

# Diet selection in overwinter caches of plateau zokor (*Eospalax baileyi*)

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**Abstract** Subterranean herbivores affect the plant community by plant consumption and burrowing activities. However, diet selection of subterranean herbivores has not been studied in detail in complex natural fields, mainly for lack of an accurate method to determine diet species, frequency, and biomass. Plateau zokors' (*Eospalax baileyi*) caching habit for the long inclement winter makes it possible to solve this problem. We studied the diet composition and biomass in caches and vicinity of plateau zokors' burrow systems. We found that plateau zokors are dietary generalist but show a significant selection among the available food items, plant parts, functional groups, organ types, and habitats. These results suggested that plateau zokors strictly selected their diet and were able to adjust their foraging strategy according to the different conditions of food abundance and quality. Plateau zokors' selective foraging can directly reduce the proportion of toxicity forbs; plateau zokors can be recognized as an important element to influence the alpine meadow plant community and cattle husbandry.

**Keywords** Alpine meadow · Foraging behavior  
Qinghai–Tibet Plateau · Subterranean rodents

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## Introduction

Burrowing mammals can modify the environment by generating habitats for other species, regulating community structure and dynamics, and altering ecosystem processes (Davidson and Lightfoot 2008). Because of their profound impacts on ecosystems, from consuming vegetation to altering the soil physically, subterranean herbivores were declared as eco-engineers (Reichman and Seabloom 2002; Zhang et al. 2003). Their influence of burrowing behavior on the soil has been intensively studied, such as tailing deposit, soil erosion, and soil heterogeneity generation, and they have an indirect influence on plant communities (Li et al. 2009a, b; Reichman and Seabloom 2002). However, their direct effects on the plant community via diet selection are poorly known.

Plateau zokors (*Eospalax baileyi*) are small (approximately 260–490 g) blind subterranean rodents inhabiting in the Qinghai–Tibetan Plateau alpine meadow at an average density of 15 animals per hectare (Zhang et al. 2003). They use strong incisors to hold roots and drag plants into the deep tunnel system (Zhang et al. 2003) and make mounds by digging, wriggling, pushing up, and mixing the soil while foraging and eradicating the plants. After a mound is made and the plants are consumed, the plateau zokors usually move to a new patch of grassland and begin a new foraging bout. As a result, plateau zokors demonstrate a tremendous destructive power to the alpine meadow. Indirect effects of plateau zokors' foraging activities have been intensively studied. Towards plateau zokors' biology and ecology and their effects on plant diversity, Zhang et al. (2003) found that zokor-made mounds may cover as much as 15–20 % of the soil surface, significantly changing plant community structure and decreasing pasture productivity. Wang et al. (2008) found a biomass increase on the edge of mounds and a biomass loss on top of the mound, and the presence of some mound-dependent

species increased the plant diversity. Plant cover and root biomass gradually recovered on zokor-made mounds but were still lower than undisturbed grassland in the 15-year-old mounds than in the undisturbed soils (Li et al. 2009a, b). Li et al. (2009a, b) suggested that plateau zokors may promote the invasions of alien plant species in an alpine meadow ecosystem, leading to higher abundances of invaders. Towards plateau zokors' influence on soil fertility and physicochemical property, mounds deposited on the surface by plateau zokors caused an increase in the area of bare ground and altered soil texture and water-holding characteristics (Wang and Fan 1987; Zhang 2000). Li et al. (2009a, b) suggested that foraging and mound making by plateau zokors have negative impacts on properties and organic matter content of the topsoil. These studies revealed that extensive excavations and their associated impacts generated a dynamic mosaic of nutrients and soil conditions that promote diversity and maintain disturbance-dependent components of plant communities. The resulted changes on soil condition and plants community may interact on each other. However, as the basement to understand the effects of subterranean herbivores on plant community structure, the interaction among predator, herbivores, plants and soil, plateau zokors, and their cognates' diet selection has been practically neglected, owing to the difficulty in quantifying their direct consumption of vegetation.

Burrowing, foraging, harvesting, caching, and dietary generalism are the results of convergent evolution of subterranean herbivores (Nevo 1979; Huntly and Reichman 1994). Diet selection in plateau zokors has been rarely studied. The only research reported about the diet habit of plateau zokor was reported by Wang et al. (2000), using stomach content analysis method. Plateau zokors' caching behavior makes it possible for us to accurately determine cache composition and their diet selection. However, caching, an important aspect of their foraging strategy, has not been investigated at all.

During half years of frozen period, plateau zokors cannot forage out and feed on caches only, so the hoarding activity and diet selection are of great importance. Our study of diet selection of plateau zokors was conducted in the study area where most of the above-mentioned researches were carried out. We asked the following questions: (1) what are the compositions and their ranks in plateau zokors' winter cache? (2) Does diet selection by plateau zokors reliably exist? (3) Does the degree of selection upon plant species differ when food composition and availability vary?

## Material and methods

### Study area

The study was conducted from 1 to 15 October 2010 and 2011 on an alpine meadow at Menyuan County (37°30'N, 101°13'E; elevation 3,200 m), Qinghai province, China. Climatic and soil

conditions of this site have been reported in detail by other ecologists (Xia 1988; Xu et al. 2009). This site is in an area of open plateau covered with an alpine meadow plant formation that consists mostly of grasses and hemicryptophytes (Buren et al. 2010; Luo et al. 1999; Zhang et al. 2007). The vegetation here is dominated by *Kobresia* meadow, including *Kobresia humilis* meadow, *Kobresia parva* meadow, *Kobresia tibetica* swamp meadow, and *Potentilla fruticosa* shrub meadow. The ratios of their belowground and aboveground biomass ranged from 10.15 to 27.82, which were much higher than that of the average value (2.8) (Buren et al. 2010). Plateau zokors habitat mainly on *K. humilis* meadow, *K. parva* meadow, and *P. fruticosa* shrub meadow, with *K. tibetica* swamp meadow an exception.

The climate of the Qinghai–Tibet Plateau can be divided into two seasons, a cold one (October to April) and a warm one (May to November). Plateau zokors begin to forage and cache food items at the end of September and continue their burrowing activity throughout October. They burrow their tunnels at an average depth of 3 to 20 cm below the surface (Zhang 1999). While burrowing, plateau zokors collect their food items and hoard them in special storage chambers in the burrow system. Autumn (late September to late October) is considered to be the most appropriate time of year to analyze food stores because both the vegetation is at its greatest variety and accessibility and because it is the only time during which the plateau zokor shows food hoarding activity.

### Food item collecting and treatment

From 1 to 15 October 2010 and 2011, we excavated the caches and collected all the food items by each burrow system (plots). A total of 57 plots were collected, 11 plots in 2010 and 46 in 2011. Before opening the nest mound, we made an observation on the distribution pattern of mounds and the vegetation in the surrounding territory to estimate the possible underground burrows between mounds. We hunted out the burrows by sticking an iron rod into the earth, then the burrows were excavated, and the caches were collected. The number of caches of each burrow system varied from one to four, and two ranked the highest frequency. The caches collected in the same burrow system were merged.

Along each burrow system, three 50-cm×50-cm quadrats were sampled. The plants along with the soil of each quadrat were dug up and packed into fiber bags through which plants can maintain respiration and be kept fresh. Plants from quadrats and caches were transported into a research station and then washed, and surface water was air-dried.

Each plant was identified according to *Flora Qinghaiica* (Liu et al. 1997), dried at 60 °C, weighed using an analytic balance of 0.01 g, and divided into two parts: the belowground part and the aboveground part, with both parts weighted respectively. The average biomass of each species in the three

quadrats of a burrow system was referred to as available plants in the vicinity, and the biomass cached in the same burrow system was referred to as selected plants.

#### Choice of selection index

The choice of index is relatively unimportant when ranking because all indices, except Strauss' index, produce the same rank order (Lechowicz 1982; Tanentzap et al. 2009). We took the most widely used indices for selection, Ivlev's selection index, as the selection index (Lechowicz 1982).  $E_i$  (Ivlev 1961) was defined as  $E_i = \frac{r_i - P_i}{r_i + P_i}$ , where  $r_i$  is the relative abundance of a plant species in a plateau zokor's diet and  $P_i$  is the plant species' relative abundance in the burrow system. According to Ivlev's selection index,  $E_i$  ranges from  $-1$  to  $1$ , and  $E_i$  in the interval of  $(-1, 0)$  means a negative selection and  $(0, 1)$  means a positive selection.

#### Data analysis

Plateau zokors show preference among 66 plant species, and  $E_i$  ranges from  $-1$  to  $1$ ; the type of data distribution was not consistent with the normal distribution. Hardly there was any case of  $E_i=0$ , which meets the null hypothesis of binomial test that two categories of negative selection and positive selection are equally likely to occur (Zar 1999). We conducted a binomial test with  $p=0.5$  to each plant species found in the 57 burrow systems. For convenience, we proposed a concept of selection degree: when most ( $p<0.05$ ) of a certain plant's  $E_i$  lies in the interval of  $(-1, 0)$ , we term these plants as negatively selected diet; when  $E_i$  lies in  $(0, 1)$  with  $p<0.05$ , we term it positively selected diet; and when  $E_i$  lies in the interval of  $(-1, 0)$  or  $(0, 1)$  but selection effects were not significant, it was referred to as having no preference diets. No preference diets may be similar to a random selection, but they were distinctly different because in random selection,  $E_i = 0$ , but in optional selection,  $E_i \neq 0$ .

In order to investigate whether plateau zokors adjust foraging strategy in different habitats or not, we classified the sampled plots by hierarchical clustering (Ward's method, squared Euclidean distance), using the availability of each species in the vicinity as classify variables. We then conducted Kruskal–Wallis H test to inspect the significance of the selection degree upon plant species differentiation among habitats. All statistical analyses were carried out in IBM SPSS 19.0.

## Results

#### Cache composition

A total of 57 plots were excavated. The number of species found in the caches ranged from 8 to 29, while that in the

vicinity ranged from 15 to 37 (Table 1). Plateau zokors hoarded a variety of plant species with biomass ranging from 0.01 to 1,449.45 g. A total of 66 different species (from 22 families and 54 genera) were found in 57 burrow systems (Table 2). The average cached species was 18.95, and the average species in the vicinity was 28.35.

A total of 66 different species (Table 2) were found in 57 burrow systems, with 59 species in caches and 62 species in the vicinity (Table 2). The most cached food items were *Polygonum viviparum*, *Gueldenstaedt diversifolia*, *Gramineae*, and *Stellera chamaejasme*; the most abundant plants in the vicinity were *Gramineae*, *K. humilis*, *K. parva*, and *Carex* sp. (Table 2).

#### Diet selection

Selection indices are calculated with respective concern to aboveground parts, belowground parts, and whole plants of each plant species. Results of descriptive statistical analysis of Ivlev's selection indices and binomial tests upon selection indices are shown in Table 3.

The selection index values for whole plants and the belowground plant component were very similar. We run a correlation analysis between the two, and the coefficient was 0.998 ( $p<0.001$ ), which meant whole plant selection indices and belowground selection indices are effectively the same thing, so we listed the selection of above- and belowground parts without reference to whole plant selection (Table 3). As for the whole plants, 22 species were negatively selected, six species were positively selected, and 35 species show no preference, with three species being unknown for having too small sample sizes. The positively selected six species took up 57.61 % in total caches of biomass and 6.12 % in total available plant biomass. To clarify synergy in description diet selection of the three groups, we looked into the result of positively selected species as an example (Table 4). Table 4 shows that six whole plant of species were positively selected, both belowground parts and aboveground parts of *S. chamaejasme*, *Cirsium souliei*, *Hypocoum leptocarpum*, *Oxytropis kansuensis*, and *P. viviparum* were preferred, but the belowground parts of

**Table 1** Number cached species and vicinity species of each burrow system

HT	Resource	No. B	Mean	SD
HT1	CS	13	18.62	3.69
HT2	CS	20	19.10	4.83
HT3	CS	24	19.00	4.42
HT1	VS	13	28.62	3.31
HT2	VS	20	27.85	4.15
HT3	VS	24	28.63	4.03

HT habitat types, No. B number of burrows, CS cached species, VS vicinity species, SD standard deviation

**Table 2** Sum of biomass and plant classification information of plant species in cache and vicinity environments

Family	Genus	Species	SUM C	SUM V	Family	Genus	Species	SUM C	SUM V
Caprifoliaceae	<i>Lonicera</i>	<i>minuta</i>	28.07	286.2	Leguminosae	<i>Gueldenstaedt</i>	<i>diversifolia</i>	1865.3	526.06
	<i>Cerastium</i>	<i>caespitosum</i>	12.11	80.32		<i>Oxytropis</i>	<i>kansuensis</i>	935.72	670.95
	<i>Silene</i>	<i>conoidea</i>	0	0.13		<i>Thermopsis</i>	<i>lanceolata</i>	672.86	792.31
	<i>Stellaria</i>	<i>pubescens</i>	9.39	91.34		<i>Trigonella</i>	<i>ruthenica</i>	52.38	151.88
Compositae	<i>Ajania</i>	<i>tenuifolia</i>	105.64	171.4	Liliaceae	<i>Allium</i>	<i>przewalskianum</i>	47.11	81.14
	<i>Anaphalis</i>	<i>lactea</i>	4.95	406.92		<i>Polygonatum</i>	<i>hookeri</i>	9.23	13.72
	<i>Aster</i>	<i>flaccidus</i>	769.53	458.76	Papaveraceae	<i>Corydalis</i>	<i>dasyptera</i>	0	0.17
	<i>Carpesium</i>	<i>abrotanoides</i>	0.29	3.64		<i>Hypecoum</i>	<i>leptocarpum</i>	25.04	3.22
	<i>Cirsium</i>	<i>souliei</i>	126.6	107.73	Plantaginaceae	<i>Plantago</i>	<i>depressa</i>	102.75	88.84
	<i>Leontopodi</i>	<i>nanum</i>	44.98	740.76		<i>Polygonum</i>	<i>sibiricum</i>	164.93	1084.9
	<i>Ligularia</i>	<i>virgaurea</i>	23.07	92.06	Polygonaceae		<i>viviparum</i>	13480	1328.6
	<i>Saussurea</i>	<i>qinghaiensis</i>	134.12	96.81		<i>Rumex</i>	<i>patientia</i>	14.18	0
		<i>superba</i>	155.19	610.89	Primulaceae	<i>Glaux</i>	<i>maritime</i>	71.46	57.84
		<i>minuta</i>	320.98	230.81	Ranunculaceae	<i>Anemone</i>	<i>imbricata</i>	206.94	189.72
Cyperaceae	<i>Taraxacum</i>	<i>Taraxacum</i> sp.	564.23	228.26		<i>Anemone</i>	<i>rivularis</i>	0.82	1.77
	<i>Carex</i>	<i>Carex</i> sp.	195.33	1892.2		<i>Delphinium</i>	<i>monanthum</i>	0	11.57
		<i>capillifolia</i>	2.81	785.42		<i>Ranunculus</i>	<i>dondrergensis</i>	1.82	0.41
		<i>humilis</i>	716.58	5466			<i>longicaulis</i>	2.72	5.21
		<i>parva</i>	0	3066.2			<i>tanguticus</i>	151.57	94.82
	<i>Sciepus</i>	<i>distigmaticus</i>	642.85	1053.9		<i>Thalictrum</i>	<i>alpinum</i>	334.95	411.59
Dipsacaceae	<i>Morina</i>	<i>chinensis</i>	35.22	66.6	Rosaceae	<i>Clerodendron</i>	<i>cyrtophyllum</i>	0.36	0
Elaeagnaceae	<i>Hippophae</i>	<i>thibetana</i>	235.68	3.18		<i>Potentilla</i>	<i>anserina</i>	970.69	1173.6
	<i>Eguisetum</i>	<i>arvense</i>	53.34	160.81			<i>bifurca</i>	32	96.04
Gentianaceae	<i>Gentiana</i>	<i>farreri</i>	254.42	530.34			<i>fruticosa</i>	45.64	1123.7
		<i>straminea</i>	369.09	208.81			<i>nivea</i>	412.09	518.14
	<i>Gentianopsis</i>	<i>paludosa</i>	0	11.85	Scrophulariaceae	<i>Lancea</i>	<i>tibetica</i>	119.34	401.68
	<i>Jaeschkea</i>	<i>microsperma</i>	2.86	168.42		<i>Pedicularis</i>	<i>alaschanica</i>	172.14	95.22
	<i>Swertia</i>	<i>diluta</i>	0	21.49		<i>Veronica</i>	<i>ciliata</i>	0.65	1.14
Gramineae	<i>Geranium</i>	<i>pylzwonianum</i>	0.67	4.9	Thymelaeaceae	<i>Stellera</i>	<i>chamaejasme</i>	1067.8	161.02
	<i>Gramineae</i>		1301.36	12632	Umbelliferae	<i>Bupleurum</i>	<i>smithii</i>	269.46	171.46
	<i>Iris</i>	<i>potaninii</i>	115.21	54.43		<i>Notopterygium</i>	<i>forbesii</i>	0.33	0
Labiateae	<i>Elsholtzia</i>	<i>densa</i>	1.62	7.98	Violaceae	<i>Viola</i>	<i>bulbosa</i>	1.18	0.86
	<i>Salvia</i>	<i>japonica</i>	14.74	40.27			<i>philippica</i>	2.64	9.06

SUM C sum of biomass in caches, SUM V sum of biomass in vicinity

*Anemone imbricata* were not favored; plateau zokors positively selected the aboveground parts of *Taraxacum* sp. and *Potentilla nivea*, but as whole plants, they show no preference.

#### Diet selection differentiation among habitats

The 57 plots were classified into three groups (Table 1). Type one took up 13 plots; they are mainly the plots on top of a hill, containing *K. humilis* plus grass meadow and *K. parva* plus grass meadow. Type two took up 20 plots; they are mainly the plots on the slope, containing grass meadow and forb meadow. Type three took up 24 plots; they are mainly the plots at the

bottomland, containing forb meadow and *P. fruticosa* shrub meadow.

To describe the general profile of the habitat, we calculated the biomass of functional groups of habitats. The total biomass proportions and selection indices of each functional group of the three habitats were shown in Table 5. Shrubs, grasses, and sedges were negatively selected; only forbs were positively selected. With the proportion of forbs increasing, the selection indices decreased (Table 5).

Furthermore, we detected diet selection differentiation at the species level. The result of selection degree differentiation of plant species among three habitats was shown in Table 6. We can

**Table 3** Binomial test results on elective indices of aboveground parts, belowground parts, and whole plants

Species	<i>E*</i> of aboveground parts				<i>E*</i> of belowground parts			
	<i>N</i>	Mean	SD	Sig	<i>N</i>	Mean	SD	Sig
<i>L. nanum</i>	52	−0.87	0.41	0	52	−0.93	0.26	0
<i>K. parva</i>	37	−1	0.02	0	37	−1	0	0
<i>J. microsperma</i>	40	−0.93	0.32	0	40	−0.93	0.31	0
<i>Gramineae</i>	57	−0.19	0.52	0	57	−0.69	0.41	0
<i>P. fruticosa</i>	45	−0.97	0.17	0	45	−0.8	0.48	0
<i>A. lactea</i>	33	−0.94	0.35	0	33	−0.91	0.37	0
<i>K. humilis</i>	56	−0.3	0.72	0.04	56	−0.61	0.54	0
<i>S. pubescens</i>	38	−0.72	0.58	0	38	−0.82	0.48	0
<i>Carex</i> sp.	53	−0.35	0.81	0.01	53	−0.61	0.66	0
<i>P. bifurca</i>	31	−0.78	0.59	0	32	−0.8	0.54	0
<i>S. diluta</i>	17	−1	0	0	13	−1	0	0
<i>H. thibetana</i>	25	−0.67	0.64	0	26	−0.55	0.67	0
<i>L. tibetica</i>	56	−0.61	0.63	0	56	−0.45	0.69	0
<i>S. distigmaticus</i>	55	−0.19	0.73	0.28	55	−0.44	0.67	0
<i>S. minuta</i>	43	−0.35	0.86	0.07	44	−0.42	0.82	0.01
<i>K. capillifolia</i>	22	−0.64	0.79	0	22	−0.64	0.79	0
<i>A. przewalskianum</i>	27	−0.36	0.83	0.12	27	−0.45	0.79	0.01
<i>S. qinghaiensis</i>	14	−0.48	0.83	0.18	15	−0.67	0.68	0.01
<i>S. superba</i>	46	−0.29	0.75	0.05	47	−0.43	0.66	0
<i>L. minuta</i>	14	−0.73	0.68	0.01	14	−0.72	0.7	0.01
<i>C. caespitosum</i>	14	−0.58	0.72	0.01	14	−0.69	0.72	0.01
<i>A. tenuifolia</i>	24	−0.47	0.87	0.02	24	−0.42	0.85	0.06
<i>S. chamaejasme</i>	12	0.02	0.85	1	14	0.68	0.44	0
<i>O. kansuensis</i>	53	0.26	0.75	0.01	55	0.25	0.74	0.01
<i>P. viviparum</i>	50	−0.11	0.83	0.89	55	0.31	0.83	0
<i>C. souliei</i>	2	−1	0	0.5	7	0.88	0.23	0.02
<i>H. leptocarpum</i>	3	−1	0	0.25	22	0.5	0.84	0.02
<i>A. imbricata</i>	41	0.32	0.85	0.03	45	0.21	0.85	0.14
<i>P. sibiricum</i>	35	−0.56	0.81	0	37	−0.33	0.81	0.1
<i>G. diversifolia</i>	53	0.15	0.74	0.17	55	0.13	0.73	0.18
<i>A. flaccidus</i>	52	0.04	0.8	0.89	52	0.15	0.81	0.13
<i>B. smithii</i>	32	0.28	0.82	0.02	33	0.17	0.83	0.16
<i>V. philippica</i>	9	−0.56	0.88	0.18	9	−0.56	0.88	0.18
<i>E. densa</i>	9	−0.38	0.93	0.51	9	−0.55	0.88	0.18
<i>G. pylzowianum</i>	2	−1	0	0.5	6	−0.66	0.81	0.22
<i>G. paludosa</i>	3	−1	0	0.25	3	−1	0	0.25
<i>P. hookeri</i>	8	0.03	0.97	1	10	0.35	0.92	0.34
<i>T. ruthenica</i>	32	−0.2	0.85	0.38	32	−0.24	0.81	0.38
<i>G. farreri</i>	42	−0.08	0.85	1	42	−0.2	0.83	0.44
<i>I. potaninii</i>	16	0.27	0.93	0.45	16	0.17	0.9	0.45
<i>Taraxacum</i> sp.	50	0.22	0.81	0.03	50	0.03	0.79	0.67
<i>C. dasyptera</i>	2	−1	0	0.5	2	−1	0	0.5
<i>D. monanthum</i>	1	−1			2	−1	0	0.5
<i>C. abrotanoides</i>	2	1	0	0.5	2	1	0	0.5
<i>P. nivea</i>	56	0.14	0.74	0.04	56	0.04	0.72	0.5
<i>P. anserina</i>	37	−0.39	0.74	0.02	37	−0.04	0.82	1
<i>P. depressa</i>	22	−0.17	0.88	0.83	22	−0.3	0.84	0.52
<i>R. tanguticus</i>	33	0.05	0.96	0.73	40	−0.13	0.91	0.64

*N* sample size, *SD* standard deviation, *Sig* significance, *E\** selection index



**Table 3** (continued)

Species	<i>E*</i> of aboveground parts				<i>E*</i> of belowground parts			
	<i>N</i>	Mean	SD	Sig	<i>N</i>	Mean	SD	Sig
<i>P. alaschanica</i>	35	−0.84	0.47	0	45	0.08	0.9	0.55
<i>S. japonica</i>	2	−1	0	0.5	6	0.33	1.03	0.69
<i>R. longicaulis</i>	11	−0.27	1.01	0.55	12	−0.17	1.03	0.77
<i>T. lanceolata</i>	37	−0.3	0.79	0.19	38	−0.2	0.76	0.87
<i>T. alpinum</i>	52	0.11	0.84	0.13	52	−0.1	0.83	0.68
<i>G. straminea</i>	41	−0.09	0.83	0.76	41	−0.12	0.8	1
<i>G. maritime</i>	22	−0.85	0.49	0	27	−0.12	0.85	0.7
<i>M. chinensis</i>	24	−0.07	0.91	1	24	−0.04	0.89	1
<i>V. ciliata</i>	6	−0.03	1.06	1	5	0.18	1.08	1
<i>A. rivularis</i>	2	−1	0	0.5	2	−0.03	1.38	1
<i>L. virgaurea</i>	18	−0.28	0.89	0.48	28	0	0.94	1
<i>N. forbesii</i>	3	−0.33	1.15	1	3	0.07	1.01	1
<i>V. bulbosa</i>	0				5	0.2	1.1	1
<i>E. arvense</i>	2	0	1.41	1	5	0.26	0.85	1
<i>R. dondrergensis</i>	3	0.33	1.15	1	3	0.33	1.15	1
<i>S. conoidea</i>	1	−1			1	−1		
<i>C. cyrtophyllum</i>	0				1	1		
<i>R. patientia</i>	0				1	1		

see that among the 66 plant species, five species show significant differentiation in different habitats. The five variably selected species (or genus) were *Carex* sp., *Potentilla anserina*, *Viola philippica*, *Thermopsis lanceolata*, and *Aster flaccidus*. These species took up a proportion of 8.07 % in the total available plant biomass and 5.96 % in the total cache biomass.

## Discussion

Attributed to high burrowing cost, non-directed search pattern, low food availability, and strong seasonality, the foraging activities of subterranean rodents may be an arduous task to meet the energy demands for burrowing, maintenance, and reproduction (Vleck 1979; Nevo 1979, 1999; Heth et al. 1989; Su 1992; Williams and Cameron 1986). To meet the tremendous energy demands, most of them have developed generalized dietary strategy (Nevo 1979; Williams and Cameron

1986; Comparatore et al. 1995; Puig et al. 1999; del Valle et al. 2001; Rosi et al. 2009; Albanese et al. 2010; Rezsutek and Cameron 2011). In environments generally with low plant food availability, the digestion of cellulose is expected to be very effective in subterranean rodents (Sedláček 2007). For example, within a certain range, pocket gophers displayed an increase in food intake when the fiber content of forage increased (Loeb et al. 1991). However, relatively lower food intakes were esteemed in many other non-subterranean rodents, such as Guinea pigs and tree porcupines, when they were fed with high fiber-content forage (Meyer et al. 2010). Wang et al. (1980) found that in plateau zokors, the digestibility of grasses ( $72.35 \pm 2.60$  %,  $n=62$ ) was significantly lower than that of forbs ( $79.56 \pm 1.51$  %,  $n=62$ ). In this study, plateau zokors only cached a small proportion of grasses, sedges, and shrubs (6.80 %, 4.93–8.25 %, 95 % bootstrap C.I., pooled data). The positively selected food species were forbs, mainly poisonous forbs. The root tuber of *P. viviparum*

**Table 4** A collection of the significantly, positively selected species based on selection indices from different plant parts

Species	Growth form	Organ type	FG	<i>E*</i> of WP	<i>E*</i> of BG	<i>E*</i> of AG
<i>C. souliei</i>	GEO	FTR	Forbs	0.87 <sup>a</sup>	0.88 <sup>a</sup>	−1
<i>S. chamaejasme</i>	HEM	Root tuber	Forbs	0.70 <sup>a</sup>	0.68 <sup>a</sup>	0.02
<i>H. leptocarpum</i>	GEO	Fleshy root	Forbs	0.51 <sup>a</sup>	0.50 <sup>a</sup>	−1
<i>P. viviparum</i>	GEO	Stem tuber	Forbs	0.30 <sup>a</sup>	0.31 <sup>a</sup>	−0.11
<i>O. kansuensis</i>	HEM	Tap root	Forbs	0.26 <sup>a</sup>	0.25 <sup>a</sup>	0.26
<i>A. imbricata</i>	HEM	FTR root	Forbs	0.24 <sup>a</sup>	0.21	0.32
<i>Taraxacum</i> sp.	GEO	FTR	Forbs	0.05	0.03	0.22 <sup>a</sup>
<i>P. nivea</i>	HEM	Root tuber	Forbs	0.03	0.04	0.14 <sup>a</sup>

GEO geophytes, HEM hemicryptophyte, FTR fleshy tap root, FG functional group, *E\** selection index

<sup>a</sup> The species was significantly positively selected

**Table 5** Total biomass proportion and selection indices of functional groups in three habitats

FG	HT	Cache bio.	PC	Vicinity bio.	PV	E*
Shrubs	1	107.91	1.76	451.95	4.16	−0.40
Shrubs	2	56.47	0.89	1,098.09	9.29	−0.82
Shrubs	3	146.29	1.63	1,362.52	8.34	−0.67
Grasses	2	340.51	5.39	1,071.51	9.06	−0.25
Grasses	1	272.36	4.45	2,677.10	24.62	−0.69
Grasses	3	688.49	7.67	8,884.03	54.35	−0.75
Sedges	3	464.57	5.18	2,372.61	14.52	−0.47
Sedges	2	966.75	15.29	3,333.46	28.19	−0.30
Sedges	1	121.06	1.98	6,558.65	60.31	−0.94
Forbs	1	5,621.66	91.81	1,187.52	10.92	0.79
Forbs	3	7,671.98	85.52	3,726.75	22.80	0.58
Forbs	2	10,989.88	173.84	6,321.99	53.46	0.53

FG functional group, HT habitat type, Cache bio. biomass in cache, Vicinity bio. biomass in vicinity, PC cached biomass proportion, PV biomass proportion in vicinity, E\* selection index

contains a lot of phenols and tannins (142.10 and 35.86 mg/g respectively; Zhang et al. 2008) that reduce nutrition digestibility (Foley et al. 1999; Lin et al. 2012). *S. chamaejasme* and *O. kansuensis* are two of the most important poisonous plants on the alpine meadow (Shi 1997), and their toxins are mainly

triterpenes and alkaloids. *C. souliei*, *H. leptocarpum*, and *A. imbricata* are also reported to be poisonous in *Compendium of Materia Medica* (Li 1596) and *Economica Flora Qinghaiica* (Guo et al. 1987). These results may indicate that rather than dealing with the high fiber-content forage, plateau zokors have forged another dietary strategy to meet the energy demands in evolutionary process: to deal with the poisonous forbs.

For plateau zokors, aboveground parts, especially those of *Taraxacum* sp. and *P. nivea*, were also a part of the diet, but belowground parts of geophytic perennials were obviously essential to overwintering (Tables 3 and 4). The reason why plateau zokors show a higher preference on belowground plant parts compared with aboveground plant parts may be similar to the preference on forbs. Forbs, especially the belowground parts, may be more digestible to plateau zokors. According to Wang et al. (2004) and Pu et al. (2005), both the biggest belowground biomass and the biggest root–shoot ratio appear in October. These results may imply that the aboveground parts of plant species on alpine meadow are withered in the winter and the nutrients are transmitted to the belowground parts. Thus, the belowground parts of the forbs are much edible than the aboveground parts.

Interestingly, the five species which show significant selection differentiation in different habitats were “no preference” diets.

**Table 6** Plant species selection degree differentiation among three habitat types

Species	H	df	p value	Species	H	df	p value	Species	H	df	p value
<i>Carex</i> sp.	8.08	2	0.02	<i>L. tibetica</i>	2.44	2	0.30	<i>S. distigmaticus</i>	0.64	2	0.73
<i>P. anserina</i>	7.42	2	0.02	<i>S. qinghaiensis</i>	2.35	2	0.31	<i>R. longicaulis</i>	0.63	2	0.73
<i>V. philippica</i>	4.57	1	0.03	<i>S. chamaejasme</i>	2.25	2	0.33	<i>Taraxacum</i> sp.	0.62	2	0.73
<i>T. lanceolata</i>	5.76	2	0.05	<i>P. depressa</i>	2.00	2	0.37	<i>P. viviparum</i>	0.54	2	0.77
<i>A. flaccidus</i>	5.74	2	0.05	<i>A. lactea</i>	1.98	2	0.37	<i>G. pylzowianum</i>	0.07	1	0.80
<i>H. thibetana</i>	4.74	2	0.09	<i>R. tanguticus</i>	1.89	2	0.39	<i>P. sibiricum</i>	0.43	2	0.81
<i>K. capillifolia</i>	4.39	2	0.11	<i>E. densa</i>	1.68	2	0.43	<i>T. alpinum</i>	0.39	2	0.83
<i>B. smithii</i>	3.82	2	0.15	<i>R. dondregensis</i>	0.50	1	0.48	<i>P. bifurca</i>	0.38	2	0.83
<i>E. arvense</i>	2.00	1	0.16	<i>Gramineae</i>	1.45	2	0.49	<i>T. ruthenica</i>	0.36	2	0.84
<i>S. superba</i>	3.66	2	0.16	<i>S. uda</i> var. <i>pubescens</i>	1.37	2	0.50	<i>P. fruticosa</i>	0.27	2	0.87
<i>C. souliei</i>	1.64	1	0.20	<i>P. alaschanica</i>	1.29	2	0.52	<i>H. leptocarpum</i>	0.19	2	0.91
<i>G. straminea</i>	3.18	2	0.20	<i>P. hookeri</i>	1.27	2	0.53	<i>G. farreri</i>	0.15	2	0.93
<i>K. parva</i>	3.11	2	0.21	<i>K. humilis</i>	1.25	2	0.53	<i>S. diluta</i>	0.00	2	1.00
<i>O. kansuensis</i>	3.10	2	0.21	<i>A. tenuifolia</i>	1.23	2	0.54	<i>D. monanthum</i>	0.00	1	1.00
<i>G. maritime</i>	3.07	2	0.22	<i>A. przewalskianum</i>	1.18	2	0.56	<i>N. forbesii</i>	0.00	1	1.00
<i>L. nanum</i>	3.06	2	0.22	<i>C. caespitosum</i>	1.14	2	0.57	<i>G. paludosa</i>	0.00	1	1.00
<i>V. bulbosa</i>	1.50	1	0.22	<i>S. minuta</i>	1.07	2	0.59	<i>C. abrotanoides</i>	0.00	1	1.00
<i>I. potaninii</i>	3.01	2	0.22	<i>V. ciliata</i>	0.25	1	0.62	<i>R. patientia</i> <sup>a</sup>			
<i>L. minuta</i>	2.87	2	0.24	<i>L. virgaurea</i>	0.94	2	0.63	<i>A. rivularis</i> <sup>a</sup>			
<i>M. chinensis</i>	2.85	2	0.24	<i>S. japonica</i>	0.22	1	0.64	<i>C. dasyptera</i> <sup>a</sup>			
<i>G. diversifolia</i>	2.82	2	0.24	<i>A. imbricata</i>	0.86	2	0.65	<i>C. cyrtophyllum</i> <sup>a</sup>			
<i>P. nivea</i>	2.73	2	0.26	<i>J. microsperma</i>	0.73	2	0.69	<i>S. conoidea</i>			

<sup>a</sup> Sample size of the species' selection indices is too small and Kruskal–Wallis H test cannot be done

These results indicate that these five plant species were moderate food material to plateau zokors. The forb-rich environment (plots on bottomland) facilitates negative selection of these five species. On the other hand, the forb poorer environment (plots on top of the hill) showed converse results. However, as a whole, they show no preference. These results revealed that at the population level, plateau zokors can adjust their foraging strategy according to the food quality and availability.

The effects of plateau zokors on vegetation can arise from diet selection, foraging behavior, and burrow structure and dynamics. Our result revealed that although plateau zokors are dietary generalist, they show a strong diet selection and tendency of diet specialization. Most of the positively selected plant species were forbs, and the shrubs, grasses, and sedges were negatively selected, that is, avoided by plateau zokors. Concerning the diets of cattle and sheep, they were mostly grasses, sedges, and shrubs; most forbs were not accepted because of their toxicity and bad palatability (Agreil and Meuret 2003; Song et al. 2008). For example, *S. chamaejasme*, *O. kansuensis*, *P. viviparum*, and other toxic forbs were avoided by stock; the abundance of these forbs are usually employed as an index to evaluate grassland degeneration (Song et al. 2008; Yao et al. 2011). It appears that there is a diet niche specialization between plateau zokors and cattle because plateau zokors' selective foraging can directly reduce the proportion of toxicity forbs and further inhibit their density through plant competition. However, immediate evidence about the diet niche specialization between plateau zokors and cattle is still devoid. Furthermore, plateau zokors' foraging damage to different functional groups of plant are not equal; to forbs with a dendritic root system, it is almost lethal, while to grasses and sedges with diffuse root systems, it may be less affected (Reichman and Smith 1985). For these reasons, we extrapolate that plateau zokors are important elements to the alpine meadow plant community and cattle husbandry.

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## References

- Agreil C, Meuret A (2003) An improved method for quantifying intake rate and ingestive behaviour of ruminants in diverse and variable habitats using direct observation. *Small Ruminant Res* 54:99–113
- Albanese S, Rodriguez D, Dacar MA, Ojeda RA (2010) Use of resources by the subterranean rodent *Ctenomys mendocinus* (Rodentia, Ctenomyidae), in the lowland Monte desert, Argentina. *J Arid Environ* 74:458–463
- Buren B, Xu G, Duan J (2010) Primary productivity and its main affecting factors of Alpine meadows on the Tibetan plateau. *Guihaia* 30:760–769

- Comparatore VM, Cid MS, Busch C (1995) Dietary preferences of two sympatric subterranean rodent populations in Argentina. *Rev Chil Hist Nat* 68:197–206
- Davidson AD, Lightfoot DC (2008) Burrowing rodents increase landscape heterogeneity in a desert grassland. *J Arid Environ* 72:1133–1145
- del Valle JC, Lohfeld MI, Comparatore VM, Cid MS, Busch C (2001) Feeding selectivity and food preference of *Ctenomys talarum* (tucutucu). *Mamm Biol* 66:165–173
- Foley JW, Iason GR, Mearns C (1999) Role of plant secondary metabolites in the nutritional ecology of mammalian herbivores: how far have we come in 25 years? In: Jung HG, Fahey GC (eds) *Nutritional ecology of herbivores*. American Society of Animal Science, Illinois, pp 130–209
- Guo B, Liu S, Lu S, Wu Z, He T, Zhou L, Huang R, Pan J (1987) *Economica Flora Qinghaiica*. Qinghai People's Press, Xining
- Heth G, Golenberg EM, Nevo E (1989) Foraging strategy in a subterranean rodent, *Spalax ehrenbergi*: a test case for optimal foraging theory. *Oecologia* 79:496–505
- Huntly N, Reichman OJ (1994) Effects of subterranean mammalian herbivores on vegetation. *J Mammal* 75:852–859
- Ivlev VS (1961) *Experimental ecology of the feeding of fishes*. Yale University Press, New Haven
- Lechowicz MJ (1982) The sampling characteristics of electivity indices. *Oecologia (Berlin)* 52:22–30
- Li S (1996) *Compendium of Materia Medica* (Reprinted in 1977). People's medical Publishing House, Beijing, People's Republic of China
- Li W, Zhang Y, Wang Y (2009a) Invasion of *Descurainia sophia* (L.) (Cruciferae) in alpine meadow is enhanced by ground disturbance made by *Myospalax fontanieri* (Milne Edwards). *Pol J Ecol* 57: 389–393
- Li X, Zhang M, Li Z, Shi X, Ma Q, Long R (2009b) Dynamics of soil properties and organic carbon pool in topsoil of zokor-made mounds at an alpine site of the Qinghai–Tibetan Plateau. *Biol Fertil Soils* 45: 865–872
- Lin G, Xie J, Cui X, Nevo E, Su J, Zhang T (2012) Effects of supplemental dietary tannic acid on digestion in plateau zokors (*Eospalax baileyi*). *Ann Zool Fenn* 49:371–377
- Liu S, Lu S, Wu Z, He T, Zhou L, Huang R, Pan J (1997) *Flora Qinghaiica*. Qinghai People's Press, Xining
- Loeb SC, Schwab RG, Demment MW (1991) Responses of pocket gophers (*Thomomys bottae*) to changes in diet quality. *Oecologia* 86:542–551
- Luo T, Li W, Luo J, Wang Q (1999) A comparative study on biological production of major vegetation types on the Tibetan Plateau. *Acta Ecol Sin* 19:823–831
- Meyer K, Hummel J, Clauss M (2010) The relationship between forage cell wall content and voluntary food intake in mammalian herbivores. *Mamm Rev* 40:221–245
- Nevo E (1979) Adaptive convergence and divergence of subterranean mammals. *Annu Rev Ecol Syst* 10:269–308
- Nevo E (1999) Mosaic evolution of subterranean mammals: regression, progression and global convergence. Oxford University Press, Oxford
- Pu J, Li Y, Zhao L, Yang S (2005) The relationship between seasonal changes of *Kobresia humilis* meadow biomass and the meteorological factors. *Acta Agrestia Sin* 13:238–241
- Puig S, Rosi MI, Cona MI, Roig VG, Monge SA (1999) Diet of a Piedmont population of *Ctenomys mendocinus* (Rodentia, Ctenomyidae): seasonal patterns and variations according to sex and relative age. *Acta Theriol* 44:15–27
- Reichman OJ, Seabloom EW (2002) The role of pocket gophers as subterranean ecosystem engineers. *Trends Ecol Evol* 17:44–49
- Reichman OJ, Smith SC (1985) Impact of pocket gopher burrows on overlying vegetation. *J Mammal* 66:720–725



- Rezsutek MJ, Cameron GN (2011) Diet selection and plant nutritional quality in Attwater's pocket gopher (*Geomys attwateri*). *Mamm Biol* 76:428–435
- Rosi MI, Puig S, Cona MI, Videla F, Mendez E, Roig VG (2009) Diet of a fossorial rodent (Octodontidae), above-ground food availability, and changes related to cattle grazing in the Central Monte (Argentina). *J Arid Environ* 73:273–279
- Sedláček F (2007) Adaptive physiological mechanisms in the underground dwellers. In: Begall S, Burda H, Schleich CE (eds) *Subterranean Rodents*. Springer, Heidelberg, pp 13–19
- Shi Z (1997) Important poisonous plants of China grassland. China Agriculture Press, Beijing
- Song R, Hasagawa N, Li G, Xu N, Cai G, Zhang Q (2008) Botanical composition and grazing behaviour of Qinghai yaks of plateau type in the natural rangeland. *Acta Ecol An Dom* 29:31–35
- Su JP (1992) Energy cost of foraging and optimal foraging in the fossorial rodent (*Myospalax baileyi*). *Acta Theriol Sin* 12:117–125
- Tanentzap AJ, Bee JN, Lee WG, Lavers RB, Mills JA, Mark AF, Coomes DA (2009) The reliability of palatability estimates obtained from rumen contents analysis and a field-based index of diet selection. *J Zool* 278:243–248
- Vleck D (1979) The energy cost of burrowing by the pocket gopher *Thomomys bottae*. *Physiol Zool* 52:122–136
- Wang Q, Fan N (1987) Studies on the digging activities and exploration about the method of number estimation of plateau zokor. *Acta Theriol Sin* 7:283–290
- Wang Z, Zeng J, Han Y (1980) Studies on the metabolism rates of the mouse hare (*Ochotona curzonlae*) and the mole rat (*Myospalax fontanierii*). *Acta Zool Sin* 25:75–84
- Wang Q, Zhang Y, Wei W, Bian J (2000) Food habit of the plateau zokor. *Acta Theriol Sin* 20:193–199
- Wang C, Wang Q, Long R, Jing Z, Shi H (2004) Changes in plant species diversity and productivity along an elevation gradient in an alpine meadow. *Acta Phytoecol Sin* 28:240–245
- Wang T, Xiong Y, Ge J, Wang S, Li Y, Yue D, Wang T, Wang G (2008) Four-year dynamic of vegetation on mounds created by zokors (*Myospalax baileyi*) in a subalpine meadow of the Qinghai–Tibet Plateau. *J Arid Environ* 72:84–96
- Williams LR, Cameron GN (1986) Food habits and dietary preferences of Attwater's pocket gopher, *Geomys attwateri*. *J Mammal* 67:489–496
- Xia W (1988) A brief introduction to the fundamental characteristics and the work in Haibei Research Station of Alpine Meadow Ecosystem. In: Xia W (ed) *Proceedings of the international symposium of alpine meadow ecosystem*, Xining, 1986. Science Press, Beijing, pp 1–10
- Xu J, Zhang B, Tan J, Yao Y (2009) Spatial relationship between altitudinal vegetation belts and climatic factors in the Qinghai–Tibetan plateau. *J Mt Sci* 27:663–670
- Yao Z, Liu Z, Wang Z, Hu T, Li Z (2011) Winter and spring diet composition of feral yak in Helan Mountains, China. *Acta Ecol Sin* 31:673–679
- Zar JH (1999) *Biostatistical analysis*, 4th edn. Prentice-Hall, New Jersey
- Zhang Y (1999) Effect of plateau zokor on characters and succession of plant communities in alpine meadow. *Zool Res (China)* 20:435–440
- Zhang Y (2000) Studies on the pattern of animal–plant interaction: the effects of plateau zokor on the biogeochemical cycling of alpine meadow ecosystem and its response to the chemical defense of plants. Ph.D. dissertation, The Chinese Academy of Sciences
- Zhang Y, Zhang Z, Liu J (2003) Burrowing rodents as ecosystem engineers: the ecology and management of plateau zokors *Myospalax fontanierii* in alpine meadow ecosystems on the Tibetan Plateau. *Mamm Rev* 33:284–294
- Zhang F, Li Y, Li H, Wang Q, Du M, Zhao L, Wang S (2007) The comparative study of the apparent quantum yield and maximum photosynthesis rates of 3 typical vegetation types on Qinghai–Tibetan plateau. *Acta Agrestia Sin* 5:442–448
- Zhang X, Long R, Dan R, Ding X (2008) Analysis of phenols content of three species of Polygonum in alpine meadows. *J Gansu Agric Univ* 43:126–129