Supplementary Material

Introduced grazers can restrict potential soil carbon sequestration through impacts on plant community composition

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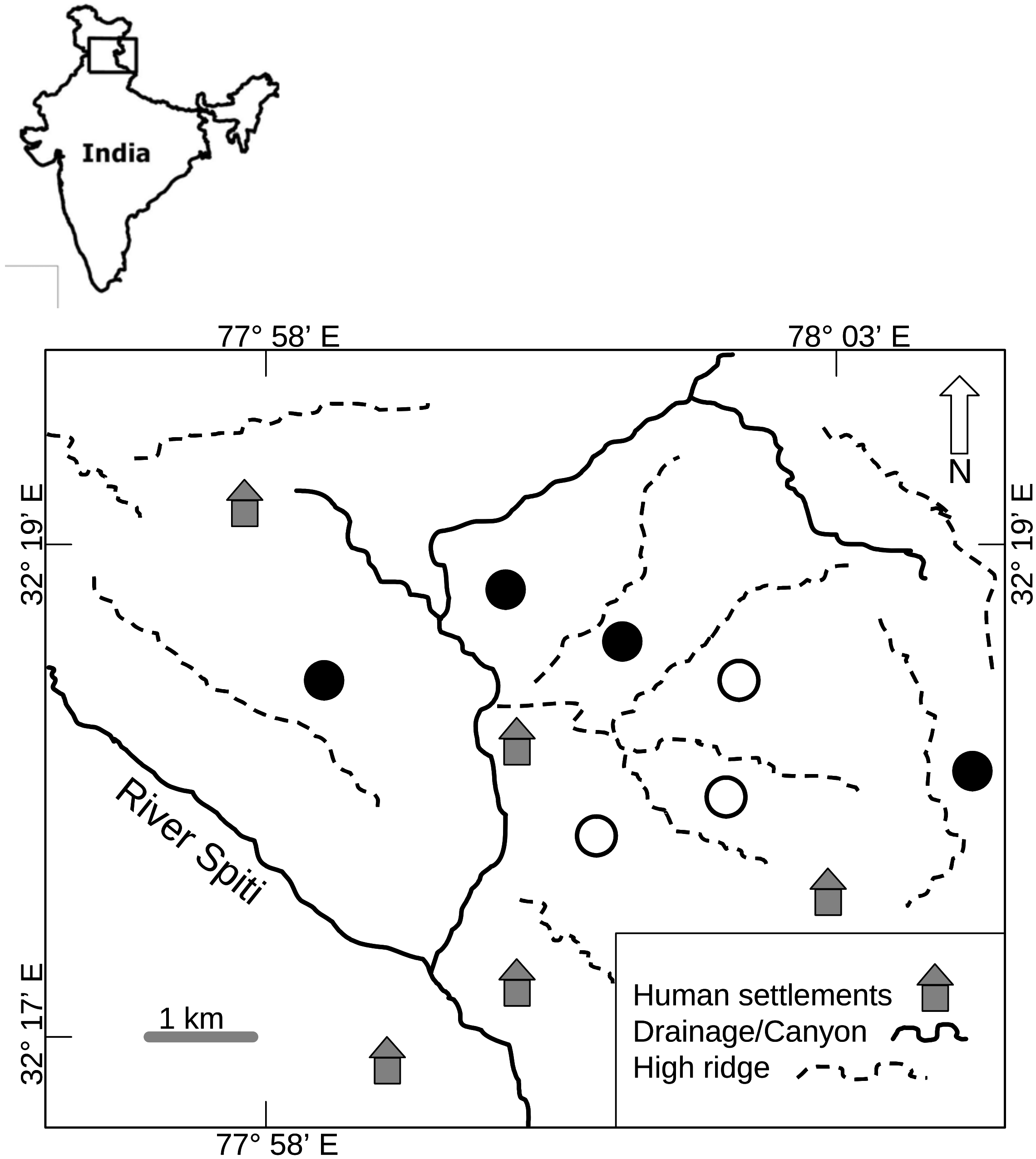
1. Map of Study area in Spiti region, northern India (32°N, 78°E)

Fig. S1. Map showing the distribution of different watersheds that were used as replicates for determining grazer impacts on ecosystem production and potential soil-C inputs. Filled circles (●) represent watersheds that are dominated by native herbivores (bharal, ibex, yak) and the open circles (○) represent watersheds that are dominated by various domesticated grazers. In each watershed, we used 3-4 permanent herbivore exclosures (n=24 total, each 100 m^2) to compare differences between native and domesticated grazers on ecosystem production and potential soil-C sequestration. These watersheds are semi-isolated by natural barriers such as deep canyons and high ridges, which restricts free movement of people and animals. Various human settlements are also shown.


India
77° 58’ E
78° 03’ E
N
32° 19’ E
32° 19’ E
River Spiti
32° 17’ E
1 km
77° 58’ E
Human settlements
Drainage/Canyon
High ridge

2. Mathematical model for additive vs. compensatory effects of herbivores

Previous work (Ritchie & Olff 1999) describing effects of multiple grazer species on plant communities has highlighted the conditions under which grazing can either lead to no net change in community composition, or, lead to directional shifts. When herbivores differentiate in diet, they can have *compensatory* effects on vegetation, presumably due to competitive pressures over acquiring limiting forage. This results in roughly uniform grazing pressure across plant species and relatively little change in plant species composition (Olff & Ritchie 1998). In contrast, when herbivores do not differentiate in diets then their net effect can be *additive*, eliciting strong change in plant species composition, and thereby on ecosystem structure (Olff & Ritchie 1998) as well as function (Schmitz 2009). This argues in favor of niche-partitioning as highlighted by classical theory (Finke & Snyder 2008). How such compensatory versus additive effects might influence ecosystem C-storage, however, remains virtually unknown as it has been difficult to disentangle ecosystem consequences of altered dietary functions from that of overstocking. Curiously, despite the ubiquity of losing diverse native grazer assemblages to non-native livestock across the world's rangelands, the ecosystem-level consequences have rarely been investigated.

Subsequent mathematical models (Casula *et al.* 2006) and experiments (Schmitz 2009) have elaborated on functional complementarity among consumer species. Below we highlight the mechanisms by which feeding complementarity among herbivores can potentially lead to contrasting effects on vegetation composition, depending on their collective foraging behavior.

Let h_j = risk of consumption from j[th] herbivore species.

Let s = proportion of plants that survive or escape consumption

Thus, s = $(1 - h_1)\ (1 - h_2)\ (1 - h_3) \ldots (1 - h_j)$

or, $s = \prod_{1}^{j} (1 - h_j)$

If, P_t is population size of plants at time =1

Therefore, $P_{t+1} = P_t \cdot s$, or, $P_{t+1} = P_t \prod_{1}^{j} (1 - h_j)$.

Now, population change due to herbivory is given by:

$\Delta P = P_{t+1} - P_t = P_t \left(\prod_{1}^{j} (1 - h_j) - 1 \right)$. In this way, relative population change is

$\frac{\Delta P}{P_t} = \prod_{1}^{j} (1 - h_j) - 1$.

Now, we consider the following definition: $\Delta h = \max(h_i - h_j)_{i \neq j}$. This measures the maximum difference between risks of consumption of a plant by different herbivores. In this way, it indicates diet selectivity of the herbivores towards different plants.

This definition for Δh can give rise to two possibilities, depending on its magnitude:

Case A (*additive effects*)—

When Δh is small, it can be denoted by $\underset{\Delta h \to 0}{Lim}$, which implies that the plant has equal risk from all herbivores. Namely, $h_1 \approx h_2 \approx h_3 \approx \ldots \approx h_j \approx \overline{h}$

Therefore, $\underset{\Delta h \to 0}{Lim} \prod_{1}^{j} (1 - h_j) = (1 - \overline{h})^j \begin{cases} \approx 0, when, \overline{h} \approx 0 \\ < 1, when, \overline{h} \neq 0 \end{cases}$

Case B (*compensatory effects*)—

When Δh is large, it can be denoted by $\underset{\Delta h \to 1}{Lim}$, which implies that the plant has unequal consumption risks from the various herbivores. Namely,

$h_1 \neq h_2 \neq h_3 \neq ... \neq h_j$

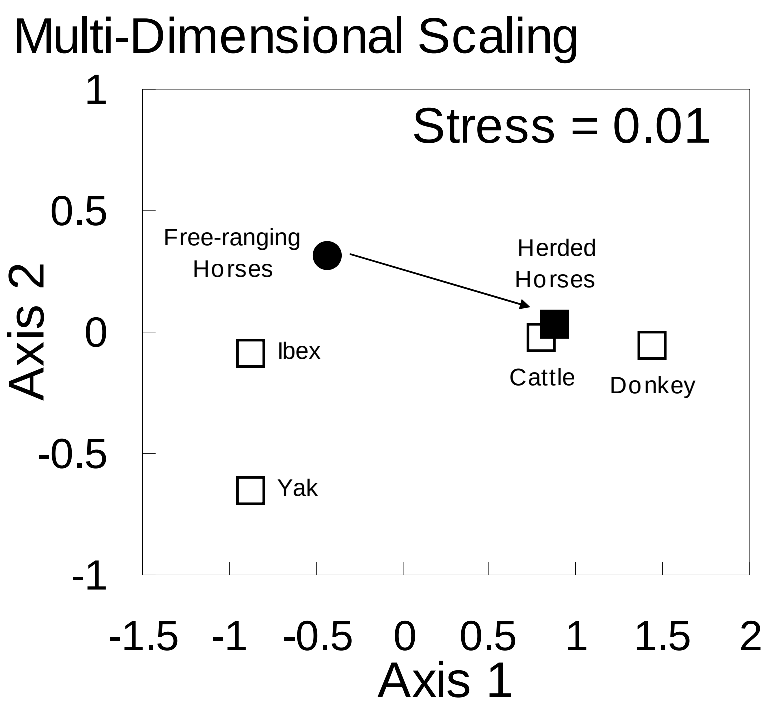
Therefore, $\underset{\Delta h \to 1}{Lim} \prod_{1}^{j} (1 - h_j) \approx 0$.

Comparing these two cases, we find $\underset{\Delta h \to 0}{Lim} \prod_{1}^{j} (1 - h_j) > \underset{\Delta h \to 1}{Lim} \prod_{1}^{j} (1 - h_j)$, which also implies $\left(\frac{\Delta P}{P_t}\right)_{CaseA} > \left(\frac{\Delta P}{P_t}\right)_{CaseB}$.

Thus, herbivores following Case A (*additive effects*) will cause greater shifts in relative abundance then Case B (*compensatory effects*). Thus, existing mathematical models of feeding complementarity (Casula *et al.* 2006) are now directly linked to net effects on vegetation as a consequence of collective foraging behaviors (Ritchie & Olff 1999; Schmitz 2009). This provides a mechanistic explanation for our results that show directional vegetation changes under livestock which lack feeding complementarity; whereas the native grazers showing considerably greater feeding complementarity led to much smaller vegetation change.

3. Comparison of diet selection among free-ranging and herded livestock

Fig. S2. Multivariate ordination (Non-metric Multidimensional Scaling along two axes) of diets of different native and domesticated herbivores from a neighboring area in Spiti region of northern India (Pin Valley National Park (Bagchi *et al.* 2004)). Here local pastoralists leave some horses as free-ranging; whereas, the rest are herded along with other animals (Bagchi *et al.* 2004). The pattern indicates that herded horses have noticeably different diet-selection from their free-ranging counterparts which is remarkably similar to cattle and donkeys. The arrow emphasizes this difference in foraging which can be attributed to effects of husbandry. Note that the diets of the other free-ranging herbivores, ibex and yaks, are also distinct from cattle and donkeys.



4. List of plant species recorded during vegetation sampling

Nomenclature follows Aswal & Mehrotra (1994). Occurrence – common: occurred in >50% of plots, moderate: 20-50% of plots, rare: less than 20% of plots.

Name	Family	Occurrence
Aconogonum molle	Polygonaceae	Rare
Allium carolinianum	Liliaceae	Rare
Astragalus grahamiana	Fabaceae	Rare
Astragalus rhizanthus	Fabaceae	Common
Arnebia euchroma	Boraginaceae	Moderate
Artemisia maritima	Asteraceae	Common
Bistorta sp.	Polygonaceae	Rare
Caragana versicolor	Fabaceae	Common
Carex melanantha	Cyperaceae	Common
Carex infuscata	Cyperaceae	Rare
Cousinia thomsonii	Compositae	Common
Dracocephalum heterophyllum	Labiateae	Rare
Ephedra gerardiana	Gnetaceae	Moderate
Eritrichium canum	Boraginaceae	Rare
Eurotia ceratoides	Chenopodiaceae	Rare
Elymus nutans	Poaceae	Moderate
Elymus longae-aristatus	Poaceae	Moderate
Festuca olgae	Poaceae	Moderate
Heraclium thomsonii	Apiaceae	Moderate
Kobresia royleana	Cyperaceae	Moderate
Lindelofia anchusoides	Boraginaceae	Common
Leontopodium himalayanum	Asteraceae	Rare
Leymus secalinus	Poaceae	Moderate
Nepeta discolor	Lamiaceae	Moderate
Oxytropis microphylla	Fabaceae	Rare
Pleurospermum sp.	Apiaceae	Rare
Poa alpina	Poaceae	Common
Poa lahulensis	Poaceae	Rare
Polygonum sp.	Polygonaceae	Rare
Potentilla bifurca	Rosaceae	Moderate
Potentilla sp.	Rosaceae	Rare
Rhodiola rosea	Crassulaceae	Rare
Salsola sp.	Chenopodiaceae	Rare
Saussurea sp.	Asteraceae	Rare
Scorzonera virgata	Asteraceae	Rare
Stipa jacquemontii	Poaceae	Moderate
Stipa orientalis	Poaceae	Common
Trigonella emodii	Fabaceae	Rare
Thalictrum foetidum	Ranunculaceae	Rare

5. Supporting References

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