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Original Investigation

Plateau zokors on the Qinghai-Tibetan Plateau follow Bergmann's rule latitudinally, but not altitudinally

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ABSTRACT

Since the first description of the Bergmann's rule, body size clines along environmental gradients have been examined in a wide variety of taxa. Broad support for Bergmann's rule has been found for endotherms and even ectotherms; many species, however, do not follow Bergmann's rule or the converse to Bergmann's rule. We tested the relationship between body size (body weight (BW), body length (BL), and 12 skull size measurements) of a typical subterranean rodent plateau zokor (*Eospalax baileyi*) collected from different geographic localities and two geographic variables (latitude and altitude) as well as some environmental factors that usually change with geographical gradients on the Qinghai-Tibetan Plateau. A total of 523 (212 males and 311 females) adult individuals from 21 sampling sites were analyzed. The results indicated that body size of both males and females was positively correlated with latitude, annual temperature (AT), and annual net primary production (ANPP) and negatively correlated with altitude and annual precipitation (AP). These results indicated that the plateau zokor latitudinally followed Bergmann's rule but altitudinally followed the converse to Bergmann's rule. The environmental factors which may influence the zokors' water balance and food availability were the major driving forces latitudinally and altitudinally shaping the body size of this species, respectively.

Introduction

Bergmann's rule predicts a larger body size for warm-blooded vertebrate species (either interspecifically or intraspecifically, see Meiri 2011) in colder areas and is assumed to be an adaptive response to environmental temperature (Mayr 1956). Since first described (Bergmann 1847), body-size clines along environmental gradients have been examined in a wide variety of taxa (Watt et al. 2010). Broad support (>50%) for Bergmann's rule has been found for endotherms; many species, however, do not follow Bergmann's rule or follow its converse (Ashton et al. 2000; Meiri and Dayan 2003; Ochocinska and Taylor 2003; Meiri et al. 2004; and also see Watt et al. 2010).

Subterranean rodents are a widely distributed group of species those live primarily underground and are highly adapted to that environment (Nevo 1999; Lacey et al. 2000). On the one hand, subterranean mammals are likely candidates of those who may not follow Bergmann's rule because they spend most of the time in favorable and relatively constant thermal conditions throughout their distribution range. Instead, other factors such as food availability (rather than heat conservation) may become a major limiting factor for animals' body size (Mayr 1956; Meiri and Dayan 2003; Medina et al. 2007). On the other hand, digging for food and shelter is an energetically demanding process that can result in heavy energy expenditure, more than that required by aboveground animals (Vleck 1979). The high energy cost makes subterranean rodents have a larger resource (e.g., food, water, etc.) demand and subsequently makes the body size of these animals sensitive to various resource constraints in local environments. Two studies investigated the relationships between environmental factors and body size of subterranean rodents both inter- and intraspecifically (Nevo et al. 1986; Medina et al. 2007), which found that subterranean rodents did vary their body size along environmental gradients, although their conclusions were partially non-coincident. Due to the scarcity of related studies, additional evidence is still needed to test the relationships between body size of subterranean rodents and environmental factors.

Plateau zokors (Rodentia, Muroidea, Myospalacinae, *Eospalax baileyi*) are a typical subterranean rodent species that spend most of their daily life underground and only very occasionally move aboveground for foraging and dispersal (Zhou and Dou 1990). The plateau zokors occur in alpine meadows and prairies in the east of the Qinghai-Tibetan Plateau's (QTP, which is the largest and highest plateau on earth) with a relatively large geographical range

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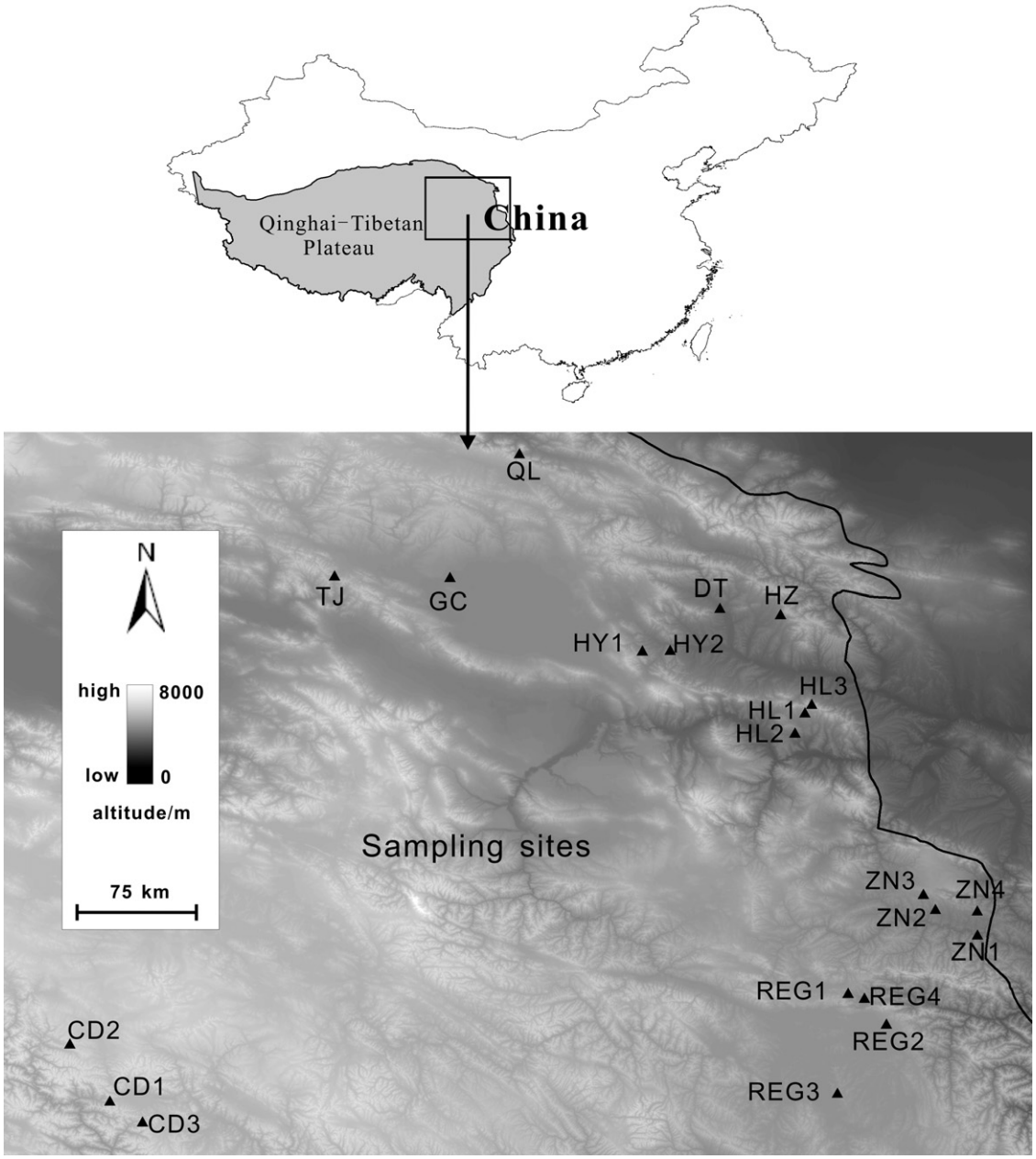

Fig. 1. Sampling sites of plateau zokor in the east of Qinghai-Tibetan Plateau located in the west of China (see Table 1 for geographical details); the lighter tint in the magnified region defines higher altitude.

(96–104°N, 33–38°E; elevations ranging from 2600 to 4600 m; see Tang et al. 2010), which facilitates their body size variation and relationships with geographical as well as climatic factors.

Latitude is usually viewed as a general geographical factor, but in QTP, altitude is also tested as an important geographical factor. At the meantime, temperature, precipitate, hypoxia (represented as altitude) and food availability are viewed as potential environmental factors that directly or indirectly influencing the body size of animals in the plateau (Liao et al. 2006; Jin et al. 2007; Lin et al. 2008). We addressed the following questions in this study: (i) whether the body-size traits (body weight, body length, and skull size) of the subterranean plateau zokors follows latitudinally and/or altitudinally the Bergmann's rule, and (ii) if size trends do occur, what environmental factors annual temperature (AT), annual precipitation (AP), annual net primary production (ANPP) and hypoxia can account for them.

Material and methods

During 2006–2007, individual zokors were caught with ground arrows which could be excited to kill zokors when they were plugging the excavated burrows (Han et al. 2003). The site distribution is shown in Fig. 1. Latitude, longitude, and altitude information (Table 1) at each sampling site were recorded using an Etrex GPS (Global Position System) unit (Garmin, Taiwan). The body weight (BW) of each animal was weighed to 1 g with a platform balance; the body length (the head and body length, excluding the tail) (BL) was measured to 1 mm by a measuring tape; the sex and age were identified by body dissection. The age was judged based on the width between the parietal crests (Zheng and Zhou 1984) and only adults were used in this study. The skulls were collected and cleaned in the laboratory and 12 morphological traits (Table 2) were measured to 0.01 mm using vernier calipers. We performed