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Seasonal variation in population characteristics and management implications for brown rats (*Rattus norvegicus*) within their native range in Harbin, China

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Abstract The brown rat (*Rattus norvegicus*) originated in north-eastern China, Siberia and Japan and subsequently spread worldwide. However, despite its importance to agriculture, public health and scientific and medical research, surprisingly few studies have focused on wild brown rat populations. There are four subspecies in China, but little is known about their original distributions. In the present study, we investigated the seasonal biological and ecological characteristics of brown rats in their native range in Harbin, north-eastern China. Trapping campaigns were conducted in June and November 2006 at a farm site and a rice site, and seasonal variation was analysed. The sex ratio was male biased at the farm site and female biased at the rice site in both seasons. Although juvenile, sub-adult and young-adult rats comprised over 80% of the population in both seasons, the age composition displayed seasonal differences, with higher proportions of juvenile rats in the summer and sub-adults in the winter. There were no significant morphological differences between different sexes or seasons, or between sites. Heavy, female and pregnant rats were captured first and heavier male rats maintained relatively higher reproductive activities than lighter ones, reflecting the link between social dominance and feeding priority. Rats had heavier reproductive organs in summer than in winter. The relative masses of the spleen and adrenal glands also showed seasonal and gender differences. This study demonstrates that brown rats in their native region have similar seasonal biological and ecological characteristics to American and European populations. This information on brown rat in north-east China will contribute to the development of management strategies for controlling this agricultural pest.

Keywords *Rattus norvegicus* · Seasonal reproduction · Age structure · Feeding sequence

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Introduction

Rodents are often the focus of population studies because of their short lifespans and their impact on humans (Boonstra et al. 1998; McGuire et al. 2006; Tkadlec and Zejda 1998; Yu and Lin 1999). The brown rat (*Rattus norvegicus*) originated in north-eastern China, south-eastern Siberia and Hondo in Japan and has since successfully colonised major ecosystems throughout the world (Aplin et al. 2003; Wilson and Reeder 2005). Brown rats have proved a useful laboratory model for studies of behaviour, physiology and genetics (Gill et al. 1989). However, as commensal pests, brown rats are often blamed for huge damage in agricultural and urban areas, as well as for the transmission of a long list of diseases (Huang et al. 1995; MacDonald et al. 1999; Patergnani et al. 2010; Traweger et al. 2006). Regarding improvements in rodent control, most studies have focused on brown rats in urban areas (Castillo et al. 2003; Traweger et al. 2006; Masi et al. 2010) and farms (Gómez Villafañe and Bush 2007; Villa et al. 1997). Moreover, most of our understanding of this species is based on studies of populations outside their native range, such as in Europe and America (reviewed in MacDonald et al. 1999; McGuire et al. 2006). In China, brown rats were divided into four subspecies based on morphologic characteristics and distribution (Huang et al. 1995; Wu 1982; Wilson and Reeder 2005). However, surprisingly, little is known about the biology and ecology of this species in China, especially in its original distribution range, with the exception of a few studies of brown rat populations in the Changjiang River region (reviewed in Zhang and Wang 1998).

Huge seasonal fluctuations in environmental conditions such as day length, food and temperature in temperate and boreal regions can cause dramatic variations in animal population sizes, population parameters and life history strategies (Nelson et al. 1990; Tkadlec and Zejda 1998; Tebbich et al. 2004). Some seasonal variations in population dynamics (McGuire et al. 2006), feeding behaviour (Berdoy and MacDonald 1991) and reproductive biology (Davis and Hall 1948, 1951; MacDonald et al. 1999; McGuire et al. 2006) have been reported in European and American brown rat populations. For example, when crops are available as food in farmlands in the United Kingdom, rats generally scatter to farmland and build temporary colonies (Middleton 1954); in the autumn and winter, however, they usually infest farm buildings and their marginal habitat is at the edge of the farm, such as hedges and fields (Greaves 1982; MacDonald et al. 1999). These results are in accord with those of our previous studies on brown rats from Heilongjiang Province, north-eastern China. Wild rats constructed gather burrows in a small area near farms or villages in spring (May–June); these burrows were abandoned after July following crop maturation and were then reconstructed at the same site in early winter (October–November) (authors' unpublished observations). This suggests that the lifestyle of the brown rat in its original distribution has seasonal features. However, we still know little about the biology and ecology of native wild populations of this globally important species, especially in terms of their seasonal characteristics. Studies of brown rats in Heilongjiang Province could thus yield potentially insightful data and provide a new context in which to interpret the results of laboratory, pest management and population ecology studies.

In this study, we analysed populations of brown rats in June (summer) and November (winter) in suburban farms near Harbin, Heilongjiang Province. Using field data collected in summer and winter, we described the biological features and compared the seasonal characteristics of the population ecology of brown rats in their native range in terms of morphology, age structure, sex ratio, feeding sequence, reproductive activities and physiological status. We tested the hypothesis that brown rats in high latitude regions are likely to show seasonal differences in biological and ecological parameters.

Methods

Study area

The field study was carried out in Harbin (45°42′N, 126°40′E), Heilongjiang, north-eastern China, in June and November 2006. Harbin has a temperate continental monsoon climate and is characterised by a short spring (from April to May), a medium summer (from June to August) and autumn (from September to October), and a long winter (from November to March of the following year). The large seasonal variations in photoperiod and temperature are remarkable features of the climate in Harbin. The maximum day length is 15 h 44 min on June 22 and the maximum temperature is 38°C in June, while the minimum day length is 8 h 43 min and the minimum temperature is −30°C, with historical records as low as −53°C. All brown rats were captured in two sites: the farm site, an experimental farm (main crops included maize, wheat, rice and potato) in a nearby suburb; the rice site, a rice-producing area adjacent to a small village. Both sites were closely surrounded by farmland and residential areas. The sites were 20 km apart, and rats collected from each site were thus considered to represent different populations. Gather burrows of brown rats were located between the margins of crop fields and residential districts and were located at the same sites in June and in November.

Trapping campaign and feeding sequence

Clear gather burrows were found at the margin of the farms at both sites. Brown rats were snap-trapped using peanuts as bait. Two or three traps were set at each hole at dusk and checked at dawn each day. Trapping campaigns lasted for 15 days in June and 6 days in November, until no further animals were captured. Data from the first 5 days of the trapping campaign and the demography of trapped animals over time were analysed as an index of feeding priority. Body weight, gender and pregnant condition of animals trapped daily were recorded and classified according to age category (see "Age structure" section).

Morphological and physiological parameters

The morphological parameters of all animals were measured, including body weight, tail length and hind foot length, following Huang et al. (1995). All animals were dissected, and their physiological organs were removed and recorded, including body weight, carcass weight (excluding splanchnic organs), body length, spleen, adrenal gland and reproductive organ weight (females: ovaries, uterus; male: testicles, epididymis and seminal vesicle). Relative organ weight was calculated as g organ mass/100 g of body weight (Zhang et al. 2004). Characteristics of the reproductive morphology of adult rats, such as the condition of the vaginal orifice and nipples, the presence of placental scars and embryos in females, and the position of the testes in males were also recorded.

Age structure

The body sizes of brown rats in Harbin are smaller than those in America and Europe, and than two of the subspecies found in China, which have adult body weights of over 180–200 g (McGuire et al. 2006; Wu 1982). We therefore determined the age structure of brown rats in Harbin according to body weight and reproductive condition. The body weight of the lightest male rat with spermatozoa in the epididymis was 74 g, while the lightest female rats with perforated vagina, placental scars and embryos were 63, 102 and 125 g, respectively. Moreover, the heaviest of all our captured rats was 331 g. We therefore considered animals weighing less than 80 g to be juveniles and those less than 120 g to be sub-adults, both of which could easily be determined, because most of them have light grey fur, while adult rats had just brown fur. Adult rats, however, had no clear reproductive features or differences in fur colour, and we were only able to divide them roughly into three classes, based on 60 g differences in body weight. Thus, all rats were classified into five age categories according to body weight as follows: (1) juvenile: <80 g; (2) sub-adult: 80–120 g; (3) young adult: 120–180 g; (4) old adult: 180–240 g; (5) aged: >240 g.

Statistical analyses

All analyses were conducted using SPSS v13.0 (SPSS Inc, Chicago, USA). A cross-tabs χ^2 test was used to compare seasonal or site differences in sex ratio, age structure and seasonal physiological parameters. One-way ANOVA was used to detect differences between groups of male and female rats in different age categories. Independent *t*-tests were used to explore differences in morphological and physiological parameters between seasons or sexes. Correlations between testis weight and body weight were analysed using Pearson's correlation. The level of significance (α) was set at 0.05 for all tests.

Results

Totals of 86 and 68 rat holes were located at both sites in June and November, respectively. Fifty-five rat holes were located at the farm site in June and 50 in November, while the corresponding numbers for the rice site were 31 and 18. Altogether, 163 brown rats were captured in June and 86 in November, including 97 in June and 62 in November at the farm site and 66 and 24, respectively, at the rice site.

Sex ratio

The sex ratios of adult rats (>80 g) were analysed at sites and in both seasons. No significant difference was detected between seasons at either site. The sex ratios were male biased at the farm site (June: 36 males, 27 females, sex ratio = 1.33; November: 30/24 = 1.25; $\chi^2 = 0.030$, $df = 1$, $P = 0.863$), while they were female biased at the rice site (June: 23/25 = 0.92; November: 6/11 = 0.54; $\chi^2 = 0.809$, $df = 1$, $P = 0.368$). No significant difference was detected between the sites in June ($\chi^2 = 0.931$, $df = 1$, $P = 0.335$) or November ($\chi^2 = 2.124$, $df = 1$, $P = 0.145$). Data from the two sites were therefore combined, and the total sex ratio was calculated. Overall, there were more males than females in June (85 males, 78 females, sex ratio = 1.09) and equal number of males and females in November (43 males, 43 females, sex ratio = 1.00). No significant difference was detected between seasons ($\chi^2 = 0.104$, $df = 1$, $P = 0.747$).

Morphology

No morphological differences were detected between sites (all parameters: $P > 0.05$), and combined data were therefore used to analyse sexual and seasonal differences. No differences were detected in most morphological parameters between adult female and male rats, except for hind foot length, which was longer in males than females ($t = -3.194$, $df = 247$, $P = 0.002$) (Table 1). No seasonal differences were found in any parameters in male or female rats. However, morphological parameters increased with increasing age in both males and females (Table 2).

Age structure

Regarding seasonal differences in the proportions of animals in each age category (Table 3), the combination of juvenile, sub-adult and young-adult rats accounted for over 80% in both seasons; however, more juveniles ($\chi^2 = 5.985$, $df = 1$, $P = 0.014$) and fewer sub-adult rats ($\chi^2 = 5.143$, $df = 1$, $P = 0.023$) were found in June than in November. In females, the proportion of young adult rats was higher in November ($\chi^2 = 5.058$, $df = 1$, $P = 0.025$)

Table 1 Morphological parameters (mean ± S.D.) of male and female brown rats in June and November

Parameters	Body weight (g)	Carcass weight (g)	Body length (mm)	Tail length (mm)	Hind foot length (mm)	*n*
Male	125.0 ± 64.5	92.9 ± 50.2	163.7 ± 28.2	124.8 ± 22.4	33.4 ± 32.8	128
Female	120.2 ± 58.2	88.2 ± 44.0	163.7 ± 27.7	126.5 ± 22.0	32.2 ± 27.6	121
Jun.						
Male	120.3 ± 62.9	89.6 ± 48.0	163.8 ± 30.1	122.6 ± 22.4	33.5 ± 3.2	85
Female	119.3 ± 62.5	87.2 ± 46.7	165.1 ± 31.1	126.5 ± 22.9	32.4 ± 2.7	78
Nov.						
Male	134.4 ± 67.3	99.5 ± 54.2	164.8 ± 24.4	129.3 ± 22.1	33.1 ± 3.2	36
Female	121.9 ± 62.5	90.1 ± 39.1	161.1 ± 20.4	126.5 ± 20.4	31.8 ± 3.0	43

Table 2 Morphological characteristics of male and female brown rats in five age categories

Parameters	Age stages	Male	*n*	Female	*n*
Body weight (g)	Juvenile	51.4 ± 13.1[a]	33	55.0 ± 13.2[a]	34
	Sub-adult	99.2 ± 11.8[b]	31	97.1 ± 12.6[b]	29
	Young adult	145.7 ± 17.6[c]	41	145.2 ± 17.2[c]	38
	Old adult	204.5 ± 19.0[d]	16	207.5 ± 16.7[d]	16
	Aged	282.6 ± 39.0[e]	7	256.9 ± 20.7[e]	4
Carcass weight (g)	Juvenile	36.5 ± 9.5[a]	32	39.7 ± 9.4[a]	34
	Sub-adult	71.9 ± 9.7[b]	31	71.3 ± 13.8[b]	29
	Young adult	108.1 ± 15.4[c]	41	105.5 ± 12.7[c]	38
	Old adult	154.1 ± 15.2[d]	16	155.6 ± 17.9[d]	16
	Aged	215.0 ± 40.8[e]	7	188.1 ± 19.2[e]	4
Body length (mm)	Juvenile	128.4 ± 13.0[a]	33	131.7 ± 11.2[a]	34
	Sub-adult	157.2 ± 9.8[b]	31	156.2 ± 12.1[b]	29
	Young adult	176.4 ± 14.9[c]	41	177.7 ± 14.0[c]	38
	Old adult	197.1 ± 11.8[d]	16	200.5 ± 12.9[d]	16
	Aged	209.0 ± 9.8[e]	7	209.8 ± 9.3[d]	4
Tail length (mm)	Juvenile	96.6 ± 9.7[a]	33	100.5 ± 10.5[a]	34
	Sub-adult	121.1 ± 7.8[b]	31	121.4 ± 8.9[b]	29
	Young adult	136.1 ± 12.2[c]	40	137.2 ± 8.4[c]	38
	Old adult	146.3 ± 12.4[d]	16	156.4 ± 10.4[d]	16
	Aged	161.4 ± 17.6[e]	7	162.0 ± 11.6[d]	4
Hind foot length (mm)	Juvenile	30.1 ± 2.0[a]	33	29.6 ± 2.5[a]	34
	Sub-adult	33.0 ± 1.9[b]	31	31.9 ± 2.4[b]	29
	Young adult	34.5 ± 2.9[c]	41	33.5 ± 1.5[c]	38
	Old adult	36.5 ± 2.2[d]	16	34.4 ± 1.4[c]	16
	Aged	37.0 ± 3.4[d]	7	35.5 ± 2.4[c]	4

The superscript lowercase (a, b, c and d) in the same column for each measurement represent significant differences among age stages in the same gender using LSD

and that of old adult rats was higher in June ($\chi^2 = 6.904$, $df = 1$, $P = 0.009$). In males, the percentage of sub-adult rats was higher in November than in June ($\chi^2 = 4.013$, $df = 1$, $P = 0.045$).

Feeding sequence

Sixty-five per cent of the total number of rats captured in June and 99% of those captured in November were trapped in the first 5 days. The body weights of rats trapped at the beginning was higher, and then declined, especially in June (Fig. 1a). This correlated with the fact that adult rats were captured more than juveniles early in the trapping campaign, and the situation was subsequently reversed (Table 4). In addition, the first 2 days of each trapping period yielded more females than males (Fig. 1b). Moreover, most pregnant females (14/16) were captured during the first 5 days in June and the numbers captured subsequently decreased (Fig. 1c).

Table 3 Total numbers and percentages of brown rats in the five categories caught in June and November in Harbin

	Total	Juvenile		Sub-adult		Young adult		Old adult		Aged	
	n	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Jun.											
Female	78	26	33.3	16	20.5	19	24.4	15	19.2	2	2.6
Male	85	26	30.6	16	18.8	29	34.1	11	12.9	3	3.6
Total	163	52	31.9	32	19.6	48	29.5	26	16.0	5	3.0
Nov.											
Female	43	8	18.6	13	30.2	19	44.2	1	2.3	2	4.7
Male	43	7	16.3	15	34.9	12	27.9	5	11.6	4	9.3
Total	86	15	17.4	28	32.6	31	36.0	6	7.0	6	7.0

Seasonality of physiological status

Differences in the gonads of adult males and females were found across seasons, with obvious regression in winter (Table 5). Rates of pregnancy were ten times higher in June than in November ($\chi^2 = 10.366$, $df = 1$, $P = 0.001$). The proportion of females with placental scars ($\chi^2 = 6.319$, $df = 1$, $P = 0.012$), perforated vagina ($\chi^2 = 4.356$, $df = 1$, $P = 0.037$) and with elongated nipples ($\chi^2 = 22.853$, $df = 1$, $P < 0.001$) were also greater at this time of year, as were the relative weights of ovaries ($F = 3.832$, $t = 3.331$, $df = 64$, $P = 0.001$) and uteri ($F = 5.531$, $t = 2.658$, $df = 68$, $P = 0.010$). Males in June were more likely to have undergone testes descent ($\chi^2 = 30.801$, $df = 1$, $P < 0.001$) and possessed heavier testes ($F = 0.050$, $t = 14.165$, $df = 91$, $P < 0.001$), epididymides ($F = 1.381$, $t = 6.621$, $df = 89$, $P < 0.001$) and seminal vesicles ($F = 20.530$, $t = 7.987$, $df = 67$, $P < 0.001$) than males trapped in November. A positive correlation between testis weight and body weight was found in both June ($r = 0.886$, $P < 0.001$, $n = 84$) and November ($r = 0.886$, $P < 0.001$, $n = 40$). However, winter males had smaller testes than summer ones with the same body weight, especially in the case of young males (body weight <180 g) (Fig. 2).

Data from adult and non-pregnant individuals revealed seasonal and gender differences in summer and winter populations. Higher relative weights of adrenal glands in females were found in both June ($F = 2.621$, $t = 6.362$, $df = 93$, $P < 0.001$) and November ($F = 0.150$,

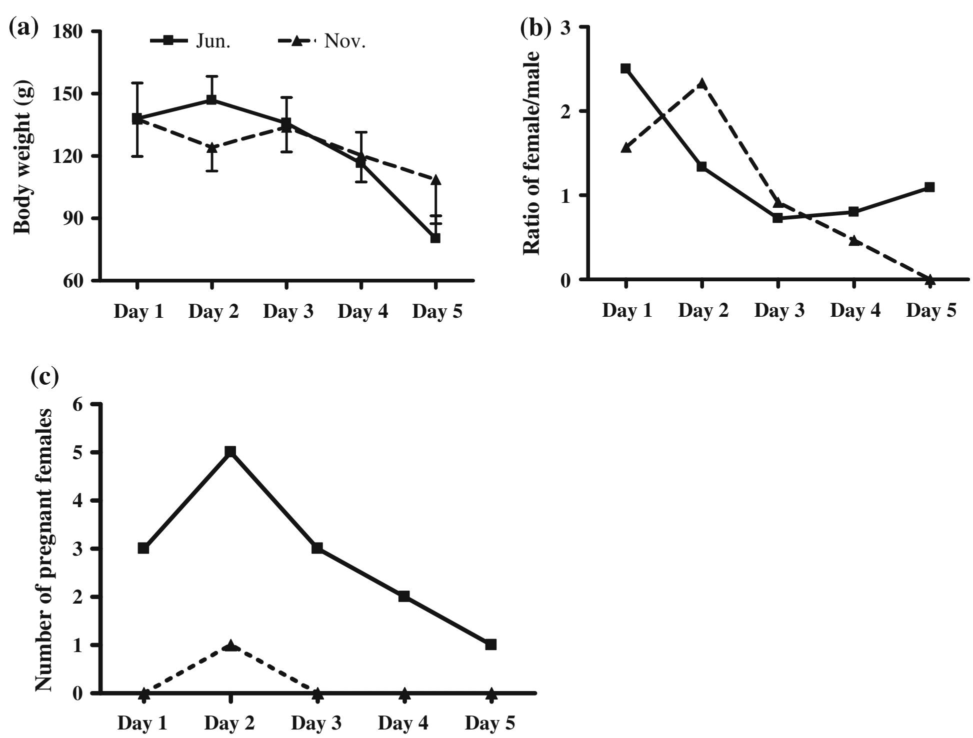

Fig. 1 Daily mean (± S.E.) body weight (**a**), ratio of captured females to males (**b**), and number of pregnant females (**c**) during the first 5 days of trapping in June and November

Table 4 Percentages of brown rats in five categories during the first 5 days in June and November

	Total	Juvenile		Sub-adult		Young adult		Old adult		Aged	
	n	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Jun.											
Day 1	17	5	29.4	–	–	6	35.3	6	35.3	–	–
Day 2	28	4	14.3	6	21.4	8	28.6	8	28.6	2	7.1
Day 3	19	4	21.0	1	5.3	12	63.1	1	5.3	1	5.3
Day 4	18	6	33.4	4	22.2	4	22.2	4	22.2	–	–
Day 5	24	14	58.3	4	16.7	3	12.5	3	12.5	–	–
Nov.											
Day 1	19	2	10.5	8	42.1	5	26.4	2	10.5	2	10.5
Day 2	20	4	20.0	5	25.0	9	45.0	1	5.0	1	5.0
Day 3	23	3	13.0	8	34.8	8	34.8	2	8.7	2	8.7
Day 4	22	6	27.3	6	27.3	8	36.4	1	4.5	1	4.5
Day 5	3	–	–	2	66.7	1	33.3	–	–	–	–

$t = 2.544$, $df = 65$, $P = 0.013$), while that of winter males was higher than summer males ($F = 0.357$, $t = -2.895$, $df = 90$, $P = 0.005$) (Fig. 3, a). A higher relative spleen weight was found in summer rats than in winter ones (males: $F = 1.395$, $t = 2.768$, $df = 90$, $P = 0.007$; females: $F = 8.137$, $t = 3.167$, $df = 68$, $P = 0.002$), but no gender differences were found (Fig. 3b).

Discussion

In Harbin, juvenile, sub-adult and young-adult rats accounted for over 80% of all captured animals in both summer and winter. However, the relative proportions of the five age classes showed seasonal variation: there were more juvenile and young adult rats in the summer and more sub-adults in the winter. In our previous surveys, we also captured more juvenile rats during May and October (author's unpublished data). These results may be explained by previous studies of American and European rat populations, which showed two major peaks (June and October) during the year (Butler and Whelan 1994; McGuire et al. 2006; Stroud 1982). The different age compositions may be the result of two birth peaks in spring (April–May) and autumn (September): summer populations were thus in a rising phase, while winter ones were in a declining phase. The sex ratios differed between the farm and rice sites, but it should be noted that the biases were stable at each site between seasons, as well as in the overall population. Previous studies also reported that sex ratios were not related to changes in population size, and the gender bias varies among different brown rat populations (male biased, Stroud 1982; female biased, Leslie et al. 1952; no bias, Butler and Whelan 1994; Davis 1951). In addition, although there were no significant differences in sex ratios, the proportion of female rats tended to increase at the farm and rice sites during the winter, possibly suggesting the occurrence of male-biased dispersal in Harbin

Table 5 Percentages of females and males in different reproductive conditions and relative weights (g/100g bogy weight) of reproductive organs (mean ± S.E.) in adult and non-pregnant rats in June and November

Reproductive parameters	Jun.	Nov.
Female		
Percentage of pregnant females	30.8 (16/52)	2.9 (1/35)
Percentage of females with placental scars	32.7 (17/52)	11.4 (4/35)
Percentage of females with perforated vagina	82.7 (43/52)	62.9 (22/35)
Percentage of females with elongated nipples	55.8 (29/52)	5.7 (2/35)
Ovaries	0.053 ± 0.004 ($n = 34$)	0.035 ± 0.003 ($n = 32$)
Uterus	0.392 ± 0.083 ($n = 36$)	0.143 ± 0.043 ($n = 34$)
Male		
Percentage of testicle descent	86.4 (51/59)	30.6 (11/36)
Testicles	1.120 ± 0.034 ($n = 59$)	0.316 ± 0.045 ($n = 34$)
Epididymides	0.241 ± 0.015 ($n = 59$)	0.084 ± 0.016 ($n = 32$)
Seminal vesicle	0.403 ± 0.040 ($n = 54$)	0.043 ± 0.021 ($n = 15$)

Using cross-tabs χ^2 test in rate of reproductive conditions; using independent *t*-test in relative weight of reproductive organs

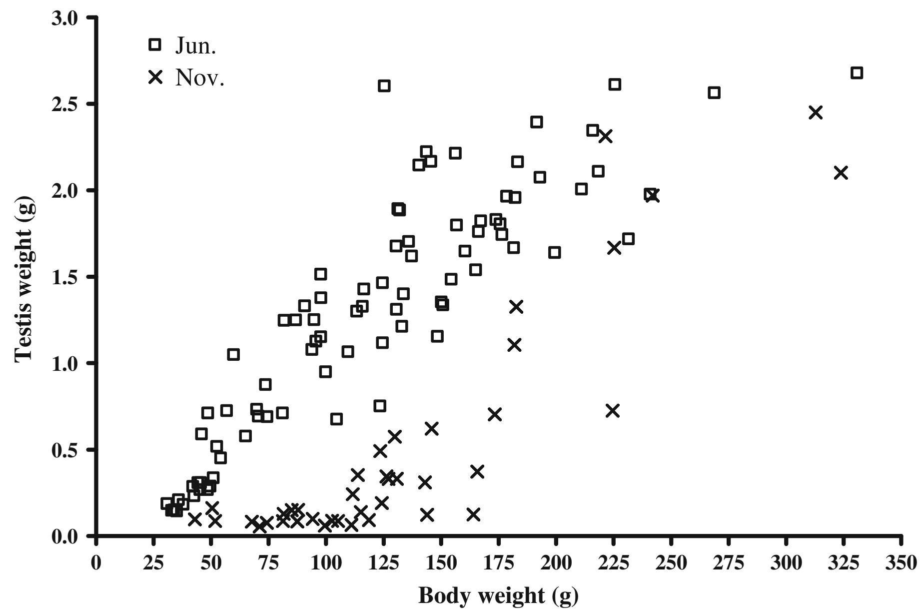

Fig. 2 Scatter plots of body weight and testis weight of male brown rats in June (*square*) and November (*times*)

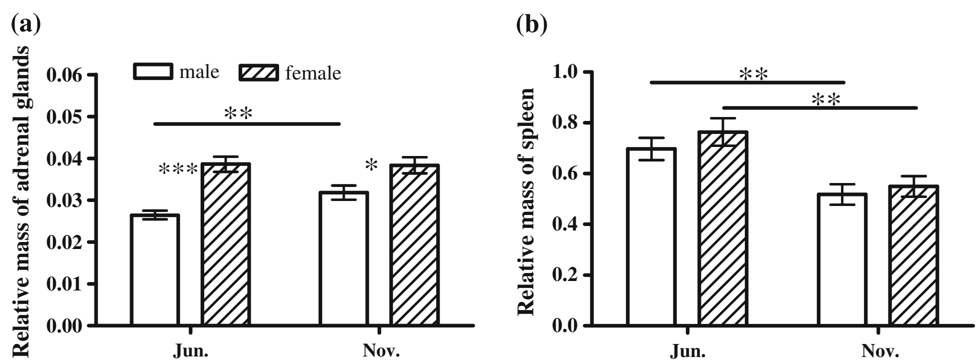

Fig. 3 Relative weights (g/100g bogy weight) of the adrenal gland (**a**) and the spleen (**b**) in adult and non-pregnant rats in both seasons. *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

brown rats, as in other rat populations (Calhoun 1962; Leslie et al. 1952) and most rodent species (Nunes 2006), to avoid inbreeding and as a result of social pressures.

Data from the trapping campaign showed an obvious sequence of feeding priorities related to age, gender and reproductive condition. Heavier, female and pregnant rats were captured first, implying a close association between social dominance and priority at food. This hypothesis may be explained by several previous studies, which reported that social dominance plays an important role in priority at food and other resource. Calhoun (1962) reported that subordinate males were compelled to migrate away from the good habitats as a result of social pressures. MacDonald et al. (1999) noted that dominant male rats usually had priority in terms of food and females. They also reported that age was a more important determinant of social dominance than body weight. However, body weight also has some effects on social dominance: when body asymmetry is over 15%, heavy rats have significantly higher social status (Berdoy et al. 1995). Although we were unable to distinguish between the effects of age and body weight using our age classification, our results still implied an effect of social dominance on feeding priority. Interestingly, pregnant female rats also had priority at food. It is possible that the higher energy consumption associated with pregnancy gives females a higher social status and drives them to collect more food during pregnancy.

Overt seasonal variations were found in reproductive activity in brown rat populations in Harbin. Many measures of reproductive condition showed seasonal changes, including the proportion of females with embryos, placental scars, perforated vaginas, elongated nipples and males with descended testes. Moreover, the weights of the reproductive organs in adult rats were significantly decreased in November compared with those in June. These data suggest that the brown rat in Harbin is a seasonally breeding species, in agreement with studies carried out in temperate Europe and North America

(Davis and Hall 1948, 1951; Leslie et al. 1952; Andrews et al. 1972; Lattanzio and Chapman 1980). However, this differs from populations at lower latitudes in southern China, such as Hunan and Guangdong Provinces, where brown rats are considered to retain their reproductive activity throughout the year (Huang et al. 1995; Zhang and Wang 1998). The mechanisms of seasonal reproduction in temperate and boreal regions have been widely researched in rodents. There are two main factors: environmental and social factors. The environmental factors include photoperiod, temperature and the availability of food and water (Bronson 1988). For example, a short photoperiod (<12 h of light per day) suppressed testis function and size for long-day breeding rodent species, such as the Syrian Hamster (*Mesocricetus auratus*) (Matt and Stetson 1979), Siberian Hamster (*Phodopus sungorus*) (Schlatt et al. 1995) and White-footed Mice (*Peromyscus leucopus*) (Young et al. 2001). Short-day photoperiod has also been shown to delay sexual maturation in some rodents (*Peromyscus maniculatus*, Dark et al. 1983; *P. leucopus*, Johnston and Zucker 1980). Low temperature and high energy consumption caused female mice to stop growth and reproductive development (Perrigo and Bronson 1985), while food and water deprivation inhibited reproduction in adult male and female rodents (Drickamer and Meikle 1988; Eskes 1983; Nelson et al. 1995). These effects are controlled by the hypothalamic–pituitary–gonadal axis, which regulates gonadal activity in response to environmental signals (Young and Nelson 2001). In Harbin, the decline in reproductive activity of brown rats in winter may be related to short day length (the shortest: 22 December, 8 h 43 min), low temperature (mean temperature from December to February is below -15°C) and lack of food, or to the integrated effects of these three environmental factors. The effect of social factors on reproduction is usually attributed to resource assignment and social stress associated with the social hierarchy. For example, interaction with adult males, as well as restriction of food intake, may suppress development of the reproductive system in juveniles in some rodents (Marchlewska-Koj 1997; Nelson et al. 1997). In our present study, both environmental and social factors should affect reproductive activity in Harbin brown rats. It should be noted that the relative testis weights in light male rats in November (body weight <150 g) were suppressed more than in heavy ones (body weight >180 g), which responded more weakly to the winter conditions. Moreover, one pregnant female rat was captured in winter. These results imply an effect of social dominance and food availability on reproduction. In light of these results regarding the above feeding priorities, we can infer that dominant male rats maintain reproductive activity in winter by exerting priority to food, while lack of food inhibits the development or maintenance of testis function in young male rats. However, the effects of environmental and social factors on reproduction in brown rats could not be conclusively determined in the present study, and further work on brown rat populations in Harbin is planned.

There were distinct seasonal differences in physiological organs in brown rat populations. The relative spleen weight decreased and the adrenal glands increased in winter, especially in male rats. Winter conditions are stressful, because high energy needs coincide with low food availability (Bronson 1988). Adrenal gland weight reflects the stress status of animals, which could be caused by environmental or social factors (Romero 2002; Amirat et al. 1980). Laboratory evidence revealed that female rats usually responded more to stress than males in terms of their adrenal gland (Armario et al. 1995; Handa et al. 1994; Kitay 1961). However, the results from the Harbin brown rat populations do not support previous views of rodent immunology, which state that the lymphoid organs, such as the spleen, in warm-blooded vertebrates should be larger in autumn and winter and smaller in spring and summer (Lochmiller et al. 1994; Nelson and Demas 1996; Sealander and Bickerstaf 1967; Valentine and Kirkpatrick 1970). However, autopsies revealed a heavier parasite burden in the liver in June and more wounds on the body than in November. It is thus possible that the increased susceptibility to parasites and pathogens in wild rats maybe be responsible for the increased spleen size in summer.

In conclusion, brown rat populations in high latitude regions display many of the seasonal biological and ecological characteristics reported for American and European populations. According to previous studies, our results suggest that new, effective and biologically based agricultural rat-management strategies for the northeastern plain in China should take account of the following guidelines: (1) management of brown rats should be timed for the end of winter, from February to March, before they come into reproductive condition in the spring; (2) the duration of poison-bait casting should depend on the time of year; more than 5 days is required, and it should be longer in summer than in winter; (3) farm margins should be considered as the key management location, because seasonal infestations of brown rats occur in farms in summer and autumn, and in buildings and villages near to farms in winter and spring.

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