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FORAGING STRATEGY OF PLATEAU ZOKORS (*EOSPALAX BAILEYI* THOMAS) WHEN COLLECTING FOOD FOR WINTER CACHES

ABSTRACT: Subterranean life style is characterized by limited food resource and energy consuming burrow behavior. Subterranean rodents are usually recognized as dietary generalists. In the current study, we investigated the species composition of winter caches of plateau zokors (*Eospalax baileyi*), and the dissimilarity of species composition in caches and in the vicinity of the burrows. We have made our research in Kobresia dominated vegetation at the altitude 3200 m a.s.l. We used the non-parametric method to test the similarities between the relative dry mass of the plant species within caches and their closed vicinity. This method was based on measures of distance between pairs of individual multivariate observations. Our results revealed that although plateau zokors cached most (60) of the plant species found in the vicinity of their burrow systems (66), the cached dry mass was dominated by a few species. Nine plant species accounted for 80% dry mass of plants present in zokors' caches, *Polygonum viviparum* (50%) and other perennial poisonous forbs constitute 70% dry mass of the caches. Results showed that the dissimilarity between the relative dry mass of plant species within caches and in their vicinity was extremely significant (for Bray-Curtis distance measure, R = 0.355, P = 0.000; for Euclidean distance measure R =0.319, P =0.000). These results showed that plateau zokors don't forage randomly when collecting food for winter caches. We suppose that rather than using a non-selective foraging strategy by dealing with high fiber-content plants, plateau zokors have forged another dietary strategy to meet the energy demands in the evolutionary process: to deal with poisonous forbs.

KEY WORDS: diet selection, foraging strategy, poisonous forbs, Qinghai-Tibetan Plateau, subterranean rodents

1. INTRODUCTION

Subterranean life style puts three important constraints on the animal's foraging strategy, namely, energy constraint, independence constraint, and seasonality constraint (Heth *et al.* 1989). The energy constraint is mainly associated with excavation and digging. The energy utilized to move underground reported is 360–3400 times greater than travelling over the same distance above ground (Vleck 1979). When animals refuse to feed on low rank food items and continue to search for preferred food items, the energy expenditure increases. In simple words, the more selective the animals are in foraging, the less value the preferred items will have. The second constraint deals with the independence of foraging events. The subterranean rodents feed by removing underground (and occasionally aboveground) parts of vegetation when they burrow through the ground. Within a foraging season, the food available to the subterranean rodents represents an independent and non-renewable resource; available food will decrease as foraging proceeds. This should reinforce the decision to take whatever already found (Schoener 1974). The third constraint deals with the seasonality of foraging of subterranean rodents. Foraging and caching during the more amenable times of the year must compensate subterranean rodents during the periods of time in which digging and, therefore, food collection is limited. This should affect the ranking of food items for subterranean rodents (Galil 1961, Smith and Reichman 1984, Heth *et al.* 1989, Su and Liu 2000). Hence, subterranean rodents must collect all relevant food species and may not consciously neglect anyone (Heth *et al.* 1989). According to the classification of Shipley *et al.* (2009), subterranean rodents are obligatory generalists. Some studies suggest that subterranean rodents are dietary generalists (Nevo 1979, Williams and Cameron 1986, Comparatore *et al.* 1995, Puig 1999, del Valle *et al.* 2001, Rosi 2009, Albanese *et al.* 2010, Rezsutek and Cameron 2011).

However, for herbivores, many plant traits such as availability, characteristic of plant chemical defense (kinds and contents of plant secondary metabolites) and physical defense (shoot thorn, prickles and fiber content) are potential to influence the edibility and diet selection on plant species (Carmona *et al.* 2011). For these reasons, some plant species may become difficult foods for mammalian herbivores to process and mammalian herbivores may show different diet selection strategy to cope with different food types. In subterranean rodents, some opposite examples rather than obligatory generalists have been reported, either through cafeteria tests (Cox 1989, Heth 1992, Jenkins and Bollinger 1989) or natural occurring diets analyses (Ward and Keith 1962, Williams and Cameron 1986, Comparatore *et al.* 1995, Wang *et al.* 2000, Rosi *et al.* 2009, Albanese *et al.* 2010).

Plateau zokor (Rodentia, Muroidea, Myospalacinae, *Eospalax baileyi*, Thomas, 1911) is a typical subterranean rodent species, spend most of their life underground and 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 with a relatively large geographical range (96–104°N, 33–38°E; elevations ranging from 2600 to 4600 m; see Fan and Shi 1982, Tang *et al.* 2010). The area of plateau zokors' home range ranges from tens to hundreds m^2, and their major axis ranges from about 30 m to 80 m (Zhou and Dou 1990). Plateau zokor spend 85–90% of their lifetime in underground nests and foraging and burrowing activity mainly takes place at a depth of 3–20 cm under the ground (Zhang 1999). The average population density of plateau zokors is usually very high on the alpine meadow (21.31 indiv. ha^{-1} Yu and Liu 2002). Because of their intensive burrowing, foraging, and high population density on alpine meadow, plateau zokors are recognized as pests. Liang and Xiao (1978) and Wang *et al.* (2000) reported that plateau zokors fed forbs rather than grasses or sedges. These studies suggested plateau zokors may have selection on food items. But for the absence of the comparison between the plant species composition of the consumed food items and that in the vicinity environment, direct evidence of the existing of diet selection for plateau zokors is still lacking.

Plateau zokors inhabit the area with low temperature, low-oxygen content, high humidity, and high carbon dioxide content. These environmental factors largely affect their foraging ability and strategy. For instance, during the long winter, zokors cannot forage by excavating the frozen soil and therefore only feed on their caches. Hence, hoarding activity and caching diet selection might play a very important role in small mammals surviving the long winter (Dearing 1997, Naderi *et al.* 2011). Plateau zokors excavate caches in their burrow systems to store food from late September to late October to provide sustenance for the long winter from late October to early May (Su and Liu 2000).

The caching behavior of plateau zokors makes it feasible to determine accurate cache composition. In this study, we collected and analyzed the plant species composition in overwinter caches and their closed vicinity of plateau zokors. We mainly addressed the following questions: (1) what are the diet composition and food ranks in overwinter caches of the plateau zokors? (2) Does diet selection exist when plateau zokors collecting their winter caches?

2. STUDY AREA

The study was conducted on alpine meadows in Menyuan County (37°30’N, 101°13’E, elevation 3200 m a.s.l). The climatic and soil conditions of this site have been reported in detail (Zhang *et al.* 2003, Xu *et al.* 2009). The topography of the study area is a plain and a gradual slope adjacent to each other. Climate is typical for alpine continental areas with no summer but with cold and warm seasons. Annual mean temperature is –20°C (range from 27.5°C in July to –35.0°C in January), and annual mean precipitation is 530 mm, 55% of which occurs between June and August (Zhang *et al.* 2003). The vegetation is mostly dominated by genus Kobresia, including *K. humilis* meadow, *K. parva* meadow, *K. tibetica* swamp meadow, and *Potentilla fruticosa* shrub meadow.

3. METHODS

3.1. Food item collection and treatment

Based on our own observation, plateau zokor has four kinds of caches, namely kitchen caches, hoarding caches, depot caches and temporary caches. The kitchen caches are the second biggest, 1.4–2 m in depth; hoarding caches are the biggest ones (40–80 cm in depth), while the remaining two kinds of caches are the smallest, near-surface caches with 20 cm in depth based on our own observations (see Fig. 1). If we excavate the caches too late, part of the cached items were transported into the deepest kitchen caches and can’t be excavated easily. This study was conducted from October first to October fifteenth during 2010 and 2011. In this study, either two burrow systems were selected for more than 100 m apart. Compared to the diameter of plateau zokor’s home range (30 m to 80 m, Zhou and Dou 1990), we assumed that each burrow systems belong to a single animal. Before opening each burrow mound we made an observation of the vegetation and mound

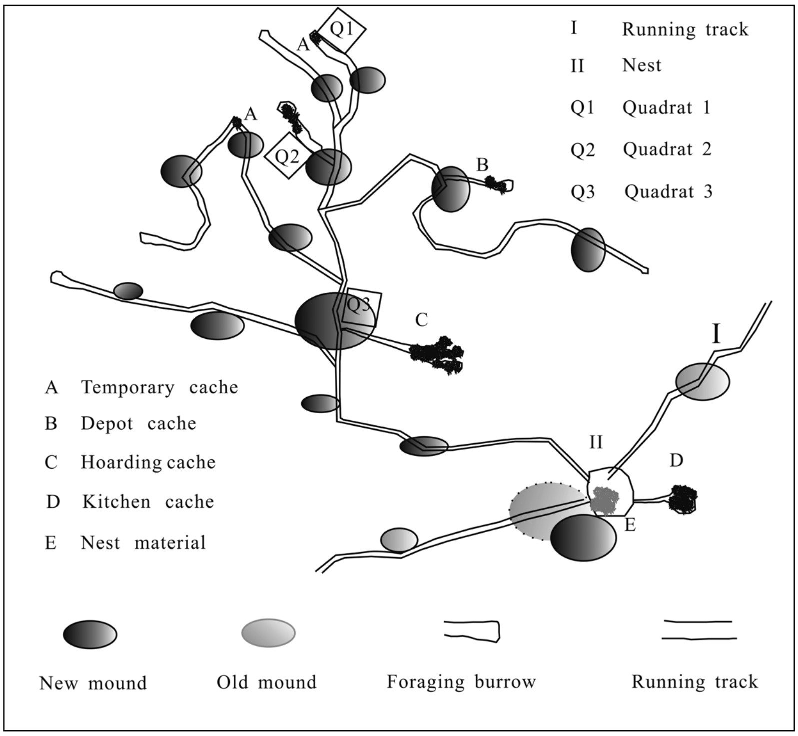

Fig. 1. Location of quadrats, distribution of mounds and caches in the burrow system of plateau zokor. Black patches (A, B, C and D) stand for caches, grey patch (E) stands for nest material. Caches are located among the newly excavated mounds, below the old mounds are running tracks and abandoned foraging burrows; In the vicinity of nest of plateau zokor, there are mixed mounds.

distribution pattern in the surrounding territory, the burrows between mounds excavated by plateau zokor were hunted out by sticking into the earth using an iron rod. Then the burrows were excavated and the caches stored by plateau zokors were collected. The number of caches of each burrow system varied from 1 to 4, and 2 ranked the highest frequency (35 burrows with 2 caches, 11 with 3 caches, 7 with 4 caches and 4 with 1 caches). If there is only one cache in the burrow system, three 50 cm × 50 cm quadrats were sampled in average distance, with 1.5 m between the adjacent ones and the middle quadrat parallels to the cache, because we found that the foraging activity of plateau zokors concentrate in a patch with radius ranged 10 m to 25 m, and the main cache mostly near the axle wire of the patch. If there are two caches in one burrow system, two quadrats were located beside the caches, the third one located on the middle. If there are more than three caches, each quadrat was set beside one of the first three caches (see Fig. 1).

The plants and the soil of the quadrats were dug up and both packed into fiber bags through which plants can maintain respiration and keep fresh. The plants from quadrats and the caches were transported into the research station and washed, surface water air-dried, sorted, identified and weighed. Each plant was identified according to aboveground and belowground properties. During collecting the caches items and plants in the vicinity of the burrow system, we observed each plant species clearly and related the belowground properties of a certain species to its corresponding aboveground properties. The aboveground parts were classified according to Flora of Qinghaiica (Liu *et al.* 1997). Moreover, abnormal organs of belowground plant parts are common in plant on the Qinghai-Tibetan Plateau, in order to distinguish the alpine plants, we investigated the distinguishing features of under-ground abnormal organs of the common plant species on the Qinghai-Tibetan Plateau. The morphological organoleptic features such as shape, size, odor, taste, color, habitat type and sectional plane properties (such as texture and color) of below-ground parts of alpine plants were described. For some species, such as species in Gramineae, *Taraxacum* and *Carex*, sometimes, they are difficult to be classified and similar in diet property to plateau zokor, we judged their contained species homogeneous and they are stated in family or genus name. After classification, plant materials were dried at 60°C, and weighed using an analytical digital balance of 0.01g. The average dry mass of each species in the three 50 cm × 50 cm quadrats of a burrow system was referred to as available plants in the vicinity, and the dry mass cached in the same burrow system was referred to as selected plants.

In order to investigate the position of poisonous forbs in the diet of plateau zokor, we divided all the plant species into three categories: non-poisonous plant species, slight poisonous plant species and poisonous plant species based on the statement of Economic Flora of Qinghai (Guo 1987) and Economic Flora of China (2012). The details are in APPENDIX.

3.2. Data analysis

To investigate whether diet selection in plateau zokor exists or not, we conducted a non-parametric analysis of similarities (ANOSIM) between the dry mass percent of selected plants in caches and that in vicinities of each burrow system. Usually, the semi-metric Bray-Curtis measure and metric Euclidean distance measures can be adopted to do non-parametric ANOSIM, and the former is better than the latter (Anderson 2001). Here, we performed both of them to do non-parametric ANOSIM. The ANOSIM was conducted in PAST (Hammer and Harper 2006), with permutation 9999. We calculated the sum of plant dry mass of each kind of poisonous degree in each cache and vicinity of burrow system, and we conducted a bootstrap descriptive statistics on dry mass of each kind of plant.

4. RESULTS

A total of 57 burrow systems were collected (32 on the plain and 27 on the gradual slope, 11 samples in 2010 and 46 in 2011). The dry weight of the caches of each burrow system ranged from 26.00g to 1645.96g, with an average of 474.35 g (369.69~590.85, 95% upper and lower bootstrap confidence inter-

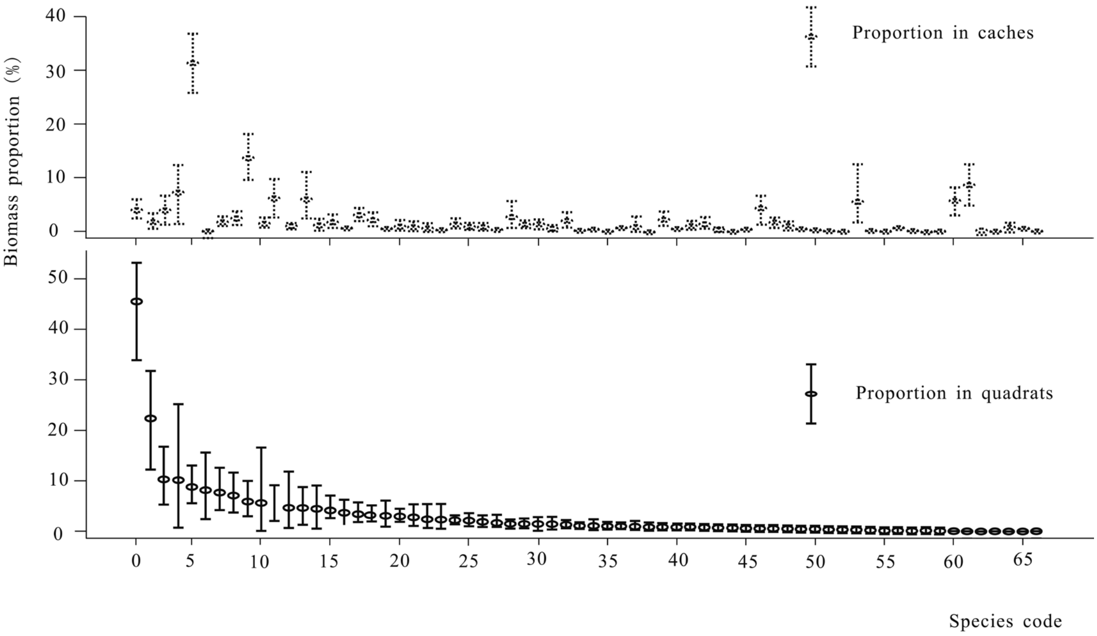

Fig. 2. Dry mass proportion of each plant species in caches and in quadrats (50 cm × 50cm). This figure was based on bootstrap descriptive statistics. Mean values of the dry mass ± 95% confidence intervals are given. For species codes see APPENDIX.

val (C.I.)). There were 66 different plant species (sometimes was family or genus, such as Gramineae, *Taraxacum* and *Carex*, we judged their contained species homogeneous because they are similar in diet property to plateau zokor) (22 families and 54 genera) found in the 57 burrow systems (from caches and vicinity) (species name see APPENDIX). The number of species found within the caches and in their vicinity ranged from 8 to 29 and from 15 to 37, respectively.

The dry mass proportion of each plant species in caches and corresponding vicinities are shown in Figure 2. The top 9 cached plants (in dry mass) account for 80% of plants present in zokor caches. *Polygonum viviparum* constitutes nearly half of the cache dry mass. Perennial forbs were the main components of the caches. Most of the cached species were geophytes (*P. viviparum*, *Potentilla anserina*, etc.) and hemicryptophytes (*Gueldenstaedtia diversifolia*, *Stellera chamaejasme*, etc.).

Underground parts were the essential components of caches, aboveground parts constitute only 11.59% (9.44~13.97%, 95% bootstrap C.I.) of the caches, they were mainly aboveground parts of the grasses and sedges. The proportion of the aboveground parts of top 9 cached plants species was very low (<10%).

Based on ANOSIM, the dissimilarity between the relative dry mass of plants in the vicinity and within caches was extremely significant (for Bray–Curtis distance measure, R = 0.355, P = 0.000; for Euclidean distance measure R =0.319, P =0.000).

Non-poisonous plants (79.46%) constituted the major component of the plants present in the vicinities of plateau zokor's burrow systems, while the proportion of slight-poisonous plants and poisonous plants were very small (8.59 and 11.95% respectively) in vicinities near the caches; but within the caches, half of the dry mass was made up of poisonous plants (48.79%), proportion of non-poisonous plants and slight-poisonous plants were very small (37.03 and 14.18%, respectively) (Fig. 3).

5. DISCUSSION AND CONCLUSIONS

The main assumptions leading to dietary obligatory generalism were energy constraint, independence constraint, and seasonality constraint (Heth *et al.* 1989). However, these three assumptions may not be the sufficient for obligatory generalism, because at least they don't take the edibility of the food items and the foraging properties of herbivores into consideration, herbivores may confront various plant species defended by chemical substances and physical weapons, and the ability to cope with these defended food items may be infinite variety to different herbivores (Shipley *et al.* 2009).

The three main assumptions mainly focused on the limited food resource and expensive energy expenditure of subterranean lifestyle. Conventionally, herbivores are classified into two kinds, namely generalists and specialists. Obligatory generalism is reasonable for energy-saving, if the forager is capable of dealing with the physical defense and chemical weapons. Generalists are capable of digesting or detoxify many available plant species (Shipley *et al.* 2009). In conditions where the food is in low quality, the digestion of cellulose is expected to be very effective in subterranean rodents (Sedláček 2007, Meyer *et al.* 2010). For example, pocket gophers displayed an increase in food intake with increasing forage fiber content within a certain range (Loeb *et al.* 1991) and dealing with fiber may be the foraging strategy of mole rat (Heth *et al.* 1989). However, relatively lower food intakes were observed in many other rodents and some subterranean rodents like Guinea pigs (*Cavia porcellus*), tree porcupines (*Erethizon dorsatum*) and pocket gophers (Geomyidae spp.), compared to voles (*Microtus* spp.) and some ruminants, when they were fed with high fiber-content forage (Meyer *et al.* 2010). Wang *et al.* (1979) found that, in plateau zokors, the potential to digest grasses (digestibility, 72.35±2.60%, n= 62) was significantly lower than that to forbs (digestibility, 79.56±1.51%, n= 62). Our result showed that diet selection did exist when plateau zokors collecting food for winter caches. Plateau zokors only cached a small proportion of grasses and sedges (6.80%, 4.93–8.25%, 95% bootstrap C.I., pooled data). Besides grasses and sedges, all other cached food species were forbs, mainly poisonous forbs. Meanwhile, plateau zokors showed preference on poisonous plants, specially the heavy poisonous plants.

Interestingly, compared to the plants that zokors seldom cached, most of the plants they cached contained a large content of plant secondary toxins. For example, the root tuber of *P. viviparum* contains a lot of phenol and tannins (142.10mg g^{-1} and 35.86mg g^{-1} respectively, Zhang *et al.* 2008) that reduces nutrition digestibility (Foley *et al.* 1999, Lin *et al.* 2012). *Stellera chamaejasme* and *Oxytropis kansuensis* are two of the most frequent and poisonous plants on the alpine meadow (Shi 1997). They are usually avoided by livestock. *S. chamaejasme* can cause cattle to vomit, scour, or even die (Song *et al.* 2008, Liu

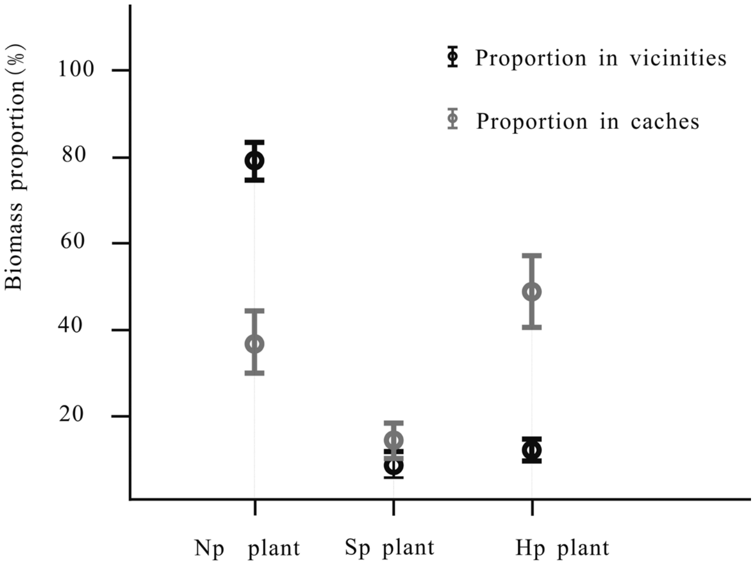

Fig. 3. Composition of proportion of plants with different degree of poisonous in caches and vicinities. Mean values and 95% confidence intervals of dry mass of three kinds of plants with different degree of poisonous are given. Np plant – non-poisonous plant; Sp plant – slight poisonous plant; Hp plant – heavy poisonous plant.

et al. 2004), *O. kansuensis* can cause cattle and deer lagging, monophagism and lastly lead to death, *O. kansuensis* can cause liver and kidney failure (Zhao 2001, Wang *et al.* 2002). Some studies reported that the contents of total alkaloids in some forbs (Wang *et al.* 2002, Yang *et al.* 2006) increased with the increase of elevation. These results may indicate that rather than dealing with high fiber-content forage, plateau zokors forged another dietary strategy to meet the energy demands in evolutionary process, to deal with the poisonous forbs**.**

The pathway plateau zokors may adopt to deal with the poisonous forbs may benefit from some hypotheses. Firstly, the plateau zokor seems to have developed efficient strategies to deal with such diets. For instance, terpenes are poisonous and reduce the food and protein digestion, widely distributed in plants. However, plateau zokors could reduce the negative effect of terpenes via reducing food intake and increasing food digestibility (Zhang 2000). Our studies suggest that zokors can reduce the harmful effects of tannins by increasing food intake (Lin *et al.* 2012). Secondly, the toxins stored in plants decay with time, thus caching could be a behavioral adaptation to circumvent the toxicity of the plant secondary compounds (Roy and Bergeron 1990, Torregrossa and Dearing 2009). Thirdly, the effects of plant secondary toxins may be mitigated by low temperatures, allowing plateau zokors to consume a more poisonous diet in the winter than they could in the summer, similar examples is observed in pikas (*Ochotona princeps*) (Dearing 2013). Fourthly, forbs high in plant secondary toxins preserve better in food caches over the winter, which can explain why pikas (*Ochotona princeps*) choose to cache them (Dearing 1997). Likely, this reason may explain why zokors choose to cache poisonous forbs. These four hypotheses may be in contradiction with each other, mainly between the first one and the other three. To consider this conflict, we need more information on the difference of zokors' immediate diet and cache diet. According to Wang *et al.* (2000), some poisonous plants such as *Ajania tenuifolia*, *Thalictrum alpinum* and Oxytropis spp. were comprised in the 9 most preferred plant species of plateau zokors' immediate diet in summer. So we can make a conclusion that plateau zokors can both consume the poisonous plants immediately and after a period of cache. In order to know the additional diet and cache selection information of plateau zokor, we need to study the composition of plateau zokors caches during spring and summer. To further test these hypotheses, the decay speed of the poisonous forbs and the different tolerance level of plateau zokors to plant secondary toxins under different low temperature level should be researched in future.

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APPENDIX

The list of names of plants found within the caches of plateau zokors and in their vicinity corresponding to species code in Figure 2 and poisonous degree (PD) corresponding to "poisonous degree" in Figure 3.

Code	Species	PD	Code	Species	PD
1	*Polygonum viviparum*	2	34	*Potentilla bifurca*	0
2	*Stellera chamaejasme*	2	35	*Trigonella ruthenica*	0
3	*Potentilla anserina*	0	36	*Salvia japonica*	1
4	*Cirsium souliei*	1	37	*Rumex patientia*	1
5	Gramineae	0	38	*Leontopodium nanum*	0
6	*Equisetum arvense*	0	39	*Glaux maritima*	1
7	*Gueldenstaedtia diversifolia*	0	40	*Anemone imbricata;*	2
8	*Thermopsis lanceolata*	2	41	*Lancea tibetica*	2
9	*Kobresia humilis*	0	42	*Morina chinensis*	1
10	*Saussurea qinghaiensis;*	0	43	*Carpesium abrotanoides*	1
11	*Hippophae tibetana*	0	44	*Polygonatum hookeri*	1
12	*Saussurea minuta*	0	45	*Potentilla fruticosa*	0
13	Carex spp.	0	46	*Anaphalis lacteal*	0
14	*Ajania tenuifolia*	2	47	*Cerastium caespitosum*	0
15	*Aster flaccidus*	1	48	*Ligularia virgaurea*	2
16	*Polygonum sibiricum*	1	49	*Stellaria pubescens*	0
17	*Scirpus distigmaticus*	0	50	*Elsholtzia densa*	1
18	*Oxytropis kansuensis*	2	51	*Ranunculus dondrergensis*	2
19	*Gentiana straminea*	1	52	*Kobresia capillifolia*	0
20	*Bupleurum smithii*	1	53	*Viola philippica*	1
21	*Gentiana farreri*	1	54	*Ranunculus longicaulis*	2
22	*Iris potaninii*	2	55	*Jaeschkea microsperma*	1
23	*Pedicularis alaschanica*	1	56	*Veronica ciliate*	1
24	*Potentilla nivea*	0	57	*Viola bulbosa*	1
25	Taraxacum spp.	1	58	*Geranium pylzowianum*	1
26	*Plantago depressa*	1	59	*Anemone rivularis*	2
27	*Ranunculus tanguticus*	2	60	*Geum aleppicum*	1
28	*Lonicera minuta*	1	61	*Kobresia parva*	0
29	*Thalictrum alpinum*	2	62	*Corydalis dasyptera*	1
30	*Notopterygium forbesii*	1	63	*Delphinium monanthum*	1
31	*Allium przewalskianum*	1	64	*Gentianopsis paludosa*	1
32	*Saussurea superba*	0	65	*Silene conoidea*	0
33	*Hypecoum leptocarpum*	2	66	*Swertia diluta*	1

Notes: 0 – stand for non-poisonous plant species, 1 – stand for slight poisonous plant species, 2 – stand for heavy poisonous plant species.