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Future impacts of changing land-use and climate on ecosystem services of mountain grassland and their resilience

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ABSTRACT

Although the ecosystem services provided by mountain grasslands have been demonstrated to be highly vulnerable to environmental and management changes in the past, it remains unclear how they will be affected in the face of a combination of further land-use/cover changes and accelerating climate change. Moreover, the resilience of ecosystem services has not been sufficiently analysed under future scenarios. This study aimed to assess future impacts on multiple mountain grassland ecosystem services and their resilience. For a study area in the Central Alps (Stubai Valley, Austria), six ecosystem services were quantified using plant trait-based models for current and future conditions (in 2050 and 2100) considering three socio-economic scenarios. Under all scenarios, the greatest changes in ecosystem services were related to the natural reforestation of abandoned grassland, causing a shift from grassland to forest services. Although the high resilience potential of most ecosystem services will be maintained in the future, climate change seems to have negative impacts, especially on the resilience of forage production. Thus, decision makers and farmers will be faced with the higher vulnerability of ecosystem services of mountain grassland. Future policies should consider both socio-economic and environmental dynamics to manage valuable ecosystem services.

1. Introduction

Mountain grasslands are the result of long-term human agricultural activities, and they have been used for mowing and livestock grazing for centuries. Many of these permanent grasslands are biodiversity hotspots (Wilson et al., 2012) owing to extensive farming practices (MacDonald et al., 2000; Schermer et al., 2016) that provide a variety of ecosystem services. While in the past mountain grasslands were managed principally for forage provision, nowadays their importance for regulating (e.g. soil stability, water provision, carbon storage) and cultural ecosystem services (e.g. aesthetic and recreational values) is increasingly recognised (Bürgi et al., 2015; Lamarque et al., 2011). However, mountain ecosystems are highly vulnerable to climate and land-use changes, both of which affect ecosystem services (Schröter et al., 2005).

During the past few decades, large areas of low-productivity grasslands have been abandoned in the European Alps, located mainly on steep slopes and at high altitudes, where their management is linked to high costs (Rutherford et al., 2008). These abandoned areas were located mainly in the subalpine zone below the actual treeline and originated from former forest clearing (Pecher et al., 2011). Subsequently, they were subject to natural reforestation, which resulted in changing landscape patterns (Tasser et al., 2007). Conversely, activity in the most productive areas in the valley bottoms has intensified, as they are used as highly intensive meadows with several cuts per season or transformed into annual or permanent cropland. Both the abandonment and the intensification have caused both a decline in biodiversity (Lambin et al., 2000; Zimmermann et al., 2010) and changes to ecosystem services (Bürgi et al., 2015; Crouzat et al., 2015; Egarter Vigl et al., 2016; Schirpke et al., 2013). For example, the abandonment of Alpine grasslands has not only reduced forage provision (Briner et al., 2013) but has also had negative impacts on some regulating services such as fire prevention (Navarro and Pereira, 2012), as well as has been negatively related to cultural ecosystem services, in particular to aesthetic landscape values (Schirpke et al., 2016). Nevertheless, positive effects have been found in terms of carbon sequestration (Levers et al., 2015; Nagler et al., 2015), erosion control (Egarter Vigl et al., 2016),

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timber production, water regulation, and recreational activities (Navarro and Pereira, 2012). These impacts occur at different time scales (Hein et al., 2016), for example, shrub encroachment several years after the abandonment of grassland will affect aesthetic values (Schirpke et al., 2013), while timber production will only be relevant after forest regrowth, which may take several centuries (Tasser et al., 2017).

In mountain areas, ecosystem services of agricultural land are influenced by socio-economic-driven management decisions at all elevations, whereas climate change affects such services more strongly at high altitudes (Briner et al., 2013). In the French Alps, climate-induced changes have been found more important than management decisions for regulating and cultural ecosystem services of mountain grasslands (Lamarque et al., 2014). Whereas manuring increases nutrient availability and changes vegetation structure (species composition), leading to higher biomass production on mown grassland (Quétier et al., 2007), higher temperatures induce a shift in plant species towards higher altitudes, resulting in reduced species richness and altered species composition (Hoiss et al., 2013). Extreme drought periods are expected to occur more frequently and affect water availability, especially in humid regions (Köplin et al., 2014; Leitinger et al., 2015), while reduced water availability, in turn, influences other ecosystem services, for example, leading to reduced forage quantity (Briner et al., 2012; Schirpke et al., 2013), altered carbon allocation (Hasibeder et al., 2015), increasing soil stability, and a lower risk of erosion (Tasser et al., 2003).

Although combined effects of land-use and climate change on ecosystem services have been studied in Switzerland (Briner et al., 2013; Bürgi et al., 2015), Austria (Kirchner et al., 2015; Schirpke et al., 2013), and the French Alps (Lamarque et al., 2014), few studies have included climate-induced impacts on the vegetation composition of mountain grassland under future scenarios (Lamarque et al., 2014). Ecosystem services can be assessed using various modelling approaches, including proxy-based and process-based methods (Lavorel et al., 2017), but trait-based models are most promising to analyse climate-induced changes in ecosystem services at the landscape level (Lamarque et al., 2014), including future shifts in species abundances (Cantarel et al., 2013). Trait-based models describe statistical relationships between biotic and abiotic properties and functional traits that can be linked to specific ecosystem services (Lavorel et al., 2011). The focus on the functional composition of vegetation communities helps not only to explain current ecosystem services but also to project future ecosystem services, accounting for functional responses and changes in species composition (Díaz et al., 2013; Lavorel et al., 2017).

Future provision of ecosystem services depends further on ecosystem resilience, defined as the capacity of ecosystems to cope with disturbance without shifting to another regime (Walker et al., 2004). A resilient system will therefore buffer shocks and disturbances, preserving related ecosystem services, but little is known about the resilience of ecosystems to provide ecosystem services in the face of environmental perturbations (Díaz et al., 2013). Such resilience depends not on the resilience of single species but on the maintenance of important ecosystem functions provided by the plant community. In case of the decline or loss of important functional species, these ecosystem functions of present species might be replaced by other species in the future; however, this depends on species richness and functional redundancy (Oliver et al., 2015). Hence, to maintain ecosystem services that depend on ecosystem functions, resilience in the latter is required (Grigulis et al., 2013; Lavorel et al., 2011). As each ecosystem service is linked to different functions, the level of resilience consequently differs between ecosystem services (Kohler et al., 2017a). Although research on resilience and its implications for ecosystem services is growing, as on mountain areas (e.g., Brunner and Grêt-Regamey, 2016; Kohler et al., 2017a; Schermer et al., 2016), the understanding of the dynamics of the resilience of ecosystem services in mountain grasslands under future scenarios is still limited.

This study addresses two research questions related to expected changing environmental and socio-economic conditions: 1) What are the potential future impacts on multiple ecosystem services in mountain grasslands? 2) How is the resilience of ecosystem services affected? We used climate (Gobiet et al., 2014) and socio-economic scenarios (Kohler et al., 2017b) to project the possible consequences of climate and land-use changes on ecosystem services for the Stubai Valley in Austria. First, we modelled current multiple ecosystem services of grassland under different management intensities and at various altitudes, including forage production, forage quality, carbon storage, soil fertility, water quality, and aesthetic value, using plant functional traits at the ecosystem scale. Then, we analysed future changes in these ecosystem services under three socio-economic scenarios, taking into account projected climate variations until 2050 and 2100 (Gobiet et al., 2014), as well as the natural reforestation of abandoned grassland (Tasser et al., 2017). Finally, we calculated ecosystem service resilience indicators to assess the resilience of the mountain grassland ecosystem services to future climate and land-use changes.

2. Materials and methods

2.1. Conceptual approach

To project the possible consequences of climate and land-use changes on future ecosystem services of the selected mountain grassland, we combined three different socio-economic scenarios with a climate scenario and analysed two different dates: 2050 and 2100 (Fig. 1). The three socio-economic scenarios (Section 2.3) were discussed with local stakeholders, who also mapped future land-use changes. These land-use change maps were combined with grassland trajectories (Section 2.3.1) to set up a sample design for the field measurements (Section 2.4.1). To assess the impacts on ecosystem services and their resilience under future changes, we first modelled current ecosystem services using trait-based models (Section 2.4.2), which were combined with future ecosystem services accounting for accelerating climate change, using a moderate climate scenario (Section 2.5). Finally, we used the ecosystem service values to calculate resilience indicators for current and future conditions (Section 2.6).

2.2. Study area

In this study, we focused on managed and abandoned grassland in the Stubai Valley, which is located between longitude 11.6′–11.25′ E and latitude 46.55′–47.15′ N in the Central Alps (Tyrol, Austria) (Fig. 2). The Stubai Valley comprises the municipalities of Fulpmes and Neustift and extends over an area of about 265 km^2, with elevation ranging between 887 m and 3484 m a.s.l. The various grassland types in the region (see Appendix Table A1) evolved from a long tradition of farming systems adapted to marginal grasslands and cover about 24% (total ~ 64 km^2) of the total area. Of these, 24 km^2 are currently used, with different management intensities. Whereas meadows in the valley bottom are fertilised and cut several times per year, grassland above 1500 m a.s.l. is cut one to two times per year or used for pasture. Abandoned grassland covers an area of about 40 km^2 and is located mainly above 1500 m a.s.l. Other land-cover types include 28% forest, 1% settlement, and 47% non-usable land (i.e. glacier and rock).

The economic situation in the Stubai Valley is positively influenced by its proximity to Innsbruck, attracting commuters