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The Density of Active Burrows of Plateau Pika in Relation to Biomass and Allocation in the Alpine Meadow Ecosystems of the Tibetan Plateau

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Abstract: Understanding the relationships between degrees of Plateau pika density and plants biomass is essential for improving the management of pika populations in alpine meadow ecosystems. Twelve survey sites with active burrow of plateau pika were classified into four degrees of density: approximately zero-density, low-density, medium-density and high-density to evaluate pika populations and biomass allocation interactions. The results revealed that plant composition, overall vegetation height and cover, dominant species were significantly different among the four sites. Additionally, plant functional groups, aboveground, belowground and total biomass, root:shoot ratios and the proportion of living roots were greatest at the zero-density site and those at the medium-density site were the lowest. Researchers postulate that pika activities may not be the source of the differences but a symptom of grassland degradation. As such, a reduction of livestock numbers, a variable rotational grazing system, restorative management techniques and community participation in co-management of the meadows are likely to effectively improve grassland productivity and deter pika outbreaks. Further, pika population fluctuations should be monitored and when the population exceeds the economic threshold of low-density (110 pikas or/and 512 active burrows ha^{-1}) or reaches high-density (200 pikas or/and 1360 active burrows ha^{-1}) integrated management strategies should be implemented to protect damage.

Key words: Active burrow ratio, burrow coefficient, Plant Functional Groups (PFGs), Plateau pika activity, Plugging Tunnels Method (PTM), root system, roots:shoots

INTRODUCTION

Plateau pikas (*Ochotona curzoniae*) are small lagomorphs, endemic to parts of the Tibetan Plateau in the People's Republic of China, India and Nepal (Bagchi *et al*., 2006; Smith and Foggin, 1999; Zhang *et al*., 1998) in areas where their grazing, burrowing, mowing, caching behaviours and food selection overlap with domestic livestock such as yak (*Bos grunniens*) and Tibetan sheep (*Ovis aries*) (Fan *et al*., 1999; Liu *et al*., 2008; Pech *et al*., 2007; Zhang *et al*., 2005). In addition, Plateau zokors (*Eospalax fontanierii*) are the only other subterranean herbivores, others species such as woolly hares (*Lepus oiostolus*), Himalayan marmots (*Marmota himalayana*), Gansu pika (*Ochotona cansus*), Daurian pika (*Ochotona dauurica*) and Qinghai vole (*Lasiopodomys fuscus*) are scarce and patchily distributed (Zhang and Liu, 2003).

In the past, Plateau pikas have been traditionally viewed as competitors with domestic livestock for forage as well as agents of pasture desertification, soil erosion and vegetation disturbances (Fan *et al*., 1999; Zhang *et al*., 2003). On the other hand, Plateau pikas also play a key role in maintaining ecosystem functions as a Keystone species for providing a food resource for large mammalian predators such as Tibetan foxes (*Vulpes ferrilata*), Steppe polecats (*Mustela eversmannii*), Chinese mountain cats (*Felis bieti*), Pallas's cat (*Otocolobus manul*) and Eurasian lynx (*Lynx lynx*) (Smith and Foggin, 1999) and avian predators such as golden eagles (*Aquila chrysaetos*), upland buzzards (*Buteo hemilasius*), saker falcons (*Falco cherrug*), goshawks (*Accipiter gentilis*), black kites (*Milvus migrans*) and little owls (*Athene noctua*) (Lai and Smith, 2003; Smith and Foggin, 1999; Zhang *et al*., 2003). Additionally, some abandoned tunnels provide homes for lizards, ground squirrel and native birds (Delibes-Mateos *et al*., 2011; Lai and Smith, 2003; Smith and Foggin, 1999). An alternative view of Plateau pikas is that they contribute to the overall health

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of alpine meadows by aerating the soil via their burrowing activities, promoting nutrient recycling within alpine ecosystems, Plateau pikas have also been shown to impact soil water retention and erosion (Li and Zhang, 2006; Smith and Foggin, 1999).

Like other small herbivores such as plateau zokors, European rabbits (*Oryctolagus cuniculus*), pocket gophers (*Thomomys bottae*), prairie dogs (*Cynomys ludovicianus*) and water voles (*Arvicola terrestris*) in various grasslands types around the world, Plateau pikas appear to have both detrimental and beneficial, direct and indirect and long-term and short-term impacts on grassland ecosystems (Arthur *et al*., 2007; Bagchi *et al*., 2006; Brown *et al*., 2006; Davidson *et al*., 2012; Delibes-Mateos *et al*., 2011; Fan *et al*., 1999; Hogan, 2010). When the pika populations reach a high density, eradication campaigns mainly by putting poison baits in burrows have been performed by local governments and organizations for many years (Fan *et al*., 1999; Zhang *et al*., 2003).

The impact of pika on grassland ecosystem is dominated to a great extent by species abundance. However, a so-called high density population and pika roles of benefit and detriment transformation are mostly based on qualitative description and calls for further quantitative research (Fan *et al*., 1999; Pech *et al*., 2007; Smith and Foggin, 1999; Zhang and Liu, 2003). To the knowledge little data exists on the impact of pika activities with population densities on community dynamics, Plant Functional Groups (PFGs), roots or biomass allocation. Researchers addressed the following three questions. How can plateau pika population density be quantified? What are the impacts of pikas activities with different active burrow densities on biomass allocation? How should herbivorous small mammal population in the alpine meadow ecosystems be managed effectively?

MATERIALS AND METHODS

Study region: The Tibetan Plateau, largely a treeless environment is located in Southwest China with a high altitude, harsh environment where the grassland ecosystems have complex, sensitive and vulnerable characteristics (Arthur *et al*., 2008; Fan *et al*., 1999; Long, 2007) and occupies 2.5 million km^2, approximately 25% of the country's area with an average elevation of >4000 m. The climate shows strong seasonality with a range of monthly mean temperature from -12.4°C in January to 9.8°C in July (Fan *et al*., 1999). There is year-round frost and extensive areas of permafrost occur in mountains and grasslands (Fan and Zong, 1991). The annual mean precipitation is 580 mm, 70% of which occurs in the Summer between June and August. Principal soil types are Mat Cryic Cambisols and Mol Cryic Cambisols (Wang *et al*., 2008). The major plant communities are alpine meadow, alpine swamp, alpine shrub, alpine prairie and alpine steppe meadow (Zhou *et al*., 2005).

This study was carried out on the South-Eastern flank of Qinghai Province, about 5 km West of the small town of Dawu, Maqin County, Guoluo Prefecture, approximately 480 km to Xining, the capital of the Qinghai Province, People's Republic of China. The area is part of the Sanjiangyuan National Nature Reserve which is one of the largest nature reserves in the world (Li *et al*., 2012). Plateau pikas had not been eradicated in this area in recent 5 years and all study sites consisted of gently undulating terrain within a similar habitat in Dawu valley with low, sparse alpine meadow grazed by yaks and sheep with heavy intensity in the cold season from September to the following May. Further, warm and cold season pastures rotational grazing were the basic and traditional management system for domestic livestock grazing in Qinghai-Tibet plateau.

Experimental design

Plateau pika burrow density survey: Large circle sampling (2500 m^2) was used to investigate Plateau pika burrow densities with the Plugging Tunnels Method (PTM) in early May 2008 (Fan and Zong, 1991; Sun *et al*., 2008). Researchers randomly selected 12 sites equally spaced around herdsman residential area with 0.5 km distance between sites where practically few subterranean zokor mounds were found and no zokors were trapped. Researchers assumed the grazing intensity of livestock and other native ungulates in this area was nearly the same. Assessing burrow count at each site took a survey team at least 4 days to complete. The survey was conducted as follows, a centre point was fixed with a stick in the observation site, then signed and positioned by GPS, an observer put the string ruler stretching to 28.2 m mark and turn around a circle with others observers who standing at one side of it along the same direction. The survey direction could be order with clockwise (from A to B, C, A) or counterclockwise (from A to C, B, A) (Fig. 1) (Sun *et al*., 2010) while the range of pikas population abundance was deduced with active burrow ratio and the local burrow coefficient (Table 1). All surveys were conducted in a relatively fixed time sequence at each site between 09:00 and 11:30 in relation to pikas frequency activities (Zeng and Lu, 2009).

On the 1st day, the total observed tunnels (including fresh, abandoned and depleted burrows) were counted and to the burrows were then plugged with soil clod, hay, dry yak dung or anything that can be used to slightly cover the open burrows by hands or portable shovels. During the following 3 days, the opening burrows were counted and plugged repeatedly until the 4th day. The count of the 1st day was the total observed burrows and the average count of next 3 days was the mean active burrows. In this study, researchers adopted the active burrow density, the number of active burrows per area to reflect the Plateau pika population fluctuations (Desmond *et al*., 2000; Sun *et al*., 2008, 2010). The burrow coefficient, the ratio of the number of practical captured pikas to the number of active burrows (Liu *et al*., 2003) was summarized from published literature and the Grassland Station of the Maqin Bureau of Animal Husbandry (Sun *et al*., 2010; Zhang *et al*., 1998).

Considering the major grassland types of alpine meadow and the status of site habitat and active burrow cluster distribution, twelve survey sites were classified into four degrees (treatments) of pika active burrow density and each treatment had three replications: Approximately Zero-Density (AZD), Low-Density (LD), Medium-Density (MD) and High-Density (HD) sites, respectively (Table 1).

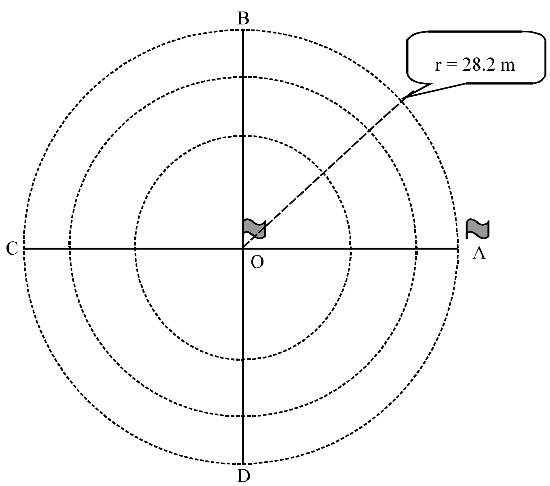

Fig. 1: A survey scheme for Plateau pika burrows demography by large circle sampling (r = 28.2 m) with Plugging Tunnels Method (PTM). Make O as fixed centre of a circle, then carefully search for burrows along counterclockwise direction from A to B, C, D, A or clockwise direction from A to D, C, B, A

Plant composition and biomass: In each site, three random quadrats of 50×50 cm were identified and the following parameters were recorded: plant species by taxonomic experts identification, overall vegetation cover (%) by vertical projection evaluation, height (cm) by natural vertical measurement and frequency (%) by small circle sampling (0.1 m^2) method in late August, biomass in late month from May to October as a whole growing season in 2008 (Wang *et al*., 2007). Above ground vegetation were sorted into four functional groups (grasses, sedges, forbs and litter) and clipped at ground level (Wang *et al*., 2008). After above ground biomass harvest, below ground biomass was estimated from 10×10 cm soil cores collected to 30 cm depth with each section 10 cm because nearly all of Kobresia meadows roots were concentrated in this depth. At each sampling, 3 soil cores were collected on each site. Based on the gravity principle, mud and soil were carefully removed by rinsing with water and the roots divided into two parts: living and dead (Poorter *et al*., 2012; Sun *et al*., 2008; Wang *et al*., 2010). All biomass materials were stored in study bags, oven dried at 75°C for 48 h and weighed.

Data analysis: To test for significant differences in active burrow density, overall vegetation cover and height, mean seasonal sedges, grasses, forbs and litter, above ground, below ground and total biomass, Root:Shoot (R:S) ratios and living roots proportion between study sites, researchers used ANOVA and LSD tests. Independent samples t-tests were used to analyze the differences in sedges, grasses, forbs and litter group in the same study site between months. Differences with a p-value of 0.05 or less were considered significant. All the statistical procedures were performed using SPSS (Version 13.0). Some related indices formulas are as follows:

- Plant Importance Value (IV) = (relative cover +relative height+relative frequency)/3
- Active burrow ratio (%) = (Active burrows per ha/Total observed burrows per ha)×100%
- Burrow coefficient = Pika abundance per ha/Active burrows per ha

Table 1: Geographical, Plateau pika abundance and burrows counts of sites AZD, LD, MD and HD (M±SD)

	Sites			
Parameters	AZD	LD	MD	HD
Total burrows (ha^{-1})	102 ± 24^a	1124 ± 86^b	2124 ± 172^c	2780 ± 233^d
Active burrows (ha^{-1})	48 ± 8^a	512 ± 54^b	864 ± 85^c	1360 ± 152^d
Pika abundance (ha^{-1})	0~15	15~110	110~200	200~300
Altitude (m)	3 771	3 769	3 740	3 751
Latitude	34°27.862'	34°27.647'	34°28.030'	34°28.197'
Longitude	100°12.182'	100°12.596'	100°12.624'	100°28.060'

*Values in the same row sharing the same letters are not significantly different from each other ($p\leq0.05$); AZD-HD denotes four sites with different active burrow densities by Plateau pikas; AZD: Approximately Zero-Density; LD: Low-Density; MD: Medium-Density; HD: High-Density

RESULTS

Plant composition and dominant species: Table 2 illustrates the plant species counts, overall vegetation cover and height, dominant species and the Importance Value (IV) for the four sites. Site AZD consisted of 36 plant species, 95% vegetation cover and 8.67 cm height with dense and homogeneous distribution, few forbs and no bare land with Cyperaceae: *Kobresia pygmaea* and *Kobresia humilis* the dominant species. Site LD consisted of 30 plant species, 75% vegetation cover and 4.46 cm height with homogeneous distribution, more grasses and less forbs with Gramineae: *Kobresia pygmaea* and *Poa annua* the dominant species. Site MD with 27 plant species, 40% vegetation cover and 3.48 cm height where forbs groups were the dominant population and palatable herbage (sedges and grasses) was less prevalent. Site HD had 28 plant species, 65% vegetation cover and 6.91 cm height where *Potentilla multifida* and *Potentilla nivea* were dominant species.

About 72% of the plant species IVs of site AZD were lower than the community mean IV (0.028) 78% of site LD species were lower than the community mean IV (0.0345) 48% of site MD species were lower than the community mean IV (0.037) and 57% of site HD species were lower than the community mean IV (0.036). The sequence of mean IVs of community species was MD>HD>LD>AZD.

There were significant differences in active burrows ($F = 9020.623$, $p<0.001$) overall species count ($F = 97.532$, $p<0.001$) besides sites MD and HD groups, overall vegetation cover ($F = 733.702$, $p<0.001$) and height ($F = 4261.326$, $p<0.001$) among the sites with different active burrows densities, moreover, all indices of site AZD vegetation were the greatest and MD was the lowest except for the mean IV.

Biomass allocation and seasonal dynamics: Figure 2 demonstrates that above ground, below ground and total biomass varied curves with growing season. Total biomass is made up of above ground and below ground biomass components. Overall there were significant differences in above ground biomass ($F = 1026.366$,

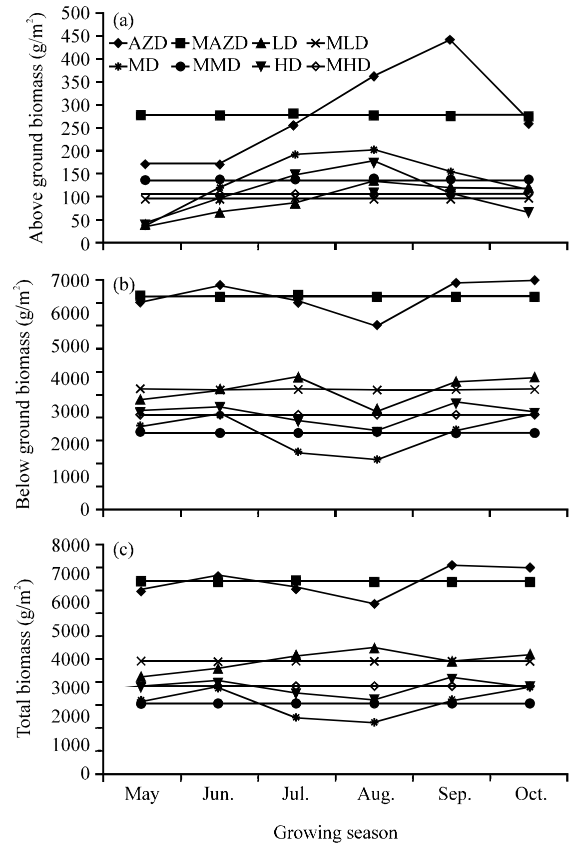

Fig. 2: a) Above ground; b) below ground and c) total biomass seasonal fluctuations of sites AZD, LD, MD and HD. Thick dash lines describe their own mean seasonal biomass, e.g., MAZD is the abbreviation of mean seasonal biomass of site AZD, etc.

Table 2: Differences in species abundance, overall vegetation cover and height (M±SD) dominant species and plant Importance Value (IV) of sites AZD, LD, MD and HD

Sites	Species count	Cover (%)	Height (cm)	Dominant species and Importance Value (IV)	Subdominant and accompanying species	Mean IV
AZD	36±4[c]	95±3[d]	8.67±1.44[d]	*Kobresia pygmaea* (0.1510), *Kobresia humilis* (0.1073) and *Poa annua* (0.0826)	*Elymus nutans*, *Stipa aliena* Keng, *Saussurea katochaete*, *Poa annua*, sum of IVs is 0.2459	0.0280
LD	30±3[b]	75±4[c]	4.46±1.01[b]	*Kobresia pygmaea* (0.1377), *Poa annua* (0.1357) and *Kobresia humilis* (0.1320)	*Elymus nutans*, *Stipa aliena* Keng, *Ligularia virgaurea*, *Anaphalis lactea*, sum of IVs is 0.4634	0.0345
MD	27±3[a]	40±3[a]	3.48±0.70[a]	*Aconitum pendulum* (0.1134), *Ligularia virgaurea* (0.0873) and *Potentilla nivea* (0.1233)	*Stipa aliena* Keng, *Elymus nutans*, *Poa annua*, *Aconitum gymanadrum*, sum of IVs is 0.7625	0.0370
HD	28±4[a]	65±5[b]	6.91±1.54[c]	*Potentilla multifida* (0.1233), *Potentilla nivea* (0.1210) and *Ligularia virgaurea* (0.098)	*Elymus nutans*, *Stipa aliena* Keng, *Ajaniatenuifolia* Tzvel. *Poa annua*, sum of IVs is 0.6158	0.0360

*Values in the same column sharing the same letters are not significantly different from each other ($p \leq 0.05$)

p<0.001), belowground biomass (F = 23754.111, p<0.001) and total biomass (F = 28369.191, p<0.001) among four sites.

Above ground biomass increased to the maximum in August (LD, MD and HD) and September (AZD) then declined rapidly in October, yet the sequence of mean seasonal aboveground biomass was AZD (278.2 g/m^2) >MD (137.1 g/m^2) >HD (106.7 g/m^2) >LD (93.5 g/m^2) (Fig. 2a). The minimum belowground biomass occurred in August and the sequence of mean seasonal below ground, total biomass was AZD (6084.2 g/m^2) >LD (3436.0 g/m^2) >HD (2748.5 g/m^2) >MD (2197.0 g/m^2) (Fig. 2b) and AZD (6362.4 g/m^2) >LD (3729.5 g/m^2) >HD (2855.2 g/m^2) >MD (2334.1 g/m^2) (Fig. 2c).

The ratios of R:S changed widely from 7.0 (MD in August) to 85.7 (LD in May) and the sequence of mean seasonal R:S ratios was LD (43.9) >MD (33.1) >AZD (24.8) >HD (23.6). Furthermore, total biomass was dominated overwhelmingly by belowground biomass and the proportion ranged from 87.6% (MD in August) to 98.8% (LD in May) and their mean seasonal proportions were 95.6% (AZD), 93.1% (LD), 94.1% (MD) and 96.3% (HD), respectively.

Above ground biomass allocation and seasonal dynamics: Figure 3 shows the sedges, grasses, forbs and litter dynamics of PFG biomass in growing season from May to October. Sedges, grasses and forbs groups firstly increased to the maximum in August or September then declined rapidly in October. Litter dynamics showed the opposite trend.

On seasonal average, the sequence of sedge biomass was AZD (71.3 g/m^2) >LD (9.5 g/m^2) >HD (6.4 g/m^2) >MD (4.2 g/m^2) (Fig. 3a) the grass sequence was AZD (50.0 g/m^2) >LD (32.6 g/m^2) >HD (15.5 g/m^2) >MD (12.5 g/m^2) (Fig. 3b) the forbs sequence was AZD (76.7 g/m^2) >MD (75.1 g/m^2) >HD (56.4 g/m^2) >LD (31.9 g/m^2) (Fig. 3c) and the litter sequence was AZD (92.2 g/m^2) >MD (41.3 g/m^2) >LD (26.8 g/m^2) >HD (22.0 g/m^2) (Fig. 3d). Palatable herbage (sedges and grasses) was AZD (121.3 g/m^2) >LD (42.1 g/m^2) >HD (21.9 g/m^2) >MD (16.7 g/m^2). The sedges (F = 1139.035, p<0.001), grasses (F = 86.204, p<0.001), forbs (F = 404.202, p<0.001) and litter (F = 95.331, p<0.001) group biomass of the AZD site were significantly higher than those of sites LD, MD and HD.

Figure 4 presents the proportions of sedges, grasses, forbs and litter group biomass of the four sites. The sequences of seasonal average PFG biomass proportions were as follows sedges, LD (36.9%) >AZD (25.3%) >HD (6.6%) >MD (3.1%); grasses, LD (20.1%) >AZD (15.0%) >HD (13.2%) >MD (8.0%); forbs, MD (57.7%) >HD (57.4%) >AZD (27.2%) >LD (23.3%); litter, AZD (32.6%) >MD (31.6%) >HD (22.5%) >LD (19.7%), moreover, palatable herbage, LD (57.0%) >AZD (40.2%) >HD (19.8%) >MD (11.0%).

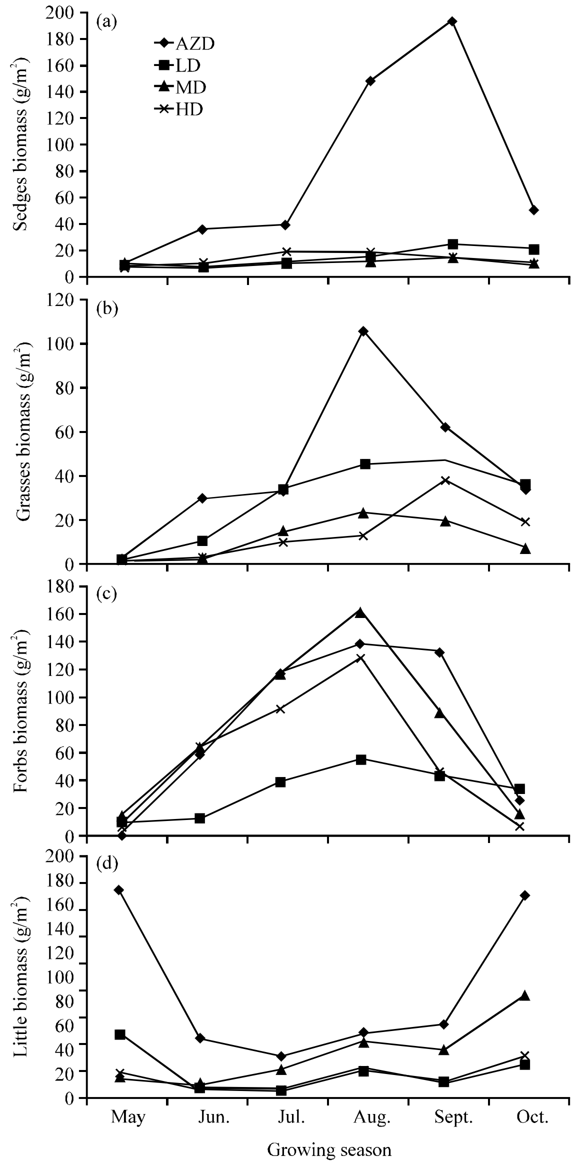

Fig. 3: a) Plant functional groups of sedges; b) grasses; c) forbs and d) litter biomass seasonal fluctuations of sites AZD, LD, MD and HD

Below ground biomass allocation and seasonal dynamics: Figure 5 shows the proportion of living root biomass and the mean seasonal ratios of four sites. Living root proportions of sites AZD and LD show a similar trend they began to increase in May to the maximum in August then declined rapidly to the lowest in October but at the MD and HD sites, the opposite trend was seen with the lowest proportion in July.

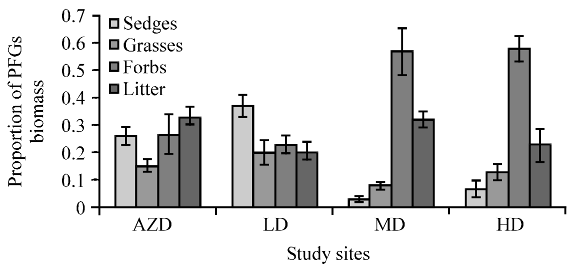

Fig. 4: Mean seasonal proportions of sedges, grasses, forbs and litter biomass of sites AZD, LD, MD and HD

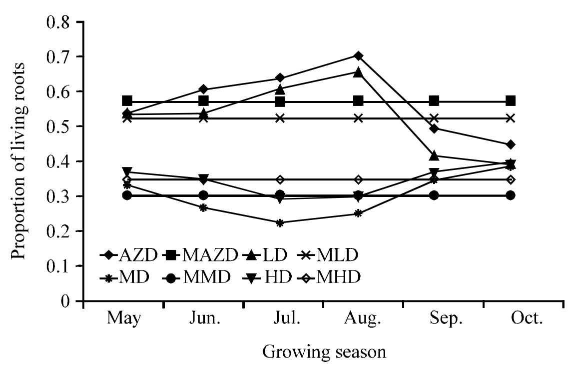

Fig. 5: Proportions of living roots biomass in growing season of sites AZD, LD, MD and HD, e.g., MAZD is the abbreviation of mean seasonal proportion of site AZD, etc.

The distribution range of the proportion of living roots during the growing season of the four sites were as follows, AZD (0.45~0.71), LD (0.39~0.66), MD (0.22~0.39) and HD (0.29~0.40), respectively. The seasonal averages for living root proportion was AZD (0.58) >LD (0.53) >HD (0.35) >MD (0.30). Although, there were no differences between sites AZD and LD ($F = 0.864$, $p = 0.365$) and sites MD and HD ($F = 0.895$, $p = 0.218$) the AZD and LD sites were significantly higher than sites MD and HD ($F = 124.327$, $p<0.01$). In general, the living roots of sites MD and HD were always smaller than dead roots but at the AZD and LD sites, living roots were greater than dead roots before August.

Belowground biomass dramatically decreased with increasing depth which presents an inverted pyramid character. Most of the root biomass and living roots were concentrated in 0~10 cm soil layer. Mean seasonal root proportions within the three layers were as follows AZD (0.83, 0.12 and 0.51), LD (0.84, 0.11 and 0.04), MD (0.75, 0.17 and 0.08) and HD (0.85, 0.12 and 0.04), respectively.

DISCUSSION

Relationship between Plateau pika density and number of active burrows: It is vital to collect the counts of Plateau pikas accurately to provide detailed information on population dynamics to allow effective management measures to be implemented (Zhong and Fan, 2002). At present there are many methods used in small animal surveys such as active and inactive burrow counts, mark-resight, mark-recapture and live-capture methods with belt transects on Plateau pikas, Plateau zokors, European rabbits, pocket gophers, prairie dogs and water voles (Brown *et al*., 2006; Dobson *et al*., 1998; Hogan, 2010; Lin *et al*., 2008; Liu *et al*., 2003, 1980). Active and inactive burrows are considered by some as the best indicator of intensity for herbivorous small mammal control (Desmond and Savidge, 1996; Desmond *et al*., 2000; Pech *et al*., 2007; Wang and Wang, 2001) but it is difficult to distinguish active and inactive entrances unambiguously through small herbivores footprint or/and fecal material (Pech *et al*., 2007). It seems that capturing individuals or mark-resight may be very close to the actual species abundance, yet it is not practical to use for a number of large experimental sites (Sun *et al*., 2010).

This study indicates that in alpine meadow ecosystems, the active burrow count to represent Plateau pika abundance using the Plugging Tunnel Method (PTM) is relatively accurate, operable and practical. Within the active burrow ratios of the survey sites where the mean active burrows ratio and the burrow coefficient were 42.8% and 0.303, over the counts of 200 pika and/or 1360 active burrows ha^{-1} could be the high-density in Guoluo pasture. However, the relationship between pika population and the total burrows (Pech *et al*., 2007) was not good. The causes may be that pika abundance show large seasonal and regional variations related to microhabitat, vegetation, precipitation and grasslands utilization (Smith and Wang, 1991) and some research pointed that the climax of pika reproduction was in late April to May (Yin *et al*., 2004).

In short, the demography of Plateau pika is a direct indicator to evaluate the impacts of pika populations on grasslands and whether their impacts are beneficial or detrimental in alpine meadow ecosystems. Pikas have the natural characteristics of transferring and moving frequently for food and exercises (Dobson *et al*., 1998) but the active burrows as dwelling homes, still are their activities assembly area. Through large-scale active burrow ratio and burrow coefficient investigation, active burrow densities could be more objectively and truly reflected the pika population fluctuations.

PFGs, above ground and below ground biomass allocation: The consumption of vegetation and burrowing can affect aboveground (shoots) and belowground (roots) which could in turn affect plant community composition, above ground biomass allocation and root system characters (Pokorny *et al*., 2005). Sedges and grasses are the dominant palatable forages resources but forbs which are usually considered to be toxic are not palatable forage for livestock some are food resources for pikas.

Biomass is allocated preferentially to leaves or roots to increase capture of the limiting external resource (Shipley and Meziane, 2002). Allocation patterns among plant organs included all components of a whole plant should be subject to strong natural selection and exterior disturbance in order to optimize growth and fitness (Craine, 2006). In alpine meadows, perennial plants turn green in May and absolutely withered and yellow in October. For sedges, however, the dominant functional group did change with altitude, site habitat, degradation and regressive succession (Wang *et al*., 2008, 2010). In this study with the pika active burrows increasing, the dominant and company species and their Importance Values (IVs) changed largely, moreover, the mean IV of site MD was greatest of all which the causes may be that some relatively tall and strong dicotyledons invaded and decreased the native plants such as *Kobresia pygmaea*, *K. tibetica* and *K. humilis*. The conclusion that pika burrowing activities may increase the plant species richness (Bagchi *et al*., 2006; Hogan, 2010) was not appeared in this research maybe it will take long-term controlled experiments to evaluate the full relationship between Plateau pika and plant diversity. However, certain plants such as *Ligularia virgaurea*, *Aconitum pendulum*, *Euphorbia ftscheriana* and *Anaphalis lacteal* nearly grow on the burrows and/or off-burrows and native Cyperaceae and secondary poaceae plants are increasingly less and less.

Above and below-ground biomass allocation is a central issue in plant ecology, however, the strategies of allocation in plants remain contentious (Yang *et al*., 2009). In the study, although mean seasonal above ground biomass, below ground biomass, total biomass and R:S ratios of site MD were the lowest of all, pika activity brought the maximum above ground biomass ahead about 1 month. Furthermore, root and shoot allocation represents the largest flux of resources within a plant and therefore should be selected to maximize benefits to plants (Craine, 2006). R:S ratios increased with belowground competition, suggesting that it is an adaptive response but it could have been affected by the activity of herbivorous animals rather than adaptive plasticity (Poorter and Nagel, 2000). Plants can also alter their living root growth in response to the presence of external disturbance and a plant adaptation strategy could alter plant rooting depths (Yang *et al*., 2009). In the study, R:S ratios were widely dispersed and the lowest value occurred in site HD, about 74.66~84.75% of total roots were found in the top soil (0~10 cm) roots occupied 87.6~98.8% of total biomass, living roots shared 29.9~57.5% in root systems which were higher than those of analogous research on alpine meadows with different conditions such as degradation, altitude and areal extent (Wang *et al*., 2008; Yang *et al*., 2009; Zhou *et al*., 2005). Pika transfers and activities disturbed the grassland habitat and increased the prevalence of community species IV but decreased biomass, palatable forage, R:S ratios, roots and living root proportions.

On the topic of alpine meadow degradation classification and criterion (Ma *et al*., 2002; Zhou *et al*., 2005), sites AZD, LD, MD and HD could be classified as non-degraded, lightly-degraded, heavily-degraded and moderately-degraded grasslands, respectively.

Moderately-degraded grasslands had the greatest rodent populations (Jing *et al*., 2006; Sun *et al*., 2008; Wang and Wei, 2005; Zhang and Liu, 2003). It is concluded that site LD with 110 pika or/and 512 active burrows ha^{-1} may be seen as an economic threshold. If the density exceeds this range, detrimental effects on grassland ecosystems are seen. In addition when the population reaches high-density with 200 pika or/and 1360 active burrows ha^{-1}, grasslands degradation is readily visible. Although, pika activities may not be the root to grassland degradation they can provoke patchy de-vegetation, the spread of concentric circles spread and even the development of black land.

CONCLUSION

This study suggests that pika activities at high-density (>200 pikas or/and 1360 active burrows ha^{-1}) is likely to have detrimental impacts and that low-densities (15~110 pikas and/or 48~512 active burrows ha^{-1}) may be safe with potential beneficial impacts on grassland ecosystems. On the contrary, researchers highlight that medium-density (110~200 pikas or/and 512~864 active burrows ha^{-1}) is a key stage because it sits between high and low-density and at these densities, succession direction is in the balance.

IMPLICATIONS

To rodents pests, management will need to move away from the broadly destructive current approach of chemical eradication toward ecologically-based solutions (Dickman, 1999). Based on the current pastoral policy in China of retire livestock, restore pasture and an economic compensation programme (Han *et al.*, 2008) reduction of livestock number and detailed rotational grazing are important. Therefore, alternate methods such as establishing artificial or semi-artificial grassland are used to manage alpine meadows with high-density pikas. After restoring the vegetation, the alpine meadow is no longer a suitable habitat for Plateau pika and the grasslands function well and self-rehabilitate which is the key to regulating and controlling pika density and to promoting the healthy development of alpine meadows.

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