Quantifying grazing intensity and ecosystem services in subalpine pastures

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Abstract. Centuries of summer grazing on subalpine pastures have created unique ecosystems providing society with food of special quality, recreation and cultural heritage. Structural change in mountain agriculture has led to rationalisation of labour and modifications of traditional grazing regimes in many regions. Both processes affect the ecosystem and the services provided. Policy makers and herdsmen are confronted with the question of how livestock management needs to be adjusted in order to maintain and improve the provision of ecosystem services. In order to understand the connections between grazing intensity and ecosystem services, both elements have to be quantified independently of environmental characteristics (soil and vegetation). We demonstrate these connections based on investigations in six summer farms in the Swiss Alps. Three ecosystem services (forage production, biodiversity conservation and carbon sequestration) were assessed on eleven plots per farm. Grazing intensity was quantified using high-frequency GPS tracking. Our results show that environmental variables explained an important part of all three ecosystem services. Nevertheless, there is independent influence of grazing intensity on plant species richness and fodder production, demonstrating the importance of appropriate management for these services. Since the effects of grazing intensity on these two services are opposite, an adjustment of grazing intensity requires consideration of the specific aims on a grazed site.

Keywords. Mountain pastures – GPS – Animal behaviour – Vegetation.

Quantifier l'intensité de pâturage et les services écosystémiques dans les pâturages subalpins

Résumé. *Des siècles de pâturage estivaux dans les alpages ont créé des écosystèmes uniques qui fournissent à la société des produits du terroir de qualité spéciale, de l'espace récréatif et un patrimoine culturel. Les changements structurels dans l'agriculture de montagne ont donné lieu à une rationalisation du travail et à des modifications des régimes de pâturage traditionnels dans de nombreuses régions. Ces deux processus ont modifié l'écosystème et les services fournis. Les décideurs et les éleveurs sont confrontés à la question de savoir comment la gestion du bétail doit être ajustée afin de maintenir et d'améliorer la provision des services écosystémiques. Afin de comprendre les liens entre l'intensité de pâture et les services écosystémiques, ces deux éléments doivent être quantifiés indépendamment de l'environnement (sol et végétation). Nous avons étudié ces relations à partir d'enquêtes réalisées dans six alpages suisses. Trois services écosystémiques (production de fourrage, conservation de la biodiversité et séquestration du carbone) ont été évalués sur onze parcelles par alpage. L'intensité de pâture a été quantifiée par un suivi GPS à haute fréquence. Nos résultats ont montré que les variables environnementales expliquent une partie importante des trois services écosystémiques. Néanmoins, l'intensité de pâture influence de manière indépendante la richesse spécifique végétale et la production de fourrage. Les décisions dans la gestion de pâture auront donc une forte influence sur ces services écosystémiques. Etant donné que les effets de l'intensité de pâture sur ces deux services sont opposés, il est nécessaire d'examiner les objectifs spécifiques sur un site pâturé afin d'y adapter l'intensité de pâture.*

Mots-clés. *Alpages – GPS – Comportement animal – Végétation.*

I – Importance of subalpine pastures

Subalpine pastures provide crucial services to society: they are habitat to specialised plant and animal species, represent areas for recreation and cultural heritage, deliver forage for grazing animals, prevent soil erosion and sequester carbon. While biodiversity is an important determinant of ecosystem functions (e.g. Diaz *et al.*, 2007), forage production has a direct economic value to farmers. Soil organic carbon (SOC) plays a role in regulating climate and soil fertility (McSherry and Ritchie, 2013). Since pasture ecosystems have been shaped by centuries of animal grazing, the provision of ecosystem services is strongly related to the intensity of grazing (Homburger *et al.*, 2013; Kampmann *et al.*, 2008). Grazing animals respond to environmental properties such as topography and vegetation (Schneider *et al.*, 2013) and, hence, there are strong interactions between such abiotic and biotic drivers of ecosystem services. At the same time, herders decide on amount, timing and duration of stocking as well as on the type of grazing animal. Grazing intensity is therefore one of the most important system variables influenced by land managers.

In order to manage grazing intensity for the provision of ecosystem services, we need to understand the connections between the two and with the environment. For this purpose, grazing intensity has to be quantified independently of environmental characteristics (soil and vegetation). In what follows, we give a brief overview on (1) techniques available for the quantification of grazing intensity in rough terrain, (2) measurements of ecosystem services in subalpine pastures and (3) the connection between the two and their interactions with the environment.

II – Quantifying grazing impact in heterogeneous terrain

In the highly heterogeneous subalpine environment, the assessment of grazing intensity remains a challenge. Since most paddocks are large, approximating grazing intensity by average stocking rate within the paddock, for example, does not account for small-scale patterns of grazing on large subalpine pastures (Homburger *et al.*, 2012). In heterogeneous environment, livestock select favoured fodder patches and avoid unsuitable areas (Adler *et al.*, 2001). Therefore, average stocking rate overestimates true intensity on a large portion of extensively grazed sites and underestimates grazing of those locations preferred by the animals. Approximating grazing intensity by average stocking rate can introduce substantial bias into estimates of its impact on ecosystem services.

Most approaches to improve estimates of local grazing intensity involve the recording of positions and activity of grazing animals. In its simplest form, this can be done by counting animals from an overview point (e.g. Jewell *et al.*, 2005). However, the technique is time-consuming and imprecise. The miniaturization of GPS receivers has greatly simplified animal tracking and allows recording positions continuously at a high temporal resolution (Fig. 1). Homburger *et al.* (2012) tracked animals at a frequency of 20 seconds, which allowed reliably attributing positions to the behavioural states of grazing, walking and resting based on behavioural observations in the field. The density of observed positions classified as grazing can subsequently be analysed for effects of environmental variables on grazing intensity (Schneider *et al.*, 2013).

III – Measuring ecosystem services

Quantifying ecosystem services in subalpine pastures requires dealing (1) with the large heterogeneity in environmental conditions and (2) the scales, at which services can be measured and at which quantification is of interest. The latter need not be similar. For example, soil C stocks are quantified based on core samples with very small volumes compared to the gigatons cycling globally. Random sampling with stratification and subsequent interpolation using statistical modelling is a prominent technique to deal with heterogeneity and can also be used to extrapolate results to larger areas (Müller, 2007).

Homburger *et al.* (2013) measured three prominent ecosystem services of subalpine pastures - plant species richness, fodder production and SOC content – on six summer farms in the Swiss Alps. The detailed measurements were carried out on eleven sites per farm. Nine of them were selected in crossed strata of terrain slope and distance from the central shed of the farm. These two environmental variables were readily available before the investigation and known to be important for the distribution of ecosystem services in subalpine pastures (Kampmann *et al.*, 2008; Peter *et al.*, 2009). In addition, two sites were selected based on information from farmers on herd management. A suitably homogenous sampling area of 25 m^2 was used to determine plant species richness (Fig. 2). Fodder production was measured as biomass dry matter production using 1 m^2 grazing exclusion cages. SOC content was quantified from 16 pooled soil cores per plot.

Fig. 1. Cow carrying a white box containing the GPS device on a subalpine pasture.

Fig. 2. Assessment plot for the measurement of the ecosystem services plant species richness, forage production and soil C storage. Arrow indicates the location of another plot on a steeper site at equal distance from buildings.

IV – Connecting the two

Homburger *et al.* (2013) used generalized linear mixed-effects models to analyze effects of grazing intensity and environmental variables on ecosystem services. They found that terrain slope had a positive effect (P<0.001) on plant species richness, in line with various other studies, e.g. Kampmann *et al.* (2008) or Peter *et al.* (2009). These studies attributed most of the slope effect to a reduced grazing intensity in steep terrain but did not really quantify it. The preliminary results of Homburger *et al.* (2013) indicate that there is an additional significantly negative effect of grazing intensity (P<0.01) on plant species richness, independent of terrain slope. This effect may be due to naturally drier and shallower soils on slopes than in flat areas.

Similar but inverse relationships were found for forage production, which was negatively related to terrain slope (P<0.01) and distance to the farm building (P <0.05) as well as positively to grazing intensity (P<0.001). The contrasting response of these two ecosystem services was also indicated by a relatively close hump-shaped relationship as demonstrated by Schneider *et al.* (2011).

Homburger *et al.* (2013) showed that only a complex model was able to partially predict SOC content. The only explanatory variable with a significant effect was soil phosphorus content, which was positively related to SOC content (P<0.001). Terrain slope, altitude and grazing intensity had effects only in interaction with one another. Homburger *et al.* (2013) concluded that grazing intensity slightly altered environmental effects on SOC storage but had no effect alone. In their recent meta-analysis, McSherry and Ritchie (2013) also found no univariate effect of grazing on SOC and highlighted the importance of the environmental and biotic context in SOC sequestration.

V – Conclusions

An independent quantification of grazing intensity and ecosystem services offers new insights into the provision of these services in subalpine pastures. Evidence suggests that different ecosystem services are not controlled by grazing intensity in the same way. Grazing intensity was most strongly connected to fodder production, to a lesser extent to plant species richness and did not explain variance in SOC content alone. Since the relationships of grazing intensity with fodder production and plant species richness are opposite, the provision of both services at a given site is difficult and an adjustment of grazing intensity requires consideration of the specific aims on a grazed site. This means that land managers need a clear view on ecosystem services provided by their pastures and the consequences of management action for these services. Since relationships are complex, as shown above, management planning on subalpine pastures should take into account multiple ecosystem services in order to guide land managers in their daily decisions.

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