Summer habitat use of plateau pikas (*Ochotona curzoniae*) in response to winter livestock grazing in the alpine steppe Qinghai-Tibetan Plateau

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ABSTRACT
Plateau pikas (*Ochotona curzoniae*), burrowing lagomorphs endemic to the Qinghai-Tibetan Plateau (QTP), are considered pests by Chinese authorities because of their association with grasslands that are characterized as degraded. Officials typically blame pikas for causing the degraded conditions, whereas studies increasingly suggest that sparse vegetation encourages population growth and high densities of pikas. Correlational investigations that document pika density while simultaneously describing grassland conditions can quantify this association, but are uninformative regarding causation. We used livestock exclosures and pika reductions in partially controlled experiments to examine how pika habitat use responds to changes in vegetation structure caused by wintertime livestock grazing. Mean counts of pikas were higher on grazed than ungrazed plots. Linear models accounting for experimental pika reduction as well as seasonal phenology indicated that grazing significantly increased pika use compared with ungrazed plots. These results show that moderate livestock density is likely consistent with both biodiversity conservation and economic activity, and that high pika populations alone are not responsible for observed degradation of the QTP alpine grasslands. Moderate levels of livestock grazing and pika presence are consistent with maintaining the integrity of the alpine steppe ecosystem of the QTP.

Introduction

The plateau pika (*Ochotona curzoniae*), a small, burrowing, nonhibernating, social lagomorph (Dobson, Smith, and Wang 1998; Smith 2018; Smith and Wang 1991) and the domesticated livestock of indigenous Tibetan pastoralists are two major drivers of grassland ecosystem processes on the Qinghai-Tibetan Plateau (QTP) in western China. The QTP occupies 2.5 million km², which is approximately 25 percent of China’s land area (Harris et al. 2016; Miller 1995). The pastoralism of domesticated livestock has influenced the grasslands that cover approximately 70 percent of the QTP for approximately 8,000 years (Miehe et al. 2009; Miller 1995). These grasslands support a unique flora and fauna (Smith et al. in press; Smith and Foggin 1999). Therefore, the current status, as well as future prospects for sustaining the integrity of this grassland ecosystem, are important at both local and regional scales.

Throughout the past few decades, the grasslands of the QTP have been perceived to be increasingly degraded (Fan et al. 1999; Foggin 2000; Li et al. 2013), yet documentation of the extent and magnitude of grassland degradation is lacking (Harris 2010). Our understanding of pastureland degradation on the QTP has also been hampered by a lack of clear consensus of what is meant by degradation. Some studies that have attempted to understand the causes of grassland degradation have claimed that pikas are a chief contributor to such degradation, especially when their populations reach high density (Fan et al. 1999; Sun et al. 2011; Wang, Zheng, and Xiao 2005; Zhao 1998). Others have attributed perceived degradation to human-induced overgrazing or poor livestock management (Bai, Zhang, and Xie 2002; Zhang et al. 2004). The arguments about the extent, causes, and remedies of degradation are highly variable, leading to controversial policy responses to address the perceived problem of...
degradation (Harris 2010). One such policy is the decades-long campaign to eradicate plateau pikas, which has been considered an essential component of grassland-management programs by policy makers aimed to mitigate and reverse degradation (Fan et al. 1999; Liu, Zhang, and Xin 1980; Sun et al. 2011; Wang, Zheng, and Xiao 2005). However, some researchers have argued that the high density of pika populations is a symptom of grassland degradation rather than a cause of the problem and that the root cause lies elsewhere (Harris 2010; Smith et al. in press; Smith and Foggin 1999). In addition, evidence from many studies has shown that pikas provide critical ecological services to biodiversity and ecosystem functioning on the QTP (Badingquying et al. 2016; Delibes-Mateos et al. 2011; Harris et al. 2014; Hogan 2010; Lai and Smith 2003; Smith et al. in press; Smith and Foggin 1999; Wilson and Smith 2015). Therefore, understanding the interactions between these herbivores (pikas and livestock) and grassland condition remains critical for making sound policy decisions.

Livestock grazing is the primary land-use practice on the grasslands of the QTP (Harris et al. 2016). These grasslands are also the natural habitat of pikas across the QTP (Smith and Foggin 1999). While livestock and plateau pikas have long coexisted (Miehe et al. 2009), in recent times dramatic increases in the density of these two major herbivores across the grasslands of the QTP have been reported (Caidan 2006; Fan et al. 1999; Harris 2010). Thus, the potential interaction between livestock and pikas is of interest: to what extent does the population density of one component (livestock or pikas) impact the other? Such an example includes a high population density of pikas being associated with increased grazing intensity by livestock (Li et al. 2013).

Pika population density has been shown to be highly dependent on local habitat conditions (Liu et al. 2009; Shi 1983; Xia 1984; Zhang et al. 1998). Habitat quality likely determines the population density of pikas because pika density tends to be higher in more degraded or overgrazed habitat than in habitat with more natural vegetation conditions, as suggested by Shi (1983) and Liu et al. (2003). However, the majority of studies examining relationships between pikas and grassland conditions have focused on the impact of pikas on vegetation communities (Bagchi, Tsewang, and Ritchie 2005; Guo et al. 2012; Hogan 2010; Sun et al. 2011). The possible reverse influence of vegetation on pikas has rarely been studied. A few studies have provided evidence that pika population density (or survival) responds to site-specific variables, such as vegetation biomass (Liu et al. 2003; Pech et al. 2007), cover (Liu et al. 2003; Shi 1983; Wangdwei, Steele, and Harris 2013), and height (Shi 1983). Other studies have subjectively categorized habitats as lightly, moderately, or heavily degraded (Li et al. 2014; Liu et al. 2003; Yu et al. 2010). Studies have not yet addressed causal relationships between pika density and habitat use or habitat conditions.

Here, we made use of livestock exclosures (Harris et al. 2015) to isolate the role that domestic livestock may play in determining pika habitat use and, ultimately, density. We hypothesized that livestock exclusion would result in greater standing vegetation biomass, which in turn would reduce pika habitat use. We reduced pika abundance to estimate the converse relationship of how pika density may impact vegetative characteristics in the alpine steppe habitat. These experiments allowed us to disentangle cause from effect—to determine whether pikas may exacerbate vegetative conditions or merely be responding to existing conditions.

**Materials and methods**

**Study location and system**

We conducted field experiments in four pastures of Village Five (approximately 35.5° N, 98.7° E), Gouli Township, Dulan County, Qinghai Province, PR China (Figure 1). The study area is characterized by mountainous terrain with low to moderate slopes adjacent to the valley bottom (elevation 3,950 m), which rises to surrounding peaks at 4,900 m (Harris et al. 2015). The major habitat type is alpine steppe grassland dominated by the genus *Stipa*, accompanied by *Leymus* spp., *Poa* spp., *Oxytropis* spp., and more than 100 other species of vegetation (primarily forbs; full details are in Harris et al. 2015, 2016). The onset of spring vegetation green-up is determined by precipitation and temperature (Shen et al. 2011); in our study area, its timing typically occurred in June. The average annual precipitation during 2008–2013 at the study area was 398 mm (SD = 53.4), and approximately 92 percent of the precipitation occurred during April through September. Mean annual temperature was −1.4°C; the annual average temperature of the warmest eight-day period was 14.0°C, and the coldest eight-day period was −16.3°C (Harris et al. 2015).

Pastures in the study area were mainly used as winter pasture; thus, they were grazed during mid-October through mid-June of the following year. Livestock were primarily domestic sheep and yaks, and a small number of goats and horses. Prior to 2010, and during the years of our investigation (2010–2013), all pastures where our field experiments were located were mainly grazed by
sheep, with a small number of goats (2016; Harris et al. 2015; Yeh and Gaerrang 2010). Pikas were the most numerous above-ground vertebrate herbivore. Other small mammal herbivores, such as Chinese zokors (*Eospalax fontanierii*), Mongolian five-toed jerboas (*Allactaga sibirica*), mountain voles (*Neodon* spp.), voles (*Microtus* spp. and *Lasiopodomys* spp.), and dwarf hamsters (*Cricetulus* spp.), were observed in the vicinity of the study site. With the exception of one active vole colony that resided approximately 700 m from one exclosure, we did not observe the presence of these small mammals on or adjacent to the experiments during our study. Himalayan marmots (*Marmota himalayana*) and woolly hares (*Lepus oiostolus*) were present nearby, but were not observed on or near our study plots (Harris et al. 2015). Wild ungulates, including blue sheep (*Pseudois nayaur*), Tibetan gazelle (*Procapra picticaudata*), and argali (*Ovis ammon*), were present, but only gazelles (occasionally and in small numbers) were observed in the vicinity of the experiments. Tibetan foxes (*Vulpes ferrilata*) were often seen around the study area, apparently searching for pikas or other prey (Harris et al. 2014; Liu, Harris, and Wang 2010; Liu et al. 2007).

**Experimental design**

To test the effects of grazing exclusion on pika habitat use, we made use of twelve 10 m × 10 m woven wire livestock exclusion fences that had previously been constructed in specifically selected locations within four active pastures in fall 2009 to study livestock–vegetation relationships (Figure 2, Appendix 1; Harris et al. 2015). We refer to each exclosure, together with its surrounding unexclosed area, as an “experiment” (Harris et al. 2015). All enclosures were on gentle slopes (mean percent slope 5%; range 0–15%) that faced southerly or southeasterly, and the experiments were distributed across the study area with only minor differences in elevation. Thus, the effects of weather variability and slope on the twelve experiments were inconsequential. Additional details on the positioning and characteristics of exclosure placements are given in Harris et al. (2015).

We refer hereafter to the 100 m² areas within each fenced livestock exclosure as “ungrazed observation plots.” In spring 2010, we randomly selected and marked a single 10 m × 10 m (100 m²) observation plot adjacent to each of the enclosures; these served as controls, in the sense that grazing was allowed to occur on these observation plots without interference. Each control plot (hereafter “grazed observation plots”) was selected by tossing a piece of dried dung toward an ungrazed plot while standing approximately 20 m away without facing the plot. The direction of the ungrazed plot where the yak dung landed was selected for a grazed observation plot. Thus, our experimental design consisted of twelve grazed plots (1,200 m² total area) adjacent to twelve ungrazed plots (also 1,200 m² total area).

**Pika reduction**

Pikas were removed by kill (snap) trapping in six of the experiments (Figure 2). To reduce incursions of pikas
from neighboring family territories (and because pika family territories are much larger than the exclosures), trapping at each pika-reduction site extended 30 m beyond the experiment boundaries (Figure 3A; Harris et al. 2015). We set fifteen to twenty traps within each experiment at around noon, and they were checked the following morning and the number of animals removed was documented (Appendix 2). When we were unable to find a trap that had been set earlier, we assumed that a pika had been killed in it because we occasionally observed Tibetan foxes carrying away traps, suggesting that missing traps indicated dead pikas. Pikas are the primary prey for Tibetan foxes in this study area (Harris et al. 2010, 2014; Liu et al. 2007), and no other hypothesis for traps to be missing was reasonable to consider. The protocol for our study was approved by the Institutional Animal Care and Use Committee at Arizona State University (Protocol #12-1231R), and the Dulan County Forestry Bureau, Dulan, Qinghai, PRC.

Thus, our experimental design (Figure 2) consisted of: (1) six replicate experiments with the exclusion of livestock grazing and no pika reduction; (2) six replicates with the exclusion of livestock grazing and pika reduction; (3) six replicates with livestock grazing and no pika reduction; and (4) six replicates with livestock grazing and pika reduction.

**Pika counts**

Two observers counted pikas while sitting approximately 15 m away from each observation plot, tallying the number of individuals that appeared during one-hour sessions during 0800–1200 h and 1400–1800 h time periods (when pika activity peaks; Fan et al. 1999; Yin et al. 2009). We selected vantage points that allowed us to clearly see pika activities inside the plot while minimizing disturbance. Pikas generally became active within several minutes of our initial disturbance at the beginning of each observation session. Counts were averaged on the rare sessions when the two observers differed in the number of pikas seen. Thus, although we cannot account for imperfect or variable detection, that the two observers rarely differed in pika counts during individual sessions suggests that little would have been gained had we been able to employ a double-observer mark-recapture approach (sensu Nichols et al. 2000). We made observations in late May, late June, and late July of each year during summers 2010–2013.

**Pika burrow counts**

Two observers also counted active pika burrows; burrows were assessed as active by the presence of fresh soil at the burrow mouth (Lai and Smith 2003). We first divided each observation plot in half, marked with flags at the central line. We counted burrows within each half starting from the opposite side of the enclosure. For accuracy, we then switched halves to recount burrows, and reported the matched count numbers. Burrow sampling was carried out in late June 2010 and in mid-July from 2011 to 2013.

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**Figure 2.** Schematic map of randomly chosen grazed observation plots adjacent to ungrazed observation plots at Gouli field study site based on UTM coordinates. The solid squares represent the exclosures and dashed squares adjacent to the exclosures represent the grazed observation (i.e., control) plots. Plots 1, 2, 3, 7, 9, and 10 represent pika removal experiments; plots 4, 5, 6, 8, 11, and 12 represent nonremoval experiments. Further details on plot selection and characteristics are available in Harris et al. (2015).
Vegetation sampling

We sampled vegetation in six randomly located plots (0.5 m\(^2\)) within the exclosures, and at six paired 0.5 m\(^2\) plots outside the exclosures. Random selection of vegetation plots was achieved by first dividing each enclosure into 100 1 m\(^2\) sections, excluding the outmost 2 m-wide strips of each (to minimize possible edge effects arising from the presence of the fence); the remaining 64 m\(^2\) were assigned random numbers (1–64, using the pseudorandom number generator in MS-Excel), and those with integers 1–6 were selected for sampling (Harris et al. 2015). Sample plots were demarcated by positioning a 0.5 m\(^2\) PVC-made quadrat at each plot (Figure 3B). Plots were permanently marked with approximately 5 mm diameter steel cable anchors inserted approximated 30 cm into the ground to facilitate repeated vegetation measurements. Each of the six paired vegetation sampling plots outside the enclosure were selected based on vegetative similarity to its pair within the enclosure. Field crews conducted vegetation sampling from mid-July to mid-September of years 2010–2013, in addition to the pre-exclosure sampling in September 2009 (Harris et al. 2015); that is, a total of (144 × 4 = 576 vegetation plot readings). Field technicians who carried out the vegetation sampling for those consecutive years were trained in species identification and field protocol (see Harris et al. 2015 for details).

We used plot-specific data on vegetation height, percent live vegetation cover, percent litter cover, percent bare soil, and fresh biomass (in grams). Species-specific height was measured using a ruler, and the mean was recorded if more than one individual of the species was present. Species-specific fresh biomass was estimated using standardized known-weight reference samples and calibration of samples from check plots (Harris et al. 2015). To increase the precision of each estimation, vegetation was calibrated by clipping samples from selected plots near the randomly selected permanent plots. Percent live vegetation cover, percent litter cover, and percent bare soil were estimated visually (Harris et al. 2015).

Data analyses and hypotheses tested

We tested for differences in Stipa height, vegetation cover, vegetation fresh biomass (green weight), litter cover, and percentage of bare soil measurements between treatments using mixed-effect linear models (lmer function in the lme4 package for R; Bates et al. 2015). For each test, we treated as fixed effects grazing (excluded or not) and whether pikas were reduced or not and also examined the interaction of these two
Table 1. Means of the total number of pikas counted from May to July (n = 739 in 312 counting bouts) of years 2010–2013, Village Five, Gouli Township, Dulan County, Qinghai Province, China. July (2010–2013) data (n = 494 in 167 counting bouts) are presented separately because vegetation measurements were not collected prior to this time, and thus data were analyzed separately.

| Time Period | Pikas Reduced or Not | Grazed Mean (SE) | Ungrazed Mean (SE) |
|-------------|----------------------|------------------|--------------------|
| May–July    | Not reduced          | 3.77 (0.04)      | 2.44 (0.03)        |
|             | Reduced              | 1.83 (0.02)      | 1.32 (0.02)        |
| July        | Not reduced          | 4.67 (0.08)      | 3.16 (0.07)        |
|             | Reduced              | 2.15 (0.05)      | 1.56 (0.04)        |

fixed effects; we treated as random effects year nested within experiment as well as Julian date, using the R program glmer (Bates et al. 2017). Our model took the form (in R syntax):

Pikas observed ~ grazing excluded × pikas reduced + (1|Julian date) + (1 | year/experiment)

To address the hypothesis that livestock exclusion or pika reduction explained the variation in the number of burrows, we applied the same model structures for predicting pika count differences between treatments, as previously. For models of both pika counts and burrow counts, we used negative binomial error structures for response variables because goodness-of-fit tests suggested poor fits to models with Poisson error structures, and because variances were much larger than means for both counts of pikas (variance = 11.49, mean = 3.41) and of active pika burrows (variance = 200.08, mean = 17.58).

We conducted statistical tests with R (version 3.2.4, R Core Team 2016). Results of all statistical tests were considered significant at p < 0.05.

Results

We counted a total of 297 pikas on ungrazed observation plots and 442 pikas on grazed observation plots (Appendix 3). Across all treatments and replicates (n = 312), the mean pika count was 2.37. Table 1 presents the means and standard errors of pikas observed across the treatments from May to July 2010–2013; Table 2 presents vegetation characteristics across the treatments. *Stipa* height, vegetation cover, litter cover, and bare soil differed between the ungrazed and grazed conditions (Table 3).

During July only, across all years, fewer pikas were observed in plots that had been subjected to pika trapping (x̄ = 2.29, SE = 0.31) than where no trapping occurred (x̄ = 4.52, SE = 0.59; t = 3.41, p < 0.01). In July only, pika counts in ungrazed observation plots (x̄ = 2.79, SE = 0.43) did not differ from those in grazed observation plots (x̄ = 4.02, SE = 0.53; t = 1.79, P > 0.05).

Livestock exclusion and pika reduction both had significantly negative effects on pika counts (pika reduction: β = −0.506, SE = 0.225, z = −2.24, p = 0.025; grazing exclusion: β = −0.499, SE = 0.143, z = −3.49, p = 0.005; interaction: β = 0.147, SE = 0.226, z = 0.54, p = 0.515; Table 4).

The total number of burrows counted across all years on the twelve ungrazed observation plots was 825 (burrow density = 0.69/m²) and on the twelve grazed plots was 863 (burrow density = 0.72/m²). We counted fewer burrows annually in plots subjected to pika reduction (x̄ = 6.78, SE = 0.98) than in plots with no pika reduction (x̄ = 16.88, SE = 2.44). Pika reduction had a significantly negative effect on counts of pika burrows (β = −0.762, SE = 0.233, z = −3.27, p = 0.001). However, livestock exclusion had no significant effect on burrow counts, with no interaction of treatments detected (Table 5).

Discussion

It has long been known that high pika population densities are associated with degraded grassland conditions (Han, Hua, and Xu 2008; Jiang 1998; Liu et al. 2003, 2009; Shi 1983; Zhang et al. 1998), as indicated by the reduction in above-ground biomass and the presence of bare soil (Han, Hua, and Xu 2008; Liu et al. 2003; Wu and Du 2007). Some have argued that the burrowing activities of pikas exacerbate degraded conditions when the pika density reaches high levels (Guo et al. 2012; Han, Hua, and Xu 2008; Su and Fan 2002; Sun et al. 2015).

However, previous work has not been conducive to disentangling cause from effect in this relationship. Pikas may cause or exacerbate vegetative conditions

Table 2. Means and standard deviations (in parenthesis) of selected vegetative characteristics habitat variables (n = 576) in 0.5 m² plots in grazed plots and ungrazed plots, as well in pika-reduced plots and plots without pika reduction, in Village Five, Gouli Township, Dulan County, Qinghai Province, China, July–September 2010–2013.

| Habitat Condition | Stipa Height (cm) | Vegetation Cover (%) | Vegetation Biomass (g/m²) | Litter Cover (%) | Bare Soil (%) |
|-------------------|-------------------|----------------------|---------------------------|-----------------|---------------|
| Grazed by livestock | 4.29 (1.21)        | 38.71 (13.88)         | 95.93 (36.60)             | 12.65 (8.70)    | 48.15 (14.63) |
| Ungrazed by livestock | 6.65 (3.23)        | 44.65 (15.58)         | 102.34 (46.42)            | 15.50 (11.19)   | 39.42 (16.69) |
| Pikas reduced      | 5.39 (3.07)        | 41.01 (14.64)         | 99.44 (42.23)             | 14.97 (10.13)   | 43.39 (15.19) |
| Pikas not reduced  | 5.55 (2.29)        | 42.35 (15.42)         | 98.84 (41.64)             | 13.19 (10.04)   | 44.17 (17.31) |
Table 3. Mixed-effect linear models showing fixed effects of the joint influence of grazing and pika reduction on selected vegetation characteristics, in Village Five, Gouli Township, Dulan County, Qinghai Province, China, July–September 2010–2013. Shown are estimated coefficients, standard errors of coefficients (SE), and t values. Variance explained by random effects plot, experiment, year, and Julian date not shown.

| Predictor | Source of Variation | Slope   | SE    | t     |
|-----------|---------------------|---------|-------|-------|
| Stipa height | Grazing exclusion  | 2.18    | 0.23  | 9.46  |
|            | Pika reduction      | -0.87   | 0.41  | -2.11 |
|            | Exclusion × pika reduction | 0.36  | 0.33  | 1.12  |
| Vegetation cover | Grazing exclusion  | 5.63    | 2.65  | 2.85  |
|            | Pika reduction      | -1.12   | 2.68  | -0.42 |
|            | Exclusion × pika reduction | 0.63  | 1.38  | 0.46  |
| Fresh biomass | Grazing exclusion  | 1.41    | 3.39  | 0.41  |
|            | Pika reduction      | -4.84   | 7.80  | -0.62 |
|            | Exclusion × pika reduction | 10.16 | 4.79  | 2.12  |
| Litter cover | Grazing exclusion  | 2.03    | 0.71  | 2.85  |
|            | Pika reduction      | -2.36   | 1.15  | -2.06 |
|            | Exclusion × pika reduction | 1.49  | 1.01  | 1.48  |
| Bare soil | Grazing exclusion  | -7.74   | 1.10  | -7.03 |
|            | Pika reduction      | 4.10    | 2.85  | 1.44  |
|            | Exclusion × pika reduction | -1.91 | 1.56  | -1.23 |

Table 5. Mixed-model negative binomial regression predicting pika burrow counts (n = 96) with fixed effects grazed (or not) and pikas reduced (or not), and random effects year, exclusion, and Julian date, Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2010–2013. Shown are slope coefficients (β), standard errors (SE), z values, and probabilities (p) for fixed effects; standard deviations (SD) and number of observations (n) for random effects.

| Predictor | Fixed Effect | β     | SE    | z     | p       |
|-----------|--------------|-------|-------|-------|---------|
| Grazing excluded |            | 0.4987 | 0.1431 | -3.49 | 0.0005  |
| Pikas reduced |            | 0.5057 | 0.2255 | -2.24 | 0.0249  |
| Excluded × reduced | | 0.1470 | 0.2258 | 0.64  | 0.5152  |
| Intercept |             | 1.0131 | 0.1854 | 5.47  | <0.0001 |

| Predictor | Random Effects | n    | SD   |
|-----------|----------------|------|------|
| Year      |                | 4    | 0.000015 |
| Julian date |               | 13   | 0.3336 |
| Exclusion (nested within year) |          | 48   | 0.0032  |

(as suggested previously), or they may respond to these conditions. By artificially controlling grazing—and thus vegetation characteristics—our study demonstrated that pika habitat use at a local spatial scale responded to vegetation characteristics. Mean pika counts in the presence of grazing were higher than in ungrazed plots across all census periods, a pattern that was similar regardless of whether or not pikas were reduced. In contrast to the marked differences seen earlier in the growing season, we noted little difference in vegetation height or biomass between the ungrazed and grazed conditions in July (Figure 4).

As expected, we counted fewer pikas and fewer pika burrows in experiments subjected to pika reduction than experiments with no pika reduction. Our pika trapping efforts resulted in reducing pika abundance by approximately half. Achieving a complete reduction of pikas was difficult because of the small size of our experiments relative to the mean size of a pika family territory (~12 m radius from the center of activities; Dobson, Smith, and Wang 1998).

In contrast to the marked effect on pika habitat use, livestock grazing exclusion showed no effect on pika burrow density. The number of pika burrows did decline with pika reduction. We interpret the decline as reflecting a temporal lag, in which the reduced use of burrows with fewer pikas led to a hastened collapse of previously used burrows. Liu et al. (2003) and Han, Hua, and Xu (2008) showed that pika population density and burrow density are positively correlated.

Our use of livestock exclosures to isolate cause and effect allowed us to demonstrate that grazing produced changes in vegetation conditions, and that pikas responded to those changed conditions. Consistent with our hypothesis, livestock grazing, which resulted in lower standing vegetation biomass, was associated with greater use by pikas than where grazing was excluded. These observations suggest that grassland habitats characterized by low height, low biomass, or both, are favored habitats for plateau pikas.

Understanding the magnitude and causes of grassland degradation remains an area of active research, but overgrazing, if it occurs, is generally thought to play a major role in grassland degradation. Increases in stocking rates and grassland degradation have occurred simultaneously throughout the past few decades (Dong et al. 2005; Jing et al. 1991; Zhang et al. 1998; Zhou et al. 2005). A high stocking rate is associated with a large percentage of bare soil patches, which is thought to be an important
indicator of grassland degradation (Li and Huang 1995; Liu et al. 1999; Yan et al. 2003).

In a related study, Harris et al. (2016) found that a combination of foraging, clipping, and burrowing activities of pikas under certain circumstances tended to perpetuate conditions undesirable to pastoralists. Our work suggests that some control of pikas, if desired, can be achieved by excluding livestock alone. However, Harris et al. (2015) cautioned that policies emphasizing restoration via a long-term grazing ban merit reconsideration, because QTP steppe plants have adapted to moderate levels of offtake and disturbance. They argued that, although the stocking rate of sheep was positively associated with bare soil and erosion (Harris et al. 2016), some plant species appear to have coevolved with, and would thus benefit from, grazing by both pikas and livestock. Taken together, these results argue that moderate livestock density is likely to be consistent with both biodiversity conservation and economic activity. Both livestock grazing and pika presence can be consistent with maintaining the integrity of the alpine steppe ecosystem of the QTP, particularly at moderate densities.

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Figure 4. Example of phenological progression of vegetation from May (a), June (b), and July (c) 2011, showing decreasing contrast of vegetation between an ungrazed and a grazed observation plot (experiment 3), Village Five, Gouli Township, Dulan County, Qinghai Province, China.
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Appendices

Appendix 1

Characteristics of four winter pastures on which the twelve experimental exclosures were established, in Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2009–2013. Further details of pasture site characteristics available in Harris et al. (2015).

| Pasture Owner | Pasture Size (km²) | Experiments | Mean Sheep/ha (2009) | Mean Elevation (m) | Mean Slope (°) |
|---------------|-------------------|-------------|---------------------|--------------------|---------------|
| Kunthar       | 6.8               | 1,3,4       | 0.05                | 4,223              | 22            |
| Balo          | 0.5               | 2,5         |                     | 4,064              | 6             |
| Sanko         | 10.1              | 6–11        | 0.15                | 4,155              | 22            |
| Ladri         | 6.2               | 12          | 0.36                | 4,280              | 16            |

Appendix 2

Number of pikas killed in twelve experiments (six with pika reduction, six without) during 2010–2012, Village Five, Gouli Township, Dulan County, Qinghai Province, China.

| Experiment | Pikas Reduced (Y/N) | Year | Total |
|------------|---------------------|------|-------|
|            |                     | 2010 | 2011  | 2012  | Total |
| 1          | Yes                 | 10   | 18    | 8     | 36    |
| 2          | Yes                 | 2    | 19    | 4     | 25    |
| 3          | Yes                 | 20   | 39    | 9     | 68    |
| 4          | No                  | 0    | 0     | 0     | 0     |
| 5          | No                  | 0    | 0     | 0     | 0     |
| 6          | No                  | 0    | 0     | 0     | 0     |
| 7          | Yes                 | 1    | 31    | 3     | 35    |
| 8          | No                  | 0    | 0     | 0     | 0     |
| 9          | Yes                 | 0    | 8     | 5     | 13    |
| 10         | Yes                 | 2    | 13    | 4     | 19    |
| 11         | No                  | 0    | 0     | 0     | 0     |
| 12         | No                  | 0    | 0     | 0     | 0     |

Appendix 3

Pikas counted during one-hour observation bouts at each of the observation plots from 2010 to 2013 at the Gouli field site, Dulan County, Qinghai Province, China. Pikas counts in 2010 were conducted only during July; two separate bouts were conducted in July 2011–2013, and these are summed here (means for these months are per counting bout).

| Plot No. | 2010 | 2011 | 2012 | 2013 |
|----------|------|------|------|------|
|          | July | May  | June | July | May  | June | July | May  | June | July | May  | June | July | May  | June | July | May  | June | July | May  | June | July |
| 1        | UG   | G    | UG   | G    | UG   | G    | UG   | G    | UG   | G    | UG   | G    | UG   | G    | UG   | G    | UG   | G    | UG   | G    | UG   | G    |
| 1        | 2    | 0    | 1    | 0    | 0    | 2    | 0    | 4    | 1    | 1    | 1    | 0    | 2    | 1    | 1    | 0    | 1    | 2    | 2    | 2    | 2    |
| 2        | 1    | 3    | 0    | 1    | 1    | 0    | 1    | 4    | 0    | 1    | 0    | 3    | 1    | 3    | 0    | 1    | 0    | 3    | 0    | 0    | 4    |
| 3        | 2    | 3    | 1    | 2    | 1    | 7    | 7    | 1    | 0    | 5    | 5    | 4    | 6    | 6    | 2    | 3    | 3    | 4    | 10   | 4    | 4    |
| 4        | 9    | 6    | 3    | 5    | 7    | 9    | 21   | 27   | 3    | 2    | 5    | 3    | 6    | 12   | 2    | 2    | 1    | 2    | 6    | 13   | 13   |
| 5        | 0    | 1    | 1    | 3    | 1    | 5    | 5    | 13   | 1    | 2    | 2    | 3    | 10   | 8    | 2    | 1    | 2    | 2    | 9    | 8    | 8    |
| 6        | 0    | 3    | 0    | 1    | 1    | 4    | 7    | 14   | 0    | 0    | 0    | 1    | 0    | 4    | 0    | 0    | 0    | 0    | 0    | 1    | 1    |
| 7        | 0    | 0    | 1    | 3    | 2    | 5    | 6    | 11   | 1    | 0    | 2    | 1    | 5    | 2    | 1    | 2    | 3    | 3    | 6    | 6    | 6    |
| 8        | 2    | 2    | 4    | 1    | 3    | 3    | 5    | 15   | 2    | 3    | 3    | 3    | 4    | 2    | 1    | 4    | 2    | 4    | 3    | 6    | 6    |
| 9        | 6    | 6    | 1    | 1    | 0    | 0    | 0    | 2    | 0    | 1    | 0    | 0    | 2    | 3    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 10       | 6    | 4    | 2    | 0    | 2    | 1    | 6    | 5    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 0    | 0    | 0    | 0    | 0    |
| 11       | 0    | 2    | 1    | 0    | 4    | 2    | 14   | 14   | 0    | 2    | 1    | 2    | 2    | 0    | 4    | 0    | 1    | 0    | 2    | 3    | 6    | 6    |
| 12       | 0    | 3    | 1    | 3    | 3    | 5    | 15   | 21   | 1    | 3    | 0    | 1    | 4    | 2    | 0    | 3    | 0    | 4    | 6    | 12   | 12   |
| Mean     | 2.4  | 2.8  | 1.1  | 1.9  | 2.2  | 3.3  | 3.7  | 5.7  | 0.9  | 1.3  | 1.7  | 1.9  | 1.6  | 2.3  | 0.8  | 1.6  | 1.1  | 2.3  | 2.0  | 2.8  |
| Total    | 29   | 34   | 13   | 23   | 26   | 39   | 89   | 137  | 11   | 16   | 20   | 23   | 39   | 55   | 9    | 19   | 13   | 28   | 48   | 68   |

UG = ungrazed observation plots; G = grazed observation plot.