Ecologically-based rodent pest management: research progress in plateau zokors on Qinghai-Tibetan Plateau

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Abstract Rodent management has been an ongoing global challenge. The emergence of ecologically based rodent management (EBRM) has improved a series of dilemmas in traditional rodent control that are poorly targeted, unsustainable, and environmentally harmful. The plateau zokor (*Eospalax baileyi*) is a key species in the Qinghai-Tibetan Plateau (QTP). In recent years, due to its high population density, this subterranean rodent has caused serious damage to the grassland ecosystems on the QTP. Currently, a series of explorations of EBRM on plateau zokors have been initiated. We review progress about EBRM on plateau zokor in this paper, which mainly includes some preliminary investigations on ecological control, biological control and fertility control of plateau zokor population, and these explorations can provide a reference for the conservation of the global grassland ecosystem.

Introduction

As typical subterranean rodents, Myospalacinae species, zokors, are widely distributed in several countries in East Asia. Their distribution spans the eastern Eurasian steppe, which contains three zonal types including meadow steppe, typical steppe, and desert steppe. The plateau zokor (*Eospalax baileyi*) is a species of great economic and ecological significance in Myospalacinae, mainly distributed in the alpine meadow ecosystems of the Qinghai-Tibetan Plateau (QTP). It is regarded as ecosystem engineer because, at a natural population density, it plays essential roles, such as promoting nutrient cycling, improving soil structure, and increasing the vegetation composition. Currently, due to the high population density, its unique lifestyle of creating their subterranean burrow system by shifting soil and building mounds is causing great damage to the grassland ecosystem in the QTP. In the context of ineffective control of population density of plateau zokor and a series of negative effects brought by traditional rodent control measures in this region, the exploration of EBRM for plateau zokor came into being.

Methods and Study Site

The experimental area was located in the Luqu County (34°14′07″–34°48′48″N, 102°10′80″–102°58′15″E), Tianzhu County (36°58′34″–37°19′24″N, 102°25′43″–103°21′38″E), Gansu Province, QTP. Detailed methods were cited in the reference. All data were analyzed with SPSS 23.00 software (IBM Corp., Armonk, NY). Two-way analysis of variance (ANOVA) was used with the treatment group and gender as fixed factors, and behavior, hormones, and gene expression measurements as dependent variables. Duncan's post hoc test was used to identify specific differences between treatment groups. The Amos Graphics 24.0 (IBM®, New York, USA) software

was used to draw structural equations.

Ecological control

Integrated pest management often requires a high level of knowledge of the biology, genetics and ecology of the target species. Plateau zokor exhibits typical intersexual, intraspecific, and interspecific phenotypic and genetic differentiation (Su et al. 2018; Kang et al. 2020; Kang et al. 2021, 2022a). As a highly controversial species, its reasonable population density has a significant contribution to the process of nutrient cycle of grasslands (Su et al. 2020), and it also has certain adaptive detoxification characteristics for the toxic plant *Stellera chamaejasme* (Tan et al. 2022). Scientific control technique of population density is essential for the exertion of ecological function of plateau zokor. The ecological control of rodent pest by optimizing grazing regime and grassland reseeding to destroy and change the suitable habitat and breeding environment of rodents is also one of the vital measures for rodent control in ecological friendly technology. Different grazing management regimes have variation effects on vegetation community succession of plateau zokor mounds, and it can be effectively restored under prohibition grazing and growing season grazing; growing season grazing can better restore the soil nutrient content of plateau zokor mounds compared with other grazing management regimes (Zhang et al. 2020; 2022). In addition, the grazing management regimes significantly affected the morphological characteristics of plateau zokor mounds with seasonal differences (Fang et al. 2022). All these studies revealed the diverse effects of different grazing management regimes on the microhabitat of plateau zokors, suggesting the great potential of ecological control to manage the population density of plateau zokor. Through Illumina MiSeq sequencing with *ITS2* barcode, Zhang et al. (2022) analyzed the changes of food composition and proportion of plateau zokor under different grassland conditions: lightly degraded, moderately degraded, severely degraded, and reseeded grassland, and the results revealed that plateau zokor prefers plants of the genus *Potentilla*; with the increasing severity of grassland degradation, the proportion of food preferred by plateau zokors increased, and the corresponding change in feeding environment reduced foraging costs, thus increasing the suitability of the environment for plateau zokors (Figure 1). This also partly explains the high population density of plateau zokors in degraded grasslands. Moreover, the relative biomass of forbs had a highly significant effect on the population density of plateau zokors ($P < 0.001$) (Figure 2); the increase in food diversity and evenness and the decrease in the proportion of forbs in reseeded grassland greatly increased the difficulty of foraging for plateau zokors, suggesting the potential role of grassland reseeding in population management of plateau zokors.

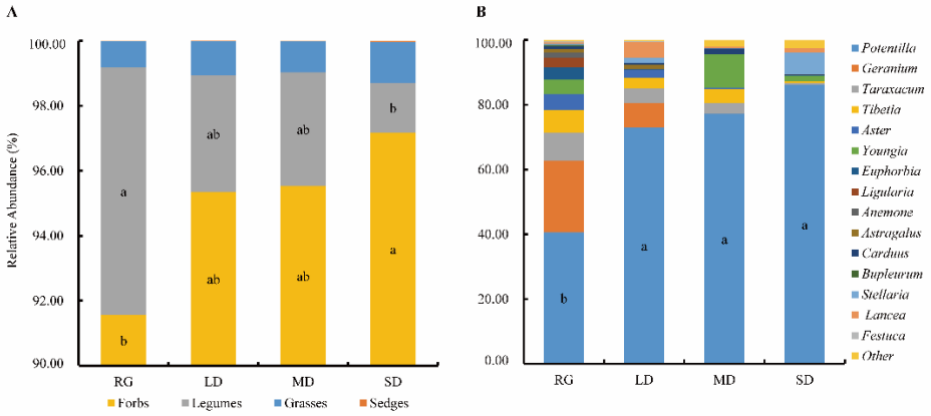


Figure 1. Food composition and proportion of plateau zokors with different functional groups (A) and plants at the genus level (B). LD, lightly degraded grassland; MD, moderately degraded grassland; SD, severely degraded grassland; RG, reseeded grassland. Different letters indicate significant differences between groups ($P < 0.05$).

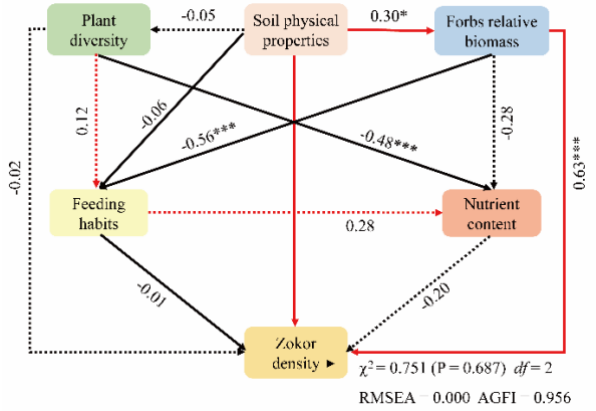


Figure 2. Structural equation model between plateau zokor density and soil physical properties, plant resources, and feeding habits. Dotted line indicates that the effect is insignificant and the black line indicates a negative correlation. * means $P < 0.05$, * means $P < 0.001$.**

Biological control

The use of natural enemies is one of the most attractive and underutilized approaches in EBRM. Guo et al. (2020) conducted a laboratory study to explore the defense response of plateau zokor to predator threat using predator odors. The researchers hypothesized that the amount of eagle owl (*Bubo bubo*) feces could represent the number of potential predators and induce different levels of anti-predator defensive responses in plateau zokors. Plateau zokors were exposed to different amounts of eagle owl feces (1, 3, and 6 g) and subsequently recorded differences in their anti-predator behavior and analyzed for changes in expression levels of physiological hormones, hypothalamic corticotropin-releasing factor (*CRF*), and *c-fos* mRNA. Compared with the control group, exposure of plateau zokors to eagle owl feces resulted in significant reductions in their feeding duration and food consumption and significant increases in the frequency of dose-dependent defensive behaviors freezing and rearing ($P < 0.001$) (Figure 3); the expression levels of physiological hormones (adrenocorticotropic hormone and corticosterone), *CRF*, and *c-fos* mRNA increased significantly ($P < 0.001$) (Figure 4). Similarly, the odor of weasel (*Mustela sibirica*) feces significantly affected food intake and triggers the expression of various anti-predator behaviors in plateau zokors (Guo et al. 2021). These results suggest that the predator odors can be used for biological control of plateau zokor population, which provides a theoretical basis for the development of biological control technologies for the rodent pest.

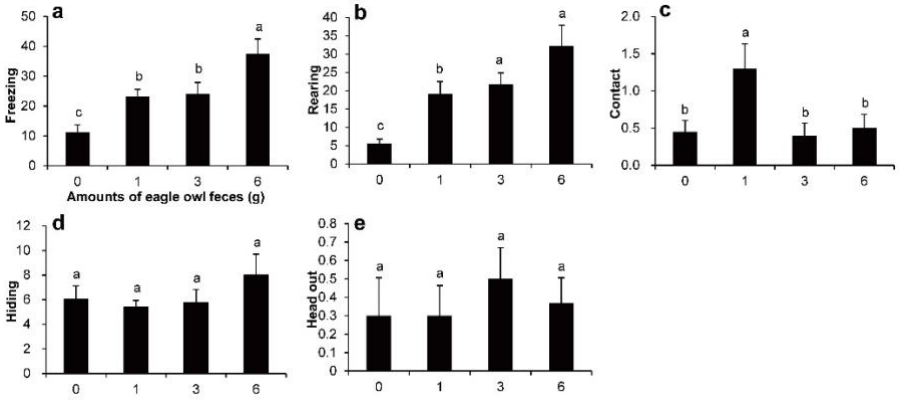


Figure 3. Behavioral responses of plateau zokor during a 30-min exposure to either distilled water or different amounts of eagle owl feces. (a) Freezing behavior, (b) rearing behavior, (c) contact behavior, (d) hiding behavior, (e) head out behavior. Bars labeled with different letters are significantly different ($P < 0.05$) and error bars represent the standard errors.

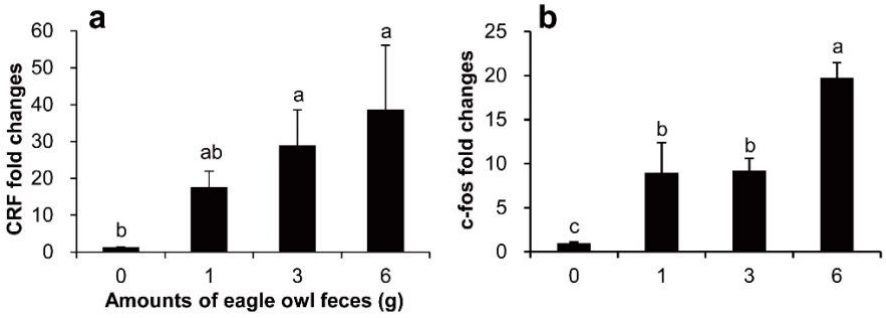
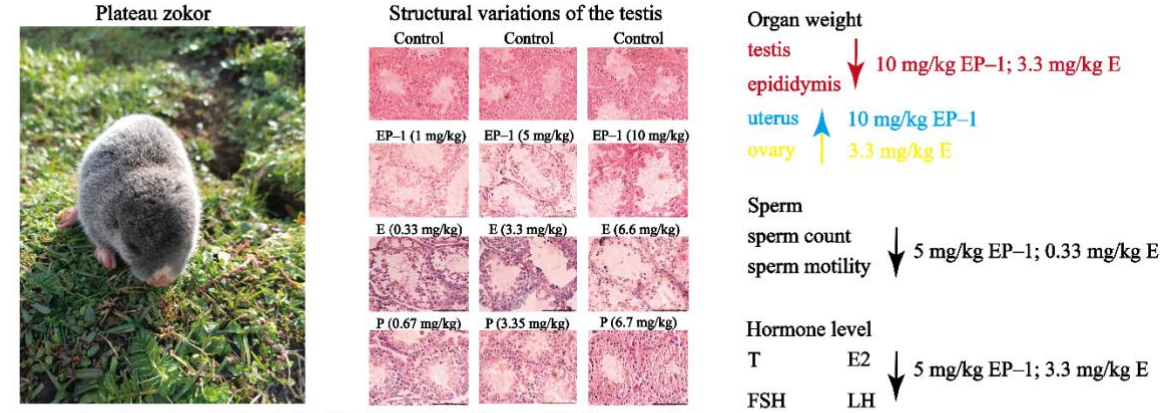


Figure 4. Mean hypothalamic *CRF* (a) and *c-fos* (b) mRNA expression in plateau zokor after a 30-min exposure to either distilled water or different amounts of eagle owl feces. Bars labeled with different letters are significantly different ($P < 0.05$) and error bars represent the standard errors

Fertility control

Since Knipling pioneered the introduction of the concept of "fertility control" into rodent population management, a new revolution has been initiated in the field of rodent control. This method can effectively reduce the birth rate and density of rodents, and is considered to be one of the most promising rodent control technologies. As with most subterranean rodents, population self-regulation of plateau zokor can balance the relationship among population size, living space, and environmental resources. Traditional rodent control measures disrupt the population self-regulation of the species, while fertility control could maintain the population self-regulation and ecological function of plateau zokors, thus achieving the desired population density. Kang et al. (2022b) reported for the first time the antifertility effects of levonorgestrel (P), quinestrol (E), and their mixture (EP-1) on plateau zokor. The captured plateau zokors were treated with the drugs for 7 successive days via oral gavage, and then continued to be fed normally for 7 days. On the 15th day, all the test individuals were killed. Changes in organ weight, sperm count, expression levels of hormone, and organ structure were analyzed. 10 mg/ kg EP-1 and 3.3 mg/kg E significantly reduced the weight of testis and epididymis. 5 mg/kg EP-1 and 0.33 mg/kg E significantly reduced sperm count and motility. The levels of serum testosterone (T), estradiol (E2), luteinizing hormone (LH), and follicle stimulating hormone (FSH) were significantly reduced by 5 mg/kg EP-1 and 3.3 mg/kg E. EP-1 and E disrupted the histological structure of the testis, epididymis, uterus, and ovary (Figure 5). The results of this laboratory study provide a theoretical basis for future fertility control of plateau zokor populations in the field.



The key stone species in the Qinghai–Tibetan Plateau (QTP) ecosystem, plateau zokors (*Eospalax baileyi*), were treated with different concentrations of levonorgestrel plus quinestrol (EP–1), quinestrol (E), and levonorgestrel (P) by oral gavage.

Figure 5 Antifertility effects of levonorgestrel, quinestrol, and their mixture (EP-1) on plateau zokor.

Perspective

Balancing the need to control rodent populations within reasonable thresholds and eliminating the negative impacts of rodent control on ecosystems is a persistent challenge, especially in grassland ecosystems with high tolerance for rodents. The great potential of EBRM in the population management of plateau zokor has gradually emerged, which provides a better alternative for the effective control of plateau zokor populations in alpine meadow ecosystems in the future. In addition to the development of control technology, rodent control cannot be achieved without effective public administration (government planning and implementation of rodent control programs, etc.). Regardless of the development level of rodent control technology, the global consideration of the relationship between rodent control and ecosystem maintenance should always be concerned.

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