THE RUFFORD SMALL GRANTS (FOR NATURE CONSERVATION)

Project Title:

TOWARDS PARTICIPATORY CONSERVATION IN THE TRANS-HIMALAYA: CONSERVING RANGELANDS FOR WILDLIFE AND PEOPLE'S LIVELIHOODS

Grantee:

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OBJECTIVES

Trans-Himalaya is a vast rangeland system in central-Asia's highlands, where indigenous pastoralists have lived for millennia. It is also the home of several fascinating mountain-mammals. People and wildlife have shared these rangelands for ages, but this coexistence is no longer harmonious. There are serious concerns over rangeland-degradation and their suitability as wildlife habitat as well as sustainability of peoples' livelihoods.

Two primary drivers of degradation have been identified as – (i) progressive increase in stocking densities that coincides with various socio-economic changes, and (ii) global climate change that has led to altered temperature and precipitation regimes over the last few decades. Thus, it is pertinent to ask questions about long-term sustainable use and conservation of these rangelands along these two lines: (i) how does grazing effect ecosystem functions such as plant production, soil water retention and nutrient cycling, and (ii) what are the likely effects of climate change and how do these in turn interact with grazing effects. Research on these questions will bridge gaps in our understanding about grazer-impacts on the plant-soil interface of the Trans-Himalaya, and will facilitate attempts at fostering key rangeland properties in order to arrest further degradation, and restore them as wildlife habitat, as well as for human livelihoods. Once human-use of these pastures is made ecologically more responsible, and tribal herders appreciate the concepts of sustained-yield; it transforms the indigenous community into an opportunity for doing participatory conservation.

This study tries to adopt such a two-pronged strategy. Below, we present results of an ongoing from Spiti region of northern India that evaluates grazer effects alongside the effects of certain elements of global climate change. The first study summarizes the findings of a study carried out to understand grazer effects. And the second study summarizes the interactive effects of pastoral use and climate change on these rangelands. Together, they shed light on possible new management strategies, as well as strengthening of existing ones, in order to facilitate their long-term sustainability.

STUDY I

GRAZING EFFECTS ON ECOSYSTEM FUNCTION

Grazing ecosystems, where a large fraction of primary production is consumed by herbivores, are unique in their ability to sustain productivity despite intense and chronic levels of herbivory. A long coevolutionary history between plants and herbivores since the Miocene, has led to many co-adaptations such as compensatory growth by plants and modulation of nutrient cycling by herbivores. Given the nature of this interaction, herbivores can exercise strong control over ecosystem functioning by influencing plant production, nutrient cycling and soil water distribution, that are conventionally studied using herbivore exclusion experiments. But, herbivore effects on ecosystem functions are known to be nearly opposite in different ecosystems (i.e., can be positive, negative or neutral). Current ecological theory explains such contrasting effects based on the compositional turnover of plant species following herbivore exclusion. In general, moderate grazing can stimulate plant production if the nutrient pool in the soil is sufficiently high, as seen in East African and North American grasslands, and cause relatively little change in plant species composition. But, on infertile soils, grazing can decelerate nutrient cycling to depress plant production and cause strong shifts in plant communities. In comparison, grazer effects on soil water availability and distribution remain poorly understood, despite most grazing ecosystems occurring in semiarid to arid conditions. Here, we provide data from a field experiment on grazer effects on plant production, nitrogen cycling, plant species turnover, and soil water retention from the nutrient-poor and water-limited Trans-Himalayan grazing ecosystem in northern India. Given low levels of soil fertility and precipitation , we expected herbivore exclusion to (1) decelerate rates of N-cycling, (2) affect plant production (positive or negative), depending on grazing intensity (high or low) (3) if plants show compensatory growth, this would enhance water requirements and reduce soil moisture levels, and (4) have weak effect on plant species composition.

METHODS

STUDY AREA

Spiti region of northern India (32° N, 78° E; 12,000 km^2, Fig. 1) is a part of the larger Trans-Himalayan landscape, that extends into Ladakh (northwards) and Tibet (eastwards). The study was carried out in rangelands adjoining the village Kibber, where average elevation ranged between 4300 and 4400-m. Climate is cold and arid with temperatures dropping below –30° C between November and March, allowing only a short growth season for plants (May-August). Soil fertility is comparable with sagebrush steppes and oak-savannas of North America, where N limits plant production. Primary production is low compared to other grazing ecosystems of the world, but grazing intensity is comparable with global averages. Vegetation is characterized mostly by C_3 perennials such as grasses (*Elymus*, *Festuca*, *Poa*), sedges (*Carex*, *Kobresia*), and shrubs (*Artemisia*, *Caragana*), while the tree layer is absent. These are grazed by wild herbivores (bharal, *Pseudois nayaur*; and ibex *Capra sibirica*) alongside various livestock (yak, cattle, yak-cattle hybrids, donkey, horse, goat and sheep). Humans are thought to have arrived in this region during Neolithic times, and pastoralism has become prominent over the last 800-4000 years. The earliest written records of Spiti's present-day Sino-Tibetan tribal community date back to 630 AD. Buddhism was introduced in this region 12 centuries ago, and at present, this tribal agro-pastoral community is entirely Buddhist. Current densities of livestock are much higher than native herbivore densities, and this poses manifold conservation challenges for this region.

Spiti's high altitude rangelands (top) are important for conservation of endangered wild herbivores such as the bharal (bottom).

FIELD AND LABORATORY METHODS

Using replicate herbivore exclosures in different rangelands of Kibber Wildlife Sanctuary (32° N, 78° E), we measured grazer impacts on plant production, N-cycling, plant species turnover, and soil moisture retention. Climate is cold and arid with temperatures dropping below –30° C between November and March, allowing a short growth season for plants (May-August). Fences (10 X 10 m, *n* = 15) were set up at the beginning of the growth season 2005 and data were collected through the growth seasons of 2006 and 2007. Each fenced plot was paired with a similar, adjacent, unfenced control plot to provide two treatment levels – grazed and ungrazed. Annual net primary productivity (ANPP) was measured in the control plots using movable cages (1 X 1 m, *n* = 2 quadrats in each plot) at monthly intervals. All live aboveground tissue was clipped to ground level from the quadrats. At the end of the growth season, biomass was clipped from similar quadrats in the fenced plots. Grazing intensity was measured from the difference in standing biomass of fenced and control plots. At the end of the growth season (August 2006), all litter including standing dead biomass was also collected separately from each quadrat in fenced and control plots. Standing belowground biomass was collected using a 2.5 cm radius and 20 cm deep, soil core from the center of each quadrat. Subsequently, the soil cores were washed in running water using 1 mm sieves to separate all belowground plant tissues (including roots, rhizomes and scaly layers) from adhering soil. All samples were oven dried to obtain dry weights. Net N mineralization (an index of plant-available N) was measured with ion-exchange resin bags (DOWEX MR-3), buried 5 – 10 cm deep at each fenced and control plot in May 2006 and removed in August 2006. Net N mineralized was considered as the sum of $[NH_4^+]$ and $[NO_3^-]$ extracted by 1N KCl solution from 5 g resin followed by analysis with a flow-injection autoanalyzer. Soil samples were collected from 4 – 6 locations in each plot from 5 – 10 cm depth and pooled and oven dried. Live plant tissue, litter and soil samples were ground and analyzed for C and N content through dry combustion on a C/N analyzer. Soil moisture was measured as Volumetric Water Content (VWC as %) at 4 – 6 random locations in each fenced and control plot at monthly intervals between May and August 2006, using a 20 cm long, time domain reflectometry probe. All data from fenced and control plots were compared using General Linear Models (GLMs) in SAS v. 9.1 (SAS Institute, Cary, USA) at $\alpha = 0.1$. Relative abundance and community structure was estimated as percentage cover of different species using the line intercept method, with 50 points at every 0.5 m along a 25 m transect. These data were collected once at the beginning of the growth season and again at the end of the growth season, to assess vegetation community shifts following herbivore exclusion. Changes in species composition were analyzed using Bray-Curtis similarity index, between the grazed and paired control plots over time.

RESULTS

Herbivores significantly reduced standing live biomass ($F_{1, 28} = 6.06$, P = 0.02) and litter quantity ($F_{1, 28} = 5.93$, P = 0.02). After 2-yr of herbivore exclusion, belowground standing biomass was 9.91 (± 1.91 se) g m^{-2} in ungrazed plots compared to 7.67 (± 1.14 se) g m^{-2} in grazed plots ($F_{1, 28} = 1.01$, P = 0.32). Grazing stimulated aboveground plant production and this effect was related to grazing intensity and available soil N (Fig. 1-2). ANPP varied considerably across sites and was 33.8 (± 3.7 se) g m^{-2} in ungrazed plots, and 58.7 (± 5.8 se) g m^{-2} in grazed plots, such that grazer stimulation of aboveground production was 84.8% (± 14.2% se). Grazing intensity was high, as herbivores removed 47.0% (± 5.0% se) of plant production during the growth season.

Results from Bray-Curtis analysis suggest that herbivore exclusion for 2 growth seasons did bring about significant changes in plant species composition (Fig. 3). Similarity (or conversely dissimilarity) in plant species composition between paired grazed and ungrazed plots changed over time, and there strength of directional community shifts was stronger in rangelands used primarily by livestock compared to those used primarily by native wild herbivores (Fig. 3).

Grazing reduced soil moisture as the growth season progressed (Fig. 4a-b), and there was a significant Grazing X Time interaction in repeated-measures ANOVA ($F_{3,84} = 10.70$, $P < 0.001$ for 2006; and similarly for 2007 as well).

After 2-yr of herbivore exclusion, net N-mineralization rates were 9.79 mg N g^{-1} resin (± 0.48 se) in grazed plots compared to 8.47 mg N g^{-1} resin (± 0.48 se; $F_{1, 28} = 3.76$, $P = 0.06$).

Plant tissue C:N ratio were 23.38 (± 1.46) in grazed plots compared to 25.91 (± 1.52) in ungrazed plots ($F_{1,27} = 2.80$, $P = 0.11$). Litter C:N ratio were 41.96 (± 4.29) in grazed plots compared to 55.54 (± 4.15) in ungrazed plots ($F_{1,27} = 5.17$, $P = 0.03$).

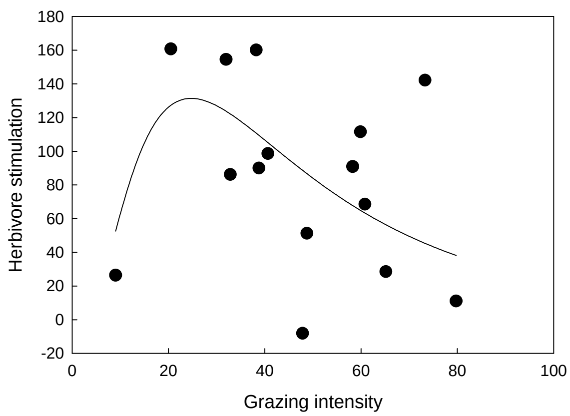

Fig. 1.
Herbivore stimulation (% ANPP in grazed plot over ANPP in corresponding fenced plot) along a gradient of grazing intensity. The unimodal relationship shows that a maximal facilitative effect on plant production is achieved at intermediate levels of grazing intensity. This provides a management opportunity to control stocking densities in a manner such that degradation is arrested and rangeland production optimized.

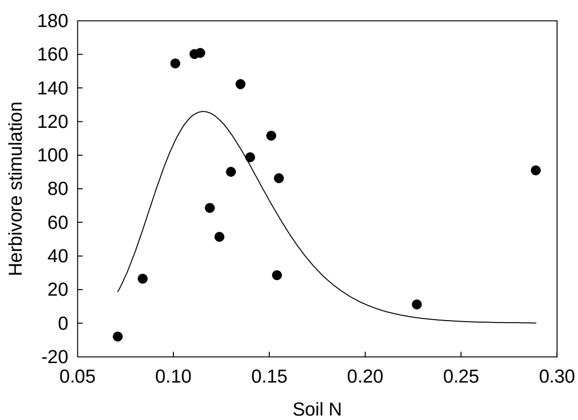

Fig. 2.
Herbivore stimulation (% ANPP in grazed plot over ANPP in corresponding fenced plot) along a gradient of soil fertility. The unimodal relationship shows that a maximal facilitative effect on plant production is achieved at intermediate soil fertility. This provides a management opportunity to optimize rangeland production based on background soil fertility.

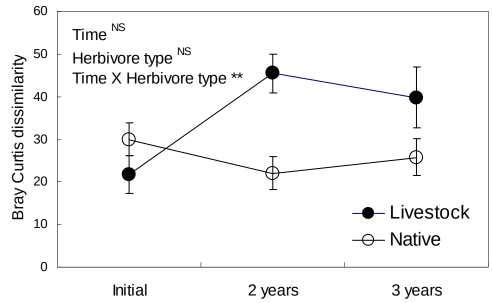

Fig. 3.
Plant community change (Bray-Curtis dissimilarity between fenced and corresponding control plot) over time. Release from grazing causes changes in plant communities, and the relative effect is stronger in areas dominated by livestock compared to areas harbouring native wild herbivores. This suggests that centuries of grazing by livestock has caused local extinctions among plant species.

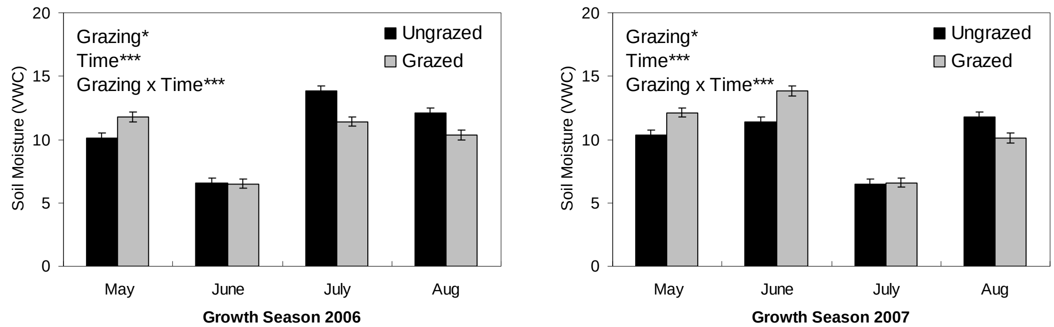

Fig. 4. Changes in soil moisture in relation to grazing over the plant growth season in 2006 (left) and in 2007 (right). The patterns are consistent, and show that grazing in general depletes soil moisture as the growth season progresses, especially after rainfall (in June-July).

CONSERVATION IMPLICATIONS

These results highlight 2 important conservation implications.
First, grazing has a positive effect on aboveground plant production, but this shows a unimodal relationship with both grazing-intensity as well as with soil N. So, primary production can be 'optimized' in these rangelands for pastoral-use by careful distribution of stocking densities between different rangelands, as determined by their inherent soil status. Simultaneously, grazing seems to have a negative effect on belowground plant biomass (although, not statistically significant after 2-yr of herbivore exclusion). So, in the long run, these rangelands appear susceptible to overgrazing, and thereby degradation, unless stocking rates are matched with differences in soil fertility among rangelands. Further, grazing depletes soil moisture as the growth season progresses. So, reducing grazing intensities in infertile or otherwise low-productivity rangelands towards the end of the growth season can have yield favourable results for long-term production. Employing site-specific rotational herding policies for these rangelands are one possible way to make their pastoral use, ecologically more responsible. This provides novel opportunities for participatory management of rangeland production and use, with the help of the local pastoralists, based on sound ecological principles.
Second, these results highlight an important difference in plant responses to grazing by livestock and native wild herbivores. The community change following herbivore exclusion was stronger in areas dominated by livestock, compared to areas where wild herbivores occur at high densities. This implies, chronic defoliation through pastoral use has caused extinctions of several plant species in the past, and only the most tolerant species occupy these areas currently. Such loss of plant diversity can have negative consequences for overall ecosystem production and nutrient cycling, as there is growing evidence from across the world. Better management of grazing intensity, as highlighted above,

can lead to recolonisation by rare plant species and their successful establishment, and improve the current status of overgrazed areas.

Plate showing one of the herbivore exclosures setup in Spiti region of northern India.

STUDY-II

PASTORAL ALTERATION OF SPITI'S RANGELANDS

The Trans-Himalayan grazing ecosystem spread across the Tibetan highlands of central Asia, has supported nomadic and settled pastoralism for centuries, alongside a diverse assemblage of native herbivores. Increasingly, such pastoral use of rangelands is becoming inconsistent with the aims of conservation and long-term sustainable use. Widespread and chronic vegetation degradation is now reported from different regions of this ecosystem. Pastoral use extends beyond just grazing by live-stock and also involves nutrient loss through removal of dung from rangelands into villages, where it is used as agricultural manure and fuel. Another factor that is often linked to degradation is long-term climate change such as increased summer precipitation. Available data from Spiti suggest that between 1997 and 2007, the region received 283-mm of summer rain annually, which is comparable to the reports from different weather stations in western Tibet (located within 100-200 km from Spiti, across the international boundary with China). Such a shift toward wetter summers started in the mid-1980's, but, the consequences for rangeland vegetation remain uncertain. There are indications of increasing annual potential evapotranspiration (PET, an index of water entering the atmosphere through evaporation and foliar transpiration) during the plant growth season since the 1960's. But, this is driven primarily by changes in wind-speed, and its relation to plant production remains inconclusive. Normalized difference vegetation index (NDVI, an index that correlates positively with standing plant biomass) during plant growth season is declining since the 1980's and this change is negatively correlated with summer precipitation which has increased over the same period.
This raises the question why increased water availability should lead to declining trends in vegetation biomass/production in an arid environment? Does this allude to the 'paradox of enrichment', where classical ecological theory has shown how increased availability of an otherwise limiting resource can lead to instability under exploitative conditions? But, extending arguments of food-web stability to ecosystem functions (such as plant production) is not straightforward. So it is pertinent, and timely, to ask questions about the long-term sustainability of these rangelands under these two types of regimes: one is human-induced through nutrient removal, and the other driven by climatic trends toward increased precipitation. When acting together, nutrient-limitation may be getting stronger for plants, while water-limitation may be weakening over time. If so, can this contrasting nature of the fate of two limiting resources provide new insights into the current patterns of degradation? If water and nutrients limit plant production, then irrigation and fertilization are predicted to increase plant production. However, these effects may depend on how plants respond to defoliation as a result of grazing, and not just on availability of limiting resources, and resultantly, there could be a wide range of responses. Specifically, these should depend on how defoliation alters phytomass allocation aboveground vis-à-vis belowground compartments, since a large fraction of plant production in shrub-steppe grazing ecosystems occurs belowground. Indeed, recent investigations posit that the observed variation in long-term vegetation trends is only partially explained by climatic drivers. And the role of grazing, especially stocking densities of animals, can be equally important. Thus, Spiti's rangelands in northern India provide a good opportunity to understand the interactive effects of water- and nutrient-limitation on plant production under grazing, using suitable combinatorial experiments.
The interactive effects of dung-removal, increased summer precipitation and grazing are evaluated over a 2-yr period in Spiti region of northern India.

Rangeland vegetation in Spiti region (top) is growth-limited by soil nutrients and water availability. Under such conditions, widespread dung-removal by pastoralists (bottom) can lead to degradation.

FIELD AND LABORATORY METHODS

In June 2005, we quantified the amount of dung that is removed from these rangelands. Upon reaching an agreement with local pastoralists, a 1-km^2 area was grazed by livestock, but, no dung was collected for a week. During this week, livestock were herded to this rangeland once, which is the normal pattern of rotation between different pastures (they return to the same pasture every 5-8 days on a rotational basis). Following this short-term hiatus in dung collection, 10 plots, each 20-m X 20-m were laid in this area, and the total amount of dung deposited by different livestock types (goat-sheep, donkey-horse, and yak-cattle) was counted. Subsequently, villagers proceeded to collect dung from this area as usual, and left-over dung was counted in the same plots after they left the patch. These villagers took about 1-hr to search the concerned area at their regular pace. The difference between the two counts estimates of the rates of dung removal. Later, 8 representative samples of dung/pellet-groups of each livestock type were oven dried to obtain dry weights. This would provide the total biomass of dung that is removed. Note that the livestock are corralled in villages at night, and a lot of their dung is never deposited in the rangelands and is automatically rendered unavailable for decomposition and subsequent nutrient cycling. N-content of the different dung-types was estimated from Kjeldahl-extracts of two sub-samples.

In May 2006, a field study was initiated to document the effects of dung removal on plant production by restoring dung in experimental plots. Two series of 4 plots, each 0.5-m X 0.5-m, were established inside permanently fenced 10-m X 10-m herbivore exclosures. Adjacent plots were separated by a buffer of 0.5-m. Using a completely randomized design for each series, 1 plot was maintained as control, and 1 each was fertilized with dung of yak-cattle. Dung was collected, and oven dried for weighing. These were gently ground to small pieces and well mixed. From this, 50-g of dung was moistened with 50-ml of water and applied uniformly over the respective plot. All plots were checked carefully for presence of any pre-existing dung, which was removed before fertilization. For the irrigation treatment, 500-ml of locally available stream water was sprinkled over the target plots at weekly intervals for 12 weeks between May and July 2006 that amounts to simulated rainfall of about 24-mm, which roughly corresponds to 10% of natural precipitation. In July 2006, one series of plots was clipped to 2.5-cm of ground level, and the other set left unclipped. Each paired-series of plots was replicated in 3 exclosures within a rangeland, and over 3 separate rangelands, each of which were characterized sedge-meadow vegetation (*Carex* and *Kobresia*). Here, rangelands are defined as distinct geographic units, each 1-2 km^2, that are separated by natural features such as high-ridges and deep canyons. In May 2007, the plots were fertilized in the same manner as earlier. Plant biomass was measured from each plot in August 2007. All live aboveground biomass was clipped to ground level and oven-dried to obtain dry weight. Belowground biomass was sampled using a 2.5-cm diameter, 20-cm deep core taken from the centre of each plot, since more than 95% of roots are concentrated within 15-cm soil depth in such sedge meadows. Roots (including rhizomes and other structures) were washed in running water using a 1-mm sieve and oven-dried to obtain dry weights.

Irrigation and fertilization were repeated in 2007, as described above. Plant biomass was estimated in August 2007, as described above. Incorporating the control plots and the plots with yak-cattle dung from the previous experiment, this provides a factorial design with three treatments – clipping (2 levels), fertilization (2 levels) and irrigation (2 levels), with a total of n = 72 replicated plots.

RESULTS

Natural dung deposition in these rangelands was estimated to be 80-110 g m^{-2} annually in these rangelands of which > 40% was removed, which is a loss of 1.9 g m^{-2} of N annually. Similar amounts are perhaps lost due to overnight retention of livestock in village corrals. In replicate permanent herbivore exclosures, 200 g m^{-2} of dung was restored in experimental plots, and the effects of fertilization were studied alongside a factorial arrangement of two additional treatments: clipping (that simulated the effects of grazing) and irrigation (that simulated 10% additional rainfall over natural levels).

The strongest increase in aboveground phytomass was seen in plots that were clipped, fertilized and irrigated (+72% of controls, Fig. 6). Fertilization did not have significant effects on belowground biomass. But, clipping reduced belowground biomass (-24% of controls) and irrigation compensated this partially (+19% of controls) when applied together (Fig. 7). Thus, plants respond to clipping/grazing by biomass allocation aboveground, at the expense of belowground structures. Under the prevalent regime of dung removal and grazing, belowground phytomass may be depleted to a point where vegetation cannot recover from defoliation, and increased summer precipitation can only partially compensate this effect.

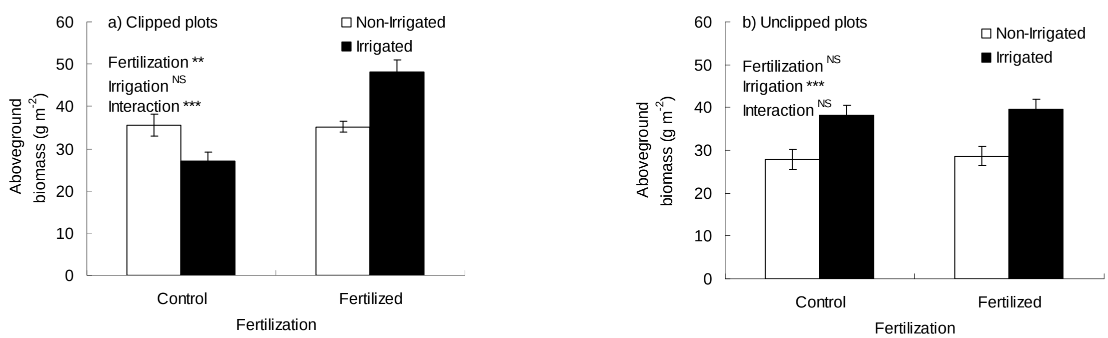

Fig. 6. Effects of clipping, fertilization and irrigation on aboveground plant production in Trans-Himalaya's grazing ecosystem. Following a significant 3-way interaction between the treatments (Table 3), these data were analyzed separately for clipped (a) and unclipped (b) plots. Data are from n = 72 plots inside permanent herbivore exclosures where clipping, fertilization and irrigation were applied in a factorial treatment design in Spiti region of northern India. Fertilization and irrigation have a significant interaction in clipped plots (a), whereas, only their main effects are significant in unclipped plots (b). Asterisk indicates statistically significant difference.

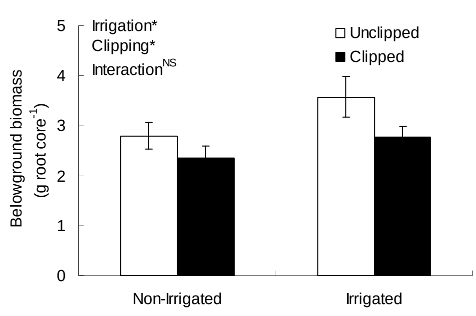

Fig. 7. Effects of clipping and irrigation on belowground plant biomass (from 2.5 cm diameter and 20 cm deep coil core) in Trans-Himalaya's grazing ecosystem, averaged across non-significant effects of fertilization. Data are from n = 72 samples inside permanent herbivore exclosures where clipping, fertilization and irrigation were applied in a factorial treatment design in Spiti region of northern India. Asterisk indicates statistically significant difference.

CONSERVATION IMPLICATIONS

Thus, the current regime of dung collection is clearly unsustainable unless atmospheric deposition can compensate these losses. Studies in east African savannas show, *c.* 0.25 g N m^{-2} y^{-1} is immobilized in corrals for up to 4 decades, and this is likely compensated by atmospheric deposition of *c.* 0.43 g N m^{-2} y^{-1}. Studies on Tibetan plateau have shown an atmospheric input of *c.* 0.8 g N m^{-2} y^{-1}, and we estimate N-loss from dung collection alone at 1.9 g N m^{-2} y^{-1}. However, since atmospheric inputs of inorganic-N can depress, enhance or have no effect on decomposition rates of organic-N; further research on N-deposition is required. These results bring forth the confounding effects of increased water availability on the interrelationships between dung-removal and grazing. When plants are not clipped; irrigation increased aboveground phytomass, regardless of fertilization status. However, when clipped; irrigation increased aboveground phytomass only in fertilized plots, and decreased it in unfertilized plots. On the other hand, irrigation increased belowground biomass. So, biomass re-allocation in response to clipping/grazing is partially compensated by irrigation. Thus, increased summer rainfall is likely to cause depletion of aboveground production if plants continue to be grazed, and the dung of livestock removed. Whereas, it seems unlikely that reduction in belowground phytomass due to clipping/grazing will be fully compensated by increased rainfall. This offers a possible explanation for vegetation degradation observed across the shrub-steppes of this high-altitude arid ecosystem, despite increasing rainfall.

Possible solutions for arresting and eventual reversal of vegetation degradation in Trans-Himalaya lie in curtailing dung removal. Further, grazing intensity and stocking density of animals need to be managed in wake of ongoing climatic changes. In the long run, increases in summer rainfall may help belowground phytomass to recover adequately from negative effects of defoliation and make the rangelands less susceptible to degradation. However, like most water stressed grazing ecosystems, these changes may not be gradual and/or linear over time. Potential nonlinear responses to grazing intensity make the vegetation susceptible to catastrophic shifts toward alternatively stable, but, degraded states, as has been seen in Sahelian rangelands of west Africa. These uncertainties arise from how plants encounter and respond to various alignments of grazing intensity and dung removal. Nutrient re-distribution through animal husbandry is characteristic of other grazing ecosystems as well. For example, corrals in east African savannas immobilize nutrients for over 40 years, before being recycled. In contrast with east Africa, removing dung for fuel offers little opportunity for re-entry of nutrients into the ecosystem in Spiti. Better management of Spiti's rangeland resources, and thereby ecosystem functions and services, require curtailing or controlling dung removal as an important step towards sustainable use, and applying the ecological understanding put forth by these data toward environmental problem-solving.

In this regard, it is important to discuss various mechanisms that traditional subsistence-based societies evolve and adopt in managing their natural resources. Given such ancient societies have survived for centuries, they are expected to have ecologically responsible resource-use strategies, and to evolve mechanisms to regulate such strategies as a necessary adaptation to their environment. Indeed, previous research has documented several such strategies are prevalent among Trans-Himalayan pastoralists. However, as these tribal societies become rapidly integrated with mainstream market economies, several such mechanisms are weakening and traditional practices are undergoing change and attrition. Till the 1990's, Spiti's pastoralists were following a traditional protocol where dung-collection was done at specific times of the year, and collection by each family was regulated by local village councils. But, with time, this mechanism has all but disappeared and at present, collection is largely unregulated. This traditional regulatory mechanism presumably allowed more time for dung to decompose, and hence, reduce the nutrient loss from the rangelands. Rangeland resources (forage and dung) are communally owned and utilized, but, livestock have individual ownership. In such a setup, external influences (both social and economic), through progressive assimilation of this tribal society into mainstream lifestyles will often lead to breakdown of traditional regulatory mechanisms. Hence, it becomes very important to resurrect and strengthen traditional mechanisms that have evolved over centuries to regulate pastoral utilization of rangeland resources. These results stress the need for careful management of grazing intensity and dung collection in Trans-Himalaya. Although the data stem from pastoral practices around a small village in Spiti, northern India, the problems they highlight are widespread and are relevant to the vast Trans-Himalayan ecosystem in general. Given the remarkable similarities among the world's grazing ecosystems, these results are perhaps applicable to other grazing ecosystems that are faced with similar problems of unsustainable pastoral use.

Unregulated dung removal is clearly unsustainable as current atmospheric N-deposition seems unlikely to compensate these losses. Solutions to degradation problems lie in better management of grazing intensity and stocking densities, as well as resurrection and strengthening of traditional mechanisms and local institutions that regulated dung removal in the past, but have weakened and often disappeared over the last few decades.