Head-body length variation in the mole-shrew (Anourosorex squamipes) in relation to annual temperature and elevation

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Abstract. Temperature change may affect physiology, distribution, morphology and adaptation of animals. Using individuals captured in Nanchong and Laojunshan Nature Reserve of Sichuan province in western China, we tested head-body length variation in the mole-shrew (Anourosorex squamipes) in relation to annual temperature and elevation. Our results indicate that head-body length of both males and females decreases with decreasing ambient temperature along an altitudinal gradient. Likewise, there is significant monthly variation in head-body length, with individuals in warmer months being larger than that colder ones. The seasonal variation in head-body length suggests the higher predator risk and lower food availability in cold months.

Keywords: Body size, Anourosorex squamipes, temperature, elevation.

Introduction

Body size has long been considered one of the most important traits of an organism because it influences nearly every aspect of its life history (Petier 1983). Temporal and spatial variation in body size of animals is related to many ecological factors, including ambient temperature, food availability, character displacement, precipitation, predator risk, seasonality and evapotranspiration (Yom-Tov 2001, Ochocinska & Taylor 2003, Yom-Tov & Yom-Tov 2005, Medina et al. 2007, Kryštufek & Quadracci 2008, Entling et al. 2010, Opell 2010, Liao & Lu 2010a,b, Liao et al. 2010). Of these factors, ambient temperature plays an important role in determining optimum body size in animals (Ashton 2002, Ashton & Feldman 2003). In this respect, Bergmann’s rule is currently defined as a within-species tendency for increasing body size with increasing latitude or decreasing environmental temperature for endothermic vertebrates (Bergmann 1847, Atkinson & Sibly 1997, Ashton et al. 2000, Angilletta & Dunham 2003). Geographical and seasonal variation in body size of small mammals across different ambient temperatures has been widely reported in recent years (Baumgardener & Kennedy 1993, Smith et al. 1995, Motokawa et al. 1996, Storz et al. 2001, Meiri & Dayan 2003, Ochocinska & Taylor 2003, Yom-Tov & Yom-Tov 2004, Liao et al. 2006, Medina et al. 2007, Lin et al. 2008). Shrews are among the smallest extant small mammals, and there are conflicting reports on correlation between body size and temperature among populations. For example, body size of the short-tailed shrew (Blarina brevicauda) negatively correlates with ambient temperature (Jones & Findlay 1954, Huggins & Kennedy 1989). On the other hand, body size of the masked shrew (Sorex cinereus) in Alaska decreases with decreasing temperature (Yom-Tov & Yom-Tov 2005). The opposite trends in body size could be probably related to food availability associated with ambient temperature in different seasons, as documented for several shrew species (Ochocinska & Taylor 2003, Yom-Tov & Yom-Tov 2005). Moreover, predatory risk may also affect body size distribution since larger individuals may be at a disadvantage to access burrows or cover (Brown 1995).

The mole-shrew (Anourosorex squamipes) is a soricine species living in forest and burrowing in leaf litter and topsoil. It is distributed in Bhutan, Assam, northern Myanmar, northern Thailand, northern Vietnam, Taiwan and western and central China from the provinces of Sichuan and Yunan to Hubei (Motokawa & Lin 2002). It is active all year round and its longevity is about 1.0 yr (Zong 1998). It occurs in a broad range of ambient temperature, including winter, when absolute minimum temperature reaches -3.4°C and summer when absolute maximum temperature is 41.2°C (Liao et al. 2005a). To date, despite the detailed studies on geographic variation and ecology of the species (Yu & Liao 2000, Liao et al. 2004, Motokawa et al. 2004, Liao et al. 2005a,b), information on temporal and spatial variation in body size is
obtained variation in ambient temperatures from Weather each 1 degree square) were extracted from Nanchong pers. Climate data (mean monthly temperatures in °C for each individual to the nearest 0.02mm using vernier cali-

body length, tail length, hind foot length and ear length of

For all individuals trapped, we measured body weight to opmental degree of ovary and testicles (Liao et al. 2005b).

Materials and methods
Study area
Fieldwork was conducted from September 2003 to Au-
gust 2004 in Nanchong (30º48′N, 106º06′E, and 310m a.s.l.) and from April to June 2005 in Laojunshan Nature Re-
serve of Sichuan province in western China. The climate of Nanchong is characteristic of eastern Asia. The study area has annual average temperature of 12.5°C (sub-zero mean monthly temperatures occur in January–February) and annual total precipitation of 1000mm. The vegetation covering the study site is characterized by Camphor tree (Cinnamomum camphora), Black locust (Robinia pseudacacia), Willow (Salix babylonica), Cedar (Cedrus deodara), Fortunes windmill palm (Trachycarpus fortunei) and Sikui (Washingtonia robusta).

Laojunshan Nature Reserve ranges from 1100 to 2008m a.s.l., has an annual average temperature of 12.5°C, and annual average precipitation of 1500mm (Liao et al. 2008). Vegetation is dominated by Hornbeam (Carpinus fargesii), Tea oil (Camellia oleifera), Liansxiang tree (Cercidiphyllum japonicum), Dove tree (Diospyros inxilacate), Common eurya (Eurya loquiana), Azalea (Rhododendron hsinewullianum) and Bamboo (Cinnamobambusa quad-
raghui). Samples were collected in Eryanping Protection Station (28º40′N, 103º51′E, and 1500m a.s.l.) and Laojun-
shan Protection Station (28º42′N, 103º53′E, and 2000m a.s.l.).

We identified adults and juveniles based on develop-
mental degree of ovary and testicles (Liao et al. 2005b).

body mass, thus do not reflect a true body size (Liao et al. 2005b). In this study we hypothesized that monthly and elevational variation in head-
body length of the mole-shrews changes with am-
bient temperature. We expected increased head-
body length with decreasing ambient temperature. As a corollary, we examined if food availability was associated with ambient temperature and body size.

unavailable. For this study we used data on head-
body length as an indicator of body size for 675 sexually mature individuals of A. squamipes. Body mass is highly correlated with metabolism in mammals and may make actually much more sense in the context of temperature/size correla-
tion (McNab 1971). However, variations in preg-
nancy of females and testicles of males influence body mass, thus do not reflect a true body size.

Statistical analysis
Sex ratio and percentage abundance (% of stomachs con-
tents were tested using the Chi-square test. Differences in head-body lengths between males and females were tested using the Student’s t-test. Correlation between head-body length and temperature was estimated using linear regression. Variations in head-body lengths were examined using a general linear model (West et al. 1997).

In the full model, we included temperature as a fixed fac-
tor. Latitude, elevation and sex were included as covari-
ates. We used partial correlation analysis rather than sim-
ple bivariate correlation analysis to indicate the relations-
hips between temperature and head-body length when the effects of elevation and season were removed. Despite the fact that there was a lack of consistency in methods used to collect data on trapping mode and effort across three sites, this would not introduce a bias in the analysis due to the fact that individuals resulting from random samples were analyzed. Statistical analyses were performed using SPSS 13.0 for Windows packages with P = 0.05 used as a threshold for significance testing. All val-
ues given are shown as mean ± SE.

Results
From September 2003 to August 2004 we collected 812 A. squamipes individuals, including 624 adults (297 males and 327 females) and 188 juveniles at Nanchong site. The sex ratio did not differ significantly from 1:1 (Chi-square test: χ² = 1.44, df = 1, P > 0.05). Average head-body length did not differ significantly between females and males (females, 97.76 ± 0.39 mm; males, 96.75 ± 0.36 mm; Student’s t-test: t = 1.87, P = 0.07). Within each month, the difference between male and female head-body length was not significant (Table 1). From April to June 2005 we collected 51 adults (13 males and 9 females at the 1500m site and 17 males and 12 fe-
males at the 2000m site). A male biased sex ratio was not found in Eryanping Protection Station (sex ratio: 1.5:1.0, χ² = 1.50, df = 1, P > 0.05) and Laojunshan Protection Station (sex ratio: 1.4: 1.0, χ² = 0.94, df = 1, P > 0.05). Head-body length of fe-
males was significantly larger than males at both sites (Laojunshan: females, 94.00 ± 1.24 mm; males, 90.61 ± 0.63 mm; Z = 2.60, P < 0.01; Eryanping: fe-
Table 1. The difference of body size between male and female *Anourosorex squamipes* during the twelve months from September 2003 to August 2004 in Nanchong, western China.

<table>
<thead>
<tr>
<th>Month</th>
<th>Sex</th>
<th>Samples</th>
<th>Body length (mm)</th>
<th>U-test</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>♂</td>
<td>14</td>
<td>92.97 ± 1.02</td>
<td>Z = 1.52</td>
<td>P = 0.13</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>19</td>
<td>91.06 ± 1.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>♂</td>
<td>19</td>
<td>92.79 ± 1.16</td>
<td>Z = 0.19</td>
<td>P = 0.85</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>10</td>
<td>92.50 ± 1.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>♂</td>
<td>24</td>
<td>100.69 ± 0.98</td>
<td>Z = 1.16</td>
<td>P = 0.21</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>32</td>
<td>98.87 ± 0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>♂</td>
<td>25</td>
<td>102.72 ± 0.83</td>
<td>Z = 1.01</td>
<td>P = 0.11</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>30</td>
<td>101.47 ± 0.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>♂</td>
<td>24</td>
<td>102.58 ± 1.08</td>
<td>Z = 1.59</td>
<td>P = 0.08</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>17</td>
<td>101.71 ± 0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>♂</td>
<td>27</td>
<td>102.33 ± 0.86</td>
<td>Z = 0.92</td>
<td>P = 0.39</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>30</td>
<td>101.77 ± 0.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>♂</td>
<td>21</td>
<td>103.81 ± 1.09</td>
<td>Z = 1.71</td>
<td>P = 0.09</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>15</td>
<td>102.60 ± 0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>♂</td>
<td>27</td>
<td>103.11 ± 0.71</td>
<td>Z = 1.08</td>
<td>P = 0.28</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>21</td>
<td>102.14 ± 0.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>♂</td>
<td>15</td>
<td>98.80 ± 1.20</td>
<td>Z = 1.77</td>
<td>P = 0.10</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>11</td>
<td>96.18 ± 0.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>October</td>
<td>♂</td>
<td>37</td>
<td>96.12 ± 1.05</td>
<td>Z = 1.51</td>
<td>P = 0.13</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>30</td>
<td>94.02 ± 1.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>November</td>
<td>♂</td>
<td>53</td>
<td>91.48 ± 0.75</td>
<td>Z = 0.86</td>
<td>P = 0.39</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>52</td>
<td>92.49 ± 0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>♂</td>
<td>41</td>
<td>93.29 ± 0.73</td>
<td>Z = 2.14</td>
<td>P = 0.21</td>
</tr>
<tr>
<td></td>
<td>♀</td>
<td>30</td>
<td>90.77 ± 0.95</td>
<td></td>
<td></td>
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</tbody>
</table>

males, 95.28 ± 0.98 mm; males, 92.38 ± 1.07 mm; Z = 1.98, P < 0.05).

Monthly variation in ambient temperature in twelve months was marked (Fig. 1; Kruskal-Wallis H-test: H = 209.00, df = 11, P < 0.001). During the twelve months, there was a significant monthly variation of head-body lengths in both sexes (Fig. 2; one-way ANOVA: females, F = 33.74, df = 11, P < 0.001; males, F = 42.26, df = 11, P < 0.001). Head-body length in males was positively correlated to mean monthly temperature (temperature = -118.01 + 1.38 body size, F = 5.42, r² = 0.35, P = 0.04). Similarly, head-body length in females was positively correlated with mean monthly temperature (temperature = -115.05 + 1.33 head - body length, F = 6.69, r² = 0.40, P = 0.03).

UNIANOVA with elevation, latitude and season as fixed factors showed that elevation and season were two main factors affecting difference in ambient temperature (elevation, F₂, 674 = 4.69, P = 0.01; season, F₁₁, 670 = 1105.94, P < 0.001), and latitude among three sites did not strongly affect the ambient temperature (F₁, 674 = 0.72, P = 0.40). Average ambient temperatures at the 2000-m site (13.1 ± 2.4°C) were significantly lower than those at both the 1500-m site (15.6 ± 2.1°C; Mann–Whitney U-test: Z = 2.29, P = 0.022) and the 310-m site (17.5 ± 3.2°C; Z = 2.34, P = 0.02) sites. Difference was also found between the later two populations (Mann–Whitney U-test: Z = 2.12, P = 0.05). Moreover, elevation had a significant effect on temperature variability (as an indicator of climatic harshness or predictability), which was higher at the 2000-m site than at both lower elevations (F₂, 17 = 3.61, P < 0.05).

We used a general linear model to gain insight on spatial variation in adult head - body length across ambient temperatures at three different elevations. This is because both the effects of elevation and seasonal variation are addressed simultaneously. An initial analysis of adult head-body length indicated that none of the possible two-way interactions between sex, latitude and temperature were significant (F₁, 674 ≥ 1.513, P ≥ 0.219). Therefore, the analysis was limited to an evaluation of the main effects only. While the effect of latitude
Figure 1. The variation of ambient temperature during the twelve months in Nanchong, western China (Data resulting from Weather Station of Nanchong).

Figure 2. Monthly variation in body size of *Anourosorex squamipes* males (empty circle) and females (solid circle) from September 2003 to August 2004 at Nanchong in western China.

was not significant ($F_{1, 674} = 0.42$, $P = 0.67$), both the elevation and season temperature terms explained significant amounts of variation in the mean head-body length of adults (season, $F_{1, 674} = 49.22$, $P < 0.001$, elevation, $F_{1, 674} = 12.67$, $P < 0.001$). Head-body length increased with increasing ambient temperature when the effects of elevation and season were removed (Fig. 3; female, $F = 14.54$, $P < 0.001$; male, $F = 13.47$, $P < 0.001$).

We only analyzed stomachs contents from 144 specimens at Nanchong site. Besides invertebrate prey, plant materials, and shed skin were identified (Table 2). Food availability (percent of empty stomachs) showed major changes during the study period (Chi-square test: $\chi^2 = 78.33$, $df = 11$, $P < 0.001$). The occurrence of empty stomachs was correlated negatively with ambient temperature (Fig. 4; $F = 58.49$, $r^2 = 0.85$, $P < 0.001$). Significant variations were recorded in the frequency of stomachs containing plant material and also invertebrate prey (Ophisthopora and Hymenoptera, but not Coleoptera) (Table 2).

Discussion

Our study demonstrated an altitudinal and seasonal decrease in head-body length with decreasing ambient temperature in *A. squamipes*. This is similar to observations made previously on small
mammals in general (Mezhzherin 1964, Freckleton et al. 2003, Yom-Tov 2003, Millien 2004, Yom-Tov & Yom-Tov 2005). However, the findings are the inverse of the increase in body size with decreasing ambient temperature in other Sorex species (Kirkland & Van Deusen 1979, Huggins & Kennedy 1989).

The heat conservation prediction indicates that temperature variation should be the best environmental explanatory variable for average body size. It also indicates that covariance of body size with temperature should be stronger for small-bodied than large-bodied species because their greater surface area to volume ratios mean that small-bodied species face more of a challenge in keeping warm than do large-bodied species (James 1970). However, there is no definitive evidence that correlations between temperature and body size should be stronger in smaller mammals (Ashton et al. 2000, Meiri & Dayan 2003, Meiri et al. 2007). Our results showed that head-body length of the mole-shrew declined with decreasing ambient temperature, thus behaving opposite to the heat conservation hypothesis, similar to other Sorex species in the northern Palearctic region (Mezhzherin 1964, Ochocinska & Taylor 2003, Yom-Tov & Yom-Tov 2005).

Body size is one of the key phenotypic traits of

![Figure 3. The relationship between ambient temperature and body size of Anuro-
sorex squamipes males (empty circle) and females (solid circle) in three sites at
different elevations in western China.](image)

<table>
<thead>
<tr>
<th>Month</th>
<th>Vegetation</th>
<th>Sichuan shrew</th>
<th>Coleoptera -imago</th>
<th>Ophisthopora</th>
<th>Hymenoptera</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>48.1</td>
<td>32.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>19.5</td>
</tr>
<tr>
<td>February</td>
<td>44.6</td>
<td>38.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>17.2</td>
</tr>
<tr>
<td>March</td>
<td>22.6</td>
<td>22.8</td>
<td>10.2</td>
<td>12.1</td>
<td>27.3</td>
<td>5.0</td>
</tr>
<tr>
<td>April</td>
<td>24.5</td>
<td>3.7</td>
<td>9.8</td>
<td>32.1</td>
<td>25.4</td>
<td>6.5</td>
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<td>May</td>
<td>26.6</td>
<td>4.7</td>
<td>11.6</td>
<td>24.2</td>
<td>28.6</td>
<td>4.3</td>
</tr>
<tr>
<td>June</td>
<td>15.8</td>
<td>2.1</td>
<td>13.4</td>
<td>32.2</td>
<td>30.8</td>
<td>5.7</td>
</tr>
<tr>
<td>July</td>
<td>16.2</td>
<td>1.5</td>
<td>16.7</td>
<td>36.6</td>
<td>27.9</td>
<td>1.1</td>
</tr>
<tr>
<td>August</td>
<td>14.9</td>
<td>2.6</td>
<td>13.6</td>
<td>27.6</td>
<td>30.7</td>
<td>0.4</td>
</tr>
<tr>
<td>September</td>
<td>18.7</td>
<td>2.4</td>
<td>10.8</td>
<td>30.5</td>
<td>28.7</td>
<td>9.9</td>
</tr>
<tr>
<td>October</td>
<td>22.9</td>
<td>8.4</td>
<td>7.8</td>
<td>29.6</td>
<td>19.8</td>
<td>12.7</td>
</tr>
<tr>
<td>November</td>
<td>33.6</td>
<td>29.4</td>
<td>5.2</td>
<td>4.6</td>
<td>10.4</td>
<td>15.8</td>
</tr>
<tr>
<td>December</td>
<td>46.2</td>
<td>37.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16.1</td>
</tr>
<tr>
<td>χ²</td>
<td>58.64</td>
<td>162.90</td>
<td>8.72</td>
<td>34.21</td>
<td>14.25</td>
<td>37.76</td>
</tr>
<tr>
<td>𝑃</td>
<td>0.000</td>
<td>0.000</td>
<td>0.37</td>
<td>0.000</td>
<td>0.008</td>
<td>0.000</td>
</tr>
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</table>
Figure 4. The correlation between the percentage abundance of empty stomachs of *Anourosorex squamipes* and ambient temperature during the twelve months from September 2003 to August 2004 in Nanchong in western China.
pattern among small mammals (Lindstedt et al. 1985, Millar & Hickling 1990).

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