Trade-offs and synergies among ecosystem services in mountain pastures

Pauler C.M.[1,2], Lüscher A.[1], Homburger H.[1,3], Scherer-Lorenzen M.[3] and Schneider M.K.[1,2]
[1]*Agroscope, Forage production & grassland systems, Reckenholz, 8046 Zurich, Switzerland;* [2]*Agroscope, Pastoral systems, Reckenholz, 8046 Zurich, Switzerland;* [3]*University of Freiburg, Faculty of Biology, Schänzlestrasse 1, 79104 Freiburg, Germany*

Abstract

Mountain pastures cover one third of Swiss agricultural land. They provide forage for grazing livestock (provisioning ecosystem service (ES)), serve as carbon sink (regulating ES), offer a habitat for an outstanding biodiversity of plant and animal species including pollinators (supporting ES) and are important places of recreation, tourism, and identity (cultural ES). However, normally not each ES is provided at the same place to the same extent. Increasing a single ES sometimes leads to a decrease of others. Thus, we aimed at disentangling trade-offs and synergies among a bundle of ES relevant for mountain pasture ecosystems. Therefore, we measured six ES indicators: (1) forage quantity, (2) forage quality, (3) soil carbon stocks, (4) resources for pollinators, (5) flower colour abundance and (6) plant species richness in 66 plots at six mountain summer farms in the Swiss Alps. We found strong synergies among forage quality and quantity on the one hand, and pollinator resources, colour abundance and species richness on the other. However, there were clear trade-offs among these two groups. We conclude that there is no one-size-fits-all strategy to realise all ES at the same place, but the large variability of mountain pastures allows many ES to be realised at the farm level.

Keywords: conservation, ecosystem services, livestock management, mountain pastures, trade-offs, synergies

Introduction

Mountains cover one third of the European surface area (Price, 2010). Often, grazing is the only agricultural option in these regions. In Switzerland, where our study was conducted, one third of agriculturally used lands are mountain summer pastures. Thus, these grasslands contribute substantially to food production (provisioning ecosystem service (ES)). However, they provide many other ES: for instance, in Switzerland, mountain pastures host 75% of all protected fens which are important sources of carbon storage (regulating ES). More than three quarters of all Swiss protected dry grasslands are placed within mountain pastures. They are rich food resources for pollinators (supporting ES). Moreover, Swiss mountain pastures are crossed by 14 000 km of hiking trails, which makes them essential places of recreation, tourism, and Swiss identity (cultural ES). Finally, mountain pastures are the habitat of 64% of all endangered plant species and 66% of all endemic plant species in Switzerland (all data based on Lauber *et al.*, 2013).

However, mountain pastures are highly heterogeneous. An ES provided at a certain place may be almost non-existent in a pasture nearby. It is also largely known that increasing a single ES can impair other ES. However, there is little systematic knowledge about trade-offs and synergies among specific ES and the strength of their relationship in mountain pastures. Thus, we aimed at (a) quantifying ES that are relevant for mountain pasture ecosystems (i.e., forage for ruminants, resources for pollinators, carbon storage, aesthetic landscape for recreation, and biodiversity conservation) and at (b) disentangling trade-offs among them.

Materials and methods

A field survey was conducted at six (sub-)alpine, mountain farms in the Swiss Alps: three in the Northern Alpine foothills and three in the Central Alps, to represent the two most relevant areas of Swiss mountain livestock farming. At each farm, we observed 11 plots of 25 m^2: nine plots were distributed along two gradients: remoteness (close to the farmhouse; medium distance; edge of the farm) × slope (flat; medium; steep). Two additional plots were placed in the most and the least frequently grazed area. The sampling did not consider shrub-encroached pastures. In each plot, six ES indicators were quantified (selection based on Richter *et al.*, 2021): forage quantity (measured as dry matter biomass cut twice a year), forage quality (percentage digestible organic matter), soil carbon stock (soil organic C content), pollinator resources (floral reward indicator of recorded plant species; derived from trait database), flower colour abundance (percentage abundance of coloured plant species in vegetation surveys) and species richness (number of vascular plant species recorded by vegetation survey). To statistically analyse the relationship among the ES indicators we used allometric line fitting (Warton *et al.*, 2006).

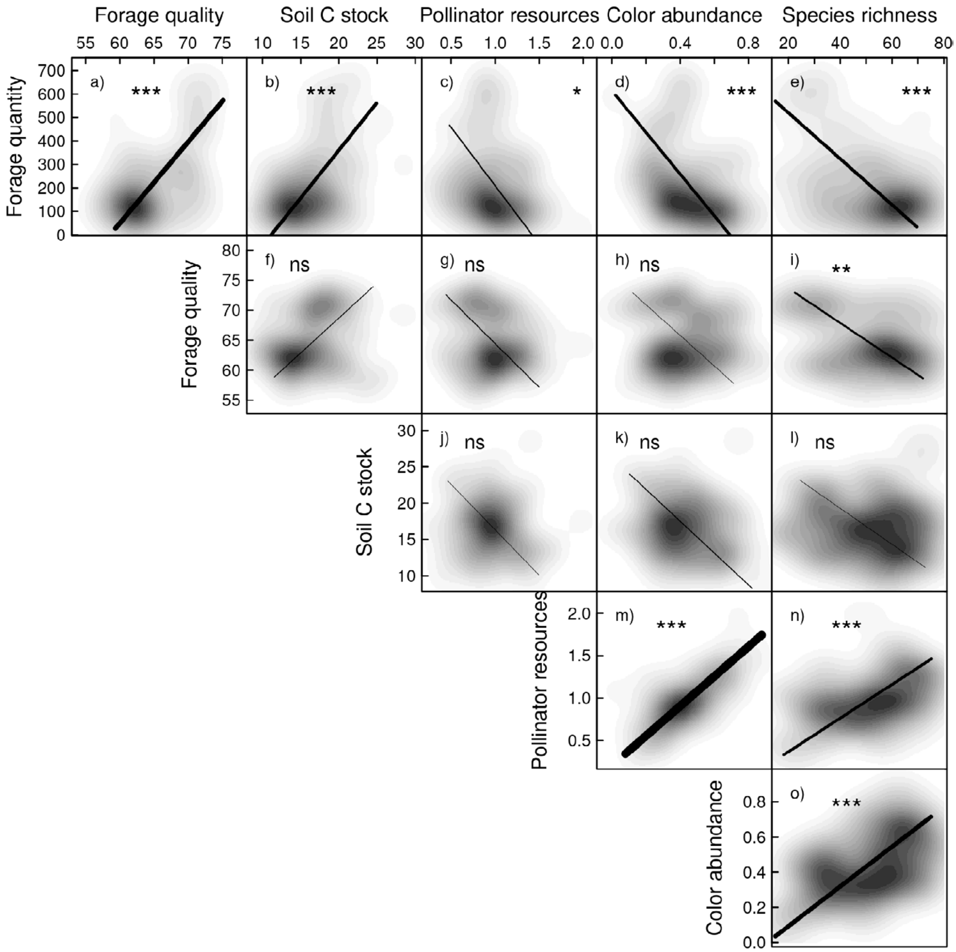

Figure 1. Allometric relations among six ecosystem service indicators of mountain pastures. Widths of allometric lines are scaled according to coefficients of determination (R^2); their significance is provided as ***P<0.001; **P<0.01; * P<0.05; ns, $P \geq 0.05$. Background shading indicates the Normal Kernel density of observations.

Results and discussion

Many ES were significantly related to other ES and, thus, there were clear synergies and trade-offs. A strong positive relationship was found between the two provisioning ES indicators forage quantity and forage quality (Figure 1a), indicating that mountain pasture which offer high amount of forage are also likely to provide highly digestible forage. In practical application, measures to increase forage amount likely also enhance forage quality, because species of high digestibility are promoted.

A second bundle of synergies was found among the three ES indicators pollinator resources, colour abundance and species richness (Figure 1m–o), indicating that a rich biodiversity comes along with supportive conditions for insects and offers an attractive sight for humans. Thus, by supporting biodiversity, farms likely also enhance pollinator abundance and public appreciation of their farmland, which can be an important factor in landscape attractiveness and therefore in direct marketing.

Remarkably, we found significant trade-offs between these two ES groups, i.e., forage quality and quantity on the one hand, and pollinator resources, colour abundance and species richness on the other (Figure 1c–e, i): Low-productive areas are more valuable for supporting and cultural ES than highly productive mountain pastures. Finally, the soil carbon storage potential of mountain pastures was largest in areas with high forage quantity (Figure 1b), probably because these are the places with deepest soil layer and high inputs of organic material. Other ES indicators were not related to soil carbon stocks (Figure 1j–l).

Conclusion

There are not only synergies, but also trade-offs among ES in mountain pastures. Thus, there is no one-size-fits-all strategy (Dumont *et al.*, 2022) and it is not possible to realise all types of ES at the same place. However, in the large variability of mountain pastures also lies an opportunity: the huge heterogeneity in environmental conditions and management strategies allows high quantity and quality forage production in close proximity to biodiversity support and recreational values in less intensively managed areas within the same farm.

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