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Climate change versus land-use change—What affects the mountain landscapes more?

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ABSTRACT

Land use and climate change are both strong drivers of landscape transformation. Using a representative valley of the Central Alps (Stubai Valley, Tyrol, Austria) we assess (1) the historical and likely future spatial patterns of land use/land cover (LULC), (2) the influence of temperature increase on the LULC distribution, and (3) the speed at which these changes will occur. Based on the historical landscape development and spatially explicit models, the effects of various land use and climate scenarios were modelled. Employing a pan-Alpine model, we were able to detect the temporal trajectory of spatial reforestation. The results show that land-use changes that already occurred during the last decades are responsible for the main future LULC changes (by secondary succession). Only an extreme land abandonment scenario and extreme climate scenarios (5 K temperature increase) would bring about similar changes in LULC distribution and expansion of the forested areas. While alpine grasslands, alpine pioneer formation and glaciers would shrink drastically, especially deciduous forests would spread. To a considerable degree, such changes might take place over the next 300 years. By contrast, the increase in forest areas triggered by temperature changes would be slower and longer termed (up to 700–800 years).

The effects and intensity of land-use change in the investigated valley, that is comparable to many regions in the Alps, will be at least equally severe and responsible for transformation of the landscape as those of a projected temperature increase.

1. Introduction

Globalization effects accompanied by structural and economic changes and climate change cause strong dynamics in land use/land cover (LULC) to be expected throughout the entire Alpine region. In the recent past, scientific debate has mostly focused on the effects of climate change on e.g. carbon sequestration (Ward et al., 2014), biodiversity (Bellard et al., 2012; Pauli et al., 2012), ecohydrology (Van Vliet et al., 2013), and the impacts on ecosystem service provision (Elkin et al., 2013; Fuhrer et al., 2014; Schirpke et al., 2013; Leitinger et al., 2015). In this context, land-use changes are often discussed only as secondary triggers of landscape transformation acting indirectly through their effects on climate change (Pielke, 2005). Only a small amount of research has analysed both processes jointly in order to unravel their interactive effects. Kaplan et al. (2012) found that carbon sequestration between 1500 and 2000 was mainly driven by anthropogenic land-use rather than by climate variability. Dirnböck et al. (2003) and Tovara et al. (2012) investigated the impacts of land-use and climate change for vegetation and biodiversity. Kouba et al. (2012) discussed the potential processes in relation to the forest dynamics in formerly managed landscapes. Starfield and Chapin (1996) presented a first model of ecosystem change in response to transient changes in climate, land use and recruitment: this model allows projections of future developments to be made for the upcoming 50–500 years. More specifically, Briner et al. (2013a,b) and Huber et al. (2013a,b) explicitly address the influence of interactions between land-use and climate change on the landscape and the provision of ecosystem services in the Swiss Alps. Briner et al. (2013a) also refer to the indirect effect of climate change. Climate change will have e.g. a positive effect on grassland yields, which will in turn influence the probability of land abandonment.

In European mountain areas an upward shift in vegetation belts and the tree line is a crucial indicator for landscape transformation (Tasser and Tappeiner, 2002; Gehrig-Fasel et al., 2007; Wallentin et al., 2008). The changes are driven by a range of different biotic and abiotic factors acting on various spatial scales. On a global scale, the location of the Alpine vegetation types is closely correlated with

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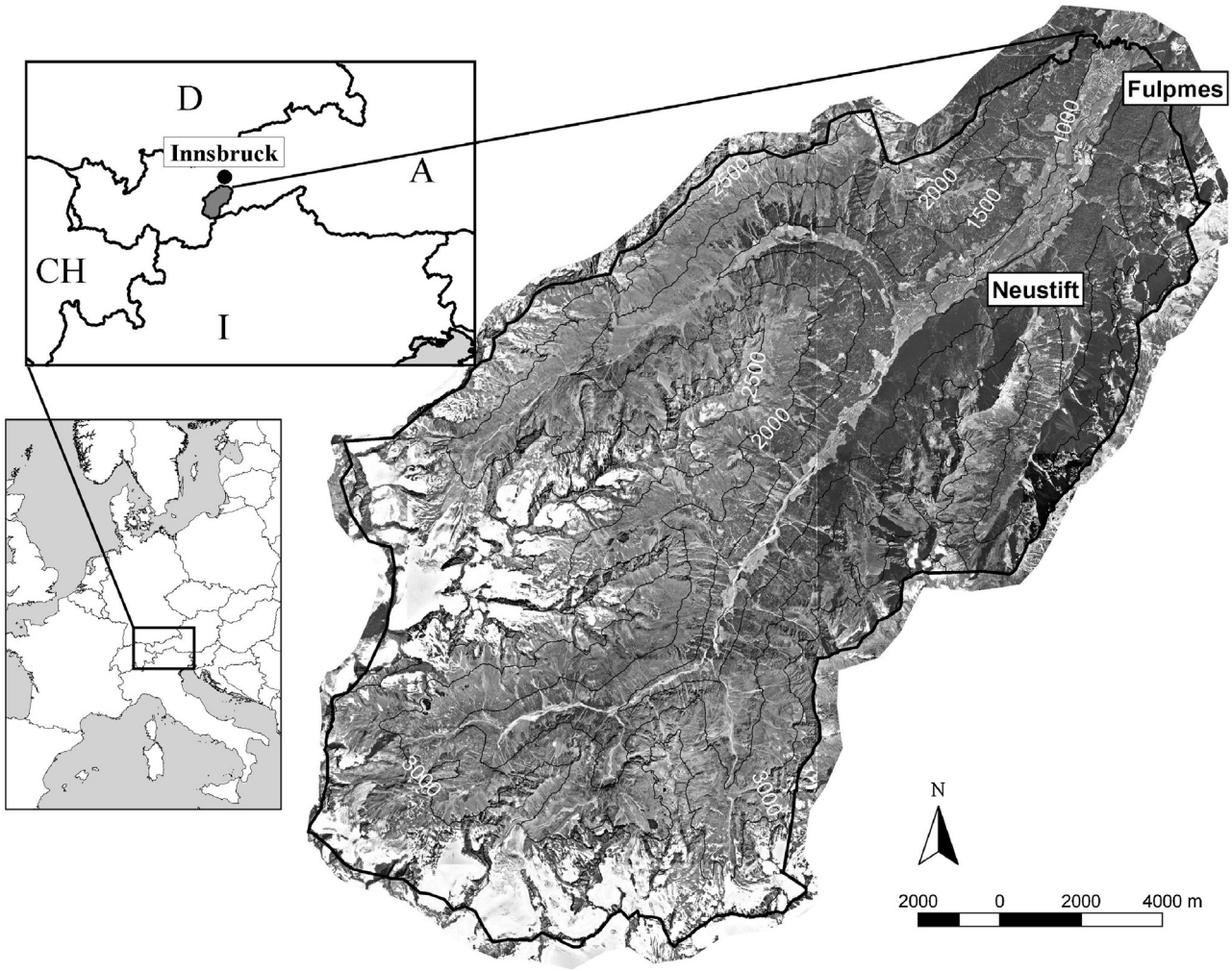

Fig. 1. The Stubai Valley runs 31 km from northeast to southwest. Its head is the glaciated main ridge of the Stubaier Alpen range, with Zuckerhütl (3507 m) being the highest point.

climatic factors, most importantly temperature and the growing season length (Briner et al., 2013a; Fuhrer et al., 2014). At the same time, the patterns of vegetation dynamics are also strongly influenced by regional land-use change e.g. the abandonment of Alpine summer pastures (Dirnböck et al., 2003; Gehrig-Fasel et al., 2007; Pauli et al., 2012).

A long-lasting agricultural impact as a consequence of a growing demand for pastoral land has caused the potential tree line to significantly shift downward by several hundred metres to the current tree line (Holtmeier and Broll, 2005; Pecher et al., 2011) and extensive forest clearing in the valleys. The forest was replaced by a variety of agriculturally used grasslands, arable areas, permanent cultures, settlements and different dwarf shrub communities, depending on the type and intensity of land use (Tasser and Tappeiner, 2002; Lüth et al., 2011). However, in 1950, it came through the strengthened influence of industrialization and globalisation to a significant reduction of the agricultural importance. As a consequence land abandonment has been observed, particularly on Alpine summer pastures and steep slopes with a strong influence on ecosystem dynamics. These formerly agriculturally used grassland communities can prevail only as long as the particular land use is continued. If the land is abandoned, the natural succession and, below the potential tree line, reforestation take place (Gehrig-Fasel et al., 2007). In this context, Briner et al. (2013a) show a difference in the combined impact of climate and land-use change for various elevation belts, e.g. between the tree line and the bottom of the valley. Some effects of the drivers are well known, whereas the effects on their spatial distribution are not yet well understood. Moreover, the rate of change for involved ecosystem processes represents one of the largest uncertainties in projecting future landscape development.

This paper investigates the impact of changes in land use and climate warming on a typical Alpine landscape in space and time. The study area is located in the Austrian state of Tyrol, namely in the Stubai Valley. Our approach is based on the use of historical and current LULC maps and various land-use and climate scenarios to detect LULC dynamics via geostatistical modelling. In particular, we asses land-use and climate change effects on the (1) historical and likely future spatial patterns of land use/land cover (LULC), (2) influence of temperature increase on LULC distribution, and (3) speed at which these changes will occur.

2. Materials and methods

2.1. The study area

The study site 'Stubai Valley' is located south of Innsbruck and comprises two municipalities Neustift and Fulpmes covering 265 km^2 (Fig. 1). The altitude extends from 600 m a.s.l. on the northern valley floor to 3450 m a.s.l. at the upper end of the val-