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# Modelling biomass of mountainous grasslands by including a species composition map

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ABSTRACT

High mountain grasslands offer multiple goods and services to society but are severely threatened by improper land use practices such as abandonment or rapid intensification. In order to reduce abandonment and strengthen the common extensive agricultural practice a sustainable land use management of high mountain grasslands is needed. A spatially detailed yield assessment helps to identify possible meadows or, on the contrary, areas with a low carrying capacity in a region, making it easier to manage these sites. Such assessments are rarely available for remote and inaccessible areas. Remotely sensed vegetation indices are able to provide valuable information on grassland properties. These indices tend, however, to saturate for high biomass. This affects their applicability to assessments of high-yield grasslands.

The main aim of this study was to model a spatially explicit grassland yield map and to test whether saturation issues can be tackled by consideration of plant species composition in the modelling process. The high mountain grassland of the subalpine belt (1800 – 2500 m a.s.l.) in the Kazbegi region, Greater Caucasus, Georgia, was chosen as test site for its strong species composition and yield gradients.

We first modelled the species composition of the grassland described as metrically scaled gradients in the form of ordination axes by random forest regression. We then derived vegetation indices from Rapid Eye imagery, and topographic variables from a digital elevation model, which we used together with the multispectral bands as predictive variables. For comparison, we performed two yield models, one excluding the species composition maps and one including the species composition map as predictors. Moreover, we performed a third individual model, with species composition as predictors and a split dataset, to produce the final yield map.

Three main grassland types were found in the vegetation analysis: *Hordeum violaceum*-meadows, *Gentianella caucasea*-grassland and *Astragalus captiosus*-grassland. The three random forest regression models for the ordination axes explained 64%, 33% and 46% of the variance in species composition. Independent validation of modelled ordination scores against a validation data set resulted in an $R^2$ of 0.64, 0.32 and 0.46 for the first, second and third axes, respectively. The model based on species composition resulted in a $R^2 = 0.55$, whereas the benchmark model showed weaker relationships between yield and the multispectral reflectance, vegetation indices, and topographical parameters ($R^2 = 0.42$). The final random forest yield model used to derive the yield map resulted in 62% variance explained and an $R^2 = 0.64$ between predicted and observed biomass. The results further indicate that high yields are generally difficult to predict with both models.

The benefit of including a species composition map as a predictor variable for grassland yield lies in the preservation of ecologically meaningful features, especially the occurrence of high yielding vegetation type of *Hordeum violaceum* meadows is depicted accurately in the map. Even though we used a gradient based design, sharp boundaries or immediate changes in productivity were visible, especially in

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small structures such as arable fields or roads (Fig. 6b), making it a valuable tool for sustainable land use management. The saturation effect however, was mitigated by using species composition as predictor variables but is still present at high yields.



## 1. Introduction

High mountain grasslands offer multiple ecosystem services to society (Gret-Regamey et al., 2008). The high mountain grassland vegetation regulates water flows and prevents erosion events with its root system (Körner, 2004; Pohl et al., 2009), whereas the grassland yield supplies the nutritional basis for local dairy and livestock production (O'Mara, 2012). High mountain grasslands further provide important cultural services, such as recreation or scenic beauty (Schirpke et al., 2013). As a result of a long term agricultural use as meadow or pasture, the high mountain grassland features a high biodiversity and unique plant species composition, significantly influencing the functioning of the mountainous ecosystem (Körner et al., 2006).

The species diversity of high mountain grassland and thus the functioning of the mountainous ecosystem with its provision of services is strongly affected by land-use changes, such as the abandonment of low-intensity agricultural practices (Cocca et al., 2012; Klimek et al., 2007). In order to prevent farmers from abandoning agricultural practices, the mode of production needs to be economically viable. Including spatially explicit information about the productivity or yield of the grassland into the land use management can help to determine the carrying capacity, livestock stocking rates and the amount of available fodder in a region, aiding in avoiding over use or abandonment.

The estimation of aboveground biomass or related variables, such as leaf area index, is a key topic in many remote sensing studies that is addressed with either multispectral (Anderson et al., 1993; Liu et al., 2007; Wu et al., 2007) or hyperspectral vegetation indices (Boschetti et al., 2007; Cho and Skidmore, 2009; Fillela and Penuelas, 1994; Psomas et al., 2011). Vegetation indices use the strong contrast between the absorption features of chlorophyll in the visible light and the high reflectance in the near–infrared region (NIR) to quantify the vegetation condition (Jackson and Huete, 1991). However, vegetation indices in general tend to saturate in areas of a high biomass or leaf area, even though the exact saturation point varies between the indices. In the past, vegetation indices were used to model pasture yields, which cover a gradient from low to moderate standing biomass (Boschetti et al., 2007; Hancock and Dougherty, 2007; Vescovo and Gianelle, 2008; Chen et al., 2009). These studies are limited by the fact that saturation of vegetation indices mainly occurs at high yields. Therefore, their relationship with high yield grassland, such as hay meadows still remains challenging. Moreover, Dusseux et al. (2015) found that biophysical variables (leaf area index and fractional vegetation cover) derived from remotely sensed imagery showed better correlations to biomass than the tested vegetation indices.

High mountain grasslands are an ideal research object, providing strong gradients of grassland productivity within gradually transitioning grassland types, offering a good example of the gradual change of species composition along topographic, and especially altitudinal gradients (Gleason, 1926). Modelling the gradual change of species composition of grasslands was already successfully performed (Feilhauer and Schmidtlein, 2011; Magiera et al., 2013; Schmidtlein and Sassin 2004). Although the relationship between biomass productivity and species richness is controversially discussed (Adler et al., 2011; Grace et al., 2012), both are clearly linked to each other (Guo, 2007). In a semi natural landscape, with low farming intensity, the environmental conditions such as nutrient availability, soil depth or water content determine both species composition and the yield.

The primary aim of this study was to derive a spatially explicit grassland yield map using remotely sensed data, in order to obtain a base map for sustainable land–use management. Our main objectives were:

i) to describe the main vegetation and topographic gradients and their relationships to biomass yield;
ii) to accurately and spatially explicitly predict above ground biomass as continuous fields;
iii) to test, whether remotely sensed patterns of species composition are suitable predictor variables for a yield model.

In order to meet these objectives, we first modelled the species composition of the diverse subalpine grassland by employing a random forest model between species composition and vegetation indices together with topographical parameters. We then related these gradients to biomass data and generated a yield map. We compared the yield model based on the species composition maps to a model, which only related multispectral reflectance, vegetation indices and topographical parameters to yield. The high mountain region of Kazbegi, Greater Caucasus, Georgia, was chosen as our test site since it offered ideal research opportunities with species rich and structurally diverse subalpine grassland types.

## 2. Material and methods

### 2.1. Study area

The study area (Fig. 1) is located in the Kazbegi district in the Republic of Georgia, which lies in the central part of the Central Greater Caucasus, a high mountain range that is characterized by high elevations, steep slopes, as well as harsh and continental climatic conditions (Akhalkatsi et al., 2006). The main village Stepantsminda (1800 m a. s. l.) stretches next to the banks of the river Tergi, which flows in a northern direction.

The land cover of the Kazbegi region is dominated by different grassland types, which are used as meadow or pasture with low-intensity (Waldhardt et al., 2011). In spring, from the snow melt until the mid of May, the first shoots of the productive hay meadows of the valley bottom are grazed by cattle. There is no application of fertilizer on the meadows, besides the cow dung from the spring pasturing. A high proportion of the actual hay meadows were used as arable land decades ago. After May, the cattle are moved to either higher elevations or less productive low land pastures (1700 m a.s.l.). A system of fences is then installed to protect the subalpine meadows from free ranging cattle. In the summer these meadows are mown once between the end of July and the end of August, which is late in the vegetation period but precipitation poor (Sakhokia, 1983). For a detailed description of the study region we refer to Magiera et al. (2013) and Tephnadze et al. (2014).