Measuring the response of pikas to control

Methods

At each site, plateau pikas were counted during four sessions, two in spring (24–28 April 2004, 17–25 April 2005) and two in autumn (10–15 September 2004, 13–21 September 2005). Walked transects were used to measure the abundance of plateau pikas at a spatial scale representative of fenced areas (i.e. we sampled from about 9 ha; Figure 7). Surveys were

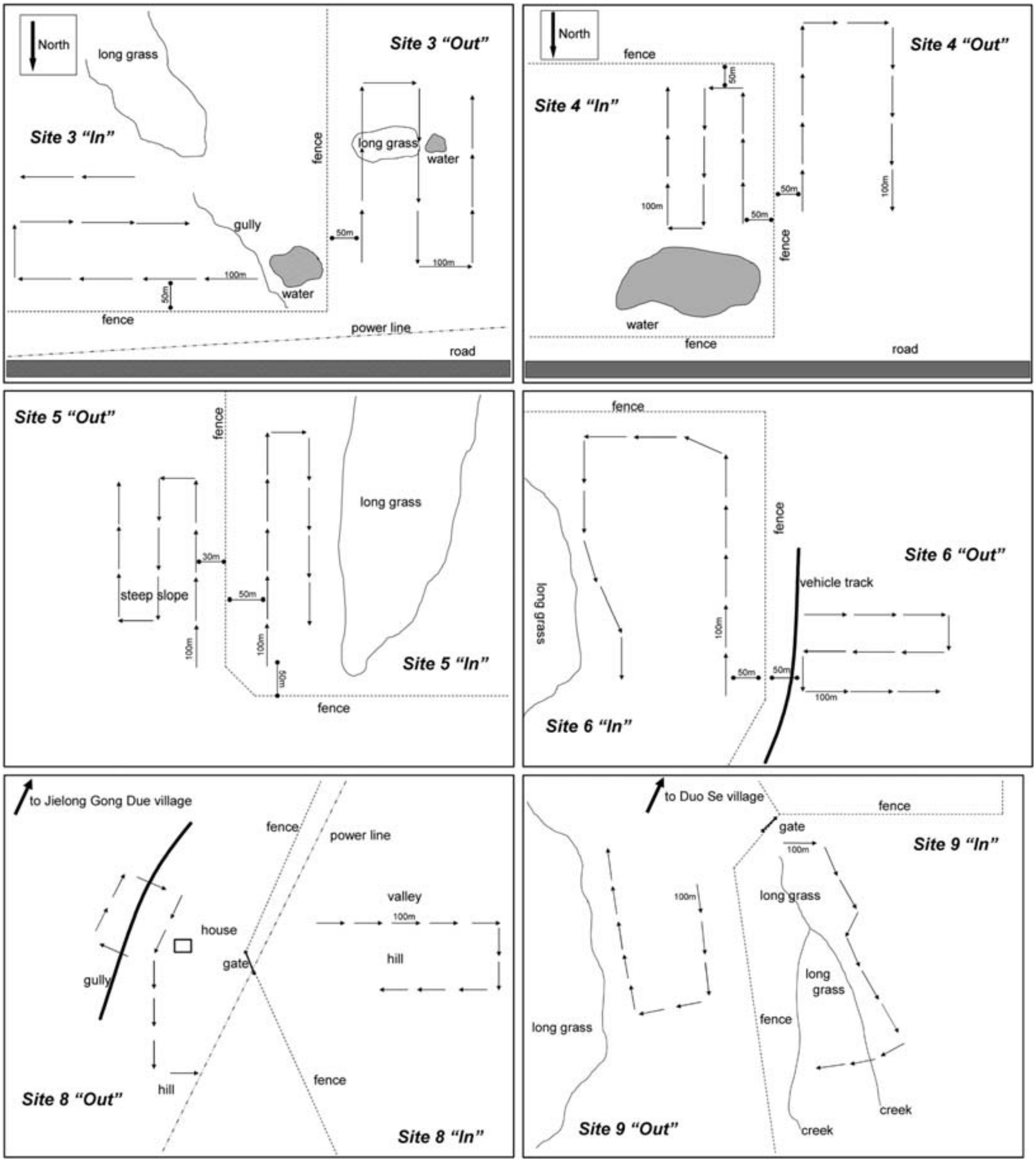

Figure 7. Schematic maps for the plots at the six key sites. The maps show the relationship of the pika transects to local features such as fences and roads. Each 100 m section of a transect is shown as a solid arrow. For most plots, the abundance of pikas was estimated using ten 100 m sections. 'In' refers to the area where grazing was restricted over summer. 'Out' refers to areas grazed all year by livestock.

conducted simultaneously on both sides of the fence ('winter' grazed vs. 'continuously' grazed) at each site between 0900 hr and 1130 hr, which is the period when almost all plateau pikas are present on the surface (Zeng, Wang and Han 1981; Zong and Xia 1987; Zhang et al. 2005). An observer counted all plateau pikas in a 20 m wide belt transect (10 m either side of the centre line), with counts recorded for each of 10 contiguous 100 m sections along a route that sampled the areas inside and outside the fence (i.e. counts covered in total 2 ha inside the fence and 2 ha outside the fence). We assumed all pikas within the strip were observed to derive a density estimate (count per unit area). For each session, the plateau pikas in each area were counted on four mornings, once by each of four observers to account for observer bias. Counts of plateau pikas (N_t at time t) were standardised for observer differences using a mixed effects model with observer as a random effect. Log transformation of the data was required prior to analysis. The exact location of the walked transect was not fixed but followed the same general route inside and outside the fence.

Results and discussion

In April 2005, populations of plateau pikas on Sites 4 and 6 had declined by 84–97% by the end of the week following control (poison effect $F_{1,7} = 133.4$, $P < 0.0001$; Figure 8), indicating highly effective short-term control of pikas using the current technique. We had to assume similar levels of control were achieved on Sites 8 and 9 in the previous year because we could not measure the effectiveness at that time. Based on discussions with the local people this assumption seemed reasonable.

Figure 9 shows the raw data on pika population density (standardised for observer) for the main sites in the study. There were strong seasonal and site differences in the abundance of plateau pikas. The population density in early spring ranged from 0.8–32.7 pikas ha^{-1} in 2004 and 5.2–30.1 pikas ha^{-1} in 2005. By the end of summer, populations had increased 2–50 fold in 2004, ranging from 17.5–51.2 pikas ha^{-1}, and 2–37 fold in 2005, ranging from 8.3–41.0 pikas ha^{-1}. These autumn values are less than maximum seasonal densities recorded at lower elevations on the Tibetan Plateau, possibly reflecting lower productivity and a shorter reproductive season at higher altitude. They may also reflect lower levels of degradation around Naqu. For example, in Dari County at an altitude of approximately 4,100 m, Wang et al. (1997) recorded a population density of 374 pikas ha^{-1}. The maximum density we observed based on a single 100 m section of transect was about 130 pikas ha^{-1}.

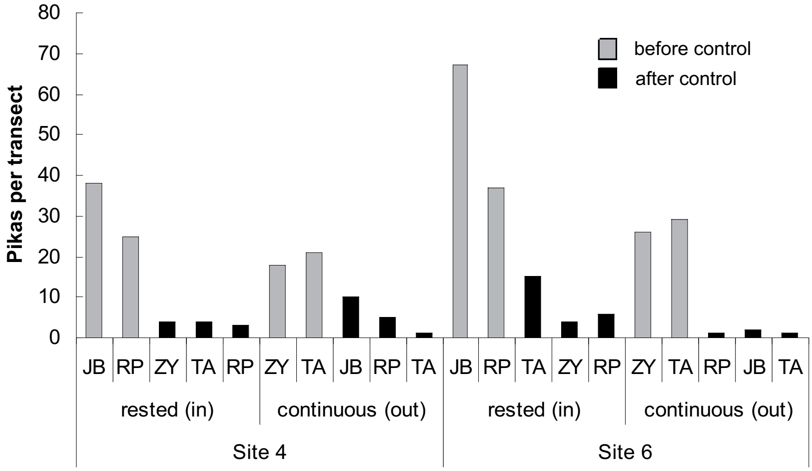

Figure 8. Abundance of pikas at Sites 4 and 6 where control programs were conducted by the local people. The estimates of pika abundance were conducted on two consecutive days before the control programs, and on days 5, 6 and 7 of the post-control period (see Table 1). The observers were Jiebu (JB), Zhang Yanming (ZY), Tony Arthur (TA) and Roger Pech (RP).

When we considered the increase in populations in the breeding season following control, measured as $\ln(N_{t+1}/N_t)$ and standardised to a weekly rate, there was a strong density-dependent increase in plateau pika populations between April 2004 and September 2004 and between April 2005 and September 2005 (ln(density) $F_{1,21} = 178.5$, $P < 0.0001$; Figure 10). There were slight differences in the relationship between summers with higher increases over the summer of 2004 compared with the summer of 2005 for a given starting population density ($F_{1,21} = 12.6$, $P = 0.002$). None of the other factors we tested affected the rate of increase of plateau pikas at this time, including fencing, the biomass of vegetation at the end of the growing season, or the availability of burrows.

The high, density-dependent rate of increase on baited sites resulted in most baited populations returning to high densities after only one summer in 2004 (Figure 11). In 2005, populations on baited sites appeared significantly lower than populations on other sites ($F_{1,10} = 5.75$, $P = 0.037$), but this was more to do with the underlying site differences than an effect of control. This is evident by comparing Figures 11 a and b, i.e. there was no evidence that the population reduction on Sites 4 and 6 in April 2005 resulted in any reduction in peak abundances of plateau pikas on these sites in September 2005 relative to other sites (model of relative population density with treatment and fence as factors $F_{3,8} = 0.319$, $P = 0.81$).

The results indicate that using current techniques greatly reduces the abundance of pikas in the short-term (by over 90%), but populations recover rapidly over the following summer, such that population sizes appear indistinguishable from uncontrolled populations in the following autumn. An estimated rate of increase of around 0.14 week^{-1} is within the reproductive capacity of pikas if summer survival of adults and young is very high, but it is possible that immigration from adjacent uncontrolled areas also contributes to population recovery because of the small spatial scale of control currently used. Our data do not allow us to distinguish between the two possibilities. However, behavioural studies suggest that most dispersal occurs at the start of the breeding season and that most pikas (usually males) disperse only to nearby burrow systems (Smith et al. 1990; Smith and Wang 1991)—a distance usually less than 20–30 m at our study sites—indicating that *in situ* reproduction is more likely to drive most of the population increase.

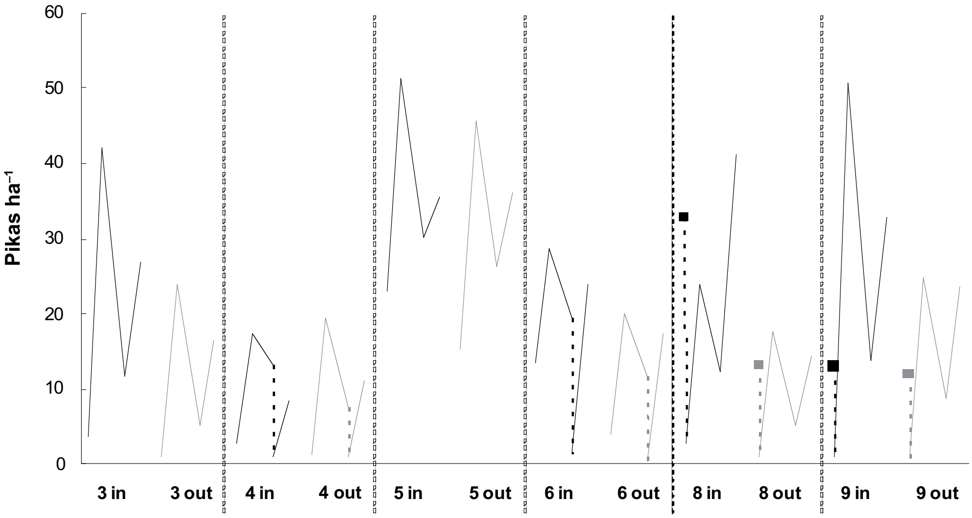

Figure 9. Pika population data obtained throughout the study. The lines follow the population from the first count in spring 2004 to autumn 2004 to spring 2005 to autumn 2005. The dotted line indicates population decline due to control. The squares indicate the starting population density at locations 8 and 9 at the beginning of the study, i.e. before they were controlled. 'In' refers to the area where grazing was restricted over summer. 'Out' refers to areas grazed all year by livestock.

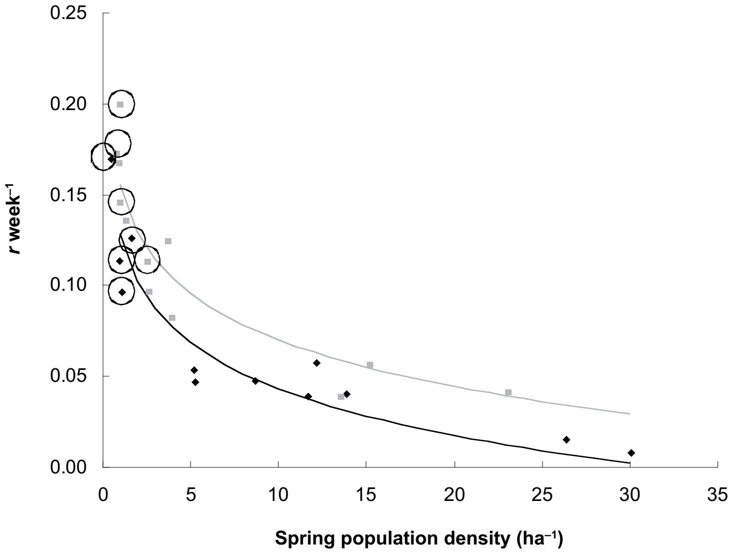

Figure 10. Rate of increase (r) over summer 2004 (grey dots and line) and summer 2005 (black dots and line) plotted against the initial spring population density for each year respectively. Populations indicated with open circles were controlled on either side of the fence at two sites in spring 2004 and on either side of the fence at two different sites in spring 2005. $r = \beta_0 + \beta_1 \ln$(population density of plateau pikas in number ha^{-1}) + β_2(summer) where: $\beta_0 = 0.155$; $\beta_1 = -0.037$; $\beta_2 = 0.0$ for 2004; and $\beta_2 = -0.027$ for 2005. Figure reproduced from Pech et al. (2007).

In Qinghai province pika populations have been reported to recover from <5 ha^{-1} to pre control density of ca. 140 ha^{-1} in 2 years (Liang 1981), similar to the rates of recovery we observed. Our results appear to contrast with the highly effective control programs inferred for parts of Qinghai province (Lai and Smith 2002). These authors suggest pika populations have been reduced and maintained at very low densities, but it seems these programs used repeated yearly control of the same area rather than the 'once-off' control strategy used around Naqu and in the studies of Liang (1981).

Effects of fencing on vegetation and pika populations

Introduction and methods

We used the fencing 'treatments' on our sites to determine whether they influenced how pikas responded to control. We also investigated their effect on the vegetation. The step-point technique (Evans and Love 1957) was used to measure the percentage cover of grass, plant litter and bare soil at each site in April, June and September in 2004, and in April and September 2005. At least 400 step-point readings were recorded on each side of the fence at each site. Each point was two steps apart, i.e. with a spacing of 1.0 to 1.5 m. Initially we used three categories: 'grass' included dry grass stems still attached to the roots, 'litter' was all detached plant material lying on the surface and 'bare soil' included stones, small rocks and cryptogam or lichen crusts on the surface. In September 2005, the 'bare soil' category was subdivided into 'loose bare soil', which was usually associated with eroded areas, and 'solid bare soil', usually consisting of a hard turf layer with a high proportion of grass roots and other organic material. After each set of 10 step points, the height of the sward within 1 m of the observer was estimated at that point. A training period was conducted at the start of each session to ensure consistent use of these categories and measurement protocols by observers.

Above-ground biomass was estimated in September 2005 by clipping 41 quadrats (25 cm × 25 cm) that were chosen randomly within a range of height and cover classes at a sample of the sites. Dominant plant species were recorded for each quadrat. Vegetation was clipped, stored in paper bags, oven dried and weighed. The relationship between biomass (dry weight) and vegetation height and cover was assessed using a linear model, which was then used to calculate biomass based on step-point cover and height measurements carried out at all sessions.

The effect of fencing and session on vegetation cover and height was analysed with a linear mixed-effects model with site and observer as random effects. Proportions were arcsine transformed prior to analysis. Height measurements were log transformed prior to analysis.

Results and discussion

Effect of grazing management on vegetation. A good visual representation of the typical fenceline 'contrast' seen each autumn is shown in Figure 4: no obvious contrast was evident in spring. Figure 12 shows the change in the percentage of bare ground and the height of vegetation for the main sites in the study. Even after the growing season with restricted grazing, the average height of alpine meadow vegetation was <2.5 cm.

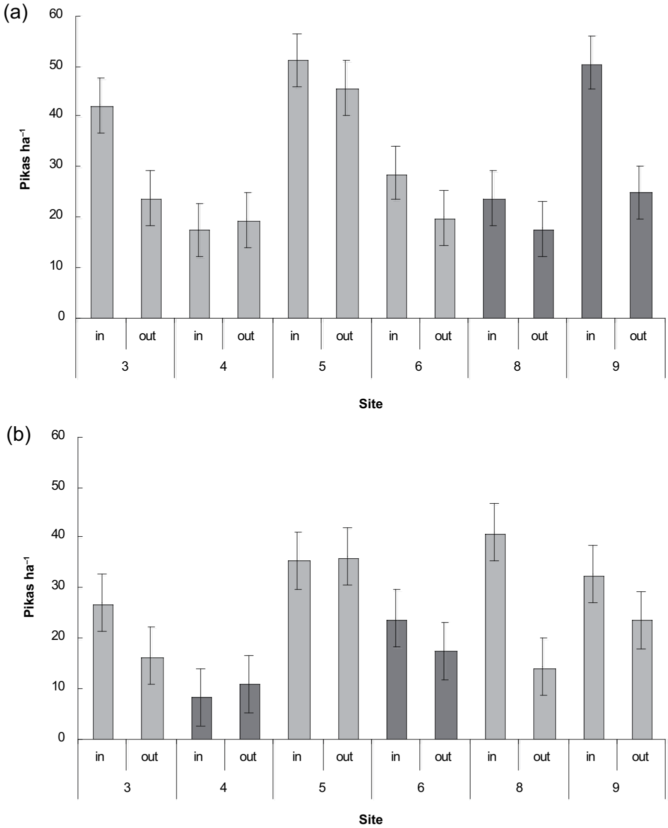

Figure 11. The density of plateau pika populations (±se) at the end of the breeding season in (a) autumn 2004 and (b) autumn 2005. The darker shaded columns indicate sites that were controlled in the preceding spring. Figure reproduced from Pech et al. (2007). 'In' refers to the area where grazing was restricted over summer. 'Out' refers to areas grazed all year by livestock.

There was less bare ground in summer and autumn following the growing season than in spring following winter ($F_{4,48} = 76.73$, $P < 0.0001$), and less bare ground inside areas conserved for winter foraging (fenced) than outside these areas ($F_{1,5} = 13.9$, $P = 0.014$; Figure 13a). On average, vegetation was taller in autumn following the growing season than in spring ($F_{3,58} = 521.0$, $P < 0.0001$), and taller inside areas conserved for winter foraging (fenced) than outside these areas ($F_{1,5} = 18.21$, $P = 0.008$; Figure 13b). However, there were also significant differences in vegetation height between sites (all terms highly significant in a Site*Session*Fence model).

For the clipped quadrats, vegetation height ($F_{1,31} = 49.2$, $P < 0.0001$) and cover ($F_{1,31} = 67.0$, $P < 0.0001$) explained 78% of the variation in dry biomass with no significant interaction. The relationship was dry biomass (g m^{-2}) = –26.8 + 1.13 (% cover of vegetation) + 2.29 (height of vegetation in mm). Applying this equation to the step-point measurements indicated very low biomass on our sites (Table 2). The main plant species were identified by local scientists as *Stipa* spp., *Kobresia* spp., *Leontopodium hapylloides*, *Potentilla chinensis* and *Carex moorcroftii*.

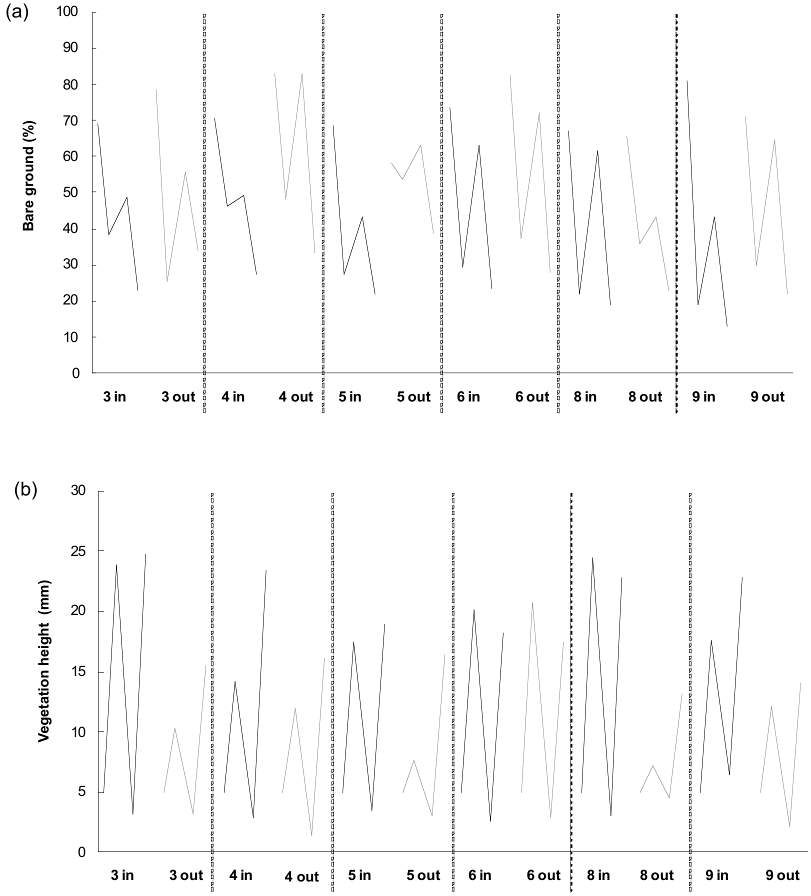

Figure 12. (a) Percentage of bare ground and (b) vegetation height, throughout the study. The lines track the changes from spring 2004 to autumn 2004 to spring 2005 to autumn 2005. 'In' refers to the area where grazing was restricted over summer. 'Out' refers to areas grazed all year by livestock.

Winter decline of pika populations in response to grazing management. There was some evidence that plateau pika populations declined more rapidly over winter outside fences regardless of the starting population in autumn, than inside fences where the population decline was more density-dependent (fence main effect $F_{1,3}$ = 18.5, P = 0.02; fence by autumn density interaction $F_{1,3}$ = 6.01, P = 0.09; Figure 14a). This resulted in much higher pika populations in spring 2005 inside fenced areas than outside fenced areas ($F_{1,5}$ = 27.40, P = 0.003; Figure 14b), consistent with what we observed at the commencement of the study (Figure 15). This may indicate that the extra vegetation inside fenced areas benefited pikas over

Table 2. Biomass estimates throughout the study based on the equation derived from measurements conducted in September 2005. We assumed the equation derived from autumn data was also applicable to spring data.

Period	Biomass of vegetation (g m^{-2})	
	Rested over winter (inside)	Continuous grazing (outside)
April 2004	4.2–26.0	2.8–33.6
September 2004	66.5–112.5	43.0–83.4
April 2005	20.7–51.9	0.0–47.4
September 2005	101.1–125.2	81.3–94.1

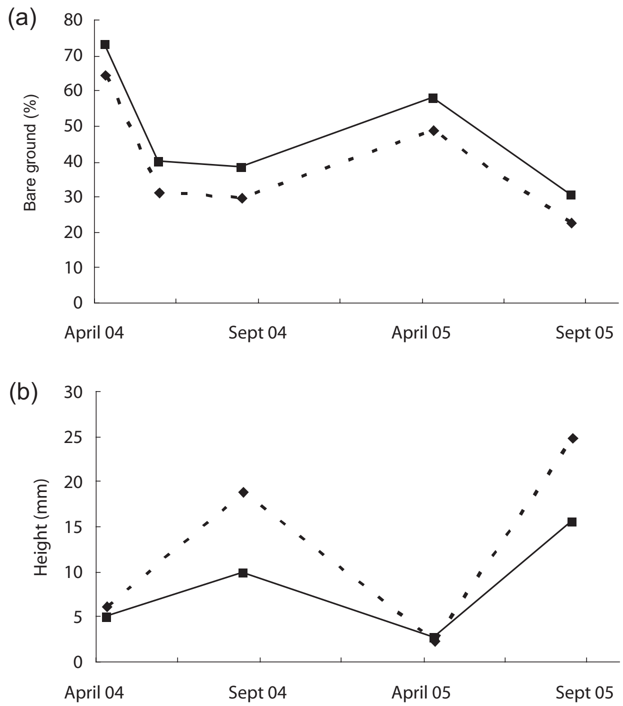

Figure 13. (a) The percentage of ground that was bare inside (dotted line) or outside (solid line) fenced areas. (b) The height of vegetation inside (dotted line) or outside (solid line) fenced areas. Areas inside fences are grazed by livestock mostly during winter. Areas outside fences are grazed year round. Figure reproduced from Pech et al. (2007).

winter, particularly when the autumn population density was relatively low. However, we could find no relationship between the over-winter decline of plateau pika populations and the amount of vegetation where this was used in the analysis rather than treating fence as a factor.

Response of vegetation to pika control. Although controlled pika populations recovered over the summer period (when vegetation grows in this system) the low post-control population starting point means that if pikas are having a significant impact on the vegetation we should still expect to see

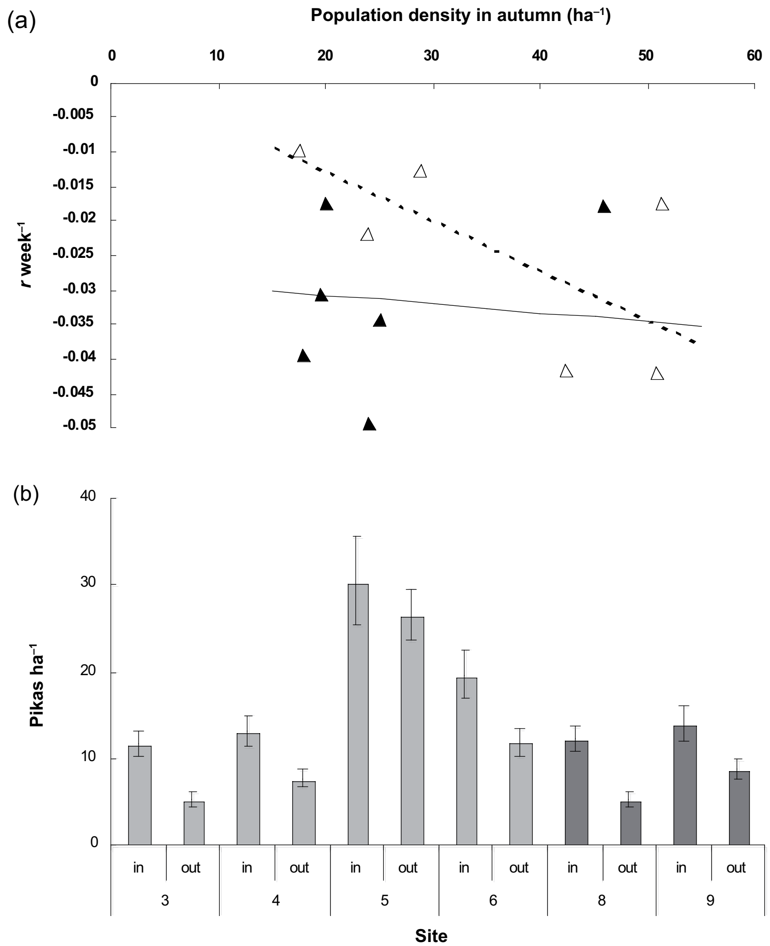

Figure 14. (a) Rate of increase of pika populations over winter 2004/05, given by ($r = \ln(N_{t+1}/N_t)$), plotted against autumn population density in 2004. More negative numbers mean greater rates of decline. Solid line and solid symbols are outside fenced areas (continuous livestock grazing), and dotted line and open symbols are inside fenced areas (rested in summer). (b) Population density of plateau pikas in April 2005 (mean ± se). The darker shaded columns indicate sites that were controlled in spring 2004. Figure reproduced from Pech et al. (2007). 'In' refers to the area where grazing was restricted over summer. 'Out' refers to areas grazed all year by livestock.

some response in the vegetation. This should be observable inside fenced areas, where grazing by livestock is restricted over summer. Compared to areas with untreated pika populations, there was no evidence that poisoning plateau pikas in April resulted in a higher biomass of vegetation inside fenced areas in September ($F_{1,9}$ = 0.027, P = 0.87). However, there was a trend towards a higher change in biomass over summer inside fenced areas that were controlled, but this was not statistically significant ($F_{1,10}$ = 2.017, P = 0.19; Figure 16). It needs to be stressed that our study was not designed specifically to measure the impact of pikas on vegetation and this type of study should be conducted in the future, incorporating the appropriate grazing treatments. Nonetheless, this result provides further evidence that the current control of pikas appears to have little impact on vegetation cover or biomass in this system.

In April, the alpine meadows had been grazed to uniformly short plant height, <1 cm, with no differences either side of the fences (Figures 4 and 13). This suggests the suite of herbivores remove virtually all usable plant biomass by the end of winter, a conclusion supported by reports from villagers that they need to purchase supplementary food to sustain their animals through winter. If winter is the critical time for food shortage, then there is no benefit of pika control in spring, because pika populations have recovered prior to the following winter. It is possible that controlling pikas prior to winter may provide some benefit to livestock in the following winter, but this could be negated by density-dependent rates of decline over winter and remains to be investigated. It is not known whether pikas can be successfully controlled in autumn, whether this would have a significant effect on the amount of vegetation available to stock over winter, or whether it is economically viable to control pikas. As a rough calculation of the impact of pikas, if: (1) the biomass is 120 g m^{-2} at the start of winter (which is 1200 kg/ha, the maximum we observed); (2) we assume the pika population declines uniformly from 50 ha^{-1} to 30 ha^{-1} over winter; and (3) we assume the average food requirement of a pika is about 420 g $month^{-1}$ $individual^{-1}$ (based on a reported yearly requirement of 5 kg $individual^{-1}$ for Mongolian pikas); then pikas will consume about 120 kg of biomass ha^{-1}, or 10% of that available, over the 7 months of winter. If pika control was effective at protecting this 10% of food, any effect would be likely to last for one winter only because pika populations would be expected to recover the following summer.

Erosion

Introduction and methods

Erosion is a serious issue on the plateau, although we are not aware of any data documenting changes in the extent of erosion, particularly during the period following large increases in livestock numbers (Figure 2). In some areas we visited in Qinghai prov-

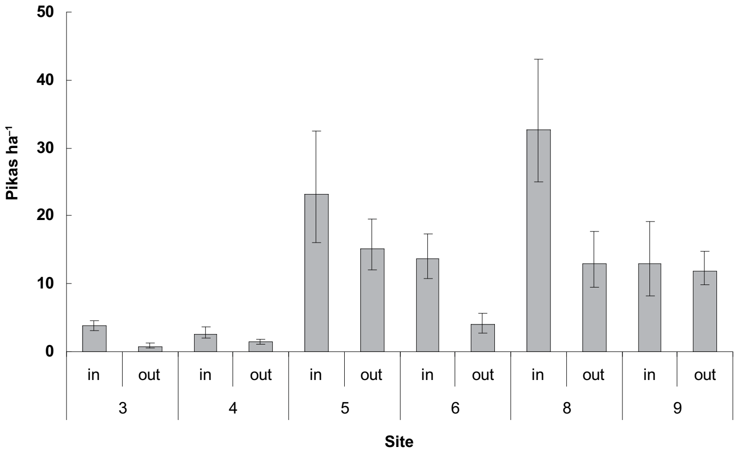

Figure 15. Population density of plateau pikas (mean ± se) at the start of the study in April 2004. ‘In’ refers to the area where grazing was restricted over summer. ‘Out’ refers to areas grazed all year by livestock.

ince the hard turf layer was almost totally gone, exposing loose soil which local people call ‘black soil’ (Figure 17). At the heart of the issue is whether increased pika populations are a cause of erosion, or a symptom of it, or some combination of the two. Pika populations may have increased for some reason and the increased populations cause more erosion, or overgrazing may have resulted in increased erosion which creates additional burrowing opportunities for pikas and hence increases their populations. We could not investigate this directly in our study, and determining the cause/s of erosion and the path to recovery should be a high priority objective of future experimental research.

As part of our project, we gathered preliminary data on the percentage of black soil at our sites and on the number of burrows (Figure 18). Belt transects were use to count burrow entrances at each site in April and September 2005. All burrow entrances were counted in 10 consecutive 4 m × 100 m strips set

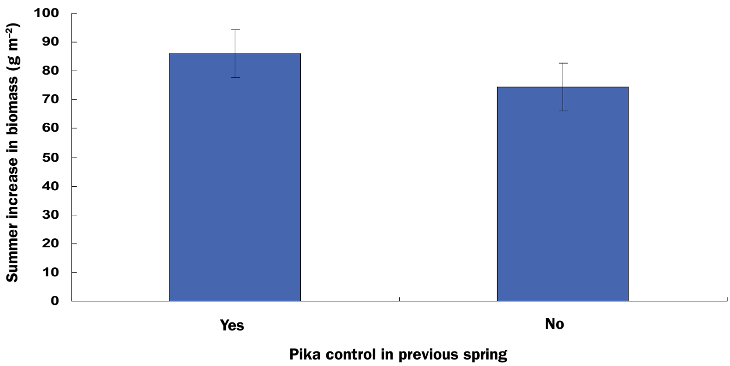

Figure 16. Increase in biomass between spring and autumn on sites with and without pika control. Although a trend was evident, the results were not statistically significant ($F_{1,10} = 2.017$, $P = 0.19$).

Figure 17. Soil erosion in the Qinghai province. Almost the entire hard surface layer is gone leaving loose soil with low productivity.

out along a route to sample the areas inside and outside the fence. In September, active entrances (characterised by clear openings and fresh soil) and inactive entrances (characterised by openings with undisturbed material such as plant litter or spider webs) were counted separately. It was not possible to distinguish active and inactive entrances unambiguously in April. The percentage of loose soil was determined by the step-point counts.

Erosion was evident on all sites, with most sites having 5–10% of their surface classed as loose soil (Figure 19). These percentages were considerably smaller than some areas in Qinghai province, but Site 5 (outside fence) already showed considerable ero-

Figure 18. Erosion patch, showing the loose subsoil that is exposed when the hard upper soil layer is removed. Pikas often burrow into the soft soil under the hard surface layer.

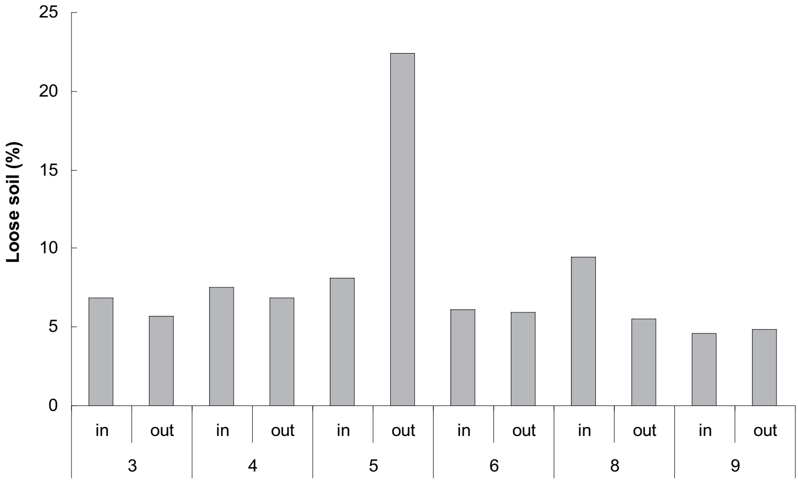

Figure 19. The percentage of loose soil at each site, measured using the step-point technique.

sion. In this case, the slope of the site was probably contributing to the problem.

There was a strong relationship between the percentage of loose soil measured in September 2005 (the first time we measured loose soil) and the number of burrows counted in April 2005 (Figure 20). This is consistent with either pika burrowing contributing to erosion, or pika populations responding to increased erosion. Cause and effect cannot be determined from this type of analysis, but it does suggest some linkage between the processes.

Using data from both inside and outside fences, there were strong relationships between the density of plateau pika populations on our sites and the number of burrow entrances counted in both spring ($F_{1,6}$ = 12.27, *P* = 0.006) and autumn ($F_{1,10}$ = 19.37, *P* = 0.005; Figure 21). Again, this does not tell us whether more pikas lead to more burrows, or easier burrowing conditions lead to more pikas.

On average there were 345 more burrows ha^{-1} inside fenced areas than outside ($F_{1,5}$ = 8.31, *P* = 0.034). There was some evidence that poisoning plateau pikas in April 2005 decreased the total number of burrows present on poisoned sites the following September by about 33%, while the total number of burrows on untreated sites increased by about 10% ($F_{1,4}$ = 9.77, *P* = 0.035). The reduced counts of burrow entrances 5 months after pika control on Sites 4 and 6 in 2005 were unexpected. Entrances through cracks and small openings in the hard turf layer appear to be relatively durable. However, many burrows were located in erosion patches (Figure 18) where lack of constant use could allow them to be covered by loose, friable soil. Trampling by livestock may also collapse the edges covering unused burrows. The reduction was not due to vegetation growing and obscuring burrows from observation following control—our observations of plant re-establishment on loose soil at unused burrows indicate that revegetation could not conceal burrow entrances within one summer, at least in areas with current levels of grazing by livestock.

Our results indicate that in the short-term at least, controlling pikas reduces the number of burrows, but this was not sufficient to prevent populations of pikas from recovering. Whether this could lead to a reduction or reversal in the breakdown of the hard turf layer if pika control is maintained for longer periods is yet to be determined. In Qinghai province, attempts have been made to restore extensive areas of degradation like that shown in Figure 17 by planting a fodder crop (pers. comm. Dr Long Ruijun, Lanzhou

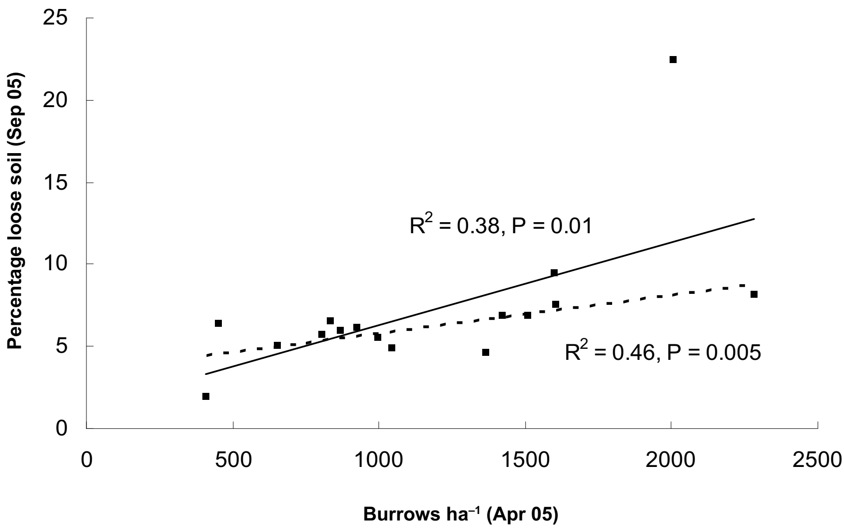

Figure 20. Relationship between the percentages of loose soil measured in September 2005 and the density of burrows counted in April 2005. We used the burrow count from April 2005 rather than September 2005 because the September burrow count was affected by the pika control applied in April 2005 (see below). Solid line: with Site 5 (out) included with the data; dotted line, with Site 5 (out) removed from the data.

University). Small mammal control is necessary during the establishment of this crop. The fodder crop grows well for about 6 years but, after this time, most of the limited nutrients in 'black soil' have been removed and artificial fertiliser is necessary to keep the system going. The crop does little to bind the soil together and is therefore not effective in putting the system on a recovery path where the hard turf layer could be restored.

Restoration is clearly far more difficult than preventing the breakdown of the surface layer in the first place. This is a key issue for the alpine grasslands in TAR that are the foundation for the livelihoods of the local people and also form the headwaters of many of the major rivers that service a large part of South-East Asia. It is essential that the cause/s of the erosion are determined and that management practices are put in place to prevent further erosion. Dr Long Ruijun feels the system can degrade to the state shown in Figure 17 in as little as 15 years, so it is critical that immediate action is taken. Recovery, if possible, may take decades in systems like these if the hard turf layer is lost.

We know that livestock numbers on the plateau have more than doubled in the past 50 years (Figure 2). At the same time there is anecdotal evidence of an increase in plateau pika abundance (Beimatsho,

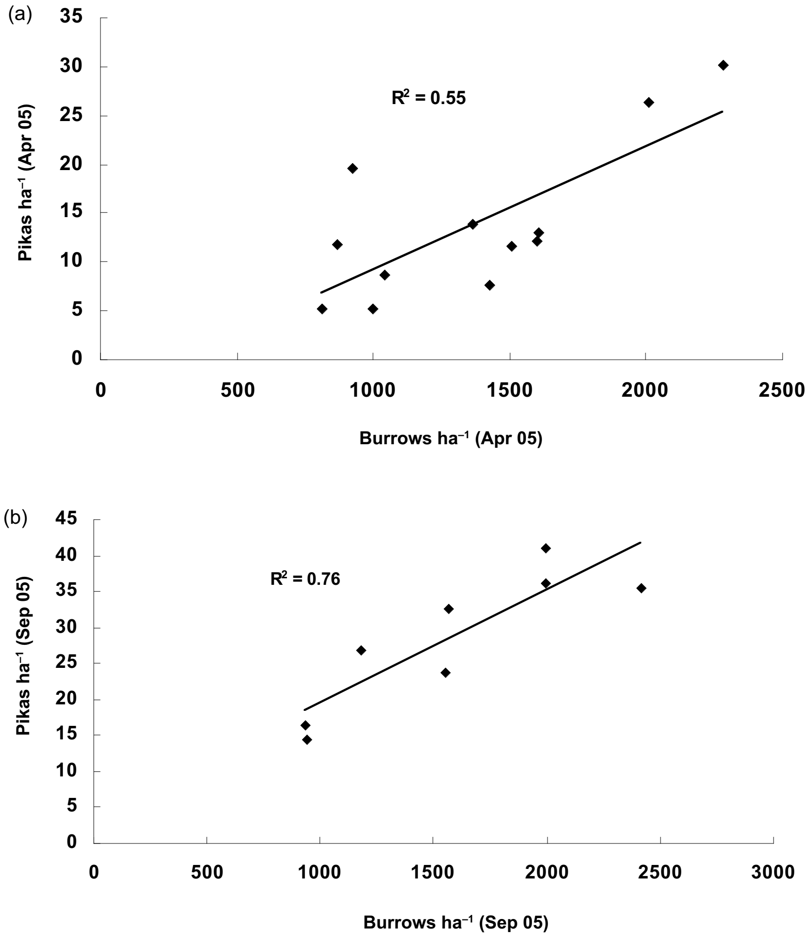

Figure 21. Relationship between the density of plateau pika populations and the total number of burrow entrances. (a) Spring; plateau pikas (ha^{-1}) = –3.4 + 0.0125 x burrow entrances (ha^{-1}) (b) Autumn; plateau pikas (ha^{-1}) = 3.58 + 0.0157 x burrow entrances (ha^{-1}). Figure reproduced from Pech et al. (2007).

unpublished report) because something in the system has changed to benefit pikas. This is likely to be due to either a change in pasture composition and/or structure, and/or improved burrowing conditions for pikas due to increased erosion. Another possibility is a longer breeding season for pikas due to climate change (Giorgi et al. 2001), although this might be offset by a change in pasture composition (Klein et al. 2007). It is likely that a reduction in livestock density is required to prevent the system from degrading further and hence moving to a highly degraded 'black soil' state. Work is required to determine how this can be accomplished while maintaining or improving the livelihoods of the local people. A focus on animal productivity will likely be one part of the solution—livestock weights at market have declined as the system has degraded. This is a typical pattern in overgrazed systems (Jones and Sandland 1974). What is not clear is how important concurrent pika control will be to buffer the system from a transition to the eroded black soil state. Ecological research is required to determine whether the pika problem will diminish with a change in livestock grazing practice (reduced grazing), or whether pika control will be required, at least in the initial stages, to help the system to recover to a more resilient state.

Plateau pikas and biodiversity on the plateau

Introduction and methods

Plateau pikas are considered a keystone species on the plateau. They are a major prey item for raptors and their burrows provide nesting sites for many small passerine birds. Because of this, concerns have been raised about the impacts of broad scale pika control on the biodiversity of the plateau (Lai and Smith 2002). These concerns are for both the potential effects of a significant reduction in pika abundance and the direct killing of non-target animals during poison baiting for pikas. These issues are complex ones, because it is not clear what management targets for plateau biodiversity should be. Overgrazing by livestock may be having significant impacts on the biodiversity on the plateau at present, so a shift away from this situation could benefit biodiversity, particularly plant species, but also potentially other organisms that feed on those plants. If pikas are a symptom of overgrazing by livestock then reducing grazing pressure may result in a reduction in pika density with consequential reductions in dependent species. Clearly removing plateau pikas from the system completely would be likely to have major impacts on biodiversity. For example, in Qinghai province, where intensive and successful pika control has been reported over large areas, the densities of raptor populations have been reduced greatly (Lai and Smith 2002). We have no information on management objectives for conserving biodiversity on the Tibetan Plateau, nor do we have answers from our study about what these objectives should be, but we have collected data on some of the species that may be affected by pika control. These data will provide a baseline against which the impacts of any future management changes can be assessed.

The relatively small scale of control applied to areas covered by our study (about 35 ha each side of a fence) did not allow us to make a direct assessment of the impact of this control on predators of pikas. However, we collected data over hundreds of kilometres which will provide a baseline for changes in the densities of these predators if management changes are implemented in the TAR. On all four project trips we counted the number of large raptors and mammalian predators while driving the 320 km between Lhasa and Naqu. From September 2004, we divided the counts into four segments, reflecting different habitat types and we also counted these species when driving between Naqu and our field sites. This is a broad scale survey method used elsewhere, e.g. bird of prey surveys in Australia, and it covers the distances required to count predators with little additional resources. From September 2005, we counted the small birds at our sites twice per session using walked transects similar to those employed for pikas. Birds were counted over 10 consecutive 100 m long, 50 m wide transects (25 m either side of the centre line).

Results and discussion

Raptors and mammalian predators. We saw small numbers of black-eared kites *Milvus lineatus*, saker falcons *Falco cherrug*, lammergeyers *Gypaetus barbatus* and common kestrels *Falco tinnunculus* on all trips. Mammalian predators were seen very infrequently and included Tibetan foxes *Vulpes ferrilata*, wolves *Canis lupus*, cats (species uncertain) and martens (species uncertain). The only species seen commonly was the upland buzzard *Buteo hemilasius*, a major predator of pikas, and the Himalayan griffon *Gyps himalayensis*, which feeds on carrion. The numbers of buzzards seen on the higher altitude sections closer to Naqu were similar to the numbers seen around Naqu as we travelled to our field sites (Table 3). However, in both September 2004 and April 2005 more raptors were seen around Naqu. It is not clear whether this reflects a real difference in the density of buzzards, or whether it reflects the generally slower speeds travelled on rural roads around Naqu. None-theless, this technique suggests that upland buzzard population abundance was relatively high in this area and these data would be sufficient for detecting large changes in the abundance of this species.

Small birds. A range of small bird species was observed on our study sites including the white-rumped snowfinch *Pyrgilauda taczanowskii* (the most common), the rufous-necked snowfinch *P. ruficollis* and Hume's groundpecker *Pseudopodoces humilis*. In April 2005 there was a positive association between the abundance of white-rumped snowfinches and the abun-dance of pika burrow entrances (Figure 22), but no association with the fencing treatment. This indicates that a reduction in pika burrows could disadvantage this species during spring when they are breeding.

In September 2005 site counts of white-rumped snowfinches indicated a trend towards higher abun-dance inside fenced areas compared with outside fences (Figure 23) but no clear association with the density of burrow entrances. This suggests that in autumn the local distribution of white-rumped snow-finches might be determined more by the availability

Table 3. The average number of upland buzzards seen per 100 km either on the trip to and from Naqu or between Naqu and our field sites. Few raptors were seen in the lower altitude sections close to Lhasa and data are not shown for these sections

Date	No. of upland buzzards per 100 km		
	Trip to Naqu Section 3[1]	Trip to Naqu Section 4[2]	Around Naqu[3]
April 04	26[4]		—
September 04	17	17	36
April 05	13	21	33
September 05	19	23	21

[1] High altitude wide valley
[2] Open plateau from top of wide valley to Naqu
[3] Observations made between Naqu and field sites
[4] Sections 1 and 2 combined

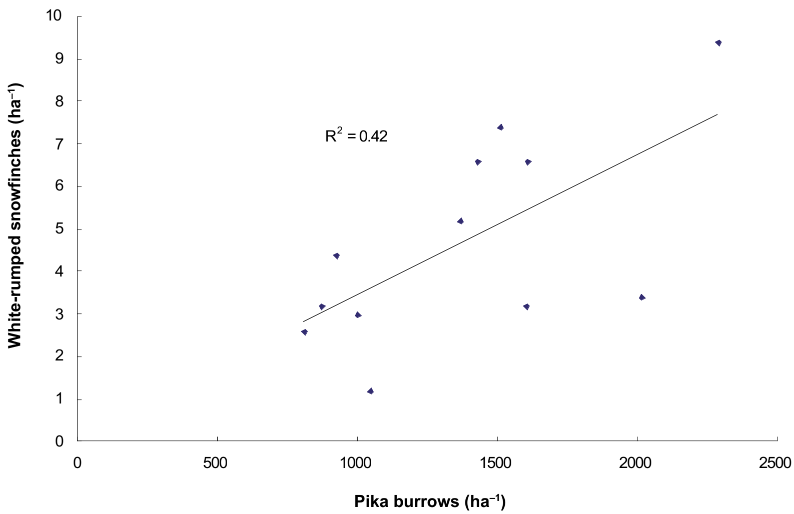

Figure 22. Relationship between the number of pika burrow entrances and the abundance of white-rumped snowfinches in April 2005 ($F_{1,10}$ = 7.11, *P* = 0.024).

of food associated with generally taller grass inside fenced areas than by nest sites in pika burrows.

We found no evidence of any immediate impact of pika control on small birds (i.e. no observations of dead birds), nor any evidence of a longer-term impact (Figure 24). Determining the impact of changed management, or long-term pika control, as reported by Lai and Smith (2002), on the abundance of species such as the white-rumped snowfinch would require further study.

Summary and discussion

The alpine meadow system on the Qinghai–Tibet Plateau is characterised by a hard turf layer which, when broken down, exposes a much looser and less productive soil which the locals call ‘black soil’. Ninety percent of the grassland is now considered degraded to some extent (some black soil) and the severity of the degradation is increasing. There is some acknowledgment that overgrazing by livestock

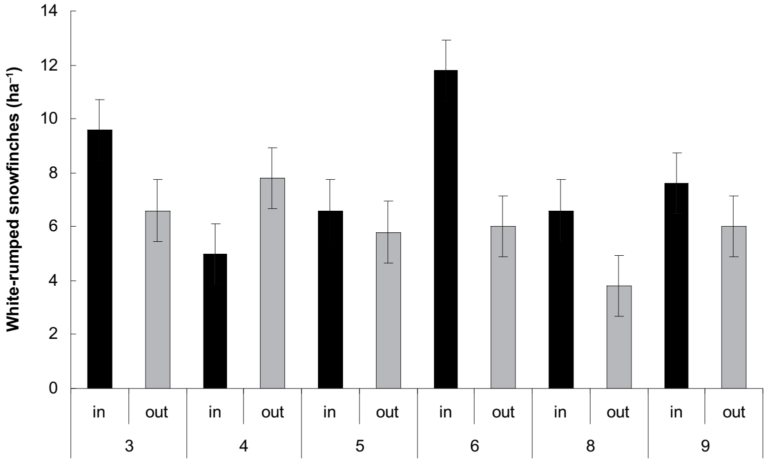

Figure 23. Estimates of the abundance of white-rumped snowfinches (mean ± se) in September 2005 (autumn). There was a trend towards higher numbers inside fences, with Site 4 the main exception ($F_{1,10}$ = 2.72, P = 0.113).

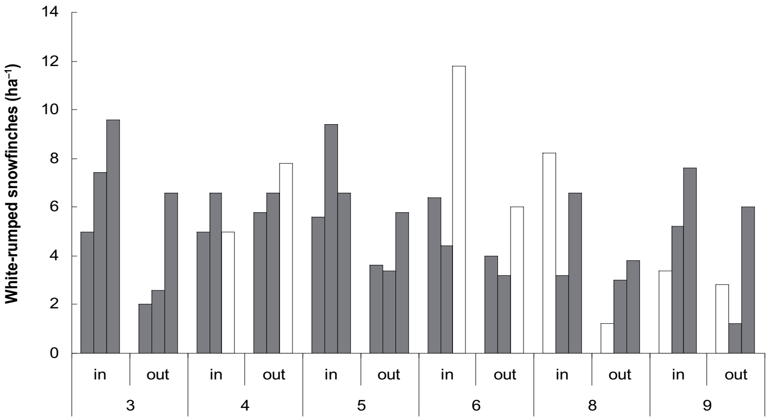

Figure 24. Density estimates of white-rumped snowfinches throughout the study. The first column is September 2004, the second column is April 2005 and the third column is September 2005. The white columns indicate counts made in the autumn after pika control the previous spring.

has contributed to this degradation, but there is also a strong belief by local people that plateau pikas (*Ochotona curzoniae*), a small native mammal, makes a significant contribution to the problem (Beimatsho, unpublished report). This has led to increasing efforts at pika control using primarily poison baiting with Botulin toxin C. However, the efficacy of this technique has been questioned. There are also serious concerns about the non-target impacts of this method.

Based on local evidence and experience elsewhere, it is clear that overgrazing is a major issue for the plateau. Livestock numbers on the plateau have more than doubled in the past 50 years. At the same time livestock carcase weight has declined (TBAAH unpublished data), suggesting that the system has been pushed to a point where animal productivity is declining (Jones and Sandland 1974). This pattern is typical of that seen in natural (Sinclair et al. 2006) and exploited grazing systems and is illustrated in Figure 25. As stocking rate increases competition between stock reduces the weight gain of individual animals. At very high stocking rates overall production declines. Managing the system at lower stocking rates produces equivalent overall production and is more sustainable. The relationships shown in Figure 25 suggest that reducing the stocking rate (say from C to A) would restore the productivity of the system. However, this depends on changes to the system that occur due to having too many stock. High stocking rates can lead to pasture compositional changes and to erosion, which could result in either a permanent reduction in the maximum productivity of the system (Figure 26), or a system that requires considerable inputs to restore its productivity. For example, restoration from the black soil state, which occurs on the plateau when the hard turf layer is lost, may not be possible.

Coincident with increased stocking rates on the plateau, anecdotal information indicates the abundance of plateau pikas has increased also probably because something in the system has changed to benefit pikas. This is likely to be due to either a change in pasture composition and/or structure, and/or improved burrowing conditions for pikas due to increased erosion. We found a relationship between the number of pika burrows and the amount of erosion, but we cannot determine cause and effect from our study—pikas may be a symptom of the problem of overgrazing, rather than the main cause of erosion. Reducing livestock densities may preclude or reduce the need for pest control, following the concepts of ecologically-based pest management which have been promoted for other systems (Zhong et al. 1991; Singleton et al. 1999; Hinds et al. 2004). However, it is not clear whether erosion and/or pika populations will decrease naturally with reduced stocking rates, or whether concurrent pika control will be required now that pika populations are at high densities.

If pika control is required, then the results from our study indicate that the current strategy of 'once-off' control in spring with Botulin toxin C on wheat bait is not appropriate in short-alpine meadow habitat. This is the main habitat where pikas are considered a problem by local people. We observed very effective immediate control of pikas (ca. 90% reduction), but pika populations were able to recover rapidly over the following summer breeding season. We also found no clear indication that this control resulted in increased pasture production over summer. The number of pika burrows present the following autumn was reduced, possibly because inactive burrows were filled by adjacent loose soil or by stock trampling on the edges. Our study was too short to determine whether this reduction in burrows would have any implications for erosion patches.

The practice of conserving alpine meadow forage for winter by restricting livestock grazing over summer with fences appears to benefit pikas, with higher populations inside fenced areas after winter than in adjacent areas outside fences. This result is not surprising given the extremely low biomass of vegetation that exists outside fenced areas at the start of winter under current grazing practices—generally much less than 50 g m^{-2} (dry weight). The pika population density remains relatively high throughout the winter season inside fenced areas, potentially providing competition to the stock. However, we have no data that directly measured this impact. We estimated that the pika populations would consume about 10% of available biomass. Considering only competition for forage, controlling pikas immediately prior to winter may have more benefit for livestock. However, we do not know whether effective control could be implemented at this time, or if it is feasible for herders to provide the necessary labour at that time of the year, or what it would cost. Population recovery the following summer is also likely to occur, meaning this control would need to be applied every year. We do not know whether this strategy would be useful for dealing with the more serious issue of erosion.

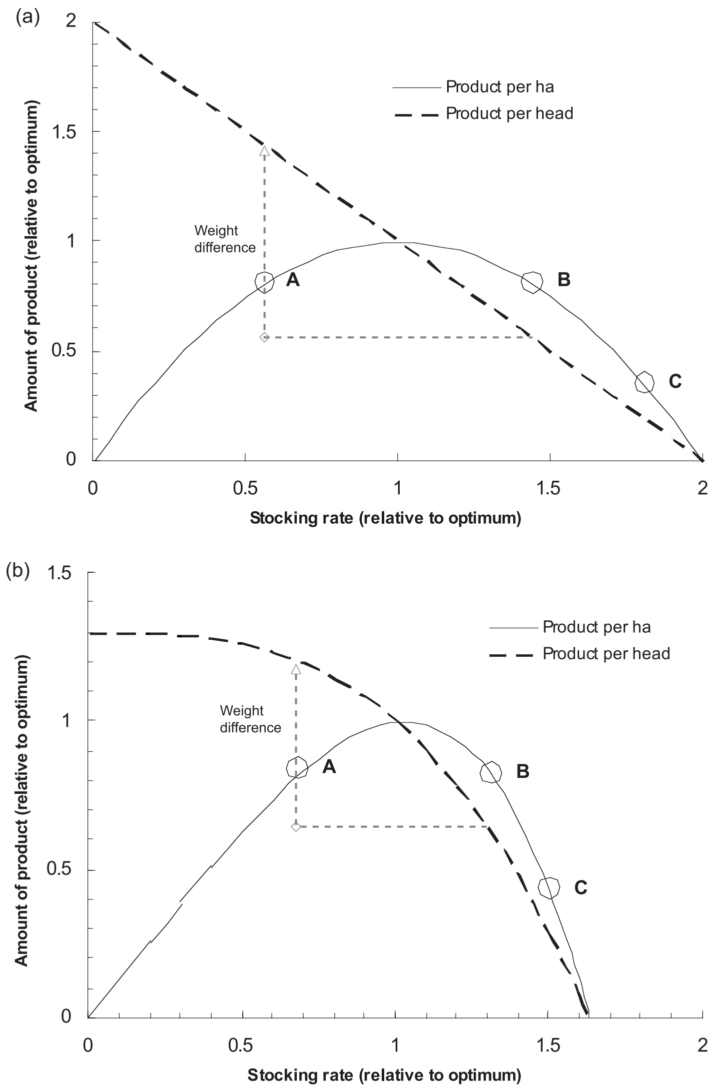

Figure 25. Relationships between animal gain per head and per hectare for young animals grown for sale. (Modified from figures provided by Dr David Michalk, based on typical relationships in grazing systems; Jones and Sandlands 1974). (a) Linear decline in production per hectare as stocking rate increases. (b) Accelerated decline in production per hectare as stocking rate increases. Production per hectare at points A and B is the same, but animals at point A have a much higher weight gain because of reduced competition between stock. As the stocking rate is increased beyond B (e.g. to C), overall production declines dramatically. The optimum stocking rate lies between A and B, but it is not feasible to manage for this point, which will vary from year to year depending on the productivity of the season (e.g. growing conditions for pasture). Managing the system around A rather than B is more likely to provide sustainable production.

Other studies have indicated that poison baiting can kill non-target species, particular birds (Lai and Smith 2002). In addition, plateau pikas are considered a keystone species because of their pivotal role in the community dynamics of these high-altitude grasslands. Hence, there are concerns about the impacts on biodiversity that broad scale control of pikas may have. This is a complex issue and it is currently unclear what biodiversity conservation objectives should be. It is likely that the current overgrazing by livestock on the plateau is having an impact on biodiversity and a reduction in grazing pressure may benefit biodiversity.

Reducing livestock grazing may result in some reductions in pika populations, with associated reductions in some native species such as ground-nesting birds. Completely removing pikas from the system is likely to have significant negative consequences for biodiversity. We have gathered baseline data for avian biodiversity against which future changes could be compared.

Recommendations

Significant degradation has already occurred on the grasslands of the Tibetan Plateau. Around Naqu, where we conducted our study, most areas are showing some signs of degradation, but the hard turf layer is still largely intact. This could change relatively quickly and, if it does, the system may never recover. There are two critical issues for the plateau. One is to restore already degraded areas such as that shown in Figure 17—a task that, so far, is proving extremely difficult. The other is to prevent areas that have limited degradation from degrading further. The latter can be more easily achieved, but a reduction in livestock density is almost certainly required. Work is required to determine how this can be accomplished while maintaining or improving the livelihoods of the local people, some of the poorest people in Asia (Fan et al. 1999). A focus on livestock productivity is likely to be part of this solution (Figure 25).

At the same time, ecological research is required to determine whether pika populations will decline naturally to levels where they are no longer considered a pest following a change in livestock grazing practice (reduced grazing), or whether pika control will be required, at least in the initial stages, to promote recovery of the alpine meadow system to a state where pikas are not benefited. Small mammals, including pikas, have the potential to provide beneficial ecosystem services through nutrient cycling and by direct physical impacts (Brown and Heske 1990;

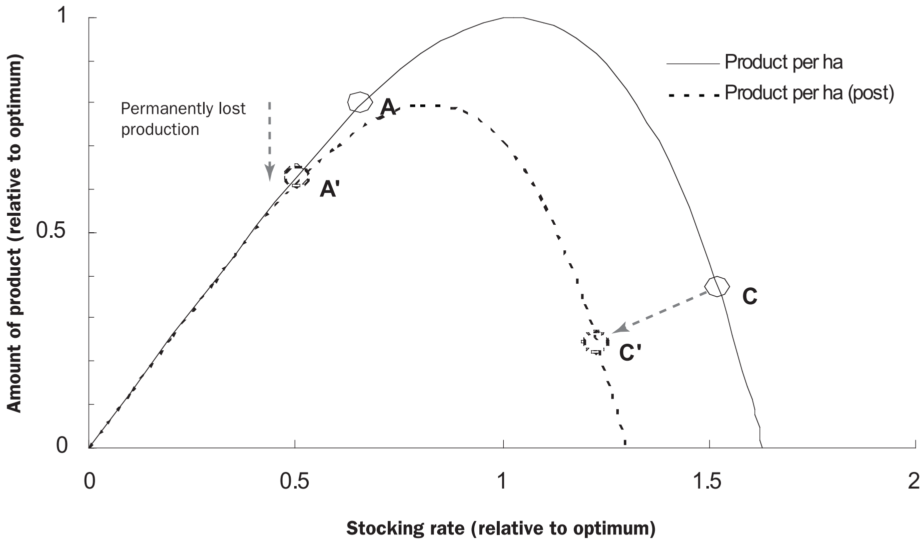

Figure 26. Diagrammatic representation of how the system can change permanently from overstocking. Permanent changes (e.g. erosion) arise from having stock numbers at C and result in a further reduction in the productivity of the system and the number of stock that can be carried to C′. Reducing stock numbers at this stage means the system returns to A′ and the productivity that once existed at A cannot be recovered.

Jones et al. 1994; Jones et al. 1997; Dickman 1999; Smith and Foggin 1999; Zhang et al. 2003a), so complete removal of pikas from the system is likely to be detrimental to its productivity in addition to the potential impacts removing pikas will have on plateau biodiversity. If pika control is required in addition to livestock reduction, then new methods or strategies will need to be developed that are effective.

Ideally, these changes will happen in an adaptive management framework so that responses to management actions can be measured. Large-scale reductions in livestock densities and pika densities in various combinations should be implemented and effort should be made to record the responses of vegetation, erosion, livestock weight and pika populations to these changes. It is essential that sustainable grazing systems and wildlife management strategies are developed quickly to protect the livelihoods of Tibetans and the unique biodiversity of the plateau.

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