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Synergies and trade-offs between ecosystem services in an alpine ecosystem grazed by sheep – An experimental approach

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Abstract

Domestic livestock drives ecosystem changes in many of the world's mountain regions, and can be the dominant influence on soil, habitat and wildlife dynamics. Grazing impacts on ecosystem services (ES) vary according to densities of sheep, but an ES framework accounting for these is lacking. We devised an experiment to evaluate synergies and trade-offs of ESs and components of biodiversity affected by sheep density at the alpine landscape scale in southern Norway. We examined the effects of increased (80 per km^2), decreased (0 per km^2) and maintained sheep densities (25 per km^2) on 'supporting', 'regulating' and 'provisioning' services and biodiversity (plants, invertebrates and birds). Overall, ESs and biodiversity were highest at maintained sheep density. Regulating services, including carbon storage and habitat openness, were particularly favoured by maintained densities of sheep. There was no overall decline in ESs from maintained to increased sheep densities, but several services, such as runoff water quality, plant productivity and carbon storage, declined when grazing increased. Our study provides experimental evidence for a positive effect of grazing on ES, but only at maintained low sheep densities. By identifying ES and biodiversity components that are traded-off at decreased and increased grazing, our study also demonstrates some of the negative impacts on ecosystems that can occur in mountain regions if management does not regulate herbivore densities.

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Zusammenfassung

Viehhaltung bewirkt in vielen montanen Regionen der Welt Veränderungen am Ökosystem und kann der dominante Einfluss auf die Dynamik von Böden, Habitaten und Wildtieren sein. Die Einflüsse der Beweidung auf Ökosystemdienstleistungen variieren mit der Dichte von Schafen, es fehlt aber ein System der Ökosystemdienstleistungen, das dies berücksichtigt. Wir entwarfen ein Experiment, um die Synergien und Zielkonflikte zwischen Ökosystemdienstleistungen und Biodiversitätskomponenten zu erfassen, die durch die Schafdichte in alpinen Landschaften in Südnorwegen beeinflusst werden. Wir untersuchten die Effekte von erhöhter (80 Ind./km^2), verringerter (0 Ind./km^2) und beibehaltener Schafdichte (25 Ind./km^2) auf "Unterstützungs-", "Regulations-" und "Versorgungsdienstleistungen" sowie auf die Biodiversität (Pflanzen, Wirbellose, Vögel). Insgesamt waren die Ökosystemdienstleistungen und die Biodiversität bei beibehaltener Schafdichte am höchsten. Regulationsleistungen wie Kohlenstoffspeicherung und Offenheit der Habitate wurden durch beibehaltene Schafdichten besonders begünstigt. Es gab keinen generellen Abfall der Ökosystemdienstleistungen von beibehaltenen zu erhöhten Schafdichten, aber verschiedene Dienstleistungen (darunter Qualität des Oberflächenabflusswassers, Pflanzenproduktivität und Kohlenstoffspeicherung) gingen mit zunehmender Beweidung zurück. Unsere Untersuchung belegt experimentell, dass es einen positiven Effekt der Beweidung auf die Ökosystemleistungen gibt, aber nur bei den niedrigen, beibehaltenen Schafdichten. Indem Ökosystemleistungen und Biodiversitätskomponenten identifiziert werden, die bei reduzierter und erhöhter Beweidung unterschiedlich reagieren, zeigt unsere Untersuchung auch einige negative Einflüsse, die in Bergregionen auftreten können, wenn die Herbivorendichten nicht reguliert werden.

Keywords: Herbivory; Ecosystem services; Livestock; Management; Optimal stocking levels; Overgrazing; Threshold

Introduction

Livestock grazing affects biodiversity and ecosystem services (ES) across all major biomes, but sustainability is often questioned in areas with high stocking rates. More than 25% of the global land area is managed for grazing (Asner, Elmore, Olander, Martin & Harris 2004), and hence understanding grazing impacts is highly important for sustainable management. Although mountain ecosystems are harsh and often perceived as remote wildernesses, land use and especially livestock grazing has prevailed for thousands of years over most mountain areas, e.g. Scandinavia, UK, Ireland and continental Europe, shaping plant community patterns and generally lowering or completely suppressing the tree-lines (Gehrig-Fasel, Guisan & Zimmermann 2007; Tasser, Walde, Tappeiner, Teutsch & Noggler 2007; Speed, Austrheim, Hester & Mysterud 2010). Land abandonment and reduced livestock densities in mountains in many European countries (MacDonald et al. 2000) are therefore predicted to be a major driver for ecosystem changes. In contrast, high sheep (*Ovis aries*) densities are still considered to cause overgrazing in some parts of the North-Atlantic region (Ross et al. 2016) and the Central Alps (Meusburger & Alewell 2008).

The strong impact of grazing on ecosystem structure and processes has been well documented, and changes in herbivore densities can lead to both negative and positive effects on biodiversity and the services provided by ecosystems (Côté, Rooney, Tremblay, Dussault & Waller 2004; Hester, Bergman, Iason & Moen 2006; Van der Wal 2011). Grazing regimes (i.e. length of the grazing season, species, breeds), habitat characteristics (e.g. productivity, land-use history) and spatio-temporal scale are all important in deciding the actual ecosystem impact of alternative herbivore densities (Milchunas & Lauenroth 1993). However, as most studies contrast heavy grazing with ungrazed exclosures (e.g. Thompson, MacDonald, Marsden & Galbraith 1995) and experimental gradients of grazing intensity are rarely established, there is a lack of knowledge on how different densities will affect ES and biodiversity and what could be defined as a stocking density for optimising ES.

Independent of herbivore density, grazing may affect all major processes important for the functioning of ecosystems and the services that could be provided, such as primary production, decomposition, nutrient cycling rates and mineralisation (Hobbs 1996). As any grazing regime that sustains some elements of biodiversity and ES could be detrimental for others (Reed 2008), conflicts may emerge from 'optimising' different services. Indeed, the protection of biodiversity for different groups of organisms is often associated with different 'optimal' grazing regimes (Briske, Derner, Milchunas & Tate 2011). Defining sustainable sheep grazing is thus a complex environmental issue which calls for an integrated approach which includes variable grazing regimes and considers a broad range of ecosystem responses. An integrated set-up also allows for a direct comparison on the resulting synergies and trade-offs for biodiversity and ES associated with variable grazing regimes.

In this study, we assess the effects of increased, decreased and maintained (i.e. unchanged) sheep densities on biodiversity and ES in an alpine ecosystem by performing meta-analyses across studies using the same experimental design. This allows for an overall evaluation on how different