Pikas, Grasslands, and Pastoralists: Understanding the Roles of Plateau Pikas in a Coupled Social-Ecological System

by

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ABSTRACT

The plateau pika (*Ochotona curzoniae*), a small burrowing lagomorph that occupies the high alpine grassland ecosystems of the Qinghai-Tibetan Plateau in western China, remains a controversial subject among policymakers and researchers. One line of evidence points to pikas being a pest, which has led to massive attempts to eradicate pika populations. Another point of view is that pikas are a keystone species and an ecosystem engineer in the grassland ecosystem of the QTP. The pika eradication program raises a difficult ethical and religious dilemma for local pastoralists, and is criticized for not being supported by scientific evidence. Complex interactions between pikas, livestock, and habitat condition are poorly understood. My dissertation research examines underpinning justifications of the pika poisoning program leading to these controversies. I investigated responses of pikas to habitat conditions with field experimental manipulations, and mechanisms of pika population recovery following pika removal. I present policy recommendations based on an environmental ethics framework and findings from the field experiments. After five years of a livestock grazing exclusion experiment and four years of pika monitoring, I found that grazing exclusion resulted in a decline of pika habitat use, which suggests that habitat conditions determine pika population density. I also found that pikas recolonized vacant burrow systems following removal of residents, but that distances travelled by dispersing pikas were extremely short (~50 m). Thus, current pika eradication programs, if allowed to continue, could potentially compromise local populations as well as biodiversity conservation on the QTP. Lethal management of pikas is a narrowly anthropocentric-based form of ecosystem management that has excluded value-pluralism, such as consideration of the intrinsic value of species and the important ecological role played by pikas. These conflicting approaches have led to controversies and policy gridlock. In response, I suggest that the on-going large-scale pika eradication program needs reconsideration. Moderation of stocking rates is required in degraded pika habitats, and Integrated Pest Management may be required when high stocking rate and high pika density coexist. A moderate level of livestock and pika density can be consistent with maintaining the integrity and sustainability of the QTP alpine steppe ecosystem.

DEDICATION

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CHAPTER ONE

A Review of Narratives of the Pika Eradication Program in the Context of Grassland Degradation, Qinghai-Tibetan Plateau, China

INTRODUCTION

The importance of maintaining the health of the Qinghai-Tibetan Plateau (QTP) grasslands has been increasingly recognized in order to sustain ecological services, maintain ecosystem function, and conserve biodiversity (Goldstein and Beall 1990; Miller 1995; Smith and Foggin 1999; Foggin 2000, 2011; Lai and Smith 2003; Cui et al. 2007; Harris et al. 2010; Harris et al. 2015). In particular, the grasslands of the QTP serve as an important socioeconomic resource that supports pastoralism, the major economic activity of Tibetan herders for thousands of years (Goldstein and Beall 1990; Miller 1995; Fan et al. 1999; Smith and Foggin 1999; Cui et al. 2007; Miehe et al. 2009; Wu et al. 2009). These grasslands harbor a large variety of unique flora and fauna, much of which is endemic or endangered (MacKinnon et al. 1996; Schaller 1998; Smith and Foggin 1999). Moreover, the grasslands are important watersheds of China and Asia's major rivers including the Yangtze, Yellow, Mekong and Brahmaputra (Xu et al. 2009; Wilson and Smith 2015). However, the grassland ecosystems of the QTP have been undergoing unprecedented degradation over the past several decades (Fan et al. 1999; Foggin 2000; Long 2003; Zhao and Zhou 2005; Harris 2010; Li et al. 2013).

Plateau pikas (*Ochotona curzoniae*) have been viewed as a major causative factor in degrading QTP grasslands (Liu et al. 1980; Shen and Chen 1984; Zhao 1998; Fan et al.1999; Wang et al. 2005; Sun et al. 2011). The belief that pikas cause grassland degradation has resulted in China framing the species as an agricultural pest

(Liu et al. 1980; Shen and Chen 1984; Zhao 1998; Fan et al.1999; Wang et al. 2005; Sun et al. 2011). Consequentially, massive poisoning programs have been carried out across the plateau for the past six decades to eradicate pikas (Fan et al. 1999; Smith and Foggin 1999; Delibes-Mateos et al. 2011). Despite the perception that pikas degrade ecosystems, pikas have been identified as a keystone species and an ecosystem engineer within the alpine grassland ecosystems of the QTP (Smith and Foggin 1999; Lai and Smith 2003; Hogan 2010; Wilson and Smith 2015). Thus, justifications for pika poisoning programs have been called into question (Smith and Foggin 1999; Lai and Smith 2003; Delibes-Mateos et al. 2011; Wilson and Smith 2015). Plateau pikas have been a major focus of attention among researchers and policy makers concerning social and economic development of pastoral society on the QTP as well as conservation of biodiversity. Researchers and policy makers share similar views that maintaining the integrity of grassland ecosystems is important. However, their perceptions of the role to the grassland ecosystems diverge. Policy makers and some researchers blame pikas for putatively causing grassland degradation thus need to be eliminated (Fan et al. 1999; Liu 2000; Zhang et al. 2006; Shang and Long 2007; Guo 2009). In contrast, many scientists argue that eradication of pika populations is wrong and that the species provides important ecological services, thus necessitating their protection (Smith and Foggin 1999; Lai and Smith 2003; Delibes-Mateos et al. 2011; Wilson and Smith 2015). These dichotomous views of the importance of plateau pikas highlight the complex coupled social-ecological system of the QTP.

This chapter presents the narratives of conflicting perceptions of the roles of plateau pikas within the context of a coupled social-ecological system, the alpine grasslands/pasturelands of the QTP. I outline the available information on the contrasting perceptions of pikas on the QTP. This chapter also serves as a contextual foundation for Chapter 4, where I present a policy framework for achieving the objectives of maintaining biodiversity and ecosystem functioning of the alpine grassland ecosystems of the QTP.

PLATEAU PIKA BIOLOGY

Plateau pikas (also known as black-lipped pikas) are one of 30 species of pikas (family Ochotonidae, order Lagomorpha) (Hoffmann and Smith 2005; Smith 2008). Pikas first appeared in Asia during the early Pliocene, and today are primarily found in western North America and Asia (Dawson 1967; Smith 2008; Smith et al. 1990). China hosts 24 species of pikas (Smith and Xie 2008), including plateau pikas that inhabit the vast alpine grasslands of the QTP, an ecosystem that extend over 2.5 million km^2 or a quarter of the area of China (Smith et al. 1986; Smith and Wang 1991; Miller 1995; Dobson et al. 1998). The grassland ecosystem where pikas occur constitutes approximately 1.4 million km^2 of the QTP (Fan et al. 1999). Plateau pikas are distributed across the alpine grasslands ranging from approximately 3,000 m to 5,000 m in elevation (Smith et al. 1986; Smith and Wang 1991; Schaller 1998; Smith and Xie 2008). The species is a generalized herbivore that forages on grasses, sedges, and forbs, which are the major vegetation groups within their habitats across the plateau (Smith 2008). Pikas are diurnal, non-hibernating animals. They are an important source of prey for a large range of carnivores (Smith and Foggin 1999; Badingqiuying et al. 2016).

Plateau pikas are social animals whose basic social unit is the family-occupied home range. Adult parents and their offspring live in subterranean burrow systems throughout the year in the treeless grasslands of the plateau (Smith et al. 1986; Wang and Dai 1990; Smith and Wang 1991; Dobson et al.1998). Soil mounds are formed near tunnel entrances resulting from burrow excavation, although some burrows (sometimes called "duck holes") do not have accompanying skirts of soil (Dobson et al. 1998). The average length of tunnels is 13 m, and can reach up to 20 m. The average depth of burrows is 0.3 m, although some extend as deep as 0.6 m (Schaller 1998; Fan et al. 1999). The distance between the center of activity of a family from the center of surrounding family territories is approximately 25 m (Smith and Wang 1991; Dobson et al. 1998; Smith 2008). Plateau pikas display various affiliative behaviors such as cuddling, grooming, parental care, and vocalization among family members (Smith et al. 1986; Smith and Wang 1991). Juveniles frequently use calls that are directed to family members as a form of social interaction, and also are used to alert conspecifics of the presence of predators with alarm calls (Smith et al. 1986). Monogamy is the basic mating system of plateau pikas, but they also exhibit other types of mating systems such as polygyny and polyandry (Smith et al. 1986; Wang and Smith 1989; Wang and Dai 1990; Smith and Wang 1991; Dobson et al. 1998) resulting from the stochastic death of individuals in a population and thus the adult sex ratio going into the breeding season. The percentage of different mating associations varies between family groups and among years (Dobson et al. 1998).

Population densities of plateau pikas fluctuate dramatically between seasons and years (Smith 1981; Smith 1988). These fluctuations are regulated both by density-dependent and density-independent factors (Smith 1988; Wang and Smith 1988). Generally, pikas are able to produce 3-5 litters at three-week intervals. The production of litters is facilitated by sufficient forage which increases through the summer reproductive time period, indicating pika mothers are able to translate food resources into offspring (Smith 1988; Smith 2008). The number of juveniles in each litter ranges from 3 - 5 individuals (Smith and Wang 1991). The result is a continuous increase of the local and regional population density from the beginning to the end of the summer reproductive time periods (Smith et al. 1986; Smith and Wang 1991). However, annual mortality of plateau pikas is very high, with only a few individuals living more than two years (Wang and Smith 1988; Dobson et al. 1998). However, Qu et al. (2013) showed that in rare cases individuals can live as long as four years.

PLATEAU PIKAS AS A CONTROVERSIAL SUBJECT

Pika Poisoning Program: Magnitude of Control

Plateau pika poisoning programs with the objective of eradicating populations have been implemented across the grasslands of the QTP since 1958 (Fan et al. 1999; Smith and Foggin 1999; Zhang et al. 2003; Zhou et al. 2005; Delibes-Mateos et al. 2011). Government bureaus at various levels have invested billions of *renminbi* (RMB; Chinese currency) and increased institutional efforts to eliminate pika populations with chemical poisons (Fan et al. 1999; Smith and Foggin 1999). The eradication programs were initiated with experimentation in the field by testing the efficiency of different types of chemical or biological poisons that were applied to eradicate pika populations (Liang et al. 1984; Fan et al. 1999; Wang et al. 2010). These trials were followed by large-scale control applications that utilized various chemical or biological poisons (Table 1). Large-scale control efforts were carried out in 1962, and from 1963 to 1965 about 130,000 km^2 of pastureland of the QTP were subjected to poisoning (Smith et al. 1990; Smith and Foggin 1999). From 1986 to 1994, nearly 75,000 km^2 of grassland were subjected to chemical treatment to eradicate pikas (Smith and Foggin 1999). Cumulatively, from 1964 - 1990, an area of 208,000 km^2 was poisoned by zinc phosphate and compound 1080 (fluoroacetate) in

20 counties of Qinghai Province (Fan et al. 1999). As of 2006, a total area of 357,060 km^2 had been poisoned to eradicate plateau pikas across Qinghai Province (An 2008). The pika eradication campaign has been carried out continuously across the QTP since its beginning in 1958. Few written sources address the eradication program in the 1970s in Qinghai Province, and most fail to provide specific information. Zhang and Wang (2006) and Fan (2014) reported that in some areas of Qinghai Province, such as Guoluo Tibetan Autonomous Prefecture and Henan County of Huangnan Tibetan Autonomous Prefecture, large scale eradication was conducted in the 1970s.

The plateau pika poisoning program has been implemented widely within the plateau pika distributional range, including the pasturelands in Gannan Tibetan Autonomous Prefecture in Gansu Province, Qinghai Province, Tibet Autonomous Region, and Sichuan Province. The priority of eradication efforts has been focused on Sanjiangyuan National Nature Reserve (SNNR), which covers an area of 31.6 million km^2 in Qinghai Province. A primary reason for designating this region a national nature reserve is that the area occurs in the headwaters of three of China's great rivers (Yangtze, Yellow, and Mekong). Approximately 20% of world's population lives in watersheds that originate from the region (Xu et al. 2009). Maintaining the health of the grassland ecosystem of SNNR is considered important for ecological security at both local and regional scales. In addition, the SNNR possesses many important wildlife species (MacKinnon et al. 1996). Controlling populations of pikas is regarded as an important measure for grassland ecosystem protection in SNNR by policymakers due the belief that pikas contribute to the perceived degradation of the grassland ecosystem in this area (Cui et al. 2007; Yang et al. 2010). Consequently, pika poisoning programs have intensified in the SNNR, and constitute a major component of "the Master Plan of Ecological Conservation and Construction for

Sanjiangyuan Nature Reserve of Qinghai Province" (BAH 2008). The state has invested a total of 800 million RMB (USD123,272,262) to eradicate the so called "rodent" infestation, which mainly refers to control of plateau pikas and also Chinese zokers (*Eospalax fontanierii*) in the Sanjiangyuan region. Prior to 2013, the state invested 157 million RMB (USD 24,713,123; 1 US Dollar = ~8.2 in 2005) to control "rodents" within a cumulative area of approximately 6,666,666 ha. Between 2005 and 2014, the state invested 650 million RMB (USD102,315,479*)* to essentially eradicate "rodent infestations" covering an area of 3,113,333 ha in the Sanjiangyuan region of Qinghai Province (Zheng 2014).

More than 10 types of rodenticides have been used to eradicate plateau pikas (Fan et al. 1999). Poison agents that have been applied to eliminate pikas include zinc phosphate (fluoroacetate), compound 1080, anticoagulants (diphacinone, gophacide, difenacoum, bromadiolone, brodiafacoum), and botulin type C toxin (Fan et al. 1999; Smith and Foggin 1999; An 2008). Fan et al. (1999) highlighted that zinc phosphate and compound 1080 were determined to be unsafe for non-target species and that their application caused serious social and environmental problems. Several chemical poison applications used earlier were abandoned due to impacts on non-targeted species and environmental contamination (Smith et al. 1990). Today, biological toxic control methods, which include botulin toxins C and D, are being used in most instances. Compound C (Botulin toxin Type C) is largely used to control small mammals today in Qinghai Province (Zhang et al. 2004; An 2008), because local agencies believe that it is relatively safe to non-target species. However, in the United States, botulinum toxin is classified as a bio-terror weapon. A single gram of crystalline toxin has the potential to kill more than one million people (Arnon et al. 2001). Although crystalline Botulin C is used in the field to eradicate pikas, potential secondary poisoning on biodiversity has rarely been investigated. Local people in Nangchen in 2010 reported that a large number of big black birds died after feeding on dead pikas following poisoning on their pastures a few years prior to 2010.

Narratives of Pikas as a Pest Species

Reports on the proportion of degraded grassland that is attributed to “rodent infestation” due to the presence of small mammal herbivores are many and involve several different regions of the QTP. Ci et al. (2007) stated that small mammals are responsible for causing degradation of 25.4% of the grassland in Qinghai Province, 30% in Gansu, and 26% in the Tibet Autonomous Region. In 2003 small mammals were identified as causing degradation of 19.2% of the grassland in Qinghai, 81.9% in the Zorge region (Sichuan Aba), and 22% in the TAR (Guo et al. 2009). Approximately 0.37 million km^2 of degraded grasslands have been attributed to small mammal activities across the plateau (Fan et al. 1999). In the literature, the use of the term “rodent infestation” also denotes the magnitude of grassland degradation putatively caused by these herbivorous species in their native habitats. And plateau pikas have been the major target of the elimination program (Fan et al. 1999; Smith and Foggin 1999).

The belief that pikas are a pest and are a causative factor of grassland degradation is mainly based on the perception of pikas causing grassland degradation derived from observation of high pika density in poor grassland conditions. In general, people intuitively link high density of pikas and poor grassland conditions as a cause-and- effect relationship, whereby the former leads to the latter. In addition, a high population density is another presumed reason that pikas are considered grassland pests (Zhao 1998; Fan et al.1999; Wang et al. 2005; Sun et al. 2011).

Pikas are thought to be a pest because of the belief that pikas compete with domesticated livestock for food. The foraging of pikas, which presumably leads to resource competition with livestock, is another assumption used to justify the pest status of plateau pikas (Liu et al. 1980; Shen and Chen 1984; Xia 1984; Fan et al. 1999). Reports on the forage consumption rate of plateau pikas in the literature vary widely (Table 2). According to an estimate by the Northwest Plateau Institute of Biology (Chinese Academy of Science), in 2004 loss of fresh forage by "rodent infestation" or the presence of small mammals is 30 billion kg/year on the plateau, which is equivalent to a reduction of carrying capacity that could support 20 million sheep (Guo 2009). Liu (2000) stated that the annual consumption of fresh forage by plateau pikas was around 4.4 billion kg in Qinghai Province, which is around one-third of the entire plateau. The forage consumption rate is extrapolated to a reduction of carrying capacity that could support 4.8 million sheep, and an equivalent economic value of the quantity of forage consumed of about 500 million RMB (approximately USD 79 million). Fan et al. (1999) stated that the combined consumption rate of plateau pikas and plateau zokors was approximately 136 billion kg of fresh grass every year over the entire QTP. The "rodent infestation" or presence of small native mammals has thus been considered as a major constraint to development of pastoralism and conservation of biodiversity (Zhu et al. 2002).

However, these arguments that pikas compete with livestock for forage are mainly based on extrapolation of pika's forage consumption rate into equivalent values if consumed by livestock. Overlap of diets may occur between livestock and plateau pikas (Jiang and Xia 1985), but using such a method as extrapolation of forage consumption rate to argue that competition between the herbivores exist may lead to a false conclusion of causal relationship. Jiang and Xia (1985) argued that pikas may compete for forage with livestock when pika populations are high (based on an investigation on the resource utilization and forage consumption rate by pikas using 25 x 25 m niche simulation with fenced plots). Their results showed pikas reduced 63.78% of aboveground biomass within five days of foraging in plots containing five pikas. While potential competition of forage by pikas with livestock may exist under certain circumstances, scientific-based investigation on forage competition between the two major herbivores is lacking.

Another reason for believing pikas are a pest is because pika burrowing activities are perceived to cause soil erosion. Some consider habitat degradation has occurred when burrow density is high (Sun et al. 2011). Caidan (2006) stated that burrows dug by rodents lead to a severe loss of soil and water. Guo et al. (2009) stated that "black beach" or bare ground occurs as a result of the sequential collapse of burrow systems. Erosion is considered to eventually occur, which threatens pastoralism as well as habitats for rare plant and animal species. However, these arguments tend to be merely assumptions because the authors failed to provide empirical data on these causal relationships. There is no indication that scientific investigations were conducted as basis of these arguments (Wilson and Smith 2015).

The belief that pikas indirectly cause flooding downstream at the major Chinese rivers is another major factor for framing pikas as a pest species. The cause of recent devastating floods, particularly in the late 1990s in the downstream drainages of the Yellow and Yangtze Rivers, is perceived to result from watershed degradation on the QTP where these large rivers originate (Zhou et al. 2004, Xu et al. 2009). Thus, plateau pikas are considered one indirect causative factor leading to floods from causing degradation of grassland habitats (Zhou et al. 2005).

Ecological Roles of Pikas

Contrary to the perception of pikas as pests, plateau pikas have been identified as a keystone species and an ecosystem engineer, and as such play an important role in the structure and function of grassland ecosystems on the QTP (Smith and Foggin 1999; Lai and Smith 2003; Hogan 2010; Delibes-Mateos et al. 2011; Wilson and Smith 2015).

Plateau pikas serve as an important food source for many species of raptors and mammalian predators on the QTP (Schaller 1998; Smith and Foggin 1999). Nearly all the raptors including little owls (*Athene noctua*), goshawks (*Accipiter gentilis)*, black-eared kites (*Milvus migrans*), upland buzzards (*Buteo hemilasius*), golden eagles (*Aquila chrysaetos*), steppe eagles (*Aquila nipalensis*), and saker falcons (*Falco cherrug*) that occur on the plateau, depend on plateau pikas as a main source of food (Schaller 1998; Smith and Foggin; Lai and Smith, 2003; Badingqiuying et al. 2016). Moreover, plateau pikas are important prey for a large variety of mammalian predators on the plateau including mountain cat (*Felis bieti*), lynx (*Lynx lynx*), Pallas' cat (*Otocolobus manul*), snow leopard (*Uncia uncia*), Tibetan fox (*Vulpes ferrilata*), wolves (*Canis lupis*), brown bear (*Ursus arctos*), Altai weasel (*Mustela altaica*), and Eurasian badger (*Meles leucurus*) (Peshikov 1957, 1976; Smith et al. 1990; Ma 1995; Schaller 1998; Smith and Foggin, 1999; Lai and Smith, 2003; Badingqiuying et al. 2016; Harris 2010, Harris et al. 2014). Pikas become the sole source of food for many predators during winter when alternative sources of food become scarce (Smith and Foggin 1999).

Pika burrows are major breeding and nesting sites for small native birds and lizards. A large diversity of small birds live in pika underground burrow systems, which they utilize to breed and nest. For example, the abundance of many bird species is much higher where there are abundant plateau pika burrows in comparison to sites with fewer pika burrows as a result of poisoning (Lai and Smith, 2003). Bird species that use burrows constructed by plateau pikas include Hume's groundpecker (*Pseudopodoces humilis*), and several species of Tibetan snowfinch: (*Montifringilla adamsi)*, white-winged snow finch *(M. nivalis),* plain-backed snowfinch *(Montifringilla blanfordi),* small snowfinch *(P. davidiana),* rufous-necked snowfinch *(M. ruficollis),* and white-rumped snowfinch *(M. tacazanowskii*) (Prejevalski 1876; Meyer de Schauensee 1984; Feng et al. 1986; Ma 1995; Schaller 1998; MacKinnon and Phillipps 2000; Lai and Smith 2003). In addition, native lizards (*Phrynocephalus, Eremias*) use pika burrows for cover and breeding habitats (Smith and Foggin 1999).

Pikas mediate plant community dynamics and promote nutrient cycling and soil disturbances. Burrowing activities by small mammals such as pikas increase oxygenation in deeper soil layers by lowering soil bulk density during burrow construction (Hole 1981). Burrow activities can also increase soil microbial activity, soil turnover, and soil fertility (Meadows and Meadows 1991). Moreover, small mammals such as plateau pikas help increase plant species diversity and richness as well as and productivity through burrowing activities (Bagchi et al. 2005; Hogan 2010). Aboveground plant biomass was improved when pika burrow density was moderate compared to high and low pika density in an alpine meadow (Zhang et al. 2016). Schaller (1998) suggested that plateau pikas control the spread of poisonous herbs that are not palatable to livestock through consumption, which helps improve available forage for livestock. Pikas also contribute to soil nutrient recycling and enhanced root biomass (Bagchi et al. 2005; Hogan 2010). Nutrients such as phosphorus and potassium were higher within burrow areas than areas without burrows (Zhang et al. 2016). Measured in plots with varying level of burrow density, soil organic carbon and nitrogen sequestration was higher in those with moderate (~230 burrows/ha) burrow density relative to low (128/ha) and high (544/ha) density (Pang et al. 2015).

Pika burrowing activities reduce the chance of flooding by increasing water infiltration. Wilson and Smith (2015) revealed that plateau pikas influence hydrological functioning of the grassland ecosystems through burrowing activities, suggesting that burrows could retain water runoff and ultimately mitigate flood risks downstream.

ALTERNATIVE DRIVERS OF GRASSLAND DEGRADATION

The worsening condition of the QTP grasslands over the past several decades is considered due to soil erosion, a decrease in aboveground biomass, and an increase in bare ground (locally called “Black Soil” or “Black Beach”). Beside considering pikas as a major cause of rangeland degradation, other key factors leading to worsening rangeland condition have been attributed to climate change, changes in the land use system, and overgrazing and overstocking of livestock (Liu et al. 1980; Shen and Chen 1984; Xia 1984; Fan et al. 1999; Zhu and Li 2000; Wei and Chen 2001; Bai et al. 2002; Yan et al. 2003; Zeng et al. 2003; Zhang et al. 2004; Bagchi et al.2005; Caidan 2006; Zhao et al. 2006; Zhang et al. 2009; Fan et al. 2010; Liu et al. 2013).

The root causes of grassland degradation on the QTP have been largely identified as resulting from the production mode of the commune system and sequential implementation of a series of grassland management programs that feature sedentarization of traditional pastoralism. These programs include privatization of pastureland, fencing of open rangeland, and resettlement programs. Each of these programs has aimed to reduce livestock mobility, increase the stocking rate on privatized parcels, and increase trampling of surface areas by livestock (Goldstein and Beall 1990; Wu and Richard 1999; Zhu and Li 2000; Zeng et al. 2003; Bagchi et al. 2005; Miller 2005; Yan et al. 2005; Caidan 2006; Klein et al. 2011; Wang et al. 2014).

Since the time of the commune system (1950s-early 1980s), the number of livestock are reported to have increased dramatically (Caidan 2006). In Qinghai Province it has been reported that livestock have exceeded the grassland carrying capacity by about 24.50% on average, with some pastures being grazing at a rate of 71.38% above their carrying capacity (Caidan 2006). The number of livestock has increased by up to 250% relative to carrying capacity since 1978 (Wei and Chen 2001; Du et al. 2004), which is partially due to inappropriate land management practices (Zhang 2007).

In addition to overgrazing as an agent of grassland degradation as argued by Bai et al. (2002), Yan et al. (2003) and Zhang et al. (2004), insects and caterpillars may contribute to degrading the QTP grasslands (Zhu and Li 2000; Zeng et al. 2003; Caidan 2006). There are 90 species and subspecies of locust and four species of caterpillar on the QTP. The locust-impacted grassland covers approximately 350 to 400 million ha, and caterpillar-impacted grassland covers around 600 to 700 million ha. Annual forage loss from insects has been reported to be 1.7 - 2 billion kg in Qinghai Province alone (Caidan 2006).

Climate change has been observed widely across the QTP (Wu et al. 2007; Xu et al. 2008; Wang 2014). This includes changes in the precipitation pattern and disappearance of permafrost, which combined may lead to accelerated grassland desertification (Ni 2003). Wang et al. (2009) reported that irregular precipitation patterns and increasing temperatures resulting from climate change are leading to deterioration of permafrost, and this in turn is one of the major reasons for degradation of alpine grassland ecosystems. In addition, warming temperatures have led to decreased vegetative productivity and plant species diversity (Klein et al. 2004, 2007; Yu et al. 2010). A general view among many Chinese researchers and policymakers is that the grasslands have been increasingly degraded due to the factors mentioned above. Yet, there is a lack of clear documentation of causes, extent and magnitude of grassland degradation. Existing hypotheses for causes of grassland degradation are also too vague to be tested (Harris 2010).

A REVIEW OF THE ARGUMENTS REGARDING PLATEAU PIKAS AS PEST

Native species are often perceived as pests when they cause degradation of habitats providing services linked to economic productivity (Stenseth 1989; Smith et al. 2006; Leirs 1994; Delibes-Mateos et al. 2011; Davidson et al. 2012), especially when their populations reach high densities (Eldridge and Simpson 2002). The view that native species are pests is often based on emotional judgments (Putman 1989) or a general social perception that is rarely supported by scientific data (Delibes-Mateos et al. 2011). Conclusions that focus on whether or not plateau pikas are a major causative factor leading to grassland degradation are mainly based on: 1) an assumption inferred from situations where the population density of plateau pikas is high and their geographic distribution widespread (Liu et al. 1980; Sheng and Chen 1984; Smith et al. 1990); 2) the realization that most studies on plateau pikas have focused on locations where their population density is very high (Smith et al. 1990); and 3) comparative studies of vegetation consumption rates between livestock and plateau pikas, whereby pikas presumably compete for forage that otherwise could be utilized by livestock (Smith and Foggin 1999).

In order to establish forage competition by herbivores, three criteria have to be met: 1) overlap of habitat use; 2) overlap of forage selection; and 3) forage scarcity. Outcomes of competition are demonstrated by a reduction of the population size of the subordinate group in the competition (Begon et al. 1996; van der Wal et al. 1998). But the arguments that pikas compete for forage with livestock are based on extrapolation of the forage consumption rate of pikas vs that of livestock (Fan et al. 1999). Thus, poisoning programs presumably lead to preservation of aboveground vegetation biomass that could benefit livestock productivity. While the logic of the argument may sound feasible, it is mostly based on assumptions rather than findings from scientific investigations. Reports of accomplishing stated objectives of pika poisoning programs are pervasive from newspapers to official documents (BAH 2008; The State Council of PRC 2014; Xinhua Net 2014), but evidence of such claims is rarely available. Very few studies (Pech et al. 2007) have investigated the effect of vegetation conditions following pika reduction.

Burrowing behavior and high density pika populations are seen as evidence for pikas causing damage to the grasslands, regardless of density variation between habitats (Table 3). The notions that pika burrows are “wounds” on the grasslands (Caidan 2006), and that burrowing activities contribute to grassland degradation (Sun et al. 2011), are largely embraced views. High burrow density might be instrumental in the conversion of already degraded grasslands into “black beach” or bare ground. However, such a mechanistic explanation of the direction of erosion in relation to pika burrows seems to be oversimplified in this complex system. This is especially true because the sequence and extent of anthropogenic and environmental factors that may be responsible for creation of bare ground are poorly understood.

Evidence shows that burrow density was lowest under healthy grassland conditions assessed by vegetation cover and biomass relative to degraded conditions (Shi 1983; Liu et al. 2003). Also, plateau pikas and their burrows may tend to accelerate the degree of grassland degradation when their density becomes high (Limbach et al. 2000). Thus, a high population density of pikas and a corresponding high burrow density might be a symptom of grassland degradation rather than a root cause of the problem (Smith and Foggin 1999).

Grassland degradation is considered to be a recent phenomenon, which coincides with transformations in pastureland use practices and grazing strategies (Sheehy et al. 2006; Zhang 2007; Harris 2010; Yan et al. 2010). The term “rodent infestation” often refers to high population density of pikas (Zhao 1998; Wang et al. 2005; Sun et al. 2011), is thought to have resulted from poor habitat condition caused by the recent socioeconomic transformations (Zhang 2007). Habitat with poor vegetative condition is believed to be optimal for pikas as demonstrated by their tendency to occur at higher population densities in these types of habitats (Shi 1983; Liu et al. 2003). Moreover, a major reason for the proliferation of plateau pikas is because the usage of chemical poisons to control pikas in the early years led to a reduction of raptors and mammalian carnivores. The resulting decline in predators, coupled with poaching of these species, has caused a rapid increase of small mammals (Guo et al. 2009). Alternatively, the high population density might result from a historical population cycle as portrayed by earlier explorers such as Prejevalsky (1876, p. 146). He described seeing hundreds of thousands of pikas on a single day in Qinghai Province. In addition, pika density can vary across the species’ distributional areas ranging from few a dozen individuals to >300 individuals per hectare (Jiang 1998; Sun et al. 2011) (Table 3).

CONCLUSION

The grassland-grazer ecosystem is an integrated system (Wu et al. 2009). Small mammals usually are an integral part of ecosystem dynamics (Jones et al. 1997; Kinlaw 1999). The assessment of a species as a pest requires sound ecological understanding of the species (Putman 1989; Stenseth 1989; Begon et al. 1996). The decades-long and on-going poisoning directed at plateau pikas has been implemented as a major measure to address grassland degradation and the presumed ecological crisis associated with these grassland ecosystems in recent times (BAH 2008). The government's stated policy objectives of the control program include restoration of degraded grassland, protection of the grassland ecosystem's function, and enhancement of the carrying capacity of pasturelands (BAH 2008). The pika poisoning program is hailed as critical to restoring and mitigating grassland degradation, and an important process for protecting the health of grassland ecosystems. However, research has found no evidence of improvement of grassland conditions and livelihoods of local pastoralists as a result of the pika poisoning program. Plateau pika populations can recover to previous levels in the following breeding season after a poisoning implementation (Pech et al. 2007). The perception of pikas as pests to a large extent appears to contradict the policy objectives of eliminating pikas. The ecological services plateau pikas provide in the grassland ecosystem support the major constituents of the policy objectives of the program. The role of plateau pikas from being a keystone species in the food chain, an ecosystem engineer that creates a crucial ecological niche for dozens of bird species and reptiles, a mediator of plant communities, and facilitator of nutrient cycling, as well as influencing ecohydrology, demonstrate that plateau pikas are a vital and integral part of the QTP grassland ecosystem (Schaller 1998; Smith and Foggin 1999; Lai and

Smith 2003; Bagchi et al. 2005; Badingqiuying 2008; Hoggan 2010; Delibes-Mateos et al. 2011; Harris et al. 2014; Wilson and Smith 2015). Thus, the role of pikas could potentially determine sustainability of the alpine grassland ecosystems of the QTP in a sense that biodiversity conservation and functioning of the grassland ecosystems rely on the ecosystem services provided by the plateau pika. Therefore, the pika poisoning program is believed to be counterproductive and contributes to further losses of biodiversity and disruptions of ecosystem processes (Smith and Foggin 1999; Lai and Smith 2003; Delibes-Mateos et al. 2011; Badingqiuying et al. 2016). The continuation of extensive control of pikas is a classic case of the science-policy divide, yielding a gridlock for achieving overarching goals to preserve biodiversity (Smith et al. 2006). Therefore, the large scale and persistent pika poisoning program needs to be reevaluated in the context of a coupled social-ecological system in order to prevent further disruptions to the grassland ecosystems of the QTP (Smith and Foggin 1999; Smith et al. 2006; Delibes-Mateos et al. 2011).

Outline of the Chapters

Given the controversies surrounding plateau pikas, a major concern about the pika poisoning program involves claims that poisoning of pikas is not based on scientific research. My dissertation chapters examine the underpinning justifications leading to pika poisoning program with scientific investigation and offer objective analyses of the arguments leading to the controversies.

- Chapter 2 investigates responses of plateau pikas to grazing. It does so by taking advantage of livestock exclosures (as well as pika reduction experiments), to examine differences in pika habitat use caused by these experimental manipulations.

- Chapter 3 investigates mechanisms of plateau pika population recovery following poisoning programs and discusses the long-term implication of these programs on conservation of plateau pikas and biodiversity, as well as ecosystem integrity as a whole.
- Chapter 4 addresses ethical questions and the religious dilemma of the local pastoralists involved in the poisoning of pikas. It offers policy recommendations based on an environmental ethics framework and the findings of the previous chapters.

TABLE 1-1. Reported areas where plateau pikas were poisoned during the corresponding years in Qinghai Province and across the Qinghai-Tibetan Plateau

Total poisoned area (km^2)	Year	Region	Source
130,000	1963-1965	QTP	Smith et al. 1990
208, 000	1964-1995	QTP	Fan et al. 1999
75,000	1986-1994	Qinghai	Smith and Foggin 1999
357,060	up to 2006	Qinghai	An 2008

TABLE 1-2. Forage consumption rates of small mammals (mainly plateau pikas), and extrapolation of the consumption rates into economic values by livestock and monetary values.

Forage consumption (kg/year)	Region	Economic value	Source
30,000,000,000	QTP	20 million sheep	Guo 2009
4,400,000,000	Qinghai	4.8 million sheep ($97million)	Liu 2000
136,077,711,000	Qinghai	-	Fan et al. 1999

TABLE 1-3. Density variation of plateau pikas and burrows between study sites with elevations from 3200 - 4600 m across the Qinghai-Tibetan Plateau. (Note: ‘-’denotes absence of data).

Pika Density (ha)	Burrow Density (ha)	Elevation(m)	Study Area	Habitat Type	Source
-	16-172	-	Menyuan, Qinghai	Alpine meadow	Shi 1983
15-300	102-2780	3700	Dawu, Qinghai	Alpine meadow	Sun et al. 2015
90-530	-	3430	Liuqu, Gansu	Alpine meadow	Jiang 1998
100-300	-	3300	Haibei, Qinghai,	Alpine meadow	Jiang and Xia 1985
122-432	-	3560	Maqu, Gansu	Alpine meadow	Jiang 1998
130	690	4500-4600	Naqu, TAR	Alpine meadow	Pech et al. 2007
175	-	3500	Senduo, Qinghai	Alpine steppe/ meadow	Dobson et al. 1998
300	-	3200	Heimahe, Qinghai	Alpine steppe/meadow	Smith et al. 1986
374	1167	4100	Dari, Qinghai	-	Wang et al.1997
-	400-2300	4500	Naqu, TAR	Alpine meadow	Arthur et al. 2008
-	1169-2780	3900	Dawu, Qinghai	Alpine meadow	Sun et al. 2011

CHAPTER TWO

Response of Plateau Pikas to Livestock Grazing in Alpine Steppe Habitats, Qinghai-Tibetan Plateau

INTRODUCTION

Plateau pikas (*Ochotona curzoniae*), a small burrowing, non-hibernating mammal (Smith and Foggin 1999), 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 km^2, which is ~25% of China's land territory (Miller 1995; Harris et al. 2016). Pastoralism of domesticated livestock has influenced these grasslands that cover approximately 70% of the entire QTP for ~8,000 years (Miller 1995; Meihe et al. 2009). These grasslands are home to a large diversity of unique flora and fauna (Smith and Foggin 1999). In particular, the Sanjiangyuan Region (360,310 km^2), which covers a large portion of the Qinghai Province (~720,000 km^2), is considered an important biodiversity habitat in China (Mackinnon et al. 1996), as well as being considered the "Water Tower" of China and Asia (Xu et al. 2009, Wilson and Smith 2015). 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.

Over the last few decades, the grasslands of the QTP have been perceived to be increasingly undergoing degradation (Fan et al. 1999; Foggin 2000; Harris 2010; Li et al. 2013). Yet, documentation of 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 (Harris 2010). Some studies that have attempted to understand the causes of grassland degradation have claimed that pikas are a chief contributor to this process, especially when their populations reach high density (Zhao 1998; Fan et al. 1999; Wang et al. 2005; Sun et al. 2011). Others have attributed perceived degradation to human-induced overgrazing or poor livestock management (Bai et al. 2002; Zhang et al. 2004). In all, the arguments about causes and remedies of degradation are highly variable, leading to controversial policy responses to address degradation (Harris 2010; Harris et al. 2015). One such policy is the decades-long plateau pika eradication campaign, which has been considered an essential component of grassland management programs by policy makers aimed to mitigate and reverse degradation (Liu et al. 1980; Fan et al.1999; Wang et al. 2005; Sun et al. 2011). 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 whose root cause lies elsewhere (Smith and Foggin 1999; Harris 2010; Harris et al. 2015). In addition, evidence from many studies has shown that pikas provide critical ecological services to biodiversity and ecosystem functioning on the QTP (Smith and Foggin 1999; Lai and Smith 2002; Hogan 2010; Delibes-Mateos 2011; Harris et al. 2014; Wilson and Smith 2015; Badingqiuying et al. 2016). 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). The co-occurrence of these two herbivores on the QTP has been long enough to affect evolutionary process on this grassland ecosystem (Harris et al. 2015, 2016). In recent times, dramatic changes in the density of these two major herbivores across the grasslands of the QTP have been reported (Fan et al.

1999; Caidan 2006). Studies have suggested feedback effects of changes in one component have likely resulted from changes in the other. Such an example includes a high population density of pikas being associated with increased grazing intensity by livestock (Li et al. 2013).

Density of pika populations has been shown to be highly variable corresponding to varying habitat conditions (Shi 1983; Xia 1984; Zhang et al. 1998; Liu et al. 2009). Habitat quality likely determines population density of pikas because pika density tends to be higher in more degraded 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 condition have focused on the impact of pikas on vegetation communities (Bagchi et al. 2005; Hogan 2010; Sun et al. 2011; Guo et al. 2012). The possible reverse influence of vegetation on pikas has rarely been studied. A few studies have provided evidence that pika population density responds to site-specific variables, such as vegetation biomass (Liu et al. 2003, Pech et al. 2007), cover (Shi 1983, Liu et al. 2003); and height (Shi 1983). Pika responses to detailed, site-specific variables that take into account the influence of grazing have yet to be studied.

Previous studies investigating the associations between pikas and habitat variables are based on criteria that required that habitat conditions be categorized as non-degraded, lightly degraded, moderately degraded, or heavily degraded (Liu et al. 2003; Yu et al. 2010; Li et al. 2014). Similarly, others studies (Jiang 1998; Han et al. 2008) investigated the effect of pikas on habitat conditions by classifying pika density and burrow density into classes proportional to the level of harm by pikas on the grassland. These methods designed to classify the level of harm by pikas to the grassland tend to be subjective due to the preconception that pikas are detrimental despite their variation in density. In addition, these studies do not address causal relationships between density of pika populations and habitat conditions. However, studying interactions of intricate biological components is difficult in the field. Employing fences to exclude one biological component or the other to isolate causal mechanisms is a practical method to conduct such studies (Harris et al. 2015). Exclusion of livestock grazing with fences in my study serves the purpose of isolating field variables, which then allows testing the influence of specific site variables on pikas. In this study, I hypothesized that livestock exclusion facilitated by fences would result in greater standing vegetation biomass, which in turn would reduce pika abundance and pika habitat use.

My objectives were to examine pika responses to habitat conditions by isolating one biological component from the other, which otherwise interact in complex ways under national circumstances. My ultimate goal was to inform policies guiding sustainably-oriented grassland management.

MATERIALS AND METHODS

Study Location and System

I conducted field experiments in four pastures of Village Five (approximately 35.5º N, 98.7º E), Gouli Township, Dulan County, Qinghai Province, PR China (Fig. 2-1). 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*., with >100 plant species in the area (Harris et al. 2016). The onset of spring vegetation green-up is determined by precipitation and temperature (Shen et al.

2011). The average annual precipitation during 2008-2013 at the study area was 398.0 mm (SD = 53.4), and approximately 92% of the precipitation occurred during April through September. Mean annual temperature was -1.4 °C, and the annual average temperature of the warmest 8-day periods was 14.0 °C and the coldest 8-day periods was -16.3 °C (Harris et al. 2015).

Pastures in the study area were mainly used as winter pasture. Livestock were primarily yaks (*Bos grunniens*), sheep (*Ovis aries*), and a small number of goats and Tibetan horses. Prior to 2010, and during the years of my investigation (2010-2013), all pastures where our field experiments were located were mainly grazed by sheep, with a small number of goats mixed in the sheep herds from around mid-October to mid-June of the following year, before these herds returned to summer pastures (Yeh and Gaerrang 2010; Harris et al. 2015).

Pikas were the most numerous above-ground vertebrate herbivore that foraged these pastures throughout the year. 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 approximately 700 m from one exclosure, I did not observe the presence of these small mammals on or adjacent to the exclosure experiments during my study. Himalayan marmots (*Marmota himalayana*) and woolly hares (*Lepus oiostolus*) were present nearby, but not observed on or near my 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 were observed in the vicinity of the exclosure experiments. Tibetan foxes (*Vulpes ferrilata*) were often seen around the study area apparently searching for pikas or other prey.

To test the effects of grazing exclusion on pika habitat use, I made use of 12 10 m x 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 (Harris et al. 2015). I refer to each exclosure, together with its surrounding unexclosed area, as an “experiment” (Harris et al. 2015). Three experiments were established on pastoralist Kunthar’s pasture, which was mostly steep and rocky. His family owned 60 yaks and 25 sheep at the inception of our study in 2009. Six experiments were located in pastoralist Sanko’s pasture, which was grazed by a herd of approximately 320 yaks in winter 2009-2010. However, the type and the number of livestock grazed on Sanko’s winter pasture differed among years. His pasture was lightly grazed during the winter of 2011, but was grazed by approximately 300 sheep owned by another sub-lease contractor during winters of 2012 and 2013. Two experiments were located on pastoralist Balo’s pasture, which was entirely fenced. Although I lack data on specific numbers of livestock present on Balo’s pasture, approximately 50 sheep prior to our work had grazed his pasture. I also observed the presence of a few horses and relatively large number of sheep and yaks grazing Balo’s pasture in May and early June of 2012 and 2013. The 12th experiment was located in pastoralist Ladri’s pasture, which supported large herds of both yaks and sheep (Yeh and Gaerrang 2010; Harris et al. 2015). All the exclosure experiments were established on pastures that ranged in elevation between 4,046 – 4,107 m. All exclosures were on gentle slopes that faced southerly or southeasterly (Harris et al. 2015). Table 2-1 presents a summary of characteristics of each pasture.

The selection of the specific locations of the exclosure experiments represented preexisting conditions that contrasted in grazing intensity (e.g., winter reserve vs more frequently grazed parcels by livestock) and vegetative characteristics.

Four of the 12 exclosures were constructed geographically independently from each other. Specifically, exclosures 3 and 4 were located in pastoralist Kunthar's land, approximately 266 m apart; exclosures 7 and 8 were located in Sanko's land, approximately 300 m apart. The remaining exclosures were constructed in pairs. Specifically, exclosures 1 and 2 were constructed adjacent to each other, separated by a preexisting fence line demarcating boundaries of pastures owned by Kunthar and Balo. A preexisting fence line demarcating Balo and Sanko's pastures separated exclosures 5 and 6. Exclosures 9 and 10 were adjacent to each other and separated by a preexisting fence line between two pastures managed by Sanko. Exclosures 11 and 12 were separated by a preexisting fence demarcating the pastures of Ladri and Sanko (Harris et al. 2015). The exclosure experiments were distributed horizontally across the study area with only minor differences in elevation (Fig. 2-2). Thus, effects of weather variability and slope on the 12 experiments were inconsequential.

Exclosure Experiment Designs

I refer to the 100 m^2 areas within each fenced livestock exclosure as "ungrazed observation plots" hereafter. In spring 2010, I randomly selected and marked a single 10 m x 10 m (100 m^2) observation plot adjacent to each of the exclosures; these served as controls, in the sense that grazing was allowed to occur on these observation plots without interference. Each control plot ("grazed observation plots" hereafter) was selected by tossing a piece of dried dung toward an ungrazed plot while standing at a short distance away without facing the plot. The direction of the ungrazed plot where the yak dung landed was selected for a grazed observation plot. Thus, my experimental design consisted of 12 grazed plots (1,200 m^2 total area) adjacent to 12 ungrazed plots (also 1,200 m^2 total area).

Pika reduction

I arranged to have pikas killed by snap trapping in six of the experiments (Fig. 2-2). Because pika family territories are much larger than the exclosures, and to reduce impacts from neighboring pika family territories, trapping extended 30 m beyond the boundaries of the plots. Thus, the total pika removal area at the six selected experiments was 8,100 m^2 (Harris et al. 2015). These six sites were selected among the 12 in summer 2010 to provide a range of vegetative conditions (Harris et al. 2015). We killed pikas by setting a similar number of traps within each experiment, generally ~15-20 traps. Traps were set out at around noon and checked in the morning of the following day, two experiments at a time. We documented the number of animals removed within each experiment daily. We then moved to the next two exclosures in the following day (Table 2-2). When we were unable to find a trap that had been set earlier, we assumed that a pika had been killed in it because on two occasions, we observed Tibetan foxes carrying away traps, suggesting to us that missing traps indicated dead pikas. 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, my experimental design consisted of: 1) six replicates of livestock grazing exclusion with no pika reduction; 2) six replicates of no livestock grazing exclusion but with pika reduction; 3) six replicates of livestock grazing exclusion and pika reduction; and 4) six replicates of no livestock grazing exclusion and no pika reduction (Fig. 2-3).

Pika counts

With the help of a field assistant, I counted pikas on all observation plots. My field assistant and I always worked together at observation plots. For each observation we sat at a location approximately 15 m away from each observation plot and counted the number of individual pikas that appeared within that observation plot during a one-hour observation time period. I selected vantage points in order to clearly see pika activities inside the observed experiment, while minimizing our disturbance to the pikas. We conducted the observations during 0800-1200 hr or during1400-1800 hr because pikas became less active above-ground around noon during the summer (Fan et al. 1999; Yin et al. 2009). Thus my observation time periods were concentrated within the range of peak activities to increase the efficiency of sampling. I recognize the possibility of not seeing every single pika within the observation plot; however, pikas generally became active within approximately seven minutes of our initial disturbance at the beginning of each observation session. In addition, we sat on chairs allowing a “bird’s eye” vantage on the relatively small observation plots, increasing our ability to detect individual animals when they appeared on the surface. The number of pikas counted for each observation session was identical between my assistant and myself for most sessions. Counts were averaged for the occasions when we differed in the number of pikas seen. We made observations in late May, late June, and late July of each year during summers 2010-2013.

Pika burrow counts

In addition to counting individual pikas, I also counted active pika burrows; I judged burrows as active by noting the presence of fresh soil at the mouth of burrows (Lai and Smith 2003). I also counted old burrows that had collapsed, but do not report those data here. To count burrows, I first divided each observation plot into two halves marked with flags at the central line. My field assistant and I counted burrows within each half starting from the opposite side of the enclosure. For accuracy, we then switched halves to re-count burrows, and reported the matched count numbers. We included all burrows that fell under the exclosure fence lines and on boundary markers of control plots. We took the average from the two data counts whenever there were discrepancies, which occurred only a few times. Burrow sampling was carried out in late June 2010, and in mid-July from 2011-2013.

Vegetation Sampling

Vegetation was sampled at six randomly located 0.5 m^2 plots within exclosures, as well as six paired plots of the same size outside the exclosures. Plots within exclosures were randomized by first dividing each exclosure into 100 1 m^2 sections. We then excluded the outermost 2 m-wide strips of each exclosure from the sampling universe to avoid possible edge effects arising from the presence of the fence. The remaining 64 m^2 were numbered sequentially, and we used the pseudo-random number generator in MS-Excel to generate a list of integers using 1-64. The first six integers on the random list for each exclosure 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 (Fig. 2-4). Plots were permanently marked with ~5 mm diameter steel cable anchors inserted approximately 30 cm into the ground to facilitate repeated vegetation measurements. Each of the six paired vegetation sampling plots outside the exclosure were selected based on vegetative similarity to its pair within the exclosure. Field crews conducted vegetation sampling in mid-July to mid-September of years 2010-2013, in addition to the pre-exclosure sampling in September 2009 (Harris et al.

2015). 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).

I used plot-specific data on vegetation height, percent live vegetation cover, percent litter cover, percent bare soil, and fresh biomass (in grams). The height of each plant species was measured using a metric 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). Readings were obtained on a total of 720 vegetation plots (144 plots x 5 years). Because I sampled pikas beginning in 2010 for my data analyses, I used vegetation data gathered between the year 2010-2013, for a total sample size of 576 plot readings.

Data Analyses and Hypotheses Tested

My analyses reflected the experimental design: a grazing treatment (excluded from grazing vs. not excluded), a pika reduction treatment (reduced on half the experiments, not on the other half), and the interactions of these two treatments (Fig. 2-3). I applied an unequal variance *t*-test (Welch) to examine if means of pika and burrow counts differed between the treatments. I analyzed differences in *Stipa* height, vegetation cover, vegetation green weight, litter cover and percentage of bare soil measurements between treatments using a two-way analysis of variance (ANOVA). For each test, I used the treatment of grazing excluded or not, as well as whether pikas were reduced or not as fixed factors. Interactions of the grazing treatment and the pika reduction treatment were also incorporated in the tests.

To test the hypotheses that grazing exclusion and/or pika reduction explained differences in the number of pika observed, I treated exclosures and reduction factors as fixed factors, and also incorporated interaction of the two predictors in the base model. Negative coefficients indicated that exclosures and/or pika reduction resulted in lower counts of pikas.

To examine if pika counts replicated within each summer season were also functions of when counts were obtained, I added Julian Date to base models.

To address the hypothesis that livestock exclusion or pika reduction explained variation in the number of burrows, I applied the same models for predicting pika count differences between treatments. I then added Julian Date in the base model, as above.

To address hypotheses that habitat variables predicted pika counts, I used the following indicators of habitat conditions as explanatory variables: *Stipa purpurea* height, total vegetation cover, vegetation green weight, bare soil, and litter cover. I built 25 candidate models by including all the explanatory variables and 1st-order interactions, and ranked each model based on the strength of evidence using ΔAIC (Akaike Information Criterion) calculated from AIC values (Table 2-12). I used AIC to compare competing models explaining pika count variations by the habitat variables and reported models with $\Delta AIC < 2$ (Burnham and Anderson 2004). I selected only *S. purpurea* for measuring vegetation height because it was the dominant, and in most cases also the tallest species in vegetation plots. *S. purpurea* also occurred in all plots except two; it also occurred in every pika observation plot. Because *S. purpurea* varied in its abundance within each vegetation plot, I multiplied height by cover to produce a standardized index. With all the vegetation variables, I examined only differences between measurements taken on the randomly selected ungrazed plot and its grazed pair. Values entering my statistical analyses were means of these differences across the six replicates within each experimental measurement, as well as their respective bare soil and litter cover measurements. The habitat variables were measured only in July; thus, I used only the July pika counts as the response variable in these models. Hypotheses testing effects of July vegetation on pika counts were conservative, because vegetation data were collected when vegetative differences between grazed and ungrazed conditions were at their seasonal minimums.

In analyses I considered Poisson regression, but discovered that the goodness-fit test suggested a poor fit; additionally, the variance (11.486) was larger than the overall mean (3.406) of pika counts (July counts: $n = 96$). Therefore, I used a negative binomial regression throughout. All data analyses were conducted using Stata/IC Software 14.0 (Stata Corp. LP, TX, USA). Results of all statistical tests were considered significant at $P < 0.05$.

RESULTS

Pika and Burrow Counts

The numbers of individual pikas within each plot during each one-hour census period are presented in Table 2-3. I counted a total of 326 pikas on ungrazed observation plots, and 476 pikas within grazed observation plots. Across all treatments ($n = 312$), the mean pika count was 2.37. Table 2-4 presents the means and standard errors of pikas observed across the treatments from May-July, 2011-2013.

The distributions of pika counts across the treatments are presented in Figs. 2-5A and 2-5B.

Across all census periods, fewer pikas were observed within ungrazed plots ($\bar{x}$ = 1.90, SE = 0.18) than within grazed plots ($\bar{x}$ = 2.83, SE = 0.22); (t = 3.35, P < 0.01). Similarly, as expected there were fewer pikas observed within the pika reduced observation plots ($\bar{x}$ = 1.57, SE = 0.13) than plots in which no reduction occurred ($\bar{x}$ = 3.11, SE = 0.23); (t = 5.82, P < 0.01).

In the July census across all years, the counts of pikas in ungrazed observation plots ($\bar{x}$ = 2.79, SE = 0.43) did not differ from the grazed observation plots ($\bar{x}$ = 4.02, SE = 0.53); (t = 1.79, P > 0.05). Again as expected, fewer pikas were observed in plots that had been subjected to pika trapping ($\bar{x}$ = 2.29, SE = 0.31) than where no trapping occurred ($\bar{x}$ = 4.52, SE = 0.59, t = 3.41, P < 0.01).

The total burrow count across all years on the 12 ungrazed observation plots was 825 (burrow density = 0.69/m^2) and on the 12 grazed plots was 863 (burrow density = 0.72/m^2). Table 2-5 presents the means and standard errors of burrow counts across the treatments. Figs. 2-6A and 2-6B present the distributions of burrow count frequency among the four different treatments. Total burrow counts within the grazed plots ($\bar{x}$ = 13.93, SE = 2.01) did not differ from burrow counts within the ungrazed plots ($\bar{x}$ = 14.49; SE = 2.09; (t = 0.27, P > 0.05). However, the burrow counts within plots subjected to pika reduction ($\bar{x}$ = 6.78, SE = 0.98) were smaller than within plots with no pika reduction ($\bar{x}$ = 16.88, SE = 2.44; (t = 4.57, P < 0.01).

Effect of Exclosures and Pika Reduction on Pika Counts

Livestock exclusion and pika reduction both had significantly negative effects on pika counts (grazing exclusion: β = -0.4321, SE = 0.1363, z = -3.17, P < 0.002;

pika reduction: $\beta = -0.6162$, SE = 0.1606, $z = -3.84$, $P < 0.001$). There was no interaction between these two treatments (Table 2-6). Incorporating the effect of the seasonal progression within each year by adding Julian Date in the same model (Table 2-7), provided similar results (grazing exclusion: $\beta = -0.4429$, SE = 0.1293, $z = -3.43$, $P < 0.001$; pika reduction: $\beta = -0.5766$, SE = 0.1549, $z = -3.72$, $P < 0.001$). Julian Date was also found to be a predictor of pika counts ($\beta = 0.0119$, SE = 0.0021, $z = 5.61$, $P < 0.001$). Pika counts increased as the summer progressed.

When adding the interaction of Julian Date and exclosure (shown in Table 2-8) as a predictor in the previous model (presented in Table 2-7), the significance of exclosure as a predictor disappeared because the standard errors increased > 3 times. Pika reduction continued to display a significantly negative effect ($\beta = -0.5732$, SE = 0.1552, $z = -3.69$, $P < 0.001$) on pika counts; and Julian Date had a significant positive trend ($\beta = 0.0107$, SE = 0.0028, $z = 3.83$, $P < 0.001$).

Effect of Exclosures and Pika Reduction on Burrow Counts

Livestock exclusion had no significant effect on burrow counts across all measurements. However, pika reduction had a significantly negative effect on counts ($\beta = -0.6134$, SE = 0.1962, $z = -3.12$, $P < 0.002$). No interaction of these two treatments was detected (Table 2-9). When seasonal progression as a predictor was added in the previous model (Table 2-10), the main effect remained similar with no influence of livestock exclusion on burrows, but pika reduction similarly had a significantly negative effect on burrow counts ($\beta = -0.6189$, SE = 0.1926, $z = -3.21$, $P < 0.001$). Burrow counts declined with Julian Date ($\beta = -0.0236$, SE = 0.0112, $z = -2.12$, $P < 0.05$). When incorporating the interaction of Julian Date and exclosure in the model (Table 2-11), pika reduction ($\beta = -0.6166$, SE = 0.1922, $z = -3.21$, $P <$

0.001) had significantly negative effects on burrow counts, but Julian Date had no effect (β = -0.0310, SE = 0.0159, z = -1.95, P = 0.051), and there was no interaction of exclosure with Julian Date.

Effect of Habitat Variables on Pika Counts

Means and standard deviations of the habitat variables are presented in Table 2-13. The top models (ΔAIC < 2; Table 2-12) included pika reduction, *Stipa* height, vegetation cover, and bare soil. These four models, including the null model, are presented in Table 2-14 for a detailed examination of habitat variables that explain pika counts.

Among the habitat variables in the top models, *Stipa* height, vegetation cover, litter cover and bare soil differed between ungrazed and grazed conditions (Table 2-15), but vegetation green weight showed no difference between the two situations in July of all years. However, *Stipa* height showed no significant influence on pika counts. There was no interaction of *Stipa* height and pika reduction. Similarly, vegetation cover had no significant effect on pika counts, and no interaction of vegetation cover with pika reduction was found. Percent bare soil was not a significant predictor of pika counts. There was no interaction of bare soil with pika reduction (Table 2-13).

DISCUSSION

Response of Pikas to Exclosures

As expected, I 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 numbers by approximately half. Achieving a complete reduction of pikas was difficult due to the relatively small size of exclosure plots compared to the average size of a pika family territory (~24 m radius from the center of activities (Dobson et al. 1998).

Pika counts in the absence of grazing were lower than in grazed plots across all census periods. Livestock exclusion facilitated by exclosures was associated with significantly less pika use than in the grazed plots. The pattern of difference in the number of pikas between the grazed and ungrazed situations was consistent regardless of pikas being subjected to reduction or not. However, pika observations did not differ between the ungrazed and grazed conditions when the July census was analyzed separately from earlier censuses. This result may be explained by the overall decreased contrasts of vegetation between the ungrazed and grazed conditions late in the growing season compared to the strong contrasts during the earlier growing season (shown in Fig. 2-7). In addition, during July, the number of pikas reached their maximum levels. The increase in pika population may have reduced space available, which presumably forced pikas to use conditions that may have been unfavorable.

The use of exclosures to isolate cause and effect between relevant biological components allowed me to demonstrate that changes in vegetation condition resulted from the experimental manipulation, and that pikas responded to the resulting changes. Consistent with my hypothesis, livestock exclusion, which resulted in greater standing vegetation biomass, reduced the number of pikas and pika habitat use relative to grazed conditions. These observations suggest that grassland with low vegetation is a favorable habitat of pikas. Also, Wangdwei et al. (2013) showed higher survival of pikas in a condition with lower vegetation cover relative to a condition with higher vegetation cover. Some studies showed that high pika population density is associated with degraded grassland condition (Shi 1983; Jiang

1998; Zhang et al. 1998; Liu et al. 2003; Han et al. 2008 Liu et al. 2009). Thus, pikas living in habitats with low vegetation achieve high density presumably due to higher reproductive rates, higher survival rates or both, compared with pikas in less favorable habitats.

As discussed earlier, an understanding of the root causes of grassland degradation remains unsettled and disputed, but overgrazing is generally perceived to play a major role in grassland degradation. Many have claimed that a rapid increase in stocking rate and grassland degradation have occurred simultaneously over the last couple of decades (Jing et al. 1991; Zhang et al. 1998; Dong et al. 2004; Zhou et al. 2005). High stocking rate is associated with 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). High-density plateau pika populations are often associated with degraded grassland habitats (Liu et al. 2003; Wu and Du 2007, Han et al. 2008), as indicated by low above-ground biomass and expanses of bare soil. Some researchers have argued that this condition is due to overgrazing (Wang et al. 1989; Cui et al. 2007). Burrowing activities of pikas then tend to accelerate the level of such poor grassland condition when the species' population density reaches high levels (Su and Fan 2002; Han et al. 2008; Guo et al. 2012; Sun et al. 2015).

Reponses of Pikas to Habitat Variables

Excluding livestock grazing resulted in differences in the habitat variables (except that green weight showed no difference) between ungrazed and grazed conditions. However, predictions of the site-specific variables for pika use of grazed and ungrazed conditions were weak with no statistical significance in the tests. Thus, I failed to find specific habitat attributes to explain the consistent patterns that showed fewer pikas in the ungrazed condition, compared to grazed condition with and without pika reduction. Such habitat variables as vegetation height, vegetation percent cover, green weight and bare soil were not significant predictors of pika observations during the July observation periods. However, the patterns of association between pika counts with *Stipa* height, and vegetation cover suggested that greater height and cover reduced the number of pikas. Also, as explained earlier, this test was conservative because July was the period representing a minimal contrast in vegetative condition between grazed and ungrazed areas. Given the conservative nature of the experiment we could test with these data, the fact that the model with *Stipa* height emerged as the top-ranking model, and that *Stipa* height was nearly significant, suggests that had I been able to examine this relationship when differences between grazed and ungrazed conditions were greater, or with a greater sample size, this association might have been statistically significant.

Vegetation cover was included in the third best fitting model (albeit lacking statistical significance), indicating that it could be an important habitat variable along with vegetation height for predicting pika habitat use. Similarly, Shi (1983) showed that vegetation height and cover, as well as vegetation biomass, were predictors of pika density variation.

Response of Pika Burrows to Exclosures

Livestock grazing exclusion showed no effect on burrow density. However, the number of pika burrows significantly declined under the influence of pika reduction. This might be explained by the reduced use of burrows due to removal of pikas, possibly leading to a gradual collapse of previously used burrows. Liu et al. (2003) and Han et al. (2008) showed that pika population density and burrow density are positively correlated. Thus, the number of burrows would be expected to increase due to the increase in the number of pikas as the summer reproductive season progressed. However, the results of my study showed that the number of pika burrows declined with the seasonal progression of the summer growing season. This decline of burrows could suggest that effect of pika reduction on burrows remained unchanged within the exclosure as a function of grazing exclusion.

CONCLUSIONS

Excluding grazing reduced grassland use by pikas. Pika response to exclosures was similar in experiments with and without pika reduction (i.e., at both high and low densities). In contrast, I observed no detectable decline of pika burrows with grazing exclusion, but pika reduction reduced burrows.

A combination of foraging, clipping and burrowing activities of pikas under certain circumstances tended to perpetuate conditions undesirable to pastoralists (Harris et al. 2015). The evidence that pikas respond to an exclosure effect could imply that controlling of high pika density, if desired could be achieved by reducing livestock overgrazing. However, (Harris et al. 2015) have warned that policies that emphasize restoration via a long-term grazing ban need reconsideration because QTP steppe plants have adapted to moderate levels of offtake and disturbance. Harris et al. (2015) argue that plant species may have co-evolved and could benefit from grazing by pikas and livestock. Yet, a high stocking rate of sheep is found to be positively associated with bare soil and erosion (Harris et al. 2016). In such a case, moderation of livestock density might be appropriate for both the health of grasslands and pikas due to the observation that a high stocking rate leads to undesirable impact on grassland health, which could lead to a high pika population density. Wangdwei et al.

(2013) suggested that a high population density of pikas is a response to grassland degradation rather than a cause. These negative feedback effects could be avoided through management of the dynamics of how changes in one biological component impact the other. Livestock grazing and pika presence can be consistent with maintaining the integrity of the alpine steppe ecosystem of the QTP, particularly at moderate densities of each.

Understanding and recognizing the complex, dynamic interactions among livestock, plateau pikas, and grassland condition is required to address perceived grassland degradation. Simplistic approaches for addressing grassland degradation and restoration such as a grazing ban under ecological migration programs (Foggin 2008), fencing of pastures (Bauer 2005) and large-scale pika eradication programs may not be consistent with high variability of regulatory regimes that govern the health of alpine grasslands on the QTP. Socioeconomic and environmental factors that may drive grassland degradation vary among the different areas of the plateau. Thus, a single panacea for addressing degradation of the alpine grasslands across the QTP may not exist, rather a management approach should correspond to specific characteristics of the pastureland undergoing degradation.

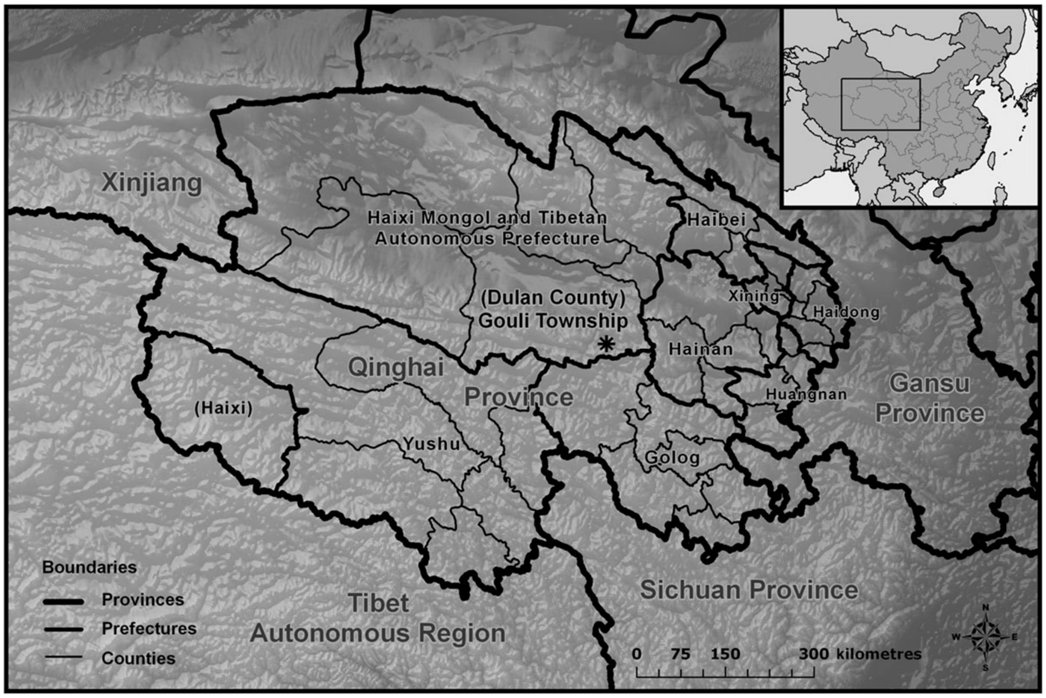

FIG. 2-1. Map of Qinghai Province, People's Republic of China, showing county boundaries (fine lines). Asterisk '*' indicates the approximate location of the study site in Gouli Township, Dulan County, Qinghai Province, China (from Yeh and Gaerrang 2010).

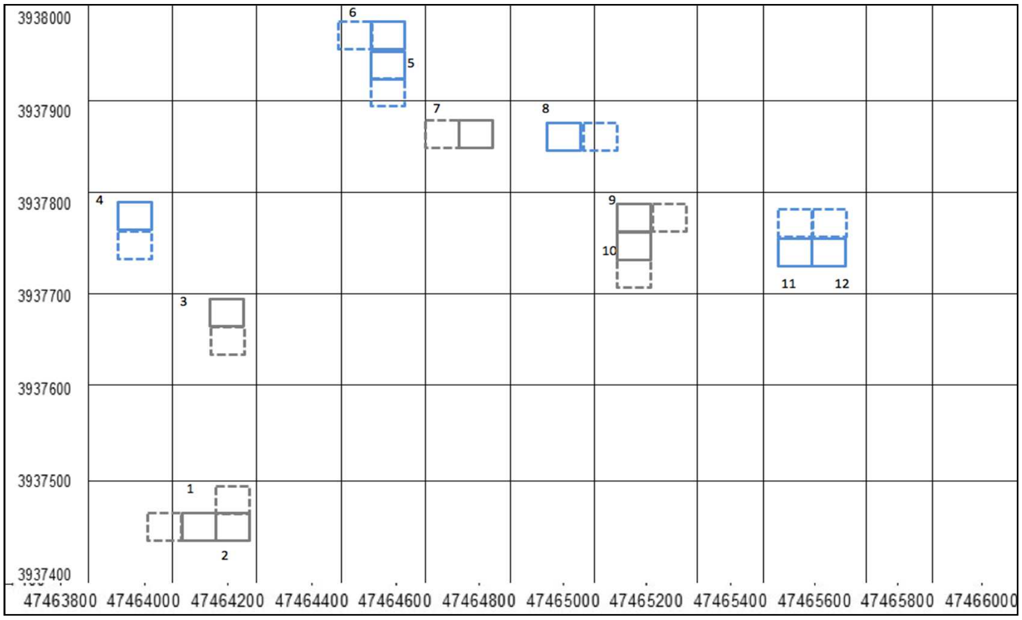

FIG. 2-2. Schematic map of randomly chosen grazed observation plots adjacent to ungrazed observation plots at Gouli field study site based on GPS coordinates. The solid squares represent the exclosures and dashed squares adjacent to the exclosures represent the control plots. Pika removal experiments are marked in grey and non-removal experiments in blue (figure modified from Harris et al. 2010).

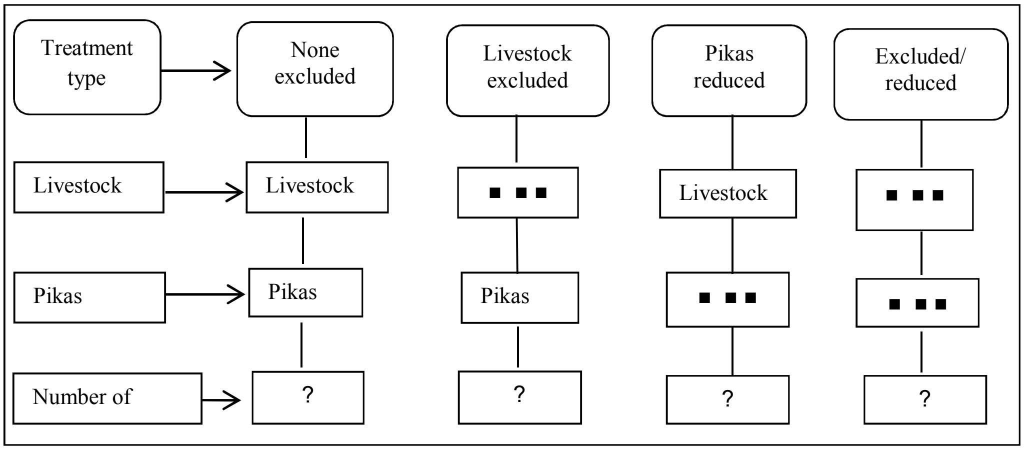

FIG. 2-3. Schematic diagram representing the exclosure experimental design for investigating the response of pikas to four different treatments. The treatments are shown in the four columns on the right. Exclusion of livestock or reduction of pikas in a treatment is indicated with "■" squares. Question mark indicates pikas to be counted within each treatment. (Modified from Harris et al. 2010).

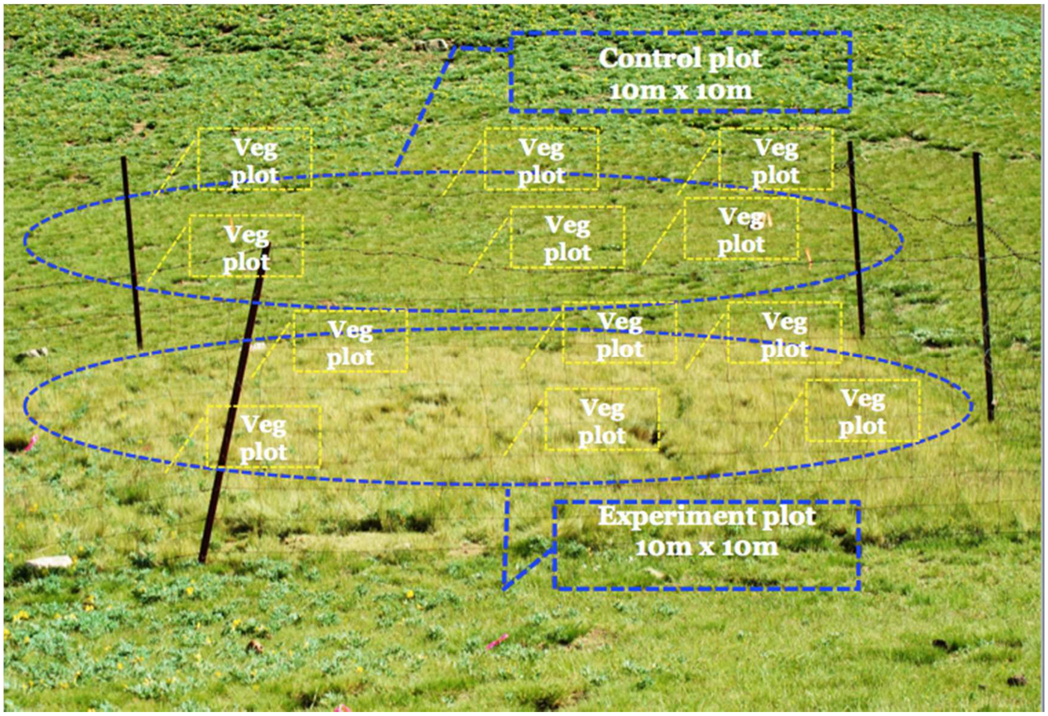

FIG. 2-4. Fenced exclosure and an adjacent, randomly selected observation plot that was grazed. Here, both are marked with blue dashed lines. Vegetation sampling plots within the exclosure and outside of the exclosure are represented by dashed markers in yellow. Not all the vegetation sampling plots were located in the randomly selected observation plot; others were located in adjacent unselected grazed plots (also 10 x 10 m).

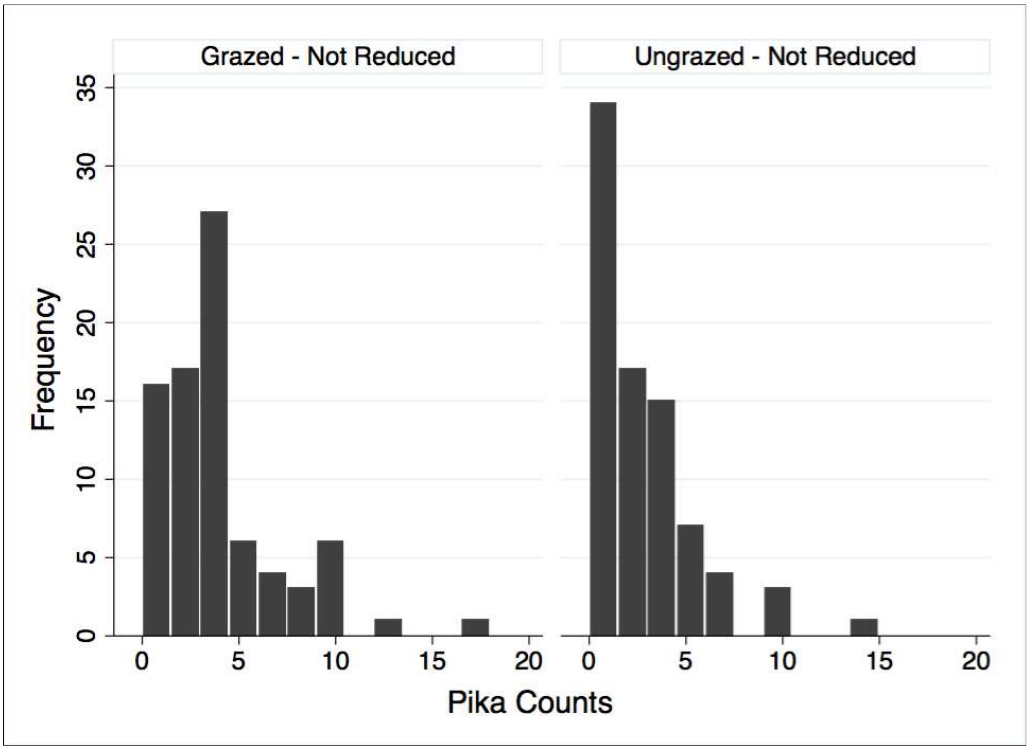

FIG. 2-5A. Frequency of pika counts inside the six (10 m x 10 m) grazed observation plots (left-hand panel) with no pika reduction; and the six ungrazed observation plots (right-hand panel) with no pika reduction; Village Five, Gouli Township, Dulan County, Qinghai Province, China, May to July of 2010 - 2013.

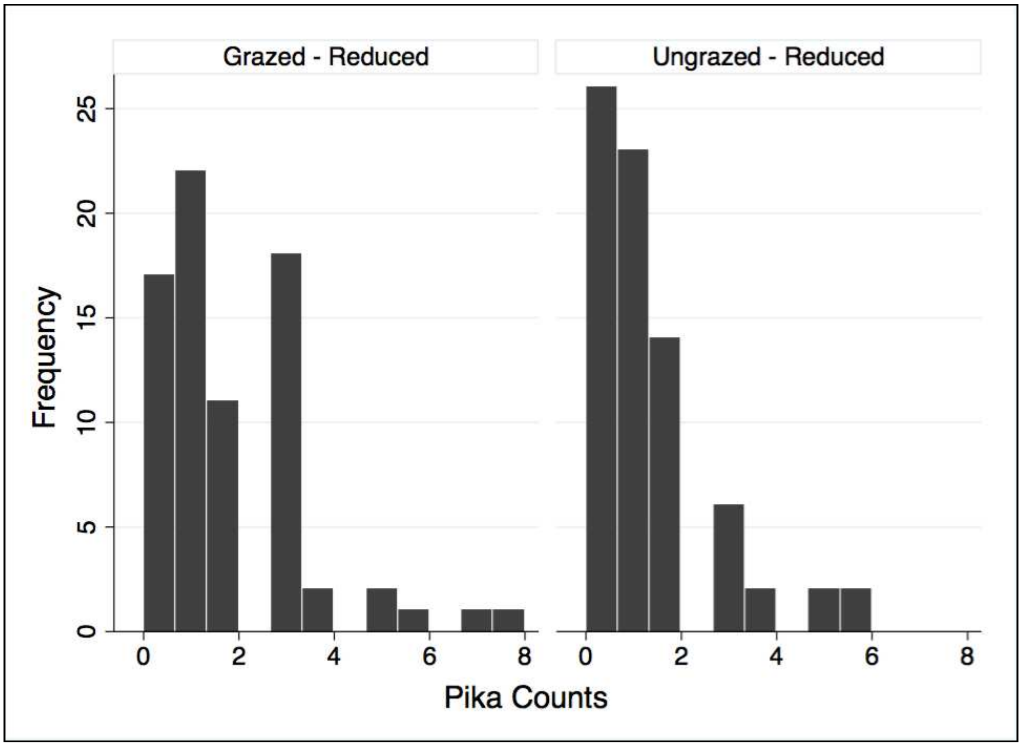

FIG. 2-5B. Frequency of pika counts inside the six (10 m x 10 m) grazed observation plots (left-hand panel) with pika reduction; and the six ungrazed observation plots (right-hand panel) with pika reduction; Village Five, Gouli Township, Dulan County, Qinghai Province, China, May to July of 2010 - 2013.

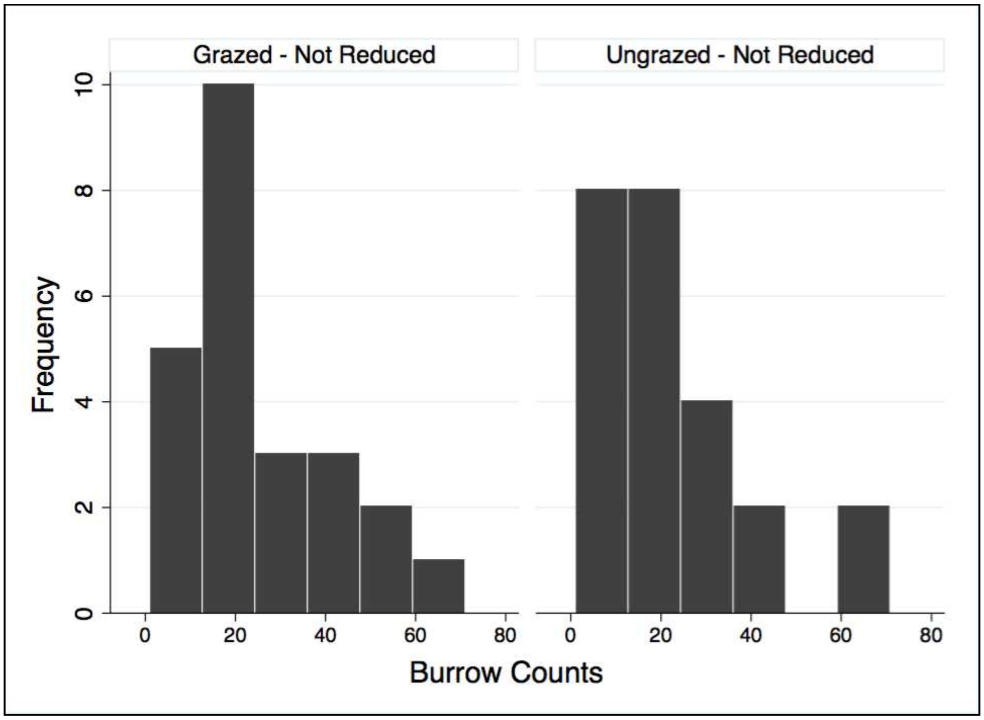

FIG. 2-6A. Frequency of pika burrow counts inside the six (10 m x 10 m) grazed observation plots (left-hand panel) with no pika reduction; and the six ungrazed observation plots (right-hand panel) with no pika reduction; Village Five, Gouli Township, Dulan County, Qinghai Province, China, May to July of 2010 - 2013.

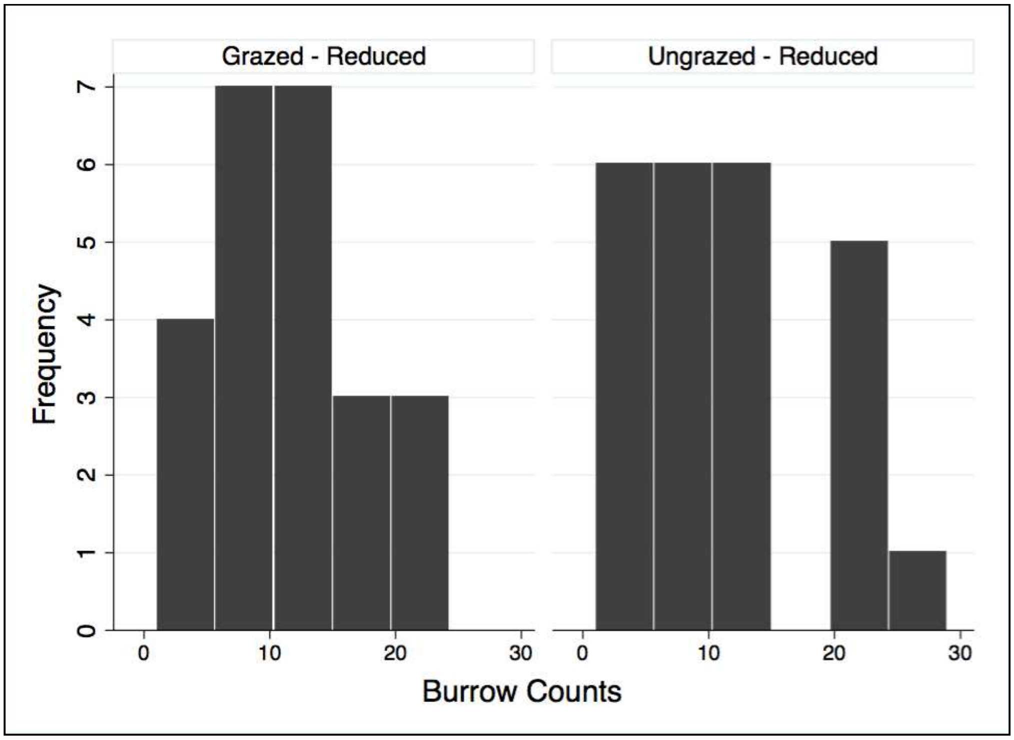

FIG. 2-6B. Frequency of pika burrow counts inside the six (10 m x 10 m) grazed observation plots (left-hand panel) with pika reduction; and inside the six ungrazed plots (right-hand panel) with pika reduction; Village Five, Gouli Township, Dulan County, Qinghai Province, China, May to July of 2010 - 2013.

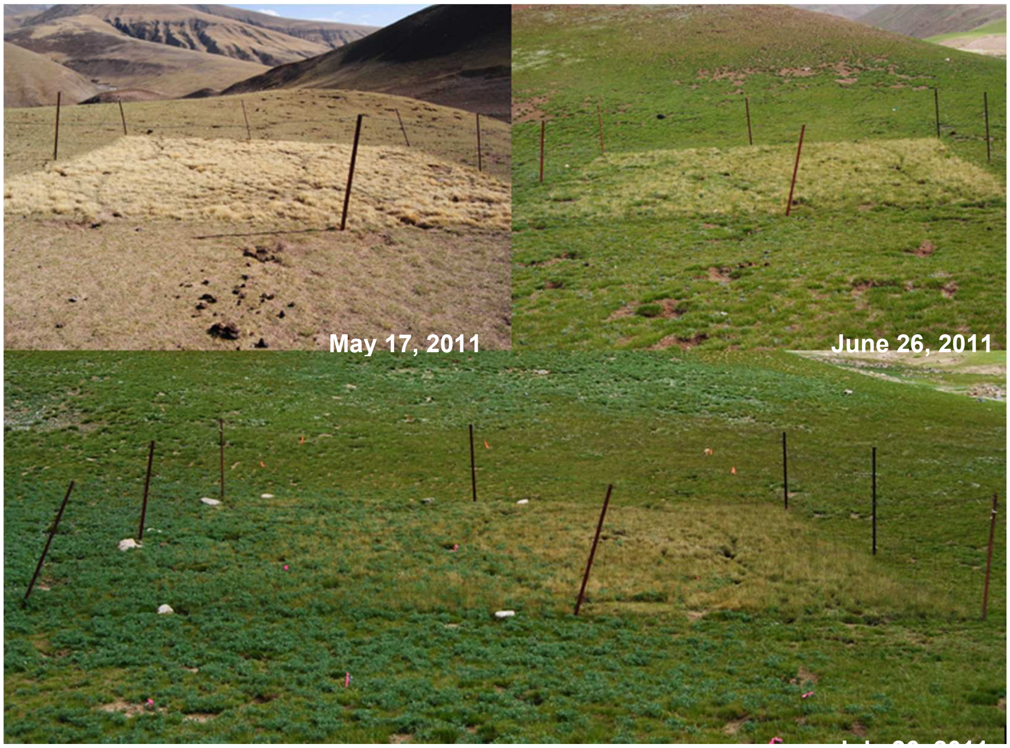

FIG. 2-7. Example of phenological progression of vegetation from May to July, 2011, showing decreasing contrast of vegetation between ungrazed and grazed observation plot; Village Five, Gouli Township, Dulan County, Qinghai Province, China. Shown is experiment 3.

TABLE 2-1. Characteristics of four winter pastures on which the 12 experimental exclosures were established; in Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2009-2013.

Pasture Owner	Pasture Size (km^2)	Experiments	Mean Sheep/ha (2009)	Mean Elevation (m)	Mean Slope (º)
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

TABLE 2-2. Number of pikas killed in 12 experiments (including six with pika reduction and six without) during 2010-2013; Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2010-2013.

Experiment	Pika Reduced (Y/N)	Year 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

TABLE 2-3. Pikas counted during one-hour observation bouts at each of the observation plots (May - July) from 2010 – 2013; Village Five, Gouli Township, Dulan County, Qinghai Province, China. Pika counts in 2010 were conducted only during July due to insufficient time.

	2010		2011						2012						2013					
	July		May		June		July		May		June		July		May		June		July	
Plot #	UG[1]	G[2]	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	1	1	1	1	0	1	0	1	0	0	1	1	1
2	1	3	0	1	1	0	0	2	0	1	0	3	0	1	0	1	0	3	0	2
3	3	2	1	3	2	1	2	3	1	0	5	5	2	3	2	3	3	4	5	2
4	9	6	3	5	7	9	7	9	3	2	5	3	3	6	2	2	1	2	3	4
5	0	1	1	3	1	5	2	4	1	2	2	3	5	4	2	1	2	2	3	4
6	0	3	0	1	1	4	3	5	0	0	0	1	0	2	0	0	0	0	0	0
7	0	0	1	3	2	5	2	3	1	0	2	1	3	1	1	2	3	3	3	3
8	2	4	1	3	3	5	2	5	2	3	3	3	2	1	1	4	2	4	1	2
9	6	6	1	1	0	0	0	1	0	1	0	0	2	3	0	0	0	0	0	0
10	6	4	2	0	2	1	2	2	1	1	1	1	0	1	0	2	2	3	1	3
11	0	2	1	0	4	2	5	6	0	2	1	2	0	2	0	1	0	2	1	2
12	0	3	1	3	3	5	6	8	1	3	0	1	2	1	0	3	0	4	2	4
Mean	2.4	2.8	1.1	1.9	2.2	3.3	2.6	4.1	0.9	1.3	1.7	1.9	1.7	2.1	0.8	1.6	1.1	2.3	1.7	2.3
Total	29	34	13	23	26	39	31	49	11	16	20	23	20	25	9	19	13	28	20	27

[1] UG = ungrazed observation plots, [2] G = grazed observation plot

TABLE 2-4. Means of the total number of pikas counted from May-July (*n* = 312) of years 2010-2013 within four experimental conditions; Village Five, Gouli Township, Dulan County, Qinghai Province, China. July (2010-2013) consensus data (*n* = 96) is presented separately because the data are used for separate analyses.

Time Period	Pikas reduced or Not	Grazed Mean (±SE)	Ungrazed Mean (±SE)
May - July	Not reduced	3.77 (0.34)	2.44 (0.29)
	Reduced	1.82 (0.19)	1.32 (0.17)
July	Not reduced	5.50 (0.88)	3.54 (0.74)
	Reduced	2.54 (0.43)	2.04 (0.41)

TABLE 2-5. Pika burrows counted within the four experimental conditions in June and July of 2010-2013; Village Five, Gouli Township, Dulan County, Qinghai Province, China (*n* = 96).

Pikas reduced or not	Grazed Mean (±SE)	Ungrazed Mean (±SE)
Not reduced	24.87 (3.47)	22.29 (3.47)
Pikas Reduced	11.08 (1.29)	12.08 (1.49)

TABLE 2-6. Negative binomial regression predicting pika counts (*n* = 312) with fixed effects grazing, and pika reduction; Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2010-2013. Shown are slope coefficient *(β),* its standard error (SE), *Z* value, and probability (*P*).

Predictor	*β*	SE	*Z*	*P*
Grazing Excluded	-0.4321	0.1363	-3.17	0.002
Pikas Reduced	-0.6162	0.1606	-3.84	<0.001
Excluded X Reduced	0.1071	0.2168	0.49	0.621
Intercept	1.3258	0.0916	14.47	<0.001

TABLE 2-7. Negative binomial regression predicting pika counts (n = 312) with fixed effects grazing, pika reduction effect, and Julian date effect; Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2010-2013. Shown are slope coefficient (β), its standard error (SE), Z value, and probability (P).

Predictor	β	SE	Z	P
Grazing Excluded	-0.4429	0.1293	-3.43	0.001
Pikas Reduced	-0.5766	0.1549	-3.72	<0.001
Excluded X Reduced	0.1169	0.2081	-0.56	0.5274
Julian Date	0.0119	0.0021	5.61	<0.001
Intercept	-0.8592	0.3987	-2.16	0.031

TABLE 2-8. Negative binomial regression predicting pika counts (*n* = 312) with fixed effects grazing, and pika reduction effect; Julian date, and the interaction of grazing exclusion and Julian date; Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2010-2013. Shown are slope coefficient *(β),* its standard error (SE), *Z* value, and probability (*P*).

Predictor	*β*	SE	*Z*	*P*
Grazing Excluded	-0.9222	0.8015	-1.15	0.250
Pikas Reduced	-0.5732	0.1552	-3.69	<0.001
Excluded X Reduced	-0.1218	0.2082	-0.59	0.558
Julian Date	0.0107	0.0028	3.83	<0.001
Julian Date X Excluded	0.0025	0.0042	0.61	0.544
Intercept	-0.6524	0.5233	-1.25	0.213

TABLE 2-9. Negative binomial regression predicting pika burrow counts (*n* = 96) with fixed effects grazing, and pika reduction; Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2010-2013. Shown are slope coefficient *(β),* its standard error (SE), *Z* value, and probability (*P*).

Predictor	*β*	SE	*Z*	*P*
Grazing Excluded	-0.1097	0.1917	-0.57	0.567
Pikas Reduced	-0.6134	0.1962	-3.12	0.002
Excluded X Reduced	0.1960	0.2777	0.71	0.480
Intercept	3.2139	0.1352	23.78	0.000

TABLE 2-10. Negative binomial regression predicting pika burrow counts (*n = 96*) with fixed effects grazing, pika reduction, and Julian date; Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2010-2013. Shown are slope coefficient *(β),* its standard error (SE), *Z* value, and probability (*P*).

Predictor	*β*	SE	*Z*	*P*
Grazing Excluded	-0.1100	0.1878	-0.59	0.558
Pikas Reduced	-0.6189	0.1926	-3.21	<0.001
Excluded X Reduced	0.2163	0.2727	0.79	0.428
Julian Date	-0.0236	0.0112	-2.12	0.034
Intercept	7.4057	1.9899	3.72	0.000

TABLE 2-11. Negative binomial regression predicting pika burrow counts (*n* = 96) with fixed effects grazing, pika reduction effect, Julian date, and interaction of grazing exclusion and Julian date, Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2010-2013. Shown are slope coefficient *(β),* its standard error (SE), *Z* value, and probability (*P*).

Predictor	*β*	SE	*Z*	*P*
Grazing Excluded	-2.6576	3.9696	-0.67	0.503
Pikas Reduced	-0.6166	0.1922	-3.21	<0.001
Excluded X Reduced	0.2284	0.2730	0.84	0.403
Julian Date	-0.0310	0.0159	-1.95	0.051
Excluded X Julian Date	0.0143	0.0223	0.64	0.521
Intercept	8.7194	2.8323	3.08	0.002

TABLE 2-12. Top 25 models constructed based on the variables of interest; the models describe influence of variables and interactions of variables on pika counts (*n = 96*); the models are ranked according to the ΔAIC and Akaike weight values (*w*).

Model[1]	ΔAIC[3]	*w*[4]
SH + PR + SH X[2] PR	0	0.2076
Null	0.2836	0.1802
VC + PR + VC X PR	0.5725	0.1559
SC + PR + SC X PR	1.2873	0.1091
SH + VC + PR + PR X SH + PR X VC	3.1516	0.0429
G + PR + G X PR	3.3607	0.0387
SH + SC + PR + PR X SH + PR X SC	3.6525	0.0334
SH + LC + PR + PR X SH + PR X LC	3.8533	0.0302
SH + G + PR + PR X SH + PR X G	3.9781	0.0284
LC + PR + LC X PR	4.0273	0.0277
SC + LC + PR + PR X SC + PR X LC	4.2558	0.0247
VC + G + PR + PR X VC + PR X G	4.3441	0.0237
VC + SC + PR + PR X VC + PR X SC	4.5114	0.0218
VC + LC + PR + PR X VC + PR X LC	4.5684	0.0211
SC + G + PR + PR X SC + PR X G	4.9259	0.0177
SH + VC + LC + PR + PR X SH + PR X VC + PR X LC	6.9514	0.0064
SH + VC + SC + PR + PR X SH + PR X VC + PR X SC	7.0100	0.0062
LC + G + PR + PR X LC + PR X G	7.1207	0.0059
SH + VC + G + PR + PR X SH + PR X VC + PR X G	7.1354	0.0059
SC + LC + G + PR + PR X SC + PR X LC + PR X G	8.0218	0.0038
VC + SC + LC + PR + PR X VC + PR X SC + PR X LC	8.1481	0.0035
VC + SC + G + PR + PR X VC + PR X SC + PR X G	8.3364	0.0032
SH + VC + SC + LC + PR + PR X SH + PR X VC + PR X SC + ->PR X LC	10.6477	0.0010
SH + VC + SC + G + PR + PR X SH + PR X VC + PR X SC + ->PR X G	10.9811	0.0009
SH + VC + SC + LC + G + PR + PR X SH + PR X VC + PR X ->SC + PR X LC + PR X G	14.5624	0.0001

[1] Model parameters: *Stipa* Height (SH); Vegetation Cover (VC); Green Weight of vegetation (G); Soil Cover (SC); Litter Cover (LC); Pikas Reduced (PR).

[2] X = denotes interactions of predictor variables.

[3] ΔAIC = Akaike's Information Criterion.

[4] *w* = AIC model weight

TABLE 2-13. Means and standard deviations (in parenthesis) of selected vegetative characteristics habitat variables ($n = 576$) in 0.5 m^2 plots in grazed plots and ungrazed plots, as well as between pika reduced plots and plots without pika reduction; Village Five, Gouli Township, Dulan County, Qinghai Province, China, July, 2010-2013.

Habitat Condition	*Stipa* Height	Vegetation Cover (%)	Vegetation Biomass (g)	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)	44.170 (17.31)

TABLE 2-14. Best fitting candidate negative binomial regression models (ΔAIC < 2), predicting pika counts from vegetative characteristics ($n = 96$), in July 2010-2013, Village Five, Gouli Township, Dulan County, Qinghai Province, China. Shown are slope coefficient *(β),* its standard error (SE), *Z* value, probability (*P*), and Akaike weight values (*w*).

Model, *w*	Predictor	*β*	SE	*Z*	*P*
Model 1					
0.2076	*Stipa* Height	-0.1582	0.0949	-1.67	0.096
	Pikas Reduced	-0.6733	0.1869	-3.60	<0.001
	Stipa Height X Reduced	0.0913	0.1097	0.83	0.405
	Intercept	1.4874	0.1233	12.06	<0.001
Null					
0.1802	Pikas Reduced	-0.6794	0.1898	-3.58	<0.001
	Intercept	1.5097	0.1256	12.01	<0.001
Model 2					
0.1559	Vegetation Cover	-0.0038	0.0029	-1.33	0.184
	Pikas Reduced	-0.6857	0.1873	-3.66	<0.001
	Vegetation Cover X Reduced	0.0003	0.0039	0.01	0.994
	Intercept	1.4952	0.1232	12.14	<0.001
Model 3					
0.1091	Bare soil	0.0027	0.0022	1.24	0.214
	Pikas Reduced	-0.6823	0.1878	-3.63	<0.001
	Bare soil X Reduced	-0.0004	0.0029	-0.15	0.878

TABLE 2-15. Two-way ANOVAs for the effects of grazing and pika reduction on selected vegetative characteristics ($n = 576$); Village Five, Gouli Township, Dulan County, Qinghai Province, China, 2010-2013. Shown are F values and probability (P). Degrees of freedom = 1.

Habitat Variables	Source of Variation	*F*	*P*
Stipa Height	Exclosure	134.26	<0.001
	Pika Reduction	0.53	0.4655
	Exclosure X Pika Reduction	1.08	0.2992
Vegetation Cover	Exclosure	23.17	<0.001
	Pika Reduction	1.18	0.2786
	Exclosure X Pika Reduction	0.06	0.8057
Green Weight	Exclosure	3.34	0.0682
	Pika Reduction	0.03	0.8626
	Exclosure X Pika Reduction	2.19	0.1394
Litter Cover	Exclosure	11.69	<0.005
	Pika Reduction	4.56	<0.05
	Exclosure X Pika Reduction	0.93	0.3361
Bare Soil	Exclosure	44.30	<0.001
	Pika Reduction	0.35	0.5548
	Exclosure X Pika Reduction	0.57	0.4520

CHAPTER THREE

Dispersal Determines Population Recovery of Plateau Pikas in Alpine Steppe Habitat

INTRODUCTION

Dispersal is an important demographic parameter for understanding the spatial distribution and abundance in populations of mammals (Taylor and Taylor 1977; Johnson and Gaines 1990). Additionally, dispersal plays a major role in population regulation (Slade and Ralph 1974; Lidicker 1975; Thompson 1978). Dispersal promotes settlement of individuals in unoccupied habitats, which results in facilitating the perpetuation of regional populations, and thus stability of the species over large geographic areas (Roff 1974; Gaines and McClenaghan 1980).

The plateau pika (*Ochotona curzoniae*) displays both dispersal and philopatric traits, which together contribute to successful establishment of individual families and annual population re-establishment following high overwinter mortality (Smith and Wang 1991; Dobson et al. 1998). As such, dispersal and philopatric traits in plateau pikas may be an evolutionary outcome involving mechanisms of population regulation.

Plateau pikas, perceived as harmful to grassland health, have been controlled using chemical and biological poisons with an attempt to eradicate their populations across alpine grassland habitats on the Qinghai-Tibetan Plateau (QTP) for decades (Fan et al. 1999; Smith and Foggin 1999; Delibes-Mateos et al. 2011). Results from assessments of pika eradication are often reported as achieving high effectiveness (90-98%) in reducing plateau pikas (BAH 2008). Sun et al. (2008) reported that pikas were reduced by 97.4% using lyophilized botulinum C toxin mixed with wheat, and 92.22% efficacy using 0.10% of botulinum D toxin as reported by Yang et al. (2011). These methods have been commonly used to control plateau pikas in recent times (Fan et al. 1999; Zhang et al. 2004; An 2008). Nevertheless, some studies have suggested pika populations can recover in one breeding season following a control application (Zhang et al. 1998; Pech et al. 2007). But, with persistent poisoning in an area, current methods of pika eradication programs could potentially lead to local population collapse, leading to a further loss of biodiversity because of the important ecological services provided by pikas in maintaining biodiversity and ecosystem functioning on the QTP (Smith and Foggin 1999; Lai and Smith 2003; Delibes-Mateos et al. 2011; Harris et al. 2014; Badingqiuying et al. 2016). However, whether the decades-long pika eradication campaigns function to disrupt the evolutionary strategies of pika population recovery has not been studied. It is not known what biological or environmental mechanisms may be responsible for repopulation of a controlled area. In addition to the high biological potential of pikas (Smith et al. 1986; Smith and Wang 1991; Dobson et al. 1998), I hypothesize that population recovery of pikas may be explained by the facilitation of residual pikas (those remaining alive following poisoning) that are philopatric, or natal dispersal from neighboring non-controlled populations into areas where all pikas had been eliminated by poisoning.

Understanding the dynamics of pika population recovery following eradication remains important for biodiversity conservation. Thus, my study objectives were to to understand mechanistic factors that may constrain or facilitate the ability of pikas to recover their populations in depopulated habitats following pika eradication programs.

MATERIALS AND METHODS

Study System

Plateau pikas are distributed widely and generally in high abundance in elevations ranging from 3,000-5,000 m across the alpine grasslands of the QTP, a region that encompasses approximately 2.5 million km^2 in the heart of Asia (Miller 1995; Smith and Xie 2008). Plateau pikas are social animals, and adult parents and their offspring live in subterranean burrow systems in the grassland habitat throughout the year (Smith et al. 1986; Wang and Dai 1990; Smith and Wang 1991; Dobson et al.1998). Individual families on burrow-system territories may represent a monogamous, polygynous, or polyandrous mating system (Smith et al. 1986; Wang and Smith 1989; Smith and Wang 1991; Wang and Dai 1991). Pikas may produce three - five sequential litters at 3-week intervals during the reproductive season, and litter size ranges between three - six young at weaning (Dobson et al. 1998). Thus, population density can reach a high of 100-300/ha at the end of the reproductive season (Smith et al. 1986; Smith and Wang 1991). However, a relatively small percentage of the pika population survives to the following breeding season due to the harsh and long winters experienced on the plateau (Wang and Smith 1988; Dobson et al. 1998). Dispersal occurs in a narrow window of time prior to the beginning of mating season (Smith and Wang 1991; Dobson et al. 1998).

Study Area

The field experiment site was located in Village Five (approximately 35.5º N, 98.7º E) at an elevation of 4,100 m, in Gouli Township, Dulan County, Qinghai Province, China (Fig. 2-1). The average yearly precipitation at the study site is 398 mm, with most of the precipitation (~92%) concentrated between April and September. The mean annual temperature is approximately -1.4ºC; the mean annual temperature of the warmest 8-day periods is 14.0ºC and the coldest is -16.3ºC (Harris et al. 2015). The habitat is characterized as alpine steppe grassland, and is dominated by the genus *Stipa* accompanied by Cardimine, Carex, *Leymus*, *Oxytropis, Poa,* and approximately 40 other vegetation species under the categories of grass, sedge and forb.

Re-colonization of depopulated family territories by plateau pikas was studied on experimental grids located on pastoralist Balo's pasture, which was mainly used as winter grazing pasture (see Harris et al. 2015). The habitat of plateau pikas overlapped with that of livestock which grazed in the pasture. The pasture could be characterized as a gentle slope relative to the adjacent surrounding areas.

Experimental Design

Two re-colonization experiments were established, each of which was comprised of a central core area of 2,500 m^2 from which pikas were removed animals, surrounded by a 37,500 m^2 control area populated by pikas (Fig. 3-1). I marked both re-colonization grids, situated at the center of control areas, with stones painted in red on the four corners and along the edges. The remaining area surrounding each re-colonization plot was inhabited by many free-living pikas occupying their family territories. The control area boundaries were marked with yellow painted stones. The stone markers were also numbered, and the location of each pika captured was recorded by the distance to and compass direction from a numbered stone.

The initial selection of the two experimental plots was based on visual differences in vegetation condition as assessed by A.T. Smith and R.B. Harris in June 2010. This was to investigate the effect of habitat condition on dispersal and pika population density, as earlier studies had shown that pika population density variation may correspond to vegetative conditions (Shi 1983; Liu et al. 2003). The criteria for characterizing the difference in habitat condition between the two control plots were formalized by sampling (*n* = 9 in each plot in each of my three years of study) vegetation height, cover, and extent of bare ground (see Harris et al. 2015 for methods.

Sampling Procedures

In order to establish a known population of pikas, I live-captured and marked individual pikas (Smith and Ivins 1983; Smith and Wang 1991; Dobson et al. 1998) within the 37,500 m^2 control area surrounding each re-colonization plot following each summer's reproductive season. The capture and marking of pikas were conducted from June to early August from 2010-2012. String nooses with red chopsticks anchored into the ground were placed around individual burrow entrances within family territories (Dobson et al. 1998). All the open burrows within a family territories were saturated with string nooses during each capturing period. Nooses were also set at burrows that were further apart from the center of each burrow system.

Each pika captured in a string noose was immediately attended to and removed from the noose for processing. One field assistant and I handled each captured pika with care while another observer watched the remaining string nooses. By following the method applied by Smith and Ivins (1983), Smith and Wang (1991), and Dobson et al.

(1998), I identified sex and age (adult or juvenile) of each captured pika. Colored ear-tags (National Band and Tag Company) were used to mark captured pikas to distinguish their sex and age. Unique color combinations were used to differentiate sex among adults and juveniles, and different color combinations were used to distinguish adults from juveniles. I did not differentiate juveniles born at different stages of the reproductive season in individual family burrow system territories, as this information was not required for this experiment. Each marked pika was released at the burrow location where it was captured. The exact location of capture of each pika was measured as the distance between designated grid markers and burrows. These locations served as a baseline for determining ultimate movements of each pika in subsequent censuses.

After all the pikas were captured and marked in one individual burrow system, we moved to the next adjacent burrow system to begin capturing and marking pikas. Upon the completion of the capturing and marking process in each re-colonization plot, were-observed each family colony, and efforts were made to assure that all the pikas were captured and marked within the marking zones and from each family burrow system territory on each plot.

Field Methods

The re-colonization experiment and data collection procedures were based on a combination of methods including marking animals at natal sites with ear-tags (Smith and Ivins 1983; Smith and Wang 1991; Dobson et al. 1998), removal trapping (Downhower 1968) from the core re-colonization plots, and re-capture and visual observation

(Armitage 1973; Smith and Ivins 1983; Smith and Wang 1991; Dobson et al. 1998) of dispersed pikas in newly occupied family territories in the core areas.

Pikas that survived overwinter were trapped out (euthanize) from each of the 2,500 m^2 core areas during March of 2011 - 2013. Removal of pikas was carried out continually during March in each year of my study to ensure the burrow systems in the re-colonization plots were vacant and that all the resident pikas within these grids were removed. The unoccupied re-colonization plots were then positioned to be colonized by dispersing pikas from surrounding areas.

I quantified pika dispersal by assessing the number of new animals found in the Upper and Lower re-colonization plots during the breeding season of each year 2011 - 2013. The initial observation of pika dispersal to each re-colonization plot was carried out in May following the dispersal time period. Two observers sat elevated on chairs approximately 15 m away from a pika family territory within the 2,500 m^2 core area and observed all pikas active within the grid with both direct visual observations and binoculars for four hours at each plot. During the observations, I estimated the number of individual pikas with or without ear tags, and evaluated if the individual pikas had established a family or not in each of the two re-colonization plots. Following these initial observations, my assistants and I live-captured all pikas that had dispersed into the re-colonization plots. Pikas that had lost ear tags (rips present in ears) or with no ear-tags were marked with different colored ear-tags to distinguish them from the remaining dispersers. Ear-tag information was recorded to identify the dispersers' sex and age, as well as to determine where they were initially captured in the surrounding control areas. Age: "Animals were classified as yearlings if they had been initially caught and tagged as juveniles the year before; adults were pikas that were adults in the previous year." For animals that could be identified by their previously applied ear tags, the direct (straight-line) distance between the location of initial capture and the site of subsequent capture was measured. I defined residency on the removal plot by this subsequent capture. My assistants and I then conducted initial observations on pikas that had dispersed to are-colonization plots to determine their occupancy of vacant burrows and the initial establishment of a mating system (number of males and females) in what appeared to be family burrow system territories.

I determined reproductive rates in pikas starting when the first newly-born litter emerged on the surface at a family territory. Pika recovery rates on the re-colonization plots were assessed by counting the number of offspring that became surface active during the breeding season. The reproductive rate at each identified family burrow system was determined by identifying the adult parents and counting the number of young from sequential litters from May to the end of July in 2011 - 2013.

During the summer reproductive period in 2011-2013, I assessed the spatial locations of individual family burrow system territories by observing the proximate cluster of each pika's center of activity and distances between neighboring families using behavioral and spatial measurements. At another site on the QTP, the distance between centers of activity of neighboring families was determined to be roughly 24 m, and the centers of activity varied little between years (an average of 5.7 m; Smith and Dobson 1994; Dobson et al. 1998). The accuracy of determining individual families was supported by observation of frequent affiliative behavior among individuals within families (see Smith and Wang 1991; Dobson et al. 1998); affiliative behaviors occurred frequently among the members of identified family groups. I also observed aggressive behavior, such as chasing and fighting, when individuals from neighboring families intruded. Aggression is a typical behavior of territorial and resource defense by male pikas (Smith and Wang 1991; Dobson et al. 1998).

Data Analyses and Statistical procedures

To determine if the number of dispersed pikas (with and without ear tags) differed between the Upper and Lower plots, I applied Fisher's exact test. To examine if dispersal distances moved by individual pikas between the Upper and Lower re-colonization plots differed, I used Welch's t-test. I used the Kruskal-Wallis test to data comparing distances moved by age and sex groups between the two plots.

I used Welch's *t*-test for differences during summer between the Upper and Lower re-colonization plots in 1) total abundance of adult parents responsible for offspring production; 2) total abundance of offspring; and 3) total pika abundance (adult parents + offspring).

The analyses were performed in Stata/IC Software 14 (Stata Corp LP, TX, USA), and some figures were produced using Excel (version 15.13.1, Microsoft2015). Statistical significance was accepted at $\alpha = 0.05$ level. Non-parametric procedures were applied if data showed unequal variance and lack of normality.

RESULTS

Vegetation Condition in the Upper and Lower Plots

Summary statistics of vegetation and bare soil measurement are presented in Table 3-1. The results showed that vegetation condition by cover and biomass were greater in the Upper re-colonization plot than to the Lower plot, and that the percent cover of bare soil was greater in the Lower re-colonization plot than the Upper plot.

Vegetation height did not differ (t = -1.04, df = 37.50, $P > 0.05$) between Upper and Lower plots. However, vegetation cover (t = -7.18, df = 47.79, $P < 0.01$), green weight (t = -3.88, df = 38.74, $P < 0.01$), as well as bare soil (t = 3.57, df = 41.64, $P < 0.01$) showed significant differences between the Upper plot and Lower plot (n = 27).

Initial Plateau Pika Population

From 2010-2012, with the help of my assistants, pikas were captured and marked on the control plots. The number marked on the Lower control plot (n = 256) was greater than marked on the Upper control plot (n = 206) (Table 3-2). The sex-ratio and the percentage of adults-to-juveniles was similar between the Upper and Lower control plots. All animals in the re-colonization plots were captured in 2011 and 2012, but sampling was incomplete in 2010 because my field study was initiated only by mid-summer in that year. The initial removal of animals from the re-colonization plots occurred in March 2011. During that time 14 pikas were removed from the Lower plot, and 10 pikas were removed from the Upper plot.

Plateau Pika Colonization Dynamics

Following the removal in March 2011-2013 of all animals in the Upper and Lower re-colonization areas, we observed the colonization of plateau pikas into these vacated spaces. A similar number of animals colonized in each of these years (Table 3-3). In 2011, 15 pikas colonized these areas (five into the Upper area; 10 into the Lower area), and of these only seven had been marked the previous summer because of the incomplete sampling of the control plots that year. In 2012, four animals colonized the Upper plot, and 11 animals colonized the Lower plot, and of these only two had not been previously marked on the control plots. All animals colonizing the re-colonization plots in 2013 (six on the Upper plot; 6 on the Lower plot) had been previously marked on the control plots. “Caveat” of small sample size in dispersal studies, the total number of dispersed pikas between the Upper and Lower plots nearly approached statistical significance (P = 0.067).

Overall, nearly twice as many animals (yearlings and adults combined) colonized the Lower plot (n = 27) compared with the Upper plot (n = 15).

Demographic Composition of Colonizing Pikas

Pooled data from 2011-2013 showed that yearling pikas were the dominant dispersing animals, comprising 75% (n = 24) of all dispersers, the remainder 25% (n = 8) being adults (Table 3-3).

There was no difference in gender of pikas dispersing to and colonizing re-colonization plots (Table 3-3). In 2012 and 2013 combined (years in which age and sex could be determined), 11 yearling females and 10 yearling males dispersed. Among adults, five females and one male dispersed.

Distances Moved by Dispersing Pikas

Almost all pikas that dispersed to and colonized the re-colonization plots originated from one of the control plots. Discounting the dispersed animals from 2011, because not all animals on the control plots were marked the preceding year, 93% (25/27) of May colonists were marked. In all cases, dispersers originated from the control plot proximal to the re-colonization plot that they colonized. Dispersal distances were short, averaging 54.5 m ($n = 32$) independent of age or sex or plot (Table 3-4). The minimum dispersal distance observed, 30 m, was by an adult female, whereas the longest distance was 78 m by a yearling male.

There were no significant differences in dispersal distances moved by pikas between the Lower and Upper plots (Welch: $t = 0.85$, df = 25.85, $P > 0.05$); no difference in the distances moved between yearlings and adults (Welch: $t = -0.26$, df = 9.2, $P > 0.05$), and dispersal distances among the dispersers by sex and age showed no difference (Kruskal-Wallis: $\chi^2 = 3.84$; df = 4, $P > 0.05$). However, dispersal distances between males and females were significantly different (Welch: $t = -2.22$, df = 23.26, $P < 0.05$) with male pikas moving longer distances than female pikas.

Family Burrow System Territory Composition on Re-colonization Plots

Dispersing pikas did not settle randomly on the re-colonization plots. Instead, they colonized burrow systems that had previously been occupied by previous (pre-removal) family territories. Six different family burrow system territories were occupied on the Lower re-colonization plot at one time or another in the three years of study, and four different family burrow system territories were occupied on the upper re-colonization plot (Figs. 3-1, 3-2). Of these, only two on each plot were colonized in every year of the study, and all possible burrow systems were colonized only the Upper plot in 2013.

Not all pikas that initially dispersed onto the re-colonization plots in May remained there until the onset of the reproductive season. In 2011, 13 pikas (4 on Upper plot; 9 on Lower plot) comprised the breeding population in June from the 15 that were initially observed on these plots. In 2012 three dispersing animals (of the initial 15) had disappeared by June, but two new dispersers had colonized by then -- a female to territory #1; a male to territory #4. Both of these new colonists had been previously marked on the control plots. Thus in that year the breeding population was comprised of 14 adults (3 on the Upper plot; 11 on the Lower plot). In 2013 one of the initial 12 dispersers in May had disappeared by June, and two new marked animals were observed by then – a female to territory #1; a male to territory #7. Thus in 2013 the breeding population was comprised of 13 adults (5 on the Upper plot; 8 on the Lower plot; Table 3-5).

Reproduction on the Re-colonization Plots

Following dispersal and settlement on the re-colonization plots, pikas initiated their seasonal breeding in parallel with pikas on the control plots. Two sequential litters were produced from all family burrow systems, except one that contained a single pika (territory #9 in 2013). Young from first litters became surface active in mid-June, with second litters appearing approximately 3-weeks later. Average litter size was similar between the first and second litters produced on each re-colonization site, but average litter size (first and second litters combined) was higher on the Lower re-colonization plot (3.31 SE± 0.22) than the Upper plot (2.7 SE± 0.37; Table 3-6).

More than twice the number of young pikas were produced on the Lower plot than the Upper plot; in 2011 and 2012 three times more juveniles became surface active on the Lower plot (Table 3-5).

Young remained philopatric on their family burrow system territory throughout the summer, thus the population density on the re-colonization plots reached maximum by late summer. On the re-colonization plots, in late summer an index of population density (number of pikas/area) in 2011, 2012 and 2013 respectively was: Upper plot – 56/ha, 48/ha, 92/ha; Lower plot – 156/ha, 152/ha, 136/ha).

DISCUSSION

Dispersal and Re-colonization of Plateau Pikas

The Lower re-colonization plot had less vegetation cover and biomass, but higher bare soil relative to the Upper plot. Thus, our initial visual assessment on the conditions of these two re-colonization plots was consistent with the results of the quantitative measurement using these criteria. Thus, this study allows comparison of the responses of dispersing pikas to the variable conditions.

The number of burrow systems I observed at the start of the re-colonization experiment in 2010 remained unchanged during the study within each plot. However, not all the available burrow systems were utilized by pikas; some remained unoccupied by pika families in one year or the other. More burrow systems (six) were found in the Lower re-colonization plot than the Upper plot (four).

Plateau pikas dispersed to the re-colonization plots with vacant burrow territories following removal of residents that had survived overwinter. More pikas dispersed into the Lower re-colonization plot than into the Upper re-colonization plot. Thus, it appears that the habitat condition with lower vegetation and more available burrow systems was associated with higher rates of colonization. Among the dispersed pikas that could be identified with ear tags, all individuals originated from the immediate surrounding control plots into the re-colonization plots prior to the breeding season. The few pikas that appeared on the re-colonization plots during the breeding season also came from the surrounding control areas, but most dispersal occurred prior to breeding season in May (as shown by Smith and Wang 1991 and Dobson et al. 1998). I could not verify if the two unmarked animals (in 2012) came from pika territories beyond the surrounding control areas or whether we failed to catch them during the previous summer.

Yearlings were the dominant dispersers among the pikas of known origin, which parallels with the study by Dobson et al. (1998). The percentage of adult pikas among the dispersers was relatively small.

Few pikas survive more than two years (Wang and Smith 1988; Wang and Dai 1989), although another study showed somewhat different results on pika mortality with some animals surviving ~4 years (Qu et al. 2013). At the end of the summer reproductive season, the pika population is largely comprised of young-of-the-year companied with the few surviving adults. Thus, the proportion of animals that survive overwinter mortality could be skewed toward pikas born during the previous reproductive season, which in turn could lead to more dispersers being yearlings.

Generally, dispersal in mammals is sex biased, with juvenile males being the dominant dispersers (Johnson and Gaines 1990). However, in my study of plateau pikas, sex ratio among dispersing males and females did not differ (male = 45.7%, female = 55.3%). This result may have implications for mate recruitment and mating system establishment. Unbiased dispersal by gender in pikas may explain monogamous mating being the dominant mating system in plateau pikas. Dobson (1982) showed that mammal species in which gender of juveniles did not differ tended to be monogamous.

Reproduction and Pika Population Density

With only one exception, dispersed pikas were able to establish families and reproduce. The reason for the solo pika remained by itself in territory 9, in the Upper re-colonization plot, may be due to the removal of residents in the re-colonization plot because (Dobson et al. 1998) suggested both philopatric and dispersing pikas contributed to family establishment and total pika abundance. So the removal intervention may have constrained dispersing pikas' chance of recruiting mates and establish families. Moreover, based on my visual observation, the abundance and extent of burrow territory 9 was smaller compared to the other burrow territories in the Upper plot. It's unclear if the solo pika that had not been able to recruit mate and establish family was explained by smaller number of burrows and burrow territory size. Possible associations between burrow abundance within a territory and chance of mate recruitment as well as family establishment has yet to be studied.

In general, pikas that dispersed and occupied a particular family territory in May remained cohesive to their respective family burrow systems throughout the reproductive season. However, I observed that a few adult pikas traversed to neighboring families apparently attempting to breed with adult of opposite sex that were not associated with those traversing pikas' primary family territories. But whether such attempts for breeding succeeded and contributed to production of offspring in those neighboring family territories was unclear.

Similar to the association between the number of dispersers and habitat conditions, the total number of pikas during the summer of each year after peak populations was greater within the Lower plot than the Upper plot. This result is consistent with previous studies, which showed that a higher population density of pikas can be supported in lower vegetative condition compared to habitat with higher vegetation (Shi 1983; Liu et al. 2003; Wangdwei et al. 2013).

Distances Moved by Dispersing Pikas

Dispersal distances in mammals, which vary largely among species, reveal important information for ecological and conservation applications (Santini et al. 2013). Distances traveled by dispersers constrain the capability of a species to colonize vacant habitats (Bowman et al. 2001). Dispersing pikas moved extremely short distances. The average distance moved by dispersing pikas was closely equivalent to two family ranges measured by pika family territory size (~24 m radius from the center of activities) (Dobson et al. 1998). Few animals dispersed as far as three family territory ranges based on this measurement. Thus, the extremely short distances traveled by dispersing pikas tended to be an important factor of population regulation.

CONCLUSIONS

Plateau pikas dispersed and re-colonized vacant burrow systems following my experimental manipulation. Burrow availability prior to dispersal tended to be important for dispersing pikas successfully settle, reproduce and re-establish populations. The number of dispersers and total pika abundance was closely associated with habitat conditions. These findings are consistent with my hypothesis that family establishment and reproduction of pikas in the vacant habitat were achieved via dispersal as well as unsaturated family burrow systems. However, the constrained ability of pikas to disperse from one territory to another could suggest important conservation implications, particularly in the context of current pika eradication campaigns being waged across the QTP. Persistent implementation of these pika eradication programs within large habitat areas could potentially lead to loss of local populations due to the combination of the pika’s inability to disperse long distances and the gradual decay of burrows. Consequently, the important ecological services pikas provide to biodiversity and ecosystem functioning in the grasslands of the QTP could be compromised (Smith Foggin 1999; Lai and Smith; Delibes-Mateos et al. 2011; Harris et al. 2014; Wilson and Smith 2015; Badingqiuying et al. 2016).

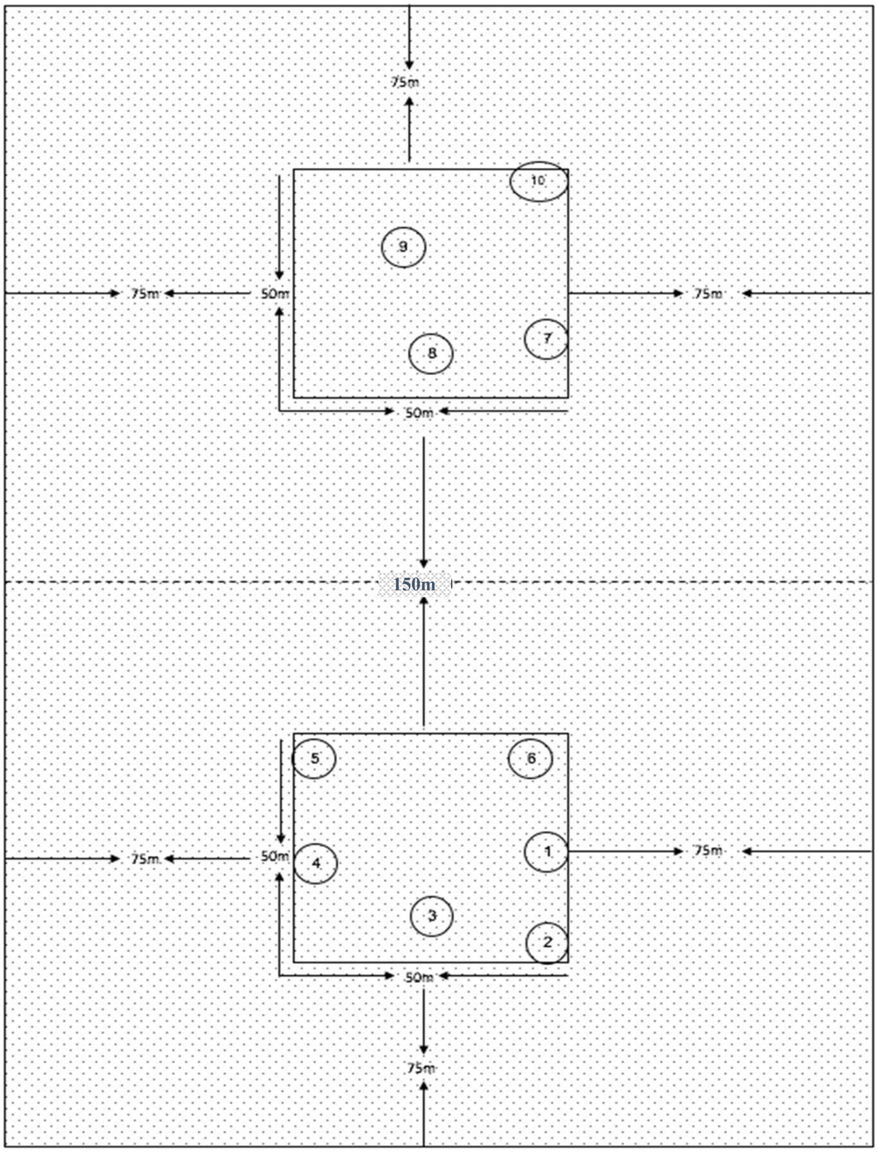

FIG. 3-1. A graphic representation of individual pika family burrow systems within the Upper re-colonization plot (2,500 m^2) with higher vegetation condition and the Lower re-colonization plot (2,500 m^2) with lower vegetation condition, each surrounded by (37,500 m^2) of control plots. The circles that are numbered represent individual burrow systems and locations of the circles illustrate the approximate center of each burrow system; Gouli Township, Dulan County, Qinghai Province.

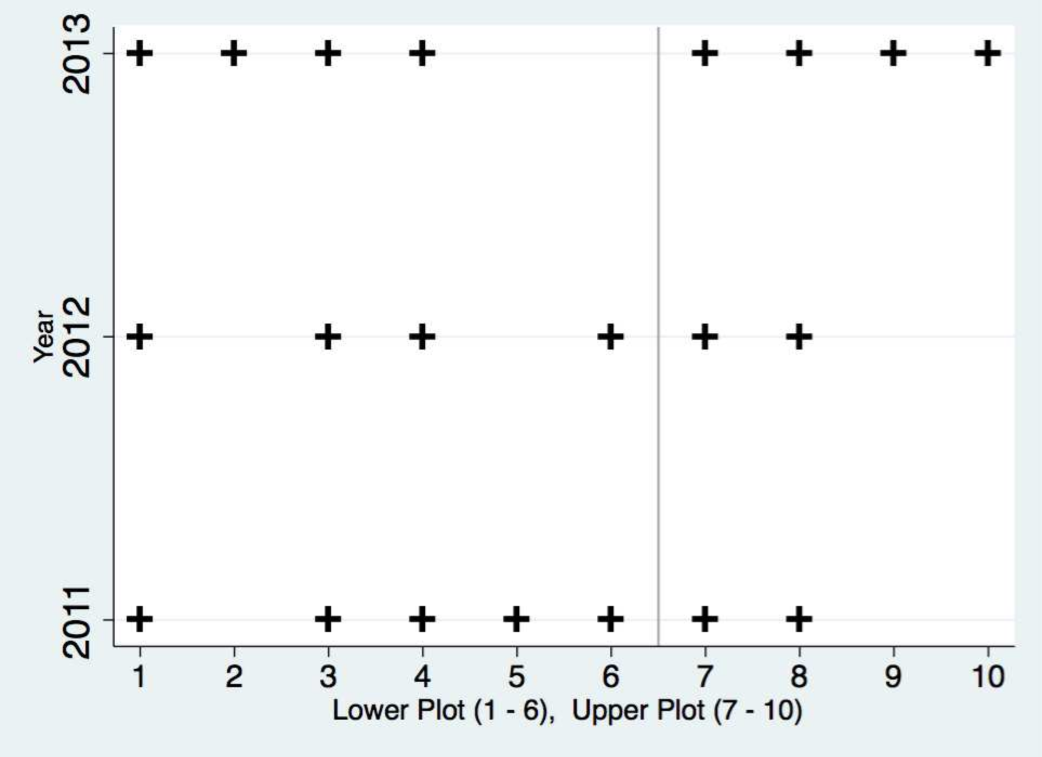

FIG. 3-2. The number of family burrow systems occupied by dispersed pikas that produced offspring following re-colonization during each reproductive season (May - July; 2011, 2012 and 2013). Numbers 1-6 represent burrow systems within the Lower re-colonization plot, and 7-10 represent burrow systems within the Upper re-colonization plot; Gouli Township, Dulan County, Qinghai Province, China.

TABLE 3-1. Vegetative characteristics in the Upper and Lower re-colonization plots; Village Five, Gouli Township, Dulan County, Qinghai Province, 2011-2013. Means and standard deviations (in parenthesis) from nine randomly located vegetation plots on each re-colonization plot are presented.

Plot	Vegetation Height	Vegetation Cover (%)	Vegetation Green Weight (g)	Bare Soil (%)
Lower Plot	15.59 (±7.07)	27.44 (±3.26)	40.83 (±6.08)	60.25 (±4.11)
Upper Plot	17.15 (±3.27)	42.59 (±2.26)	67.10 (±2.98)	43.52 (±2.27)

TABLE 3-2. Number of plateau pikas live-caught and tagged on the Lower and Upper control plots from 2010-2012; Village Five, Gouli Township, Dulan County, Qinghai Province, China.

Plot	Year	Adults		Juveniles		Total
		Male	Female	Male	Female	
Lower	2010	7	5	30	14	56
	2011	23	27	26	48	124
	2012	8	13	22	33	76
	Total	38	45	78	95	256
Upper	2010	5	8	19	13	45
	2011	13	17	27	47	104
	2012	14	10	19	14	55
	Total	32	35	65	74	206
Total		70	80	143	169	462

TABLE 3-3. Number of pikas that dispersed to and colonized the Lower and Upper re-colonization plots in May 2011-2013; Village Five, Gouli Township, Dulan County, Qinghai Province, China.

Plot	Year	Adults		Yearlings		Unknown		Total
		Male	Female	Male	Female	Male	Female	
Lower	2011	0	1	1	1	4	3	10
	2012	0	3	4	3	1	0	11
	2013	1	1	2	2	0	0	6
	Total	1	5	7	6	5	3	27
Upper	2011	0	1	3	0	1	0	5
	2012	0	0	1	2	1	0	4
	2013	0	1	3	2	0	0	6
	Total	0	2	7	4	2	0	15
Total		1	7	14	10	7	3	42

TABLE 3-4. Summary statistics of dispersal distances by pikas from where they were captured in the previous year to the site of their newly colonized burrow system within the two re-colonization plots; Gouli Township, Dulan County, Qinghai Province, 2011-2013. Here yearling refers to animals born during the previous year that became adult by the time of dispersal.

Plot	Sex/Age	*n*	Mean (SD)	Min. (m)	Max. (m)
Lower Plot	Adult Female	5	48.33 (18.01)	30	66
	Yearling Female	6	46.43 (10.93)	33	60
	Adult Male	1	-	-	74
	Yearling Male	7	58.11 (15.02)	34	77
	Total	19	52.86 (14.69)	34	75
Upper Plot	Adult Female	2	54.50 (0.71)	54	55
	Yearling Female	4	52.50 (11.15)	38	65
	Yearling Male	7	61.20 (13.05)	47	78
	Total	13	56.81 (11.12)	38	78

TABLE 3-5. Number of adult parents and young produced in the Lower and Upper re-colonization plots in June of years 2011-2013, Gouli Township, Dulan County, Qinghai Province.

Year	Plateau Pikas	Upper plot	Lower plot
2011	Adult Parents	4	9
	Young	10	30
	Total	14	39
2012	Adult Parents	3	11
	Young	9	27
	Total	12	38
2013	Adult Parents	5	8
	Young	18	26
	Total	23	34

TABLE 3-6. Litter sizes on the densely and sparsely Upper and Lower plots during the summer reproductive season 2012-2013; Village Five, Gouli Township, Qinghai Province, China.

Litter	Upper Plot (±SE)	*n*	Lower Plot (±SE)	*n*
First litter	2.6 (0.51)	13	3.37 (0.37)	27
Second Litter	2.8 (0.58)	14	3.25 (0.25)	26
Combined Litters	2.7 (0.37)	27	3.31 (0.22)	53

CHAPTER FOUR

An Ethical and Progressive Policy Approach to Managing Plateau Pikas

"A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community [and] wrong when it tends otherwise" – Aldo Leopold (1949)

INTRODUCTION

Managing plateau pika (*Ochotona curzoniae*) populations is a controversial subject. As highlighted in Chapter 1, one line of evidence points to pikas being a pest, which has led to massive attempts to eradicate pika populations. A dramatically different point of view is that pikas are a keystone species in the grassland ecosystem of the Qinghai-Tibetan Plateau (QTP). These stances stand in sharp contrast, but they do not tell the whole story about the human dimensions of plateau pika management. Not considered by either of these perspectives is that the management of pikas presents an ethical dilemma for local pastoralists.

Here I will examine this dilemma. To do so, I will first examine the anthropocentric (human-centered) ethical underpinnings of pika control, and whether current pika control programs are meeting even their own anthropocentric goals. I then will examine pika control through the lens of non-anthropocentrism (i.e., nature-centered ethics), including biocentrism (life-centered), zoocentrism (animal-centered), ecocentrism (ecologically-centered), and the explicitly non-anthropocentic ethical beliefs of Tibetan Buddhism. A consideration of these pluralistic and more holistic ethical approach is important because it 1) addresses a wide range of difficult ethical questions involved in the lethal management of pikas; 2) may help bridge the tensions among stakeholders as deliberation over the multiple natural and human values in this case offers the possibility of identifying overlap in normative views and convergence on policy choice and; 3) highlights the rational and pragmatic reasons for adopting non-anthropocentric environmental ethics approaches (in addition to moral ones) in issues of environmental policy. Finally, I close by presenting an alternative policy framework, based on an acceptance of environmental value pluralism, which could move the QTP's grassland policy closer to a more sustainable future.

ENVIRONMENTAL ETHICS: A BRIEF OVERVIEW

Environmental ethics focuses on how people relate to nature as a question of value, duty, and moral responsibility. In the West, environmental ethics emerged as a discipline as part of an increasing environmental consciousness connected to the environmental crises of the 1960s and 1970s (Callicott 2004; McShane 2009). As contributors to this developing field, a new generation of environmental philosophers believed that the anthropocentric ethical systems of the day, which were centered around the idea that humans are both the source and terminus of all values (Vucetich et al. 2014) -with non-human nature only having value insofar as it directly or indirectly serves human interests (McShane 2007b) -- failed to capture the full or "true" value of the natural world (Minteer 2009). This shift in thinking led to environmental philosophers' development of explicitly non-anthropocentric viewpoints, which emphasize that the natural world has intrinsic value, i.e., a "good of its own" or a worth beyond its direct or indirect usefulness to humans (Callicott 2004).

Many environmental philosophers and nature protectionists (Callicott 2004) have argued that anthropocentric approaches toward management of natural resources, species and ecosystems have proven to be inadequate for addressing human-induced environmental transformations. Many of these same thinkers suggest that non-anthropocentric environmental views have helped to redefine the human-nature relationship as a counter to the prevailing and dominant Western ethics of anthropocentrism (Rolston 2009). It's an argument, particularly in the American case, that draws from deep reservoirs in conservation history and nature writing. The writings of John Muir and Aldo Leopold, for example, are widely considered to have led to the birth of environmental ethics as a discipline (Norton 1991; Minteer 2003). As a field, environmental ethics has historically been dominated by some version of non-anthropocentrism as its philosophical foundation, appealing to it as the principle intellectual and political justification that addresses the intrinsic value of all life (Minteer 2011).

EVALUATING PLATEAU PIKA CONTROL AS AN ETHICAL PRACTICE

The Anthropocentric View

The primary aim of plateau pika control programs is the widespread eradication of pikas for the perceived benefit of local pastoralists In this way plateau pika control programs ignore any intrinsic value pikas may be claimed to possess (on an objective view) or attributed with, making these programs narrowly anthropocentric by nature. The pika control programs are based on the belief that the species is a pest, causing degradation of the grasslands across the QTP (Fan et al. 1999; Liu 2000; Zhang et al. 2006; Guo 2009).

Mechanistically, researchers claim that pikas reduce vegetation biomass and cover, promote bare soil or so called “black-beach,” and degrade the grassland ecosystem’s ability to retain water and control downstream flooding (Liu et al. 1999; Zhou et al. 2005; Shang and Long 2009). As pikas are viewed as the root cause of each of these ecological problems, it is assumed that removing pikas will result in increased ecological quality for local pastoralists as well as downstream/downwind communities. In this way, pika control is a classic example of a narrowly anthropocentric ecosystem management program in that it is designed to improve environmental quality for humans in the present by significant human intervention in the natural system. Similarly, other examples of eradication programs that operate according to a narrow/short sighted anthropocentric calculus, which were not informed by a sufficiently ecological perspective include eradication programs that targeted grey wolves (Curnow, E. 1969; Mech 1970) and prairie dogs (*Cynomys spp*.) in North America during the 19th and earlier 20th centuries (Whicker and Detling 1988; Summers and Linder 1978). These eradication interventions were responses to perceived conflicts between human interests and wildlife, which has led to huge ecological and conservation costs in the region.

Such anthropocentric ecosystem management approaches fail to recognize and respect the intrinsic values of natural entities (Callicott 2004; McShane 2009), which will be discussed below. However, it is important to note that by ignoring the intrinsic value of nature such approaches not only fail to capture the value of the natural world, but also produce unintentional negative outcomes for both humans and nature (Sessions 1974; McShane 2007a). This is likely due to the fact that narrowly anthropocentric views on the relationship between humans and nature, especially those that adopt short time horizons and take a reductive approach to the science of environmental management, often fail to take into consideration basic lessons of ecology (Leopold 1949; Taylor 1980; Callicott 1989a; Holland 1996).

The case of pika eradication programs fits this management scenario well. While the intention of pika control is to improve grassland quality for people, the control program has been largely criticized for its counterproductive outcomes resulting in increasing calls for a wholesale reversal of the policy (Smith and Foggin 1999; Lai and Smith 2003; Delibes-Mateos et al. 2011; Wilson and Smith 2015; Badingqiuying et al. 2016). Specifically, researchers fear that the large scale poisoning of pikas may jeopardize other ecosystem functions and services they provide (Smith and Foggin 1999; Lai and Smith 2003; Delibes-Mateos et al. 2011; Wilson and Smith 2015). A detailed analysis of pika control programs can be found in Chapter 1 (also see Meadows and Meadows 1991; Smith and Foggin 1999; Lai and Smith 2003; Bagchi et al. 2005; Arthur et al. 2007; Pech et al. 2007; Hogan 2010; Harris et al. 2014; Badingqiuying et. al. 2016; Zhang et al. 2016).

Interestingly, an analysis of pika control programs (see also Chapter 1) reveals that they fail to meet even their narrow anthropocentric policy goals. This is because they:

- Fail to recognize the ecosystem services pikas provide, including the regulation of vegetative biomass and local hydrology;
- Show either no or few (Harris et al. 2015) measurable benefits to the grassland condition and thus the livelihoods of local Tibetan pastoralists;

- Create a lose-lose situation from a cost-benefit analysis due to the enormously high cost of the programs vs their failure to reach their objectives; and
- Fail to recognize that plateau pikas maintain plant species diversity and richness, which underlies ecosystem functioning.

This analysis suggests that the pika eradication program is, as with many short-sighted and narrow (i.e., commodity-oriented, mechanistic) anthropocentric management programs, not actually effective at meeting its own goals.

A Non-anthropocentric Perspective on Plateau Pikas

In contrast to the narrow anthropocentric position, non-anthropocentric environmental ethics are based on the premise that natural objects possess intrinsic value independent of any instrumental value they may hold (Naess 1973; Regan 1983; Callicott 1989; Rolston 1989; Elliot 1992; Vucetich et al. 2014). Among the advocates of intrinsic value of nature, some environmental philosophers believe that intrinsic value is projected by humans onto nature, thus ultimately that intrinsic value of natural objects depends on human valuers (Callicott 1984). Others argue that intrinsic value is an objective quality in the natural world (Rolston 2012). Yet, the necessity of intrinsic value for environmental protection is the central topic in non-anthropocentric environmental ethics (McDonald 2012), highlighting that nonhuman entities have their own interests, with ends, goals, or purposes of their own (Taylor 1986).

The principal approaches of non-anthropocentric environmental ethics include "zoocentrism," the view that individual animals possess intrinsic value (Singer 1975; Regan 1983; Hettinger and Throop 1999); "biocentrism," the view that intrinsic value is present in all living organisms (Taylor 1981, 1986; Attfield 1987); and “ecocentrism,” an ecosystem-centered principle that recognized the intrinsic value of ecological collectives including populations, species and ecosystems (Callicott 1989).

Zoocentrism

Zoocentric ethics argue that animals possess the ability to experience pleasure and pain, as well as a capacity to reproduce and flourish (Singer 1975; Nelson and Ryan 2015). Individual animals that are capable of these feelings as sentient beings could include a large arrays of species of birds, amphibians, reptiles and mammals. Among these, mammals are the paradigm case of sentient beings as scientific evidence has demonstrated that mammals possess the capacities of experiencing a broad array of (Criado 2010).

By these criteria pikas possess intrinsic value. Moreover, plateau pikas are social animals. Adult parents live with their young in family territories. Members of a family react to other members in such ways as huddling, nose-rubbing, and other affiliative behaviors. Individual pikas also give warning calls to their family members when they have detected predators, thus exposing themselves to predation risk (Smith 1981; Smith et al. 1986; Smith 2008). These “sensual” behaviors of plateau pikas suggest that individual pikas have the capacity for feeling.

Biocentrism

Biocentrism argues that each individual living thing in nature is a teleological center of life (i.e., each organisms pursues its own good or goal), thus all living organisms including plants, microorganisms or animals have equal intrinsic value, regardless of their usefulness to human interests (Taylor 1981, 1986). On this view, intrinsic value is attributed to each individual organism (Callicott 2002a), as reflected instinctively to how we feel about ourselves as individuals (Vucetich et al. 2014). Thus biocentrism demands that individual organisms should be recognized and respected (Frierson 2010). Pikas, as living organisms, clearly meet the criteria of having value from a biocentric perspective.

While zoocentric and biocentric perspectives on pikas offer an important ethical "corrective" to the perception that pikas are grassland pests, an ecologically-informed pika policy on the QTP will require a more holistic perspective, one that recognizes the value of populations, species, and ecosystems, as well as human communities.

Ecocentrism

In contrast to both zoocentric and biocentric positions in intrinsic value, ecocentrism argues that intrinsic value exists at the level of the ecological collective, such a species or an ecosystem (Mulvaney 2011). As Leopold (1949) clarified: "*All ethics evolved so far rest upon a single premise: that the individual is member of community of interdependent part.*" Callicott (2004) further argued that the intrinsic value of nature from an ecocentric view is based on our understanding of "biotic community," an argument similar to that of Leopold's (1949) Land Ethic. In contrast to the claims that pikas cause ecosystem level degradation, pikas as a keystone species, clearly have value as a species, playing an integral role in the QTP grassland ecosystem. Given that pika control programs clearly aim for the wholesale elimination of pikas at the population or species scale, pika poisoning is a clear and present danger to the intrinsic value of pikas as defined by ecocentrism.

According to many environmental philosophers, non-anthropocentric environmental ethics have played an influential role in shaping both conservation policy and our attitudes toward nature (Callicott 1998; 2004; McShane 2009). More than a few environmental philosophers have argued that analysis of key international documents demonstrate that the United Nations, many governments, and non-governmental organizations recognize and have sought to promote the intrinsic value of nature in environmental conservation and protection efforts (Callicott 2002a; Vucetich et al. 2014). Such examples include the Earth Charter Commission 2000, which concludes that all beings are interdependent and have value independent of their usefulness to humans. The US Endangered Species Act has also been argued to acknowledge the intrinsic value of species (Callicott 1989). Moreover, the notion that nature has intrinsic value is the first of five "organizational values" held by the Society for Conservation Biology (SCB 2011). Though the importance of nature's intrinsic value is explicitly justified by scholarship (Naess 1973, Vucetich et al. 2014), recognition of nature's intrinsic value clearly extends beyond academia to many mainstream efforts to address an array of environmental issues (Vucetich et al. 2014) and is increasingly recognized as having had a powerful impact on informing conservation action (Robinson 2011).

Callicott (2004) argues that a concern for the intrinsic value of nature shapes the work of many environmental activists, and gives them pragmatic power to shape public opinion and decisions (Callicott 2004). Conservation policies based on intrinsic value are likewise thought to have consistently created more robust policies than those based on an anthropocentric approach (Callicot 2004; Vucetich et al. 2014). However, an alternative to these views of non-anthropocentrism as well as to the narrow or strong anthropocentric world view is “enlightened” or “weak” anthropocentric environmental ethics. This alternative approach is thought be compatible with an ecologically enlightened worldview, one in which experiencing nature leads to transformation of exploitative attitudes to preferences that are environmentally friendly (Minteer 2003). The highlight of “enlightened” or “weak” anthropocentric ethics is the “convergence hypothesis” proposed by Norton (1991), who argues that there is practical consensus among weak anthropocentric and non-anthropocentric environmental ethicists, policy makers and citizens in terms of valuing nature (see Minteer 2009). Norton suggests that “weak” anthropocentrism is a more pragmatic approach to solving contemporary environmental issues. Given that most people are already anthropocentrists, the enlightened/broad version he champions captures much, if not most, of what the non-anthropocentrists value in nature (Norton 1995; Minteer 2003). Thus, weak anthropocentrism converges on many consider sustainability science – a platform to use resources sustainably for the benefits of people while ensuring their existence for future generations.

Non-anthropocentrism in Practice: The Pika Eradication Program as a Dilemma to Tibetan Pastoralists

How do the perstives of Western environmental ethics translate to Tibetan spiritual traditions and practice? The beliefs and actions of Tibetan pastoralists are profoundly governed by the teachings of Tibetan Buddhism, which contains a number of non-anthropocentric elements. For example, compassionate thoughts and attitudes toward sentient beings, a term used in Tibetan Buddhism that is roughly equivalent to the individual in zoocentrism (Varner 1998), are core tenants in Tibetan Buddhism. Causing suffering to sentient beings, particularly taking their lives, is considered the most sinful deed in Tibetan Buddhism. This concept of compassion emphasizes equal treatment of all sentient beings. In addition, it is believed that "at one time or another every sentient being in the universe has been our mother, who gave us life and showed us only kindness" (Phelps 2004) in the cycle of rebirth. Therefore, compassionate thoughts and actions toward sentient beings are held as being the most important spiritual values in the Tibetan community. Such religious ideas are deeply rooted in the belief system of the Tibetan people's daily life and serve as spiritual guides for their attitudes and behaviors toward other sentient beings. In this belief structure pikas have obvious value, and the eradication of pikas, in which pastoralists are directly or indirectly involved, is considered to be a sinful deed that has karmic consequences.

Balancing their religious beliefs and the incompatible view that a particular life, form is a nuisance and must be destroyed is an inconvenient choice. On the one hand, this approach for addressing grassland degradation involves the mass killing of pikas, which is rejected by their religious belief. On the other hand, the worsening of grassland condition directly impacts their well-being. Rhetoric connecting pikas to grassland degradation has led to a generally perceived notion that pikas need to be controlled in order to improve grassland condition. However, in alignment with increasing scientific evidence (Pech et al. 2007; Delibes-Mateos et al. 2011), no or few observable improvements have occurred as a result of pika eradication programs. For example, Pech et al. (2007) concluded that "there was no apparent increase in forage production in areas where plateau pikas were controlled" and that "it was not evident that control programmes are warranted or that they will improve the livelihoods of Tibetan herders." The most comprehensive examination of this relationship found mixed results (Harris et al. 2015), pika reduction resulted in effects that pastoralists might value. Such effects include less rapid increase in erosion, control of bare soil expansion, and tempering the decline of *Stipa purpurea* in some experimental plots. But other experiments showed no temporary improvement in grassland conditions as a result of pika reduction (Harris et al. 2015).

This disconnect between religious beliefs and daily life was expressed by many local pastoralists from Nangchen, Chengduo and Dulan counties of Qinghai Province that I interviewed between the years 2009-2013. Local pastoralists are increasingly frustrated with the continuation of the pika control program, its karmic costs, and its failure to produce any significant improvement in grassland condition. Based on my experience prior to and during my field research, the perception of control programs as "worthless" is increasingly becoming the consensus among Tibetan pastoralists across the QTP. Many interviewed pastoralists believed that control of pikas actually worsens the situation, as they have observed a higher density of pikas following implementation of control measure. Some pastoralists expressed enormously difficult emotions witnessing countless remains of pikas following control implementation on their land. As a result, the religious burden from the control of pikas has not paid off and thus appears unjustified.

A PROGRESSIVE AND PRAGMATIC POLICY FRAMEWORK FOR PIKA MANAGEMENT

By any reasonable standard pika eradication is a failed policy. From an anthropocentric perspective, eradication has failed to increase ecosystem functioning or ecosystem services for local people or those living in downstream communities (Meadows and Meadows 1991; Smith and Foggin 1999; Lai and Smith 2003; Bagchi et al. 2005; Arthur et al. 2007; Pech et al. 2007; Hogan 2010; Harris et al. 2014; Badingqiuying et. al. 2016; Zhang et al. 2016). From non-anthropocentric perspectives, pika control clearly discounts the intrinsic value of pikas. Perhaps most importantly, pika control clashes with the non-anthropocentric religious beliefs of local people, even though ostensibly these programs are enacted for their benefit. While grassland degradation is a serious concern for both the QTP and China as a whole, pika poisoning is simply not an effective nor an ethically robust method for addressing this legitimate problem. Policy makers must find another way.

To their credit, policy makers have begun to recognize this need, transitioning from a policy of pika eradication to one of “integrated pest management (IPM)” (An 2008; Wang et al. 2010; Zhang and Li 2015). While this concept is still intrinsically hostile to pikas (e.g., “pest”) and generally includes some poisoning, this modified version of pika control does not seek the wholesale elimination of pikas, focusing instead on limiting pika population size by controlling the naturally occurring bottom-up and top-down controls of pika populations. From a top-down perspective, Guo et al. (2009), for instance, suggests the most sustainable way to control high pika density lies with protection of mammalian carnivores and raptors that prey on pikas, arguing that poaching of carnivores in the 1980s greatly reduced the natural predators of pikas. The presence of predators is envisioned to restore nature's balance between pikas as a prey species and their environment. Yang et al. (2011) reported that a protocol of initial poisoning coupled with the building of raptor posts (large poles, similar to telephone posts in size and shape, designed to provide raptors increased visibility and hunt success) achieved a significant reduction of burrow density after three years in Anduo County, Tibet Autonomous Region. A similar result was reported by Liu et al. (2004), who found that the occupancy of the posts by raptors reached 72% one year after their construction within an area of 6,700 km^2 of pika habitat in Maduo County. From a bottom up perspective, Shi (1983), Hou (1995), Fan et al. (1998), and Ci et al. (2007) have suggested that artificially planting native grasses within degraded habitats following poison control should operate as an ecological way to control plateau pikas. This approach to manage plateau pikas is based on the association between high population density of pikas and poor habitat quality. Thus, these researchers believe that improving the condition of habitat quality may help to moderate pika populations in the long term. Both these top-down and bottom-up approaches take a "pragmatic" form of ecocentrism, recognizing that pikas (as a population and species) exist within the complicated QTP ecosystem, but seek to manage them through human intervention.

However, IPM is not a complete solution. Pika management, and more broadly grassland restoration, involves ethical, socioeconomic, political, cultural, and conservation concerns. In situations that require addressing contested value pluralism, trade-offs between values, groups, and outcomes are unavoidable (McShane et al. 2011; Minteer and Miller 2011; Robinson 2011). McShane et al. (2011) suggest that trade-offs and hard choices are the norm when it comes to biodiversity conservation. It is important to recognize that when something is gained, often other factors are lost. By requiring compensating and compromising adjustments between conservation and human well-being to resolve potential conflicts in the decision-making process, trade-off frameworks have the capacity to bring together competing groups into common recognition where they can openly discuss gains and losses, eventually resulting in a solution that is more resilient and sustainable for the whole (McShane et al. 2011). Therefore, trade-off frameworks offer important tools to develop solutions in difficult situations in which competing values are involved.

However, for trade-offs to be analyzed, goals must be identified. For this purpose, I suggest that grassland policies should seek to increase the health of local ecosystems while respecting the non-anthropocentric views of local pastoralists as much as possible. In this context, trade-offs between policy interventions can be evaluated. Although there is value in the zoocentric and biocentric worldviews, the more holistic perspective is preferred in this case. What the zoocentric and biocentric arguments provide, though, is a case for saying that each animal matters and that we shouldn't condemn them to being mere "things" by labeling them pests and destroying them. Ultimately, however, the management challenge will require a balancing approach focused on promoting (at the same time) the good of the species, the health of the ecosystem, and the viability of local livelihoods. This holistic, ecocentric approach may be called pragmatic ecocentrism, or an ecologically-informed sustainability ethic for the QTP.

I believe that the first step in any such policy suite is to curtail mass eradication programs targeting pikas. From a trade-off perspective this decision is simple: as established above, pika eradication does not increase grasslands quality and actively clashes with local values. While challenges may be involved in abandoning the on-going pika eradication program due to high political risks, curtailing the current poisoning control programs is the most critical first step in addressing the current policy gridlock and tensions among the stakeholders. Also, this could lead to a convergence of ecosystem services and anthropocentric ethic stance toward a shared policy space.

A second step is to lower the current stocking rate of livestock. It is widely acknowledged that pika densities, thus the pressure to poison these populations, are higher on overgrazed landscapes (Fan et al. 1999; Zhang et al. 2003; Zhou et al. 2005). Fan et al. (1999) stated that "overgrazing by livestock leads to grassland degeneration which results in rodent [pika] infestation and further grassland degeneration. Human activities, especially cultivation and livestock grazing, play an important role in this vicious cycle." Zhang et al. (2003) stated "overgrazing is the major factor causing serious rodent [pika] infestation." Therefore, managing carrying capacity of livestock on the QTP to minimize overgrazing is a necessary condition of an IPM designed to control pika populations.

From here the picture grows murkier. If high-density pika populations are found to be accelerating the process of initial degradation of grassland as suggested by some researchers (Liu et al. 1980; Guo et al. 2009; Sun et al. 2011; Yu et al. 2014), IPM may be a logical next step. While the removal of pikas via IPM has clear ethical costs from a zoocentric or biocentiric perspective, this method of controlling pikas *when absolutely necessary* is in alignment with the value framework of ecocentrism and Leopold's "Land Ethic" (1949). Therefore, this ecocentric approach may be worth the zoocentric and biocentric costs when pikas are known to have exceeded “optimal” population levels for the maintenance of ecosystem integrity and sustainability.

However, differing from IPM, the costs of improving grassland health cannot and should not be borne by pikas alone. Grassland degradation is likely caused by a complex interplay between altered pastoral traditions, increased stocking rates, a changing climate, and, possibly, the role of pikas (Harris 2010). Therefore, attaining the benefit of increased grassland health will require action on each of these fronts. Coupled with compensation from government sources (e.g., McShane et al. 2011), livestock numbers should be reduced to a reasonable carrying capacity. Traditional transhumant pastoralism, which is known to better support livestock in the QTP region (Foggin 2000; Shang et al. 2014), should also be restored. This will require the dismantling small-scale fences, as fencing reduces livestock mobility and flexibility (Klein et al. 2011) and is thought to be another root cause of grassland degradation by some researchers (Li 1993; Wu 1998; Bauer 2005). Because IPM significantly infringes on the intrinsic value of individual pikas, IPM should only occur when coupled with concomitant changes in the grazing system designed to best support the sustainability of the QTP.

These changes will have both costs and benefits for local populations, which are important to examine when planning conservation projects (Minteer and Miller 2011). Aiming to maintain the population density of pikas at an “optimal level” by improving overall grassland condition may lead to another moral dilemma because of potential conflicts between conservation of biodiversity and livelihoods of pastoralists. However, these recommended policies will undoubtedly improve pastoral livelihoods relative to the current policy context. For more than 20 years, China’s Central Government has implemented programs to remove and relocate local pastoralists from their traditional pastureland to towns (Wan et al. 2005; Foggin 2008; Lu et al. 2009; Liu 2010; Ma 2010). The resettlement program has been criticized for degrading sociocultural integrity and livelihood dependency of local pastoralists (Bauer 2005; Foggin 2008; Yeh and Gaerrang 2010; Guan and SuonanWangjie 2012). Improving grassland condition by addressing livestock-induced grassland degradation (by means of pika control or otherwise) could potentially lead to policy incentives that reinforce the current resettlement program. However, as mentioned above, the policy described here recognizes that transhumant pastoralism is an integral part of the QTP landscape (Harris et al. 2015). In this way the progressive grassland management policy I am suggesting is a sustainability-oriented policy design that could benefit both the environment and the human society at local and regional scales for the long term. Promotion of such a vison is critical in the "Age of Sustainability" as suggested by Minteer and Miller (2011).

CONCLUSION

People tend to judge the values of nature, ecosystems, and species based on their instrumental, moral, and aesthetic value (Sagoff 1991). The pika eradication program cannot be justified on instrumental grounds as pika eradication fails to meet its anthropocentric goals. From a moral perspective, the eradication of pikas violates our moral obligation to protect species as suggested by Rolston (1975), while also stressing the non-anthropocentric value system of local pastoralists as practicing Buddhists. Finally, by causing significant losses to biodiversity (Smith and Foggin 1999; Lai and Smith 2003; Delibes-Mateos et al. 2011; Badingqiuying et al. 2016), pika eradication destroys their significant aesthetic values. Therefore, pika eradication programs are lose-lose situations by any justification -- not only expensive, but also destructive to the instrumental, moral, and aesthetic value of the QTP. A policy that supports the widespread eradication of plateau pikas cannot be justified.

Broadly, acknowledgement of nature's intrinsic value is important for its effects on our attitudes and behaviors toward natural objects, which are necessary to reach conservation goals (Vucetich et al. 2014). It has profound influence on intellectual and policy levels as seen in practices around the world, leading to conservation of nature as a common goal. As discussed above, from the vantage of non-anthropocentric environmental ethics, pikas have clear intrinsic biocentric, zoocentric, and ecocentric value. More importantly, pikas also contain significant intrinsic value as sentient beings in the belief system of local people. Intrinsic value of animal (counted singly and as population/species) is an important part of local religious belief systems, so it must be acknowledged. Ultimately, however, management must entertain other values, such as grassland health and human livelihoods. So it is a difficult situation, but the target of ecosystem health unites plural interests, and if a more pragmatic view of the value of individual animals is adopted, then a management policy that avoids the destructiveness of wholesale poisoning while still exercising some degree of population control, is possible.

In summary, grassland management for the QTP should aim to improve grassland health while respecting the beliefs of local people. The first step in such a policy is to stop the mass eradication of pika populations. From there, a trade-off framework should be employed for balancing the sometimes competing interests of pika population density, traditional livelihoods, and economic productivity. Management intervention to maintain an "optimal" density of pikas may be required where their otherwise high-density pika populations can be definitively proven to contribute to worsening of grassland condition. This policy will also require a reduction of grazing pressure where pika density is high and overgrazing occurs. Livestock reduction, when required, should be accompanied by a compensation mechanism. Reassessment of current grassland management practices, including fencing of land, is also recommended in order restore the flexible grazing system employed by pastoralists for centuries (Miller 1995; Miehe et al. 2009). These suggested trade-offs are in alignment with the central concept of strong sustainability, which assumes complementation between human and nature is required for achieving sustainability of a human-dominated ecosystem (Wu 2013). If these steps are taken, I am confident that the QTP, its people, and its pikas can reach a sustainable future.

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