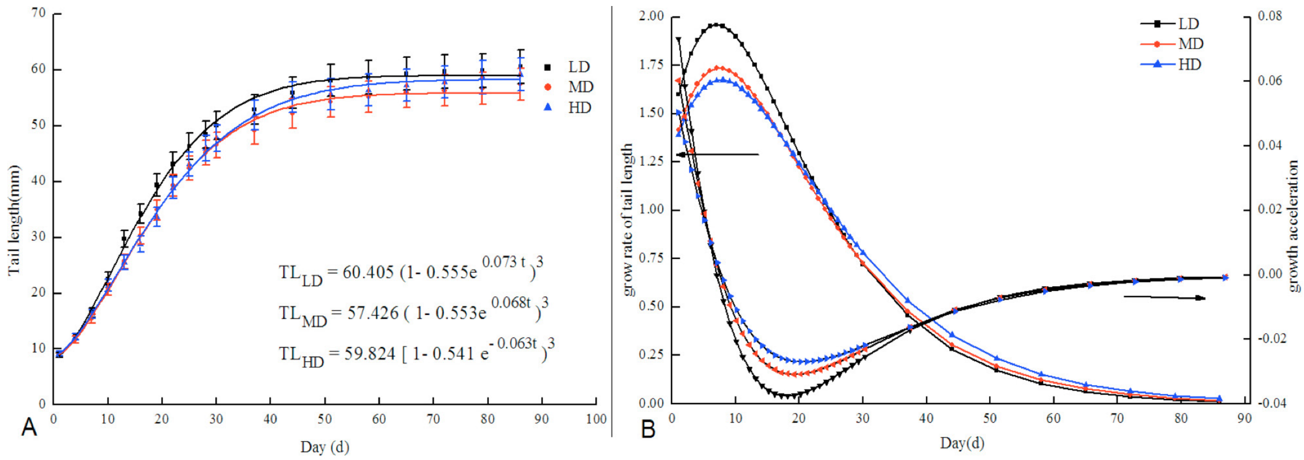

Fig. 3. Growth curve (A), growth rate and growth acceleration (B) of tail length for different density group of Yangtze vole *Microtus fortis*.

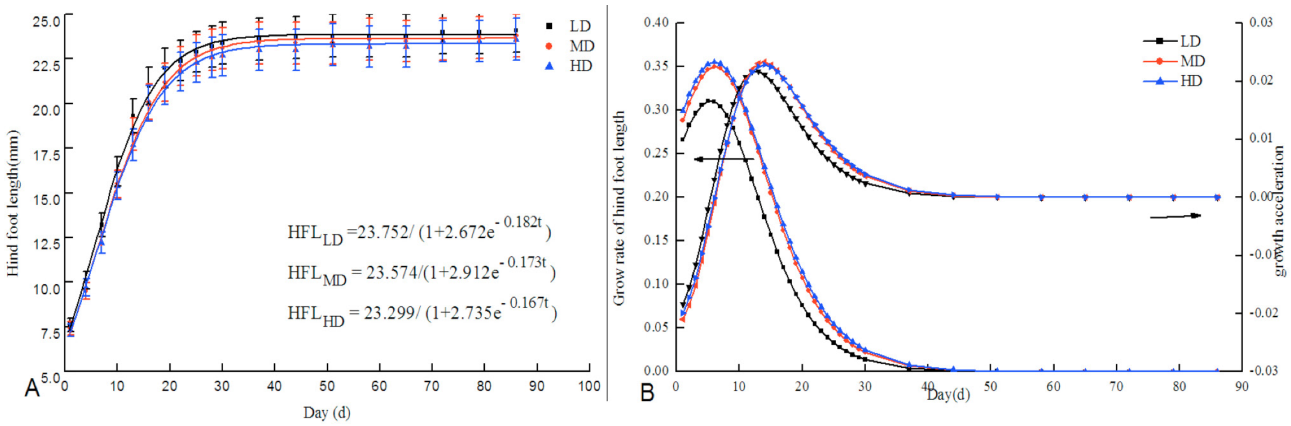

Fig. 4. Growth curve (A), growth rate and growth acceleration (B) of hind foot length for different density group of Yangtze vole *Microtus fortis*.

was positive value, and reached the maximum at 14 or 15 days, and slowed down again. Thereafter, HFL gradually tended to be the asymptotic value, while the growth rate and growth acceleration tended to be zero. The maximum daily length of HFL at LD was 2.161 cm, and 2.039 cm, 1.945 cm at MD and HD, respectively. The maximum growth rate at LD was 0.308, at MD and HD 0.348, 0.354, respectively (Fig. 4B).

Significance of external measurements at different population densities

The increase in BD, BL, TL, and HFL of Yangtze vole at different population densities is shown in Table IV. The difference in the BW of neonates from different density groups was highly significant ($F_{(2,72)}$ =5.273, P <0.01), but non-significant in the BL, TL, and HFL (BL: $F_{(2,72)}$ =2.944, P >0.05; TL: $F_{(2,72)}$ =0.983, P >0.05; HFL: $F_{(2,72)}$ =0.965, P >0.05). The BW difference was significant or highly significant from birth to day 79, for BL, it was significant from day 2 to day 86, and for TL, it was significant from day 4 to day 58; the difference of HFL was not significant from day 21. These results indicate that in neonates growth is density-dependent, while in adults it is independent. Interestingly, these findings indicate that HFL and TL reach maturity earlier than BW and BL.

DISCUSSION

The study of growth and development of rodents forms the basis of understanding reproduction ecology, in relation to estimating the age of wild animals and reflecting phylogenetic relationships among related species; and revealing the evolution of animal life history characteristics and adaptations to the environment (Creighton and Strauss, 1986; Dingle, 1992). Many studies on the growth and development of rodents have been conducted on *Spermophilus belding belding* (Morton and Tung, 1971), *Scotinomys teguina* (Hooper and Carleton, 1976), *Perognathus longimembris (Heteromyidae)* and *Rattus exulans (Murinae)* (Creighton and Strauss, 1986), *Spermophilus mollisand* (Rickart, 1986), *Apodemus semotus* (Lin *et al*., 1993), *Lagurus lagurus* (Jiang *et al*., 1995) as well as other animals like *Hydrochaeris hydrochaeris* (Kanashiro *et al*., 2009), *Eubalaena glacial*is (Fortune *et al*., 2012), Angus pasture-fed cows (Goldberg and Ravagnolo, 2015), *Unio terminalis delicates* (Şereflişan and Gökçe, 2016). Our results showed that, indeed, population density influenced the growth parameters of neonates of Yangtze vole, such as body weight, but did not interfere with the same parameters in adulthood.

Growth models present a visual assessment of growth (Cak et al., 2017). The growth curves (fitted) of organisms

Table IV.- Growth comparison of body weight, body length, tail length and hind foot length at different population densities of Yangtze vole *Microtus fortis* (ANOVA).

Age (day)	Body weight (g)	Body length (mm)	Tail length (mm)	Hind foot length (mm)
1	5.27**	2.94	0.59	1.44
2	11.04***	6.49**	1.18	4.61*
3	16.52***	5.48**	2.25	6.04**
4	14.04***	6.67**	1.48	2.65
5	8.68***	3.02	3.44*	7.03**
6	8.53***	9.87***	6.53**	4.69*
7	7.94**	3.68*	2.39*	4.69*
8	5.89**	5.35**	5.17**	6.32**
9	5.85**	3.03	5.85**	7.37**
10	8.14**	7.56**	2.08	2.05
11	8.17**	6.45**	4.64**	4.74*
12	11.82***	9.61***	7.83**	7.30**
13	13.04***	8.63***	8.64***	8.29**
14	14.81***	14.07***	7.80**	8.65***
15	12.58***	9.23***	7.44**	7.40**
16	10.16***	10.59***	8.15**	4.17*
17	9.81***	9.02***	9.39***	4.63*
18	7.43**	7.10**	5.84**	3.56*
19	6.84**	6.26**	10.04***	4.08*
20	4.52*	5.67**	6.70**	4.22*
21	4.03*	4.37*	6.62**	2.51
22	4.27*	3.12	5.89**	2.07
23	4.34*	3.85*	4.85**	2.28
24	5.55**	5.02**	5.24**	2.56
25	5.43**	8.60***	6.01**	2.98
26	5.60**	6.29**	3.96*	2.61
27	5.52**	6.84**	3.78*	2.73
28	5.23**	10.95***	3.95*	3.98*
29	5.09**	12.32***	6.51**	2.80
30	6.53**	9.88***	5.03**	4.18*
37	7.43**	15.63***	6.23**	2.52
44	4.79*	4.91*	6.06**	9.65
51	4.41*	5.97**	4.50*	1.44
58	3.31 *	7.53**	3.21*	3.16*
65	3.37*	4.76*	2.46	2.36
72	3.17*	6.31**	2.91	1.65
79	5.44**	8.18**	2.53	1.41
86	2.06	7.61**	2.10	1.50

*, P < 0.05; **, P < 0.01; ***, P < 0.001.

have frequently been modeled by sigmoidal equations (Zullinger *et al*., 1984). The process has been adopted in the study of reptiles such as lizards, *Phymaturus spectabilis* (Cabezas-Cartes *et al*., 2015), mammals (Cak et al., 2017; Unnsteinsdottir *et al*., 2014; Zullinger *et al*., 1984), birds (Aplin *et al*., 2015) as well as plants (Gregorczyk, 2014; Shi *et al*., 2016). Three sigmoidal models, *i.e.,* Logistic, Von Bertalanffy, and Gompertz equations have been proposed (Ricker, 1979). Zullinger *et al*. (1984) studied the growth curves of 49 mammalian species drawn by fitting the data to the three models while varying only two parameters (*i.e.,* asymptote fixed) and found that the von Bertalanffy model resulted in the least error mean square for 29 of the 49 species than did the other two models (Gompertz for 15 species, and the *logistic* for five species). Hu *et al*. (2003) fitted the weight gain curve of 17 groups of nine species of rodents using the three sigmoidal growth models, *i.e.,* Logistic, Gompertz and Von Bertalanffy equations and the result was similar to Zullinger *et al*. (1984), and concluded that the Von Bertalanffy equation better represented the growth of BW in previous studies; it was demonstrated that the fitting of BW when adult animals included in the study was similar to that when adult animals were excluded. Therefore, our weight data contained data both for young and adults. Although the growth rates that could be estimated from various growth equations were powerful and useful for making interspecific comparisons of growth (Ricker, 1979), the rates did not vary among different equations. Therefore, using the Von Bertanlanffy equations suggested by Hu *et al*. (2003, 2006), were fitted to study the growth curve of BW, BL and TL, the Logistic equation fitting HFL growth, meanwhile, growth rate (Su *et al*., 2001) and growth acceleration (Chen *et al*., 2002) was used to calculate animal's postnatal growth. The results fitted well and all R squared were above 0.99.

Previous studies have proved that the external environment exhibits a strong relationship with the growth and development of rats (Liu and Fang, 2001; He *et al*., 2010; Fang *et al*., 2012). The effect of plant phenolic compound on the growth and organ development of reed voles (*Microtus fortis*) has been studied by maintaining them on diets at concentrations of 0% (control), 3%, or 6% (He *et al*., 2010). It was noticed that when dietary protein was at 10%, the masses of individuals fed 3% and 6% phenolic compound diets decreased by 16.4% and 32.1% after 30 days of treatment ($P < 0.05$), and by 16.3% and 35.4% after 60 days of treatment ($P < 0.05$), respectively, compared to the control group. Meanwhile, studies have confirmed that the population density was closely related to the growth and development of animals as well (Armario *et al*., 1984; Gamallo *et al*., 1986; Li *et al*., 2003). Crowd-reared rats (*e.g.,* 10 animals per cage) showed a considerably lower BW than control rats (*e.g.,* 3-5 per cage) during the experimental period (Armario *et al*., 1984; Gamallo *et al*., 1986). Moreover, Li *et al*. (2003) demonstrated that final BW and male reproductive organ weights decreased with increasing population density. Our results showed that the age at the inflection point of BW was higher than those of BL, TL, and HFL. Moreover, HFL approached the size of mature voles earlier than did BW, BL, and TL, which is consistent with the results of Hu *et al*. (2003). Wu *et al*. (1996) reported that under natural conditions, the mean litter size was 4.6, and the sex ratio 0.76. Under artificial rearing conditions, we found that the males were more abundant than females; the sex ratio being 0.78: 0.22 (39/50), similar to the findings of Wu *et al*. (1996); sex ratio in the laboratory is consistent with that under natural conditions, indicating that the genetic characteristics of the Yangtze voles in different environments are relatively stable.

In summary, this study shows that population density affects the growth of young Yangtze voles, although in adulthood development is not affected. Due to the influence of environmental factors such as nutrition (He *et al*., 2010; Soltis *et al*., 2017), genetics (Jia *et al*., 2008; Zhang *et al*., 2014; Qiang *et al*., 2015), light (Nelson *et al*., 1996; Liu *et al*., 2001; Langgartner *et al*., 2016), and anthropogenic interference (Papaerna *et al*., 2004), individuals may differ in their reproduction and growth stage. Therefore, it is necessary to elucidate the properties of growth and development of Yangtze voles under laboratory conditions, which could provide theoretical basis for breeding of Yangtze voles and laboratory domestication in animal ecology.

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Statement of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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