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Geographical heterogeneity in mountain grasslands dynamics in the Austrian-Italian Tyrol region

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ABSTRACT

Agricultural land abandonment and transformation of the rural mountain landscapes have been of widespread occurrence in the European mountains. Such changes have strongly affected agricultural land, particularly traditionally used grasslands, which are hotspots of biological and cultural diversity in Alpine countries. We investigated the land use/cover changes and drivers of those changes between 1990 and 2010 in the Austrian and Italian bi-national region of Tyrol. We focus on grasslands as they covered around 94% of the utilized agricultural area since 1990. We mapped changes in grassland areas and assessed the socio-economic and biophysical factors associated with those changes using statistical modelling. Both sub-regions of Tyrol experienced changes in grasslands, but national and local scale factors mediated the impact of regional integration on land use decisions. Marginal grasslands decreased more rapidly in Austria's than in Italy's Tyrol, mostly in high elevation areas. High-management intensity grasslands slightly expanded in Austrian Tyrol, while in Italy's South Tyrol their conversion to other land uses such as permanent crops was more frequent. In the whole Tyrol region, grasslands of high management intensity expanded mostly in municipalities with a larger population, greater livestock density, smaller farms, more remote location, and fewer municipal grasslands and natural parks. Our findings suggest that grasslands conversion is a geographically heterogeneous process. Notwithstanding the de-agrarisation of the Tyrolean landscapes that took place in some Alpine areas, an expansion of grasslands was observed in others. These changes have ecological and social implications.

1. Introduction

Regional economic and political integration have led to changes in agricultural land use and to a transformation of rural landscapes in Europe. The selective restructuring of regional and sub-regional economic spaces has particularly impacted mountain areas such as the Alps (Jepsen et al., 2015). This led to critical levels of land abandonment in marginal regions (NORDREGIO, 2004; Maestre et al., 2009; Komac, Kefi, Nuche, Escós, & Alados, 2013; Rutherford, Bebi, Edwards, & Zimmermann, 2008; Zimmermann, Tasser, Leitinger, & Tappeiner, 2010) and drastic changes in agricultural practices (MacDonald et al., 2000; Regos, Ninyerola, Moré, & Pons, 2015). Changes, however, have not been homogenous across the rural space (Munroe, van Berkel, Verburg & Olson, 2013). Agriculture in lowlands and in favourable inner Alpine valleys has experienced mechanization, specialization and intensification while traditional livestock farming, predominantly located in high mountain areas, generally decreased. This was associated with shrub and tree encroachment in landscapes that were traditionally dominated by grasslands (Hellesen & Levin, 2014; Tasser, Walde, Tappeiner, Teutsch, & Noggler, 2007). Abandonment in marginal mountain areas frequently came along with intensification of grasslands in favoured areas, mainly in valley floors (Niedertscheider et al., 2017; van Vliet et al., 2015). Historically, deforestation of the subalpine belt resulted in the transformation of forests into summer grasslands for transhumant flocks, yet a recent decline in transhumance favours forest expansion (Sanjuán et al., 2018).

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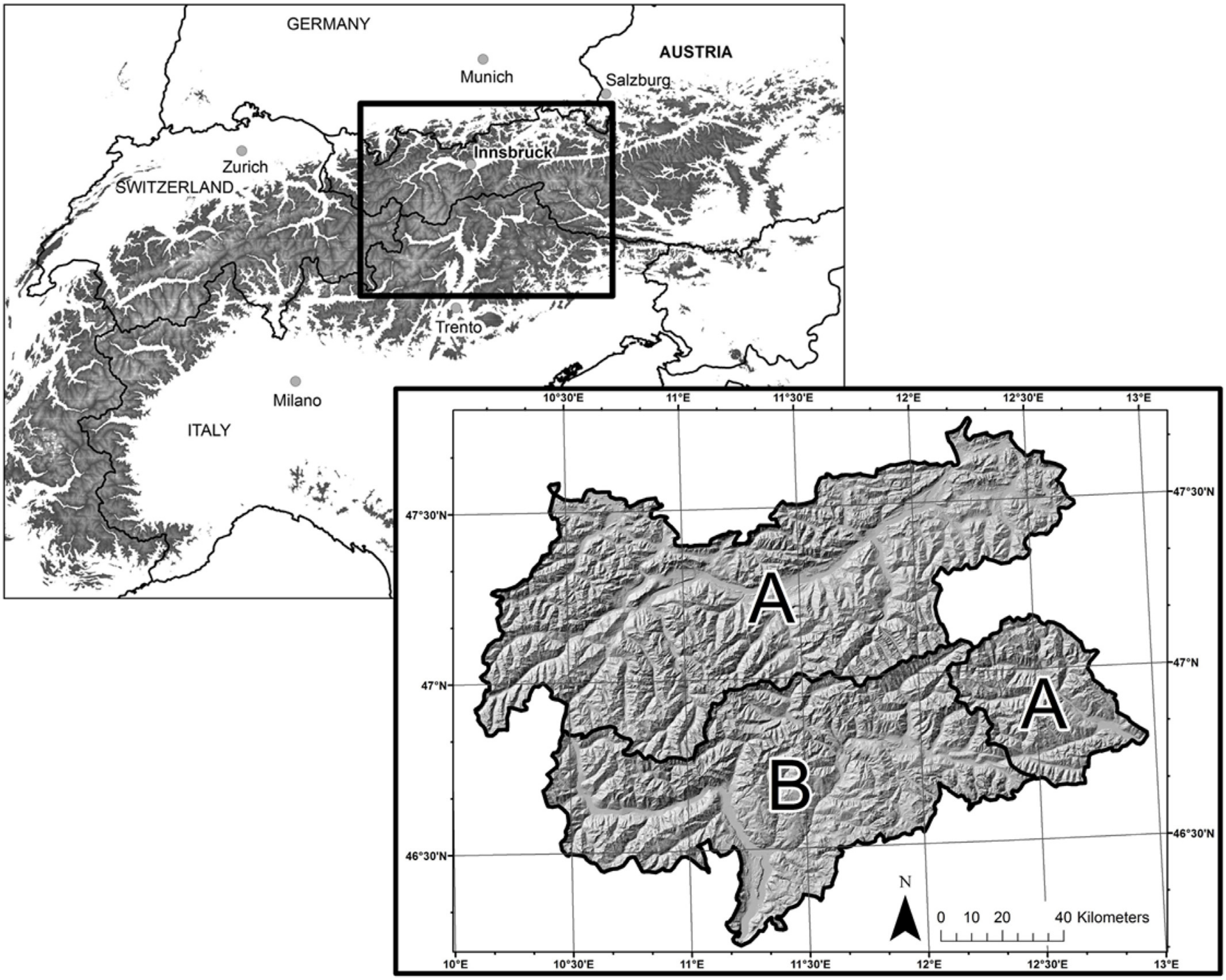

Fig. 1. The study area: bi-national territory of the Tyrol region ('A' indicates Austria's Tyrol and 'B' Italy's South Tyrol).

These land use/cover changes (grassland changes) in mountain regions have had diverse social and ecological impacts. Alterations of agricultural activity and conversion of grasslands areas have been associated with biodiversity changes and a loss of cultural heritage in mountain landscapes (Hellesen & Levin, 2014; Keenleyside & Tucker, 2010; Navarro, Rodrigues, Reichelt, Munro, & Queiroz, 2014; Shucksmit & Rønningen, 2011). In Mediterranean mountain environments, shrub encroachment after abandonment increases the risk of fires (Nunes et al., 2005; Pavlek et al., 2017). Agricultural land abandonment may also have positive effects on forest ecosystems, for example through forest succession (Carrer, Soraruf, & Lingua, 2013; Foster, Swanson, Aber et al., 2003) and carbon accumulation (Niedertscheider et al., 2017). The creation of extensive low disturbance habitats facilitates the recovery of some flora and fauna. Likewise, reforestation and afforestation, by reducing landscape fragmentation, reduce mountain soil erosion (Renwick et al., 2013). On the other hand, maintenance or intensification of mountain use play a central role for provisioning services such as food and fodder production. The maintenance of open landscapes is also linked to other ecosystem services of great importance to society (Pecher, Bacher, Tasser & Tappeiner, 2017). This includes the maintenance of open cultural landscapes (Lindemann-Matthies, Briegel, Schüpbach, & Junge, 2011), the conservation of biodiversity on marginal areas (Niedrist, Tasser, Lüth, Dalla Via & Tappeiner, 2009; Tasser & Tappeiner, 2002), and the protection of fertile soils (Tappeiner and Cernusca, 1998). In the Tyrol region, conversion of grasslands led to a decrease in biodiversity (Tasser & Tappeiner, 2002). In the Urbión Mountains of northern Spain, land cover reorganization led to a progressive contraction of shrublands, mainly substituted by dense forests in high elevation areas and an average 200 m altitudinal advance (Sanjuán et al., 2018).

Recent studies in the French Alps revealed a lower occurrence of land abandonment in high-compared to medium-altitude mountain areas, despite the effects of remoteness and marginalization (Hinojosa, Napoléone, Moulery, & Lambin, 2016a; 2016b). This suggests that marginal areas can play a positive role in conserving mountains' cultural landscapes and their associated ecosystem services. Based on a meta-analysis of land-use trajectories in mountain areas, Locatelli, Lavorel, Sloan, Tappeiner and Geneletti (2017) identified several archetypes of ecosystem services trajectories and highlighted the importance of land-use intensity in driving concurrent changes to multiple services. Given the multiple and sometimes conflicting effects of grassland changes on social-ecological systems, it is important to understand the spatial distribution of these changes and the factors explaining their spatial heterogeneity and impacts (Egarter Vigl, Tasser, Schirpke & Tappeiner, 2017; Zimmermann et al., 2010).

The objective of this study is to better understand land use dynamics in European mountain regions through a comparative case-study research on the bi-national region of Tyrol, i.e., the territory comprising

Austria's Tyrol and Italy's South Tyrol. While the ecology and historical socio-demographic changes in this region have already been studied (Pecher, Tasser, Walde, & Tappeiner, 2013; Tappeiner, Borsdorf, & Tasser, 2008; Tasser, Schermer, Siegl, & Tappeiner, 2012), the connections between socio-economic factors and grasslands conversion remains underexplored. This region has a long history of agricultural conservation policies associated with multiple political regimes. The differences between the Austrian and Italian Tyrol sub-regions offers a natural experiment as the Tyrol is a relatively homogenous geographic region but each sub-region has been influenced since 1918 by different national institutions and policies. Through a quantitative analysis of grassland changes at the municipality level over the 1990–2010 period, we address the following questions: Are patterns of grasslands conversion and modification different between the two sub-regions in the Tyrol? What factors do explain these differences? How do institutional differences between the two sub-regions influence changes in land use management, including grassland intensification? We define grassland conversion as the change from grasslands to a different land use category, which includes abandonment and conversion to cropland, including orchards and vineyards. We define grassland modification as a change in management, including intensification of grassland use. Regional-scale changes such as the European integration are expected to induce the economic marginalization of territories that are disadvantaged due to their bio-physical characteristics, such as mountain areas. However, our hypothesis is that local strategies of land use intensification and diversification, as influenced by national land use and agricultural policies, produce different patterns of grassland changes. In some places, these factors counteract processes of marginalization, therefore reinforcing the geographic heterogeneity in land use trends.

2. Study area

The region of Tyrol includes Austrian and Italian territories in the Central and Eastern Alps. The region lies between 47°36' - 46°02′ N and 10°08' - 12°45′ E. (Fig. 1). Austria's Tyrol is politically organized in 297 municipalities and Italy's South Tyrol in 116 municipalities of diverse sizes, from 0.11 km^2 (Rattenberg) to 467 km^2 (Sölden). The whole region covers 20036 km^2 with altitudes ranging between 194 and 3905 m. a.s.l. Average annual precipitation ranges from 350 mm to 2000 mm, with maximum rainfall from June to July (Fliri, 1998). Mean annual temperature ranges from 0 °C to 9 °C. The bedrock is comprised of calcareous sedimentary rocks in the northern and southern regions, and of primary rocks at the main chain of the Alps, sometimes with superimposed calcareous isles (Bögel & Schmidt, 1976). Areas above 2000 m.a.s.l. represent 40% of the entire territory. According to Corine Land Cover data 2006 (Corine land cover 2006, Version 16 (04/2012); EEA, 2007, p. 130), 38.6% of the region is covered with forests, predominantly spruce and pine forests, 6.4% being mixed deciduous forests. Agricultural areas cover 28.1% of the territory, most of it being grasslands, 8.7% being grasslands intensively used as fodder meadows, 1.3% arable farmland, and 1.1% permanent crops. The remaining non-agricultural area is made up of alpine grasslands, rocky areas, and glaciers, wetlands and water bodies, and urban zones.

The current typical Tyrolean landscape emerged under continuous rule of the Habsburg Empire from the 6th to the 15th centuries (Siegl & Schermer, 2012). Protection of agriculture was of particular interest for the sovereign Maria Theresia, who enacted in 1770 a new agricultural law restraining farm segmentation, establishing inheritance, and ruling a tax on land and buildings based on the Francisco-Josephinian Cartographical Register. Farm inheritance enabled families to make a living from agriculture. Hence, the depopulation of rural areas prompted by the socio-economic transformation of the country in the 19th and 20th centuries was modest in the Tyrol region. In its essence, this law is still present in today's Austria's Tyrol. In South Tyrol, which passed under Italian control after World War I, the law had a short-term reversal in 1929 but was reintroduced in 1954 as the first South Tyrolean farm-law.

After World War II and the subsequent economic modernization of Europe, the pressure on agriculture increased. Farming activity in the Alps was increasingly marginalized due to its bio-physical disadvantages. Traditional mountain farming was oriented towards self-sufficiency and crop diversity. A specialization on cash crops with regional economic integration occurred already in the 1960s and 1970s in the whole Tyrol region, leading to a conversion of some grasslands to permanent crops. Support to agricultural change was implemented in Austria based on national funds. Since the early 1990s, integration of the country into the European Union (EU) brought European support for the adaptation of farms to the Common Agricultural Policy (CAP). Nonetheless, the competitiveness of mountain agriculture decreased due to high production costs. To prevent a collapse of farming, additional support was provided through public investment in infrastructure and communication (roads, electricity, telecommunication) and incentives for artisanal enterprises (Pasquali, Bassetti, & Fumai, 2002). While EU support to rural areas in Italy's South Tyrol started just after the creation of the European Single Market, in Austria income compensation was financed by the national government since the 1970s and also by the EU since 1995. The EU support for mountain areas was framed within the Austrian Agri-environmental Program (ÖPUL).

A rapid decrease in agricultural population started in the 1960s in Tyrol (Tappeiner, Tappeiner, Hilbert, & Mattanovich, 2003). This entailed a shift from full-time to part-time farming. It was followed by a selective abandonment of small-scale farms managed by part-time farmers, while the decrease of larger farm enterprises slowed down (Schermer, 2014). Regional integration also induced livelihood diversification, particularly through mountain tourism, and an adjustment of farming systems. Consequently, the processes of de-agrarisation, de-ruralisation and migration to large cities, observed in many parts of the Alps, were less pronounced in the Tyrol region.

3. Method

3.1. Data

Identification of grassland changes at the municipality level (i.e., *Gemeinde* in Austria and *commune* in Italy) is based on agricultural census data for 1990 and 2007 in Austria's Tyrol, and 1990 and 2010 in Italy's South Tyrol. This covers a sufficient time span to uncover factors affecting land use conversion. All agricultural and socio-economic data correspond to censuses of Austria's Tyrol and Italy's South Tyrol in 1990 and 1991, respectively. Descriptive statistics of the variables used in modelling are presented in Table 1.

3.2. Model of the causes of grassland changes

Our analysis of grasslands dynamics covers all municipalities of the Tyrol bi-national region. We analysed changes in two land use classes: grasslands of high management intensity and marginal grasslands. The former indicates grasslands that are mown and fertilized with slurry or manure twice or more a year. Marginal grasslands are mown at most once a year or grazed with low intensity, but not fertilized. We focus on grasslands given their predominance in the composition of the utilized agricultural area (94% for the whole region, 97% in Austria's Tyrol, and 88% in Italy's South Tyrol in 2007).

Relationships between grassland changes and bio-physical and socio-economic variables were examined by multiple regression analyses. To avoid endogeneity, our models estimate relationships between grassland changes in the inter-census period and independent variables at the beginning of the period (following Breustedt & Glauben, 2007). To represent differences in national land use and economic policies, we used a dummy variable (subregion) that differentiates between municipalities located in Austria from those in Italy.

We included three groups of factors: location, farm organization,

Table 1
Variables at the municipality level used in estimation and sample statistics.
Source of census data: Statistik Austria (1991, 2000, 2010; www.statistik.at), ISTAT (1990, 2000, 2010; www.istat.it), ASTAT (2014)., Source of other data: Jarvis, Reuter, Nelson, and Guevara (2008), Pecher, Tasser, and Tappeiner (2011), Graf (1880, 1882), Bundesanstalt für Agrarwirtschaft (2015), Tele Atlas (2006).

Variables	Description	Bi-national Tyrol region (395 municipalities)		Austria's Tyrol (279 municipalities)		Italy's South Tyrol (116 municipalities)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Dependent variables (percentage change by grasslands category)							
LUCC-intensive (a,b)	Changes in grasslands of high management intensity	−1.40	8.03	0.04	8.26	−4.84	6.25
LUCC-marginal	Changes in marginal grasslands (extensively used pasture and meadows, alpine pastures and alpine meadows)	−7.57	19.78	−8.81	19.69	−4.62	19.77
Explanatory variables							
Subregion	Dummy, proxy for the influence of national governance (Austria's Tyrol = 1, Italy's South Tyrol = 0)	0.71	–	–	–	–	–
Altitude	Classes of mean altitude of settlement per municipality (m.a.s.l.): medium mountain (400–800 m) = 0; high mountain (800–1200 m) = 1[a]	0.59	–	0.59	–	0.59	–
Slope	Share of utilized agricultural areas with a slope > 27° that are accessible by tractors and four wheel drive vehicles, but only manageable with special machineries or by hand.	30.58	16.50	30.79	17.21	30.08	14.73
Remoteness	Travel time to work (minutes) from the municipality to the nearest labour market centre [d]	16.67	10.55	16.07	10.32	18.11	10.99
Potential forest area	Share of the municipality area situated below the potential treeline	89.16	14.94	88.56	15.40	90.60	13.74
Population (a,b)	Number of inhabitants residents	2713	8050	2263	7262	3797	9637
Farm size (a,b)	Mean (ha per farm) of the reduced utilized agricultural area (UAA) [b]	6.69	3.51	7.35	3.27	5.10	3.58
Livestock density	Livestock units per reduced UAA (without arable land and permanent crop area) [c]	2.35	2.12	2.44	2.17	2.14	1.97
Part-time farms (b)	Share of part-time farms of the total number of farms	69.76	16.00	70.72	17.96	67.45	9.47
Municipal grasslands	Share of marginal grasslands owned by a municipality of total marginal grasslands [e]	30.69	41.92	31.42	43.21	28.96	38.79
Communal grasslands	Share of marginal grasslands owned by agricultural communities (Agrargemeinschaf) or cooperatives of total marginal grasslands	29.34	37.38	30.68	38.79	26.14	33.67
Park (a,b)	Share of Natura 2000 sites of the total municipality area [f]	8.76	20.19	6.09	17.73	15.17	24.03

Notes: (a) and (b) stands for significant differences between the sub-regions of Austria's Tyrol and Italy's South Tyrol at 0.05 level, measured by the Independent-Samples Median Test and the Kruskal-Wallis test, respectively.

[a] Combination of DEM with settlement centres in ArcGIS resulting to two classes.

[b] The reduced UAA comprises grasslands areas with standard yield potential in favourable areas (meadows mown several times and cultivated pastures) and the extensive permanent grasslands areas (meadows mown once, rough grazing, litter meadows, alpine pastures and mountain meadows) converted with a reduction factor. The reduction for extensive permanent grasslands in alpine pastures and mountain meadows amounts is a result of lower yield, equal to 12.5% of a fodder meadow in the valley bottom.

[c] Numbers of animals are converted to livestock units (LU) following the EU livestock schemes: sucker cows, dairy cows, male bovines and horses over 24 months: 1 LU; male bovines and heifers 6–24 months: 0.6 LU; sheep and goats: 0.15 LU, pigs: 0.30.

[d] Market centres are rural or urban municipalities with over 10000 inhabitants or more than 5000 jobs with a positive commuter balance. These agglomerations are economically important by the pull in effect over neighbouring municipalities (see, also, Tappeiner et al., 2008).

[e] The values reflect the proportion of the total marginal grassland owned by the agricultural community (co-ownership) or municipality. Agricultural community grasslands include grasslands owned by agricultural communities (Agrargemeinschaften) and cooperatives. In general, community grasslands are rather rare and have lost importance since the end of the 19th century at the expense of private ownership (more details at Tasser, Aigner, Egger, & Tappeiner, 2013).

[f] Natura 2000 is an EU-wide network of protected areas, established to preserve the biological diversity in the EU.

and institutions. Firstly, we tested the effect of location on agricultural decline and grasslands conversion. The Ricardian theory of marginality in land use (Jäger, 2009) suggests that remote areas are characterised by high emigration rates and experience land abandonment (Brouwer, Baldock, Godeschalk, & Beaufoy, 1997; Keenleyside & Tucker, 2010; Terres, Nisini, & Anguiano, 2013). As in mountain areas, remoteness is often associated with bio-physical characteristics (Rey Benayas, Martins, Nicolau & Schulz, 2007; Flinn, Vellend, & Marks, 2005), we used the following proxy variables for this location effect: i) location in either a medium or a high mountain zone (altitude) (Hinojosa et al., 2016a), ii) slope steepness, and iii) municipality area below the natural tree line (potential forest area), as a proxy for agricultural suitability (Pecher et al., 2011). Remoteness is also associated with weak connectivity (Dax & Hovorka, 2004; Naumann, Davis, Kaphengst, Pieterse, & Rayment, 2011). Transportation infrastructure can make marginal land more productive by lowering exploitation costs (Patarasuk, 2013) and facilitate non-farm rural activities such as tourism (Kariel, 1989). However, livelihood diversification induced by connectivity may also lead to a shortage of agricultural labour and thus to farm abandonment (Hatna & Bakker, 2011). We tested the effect of connectivity through a variable measuring the travel time to commute to the closest labour market centre (remoteness) (Tappeiner et al., 2008).

Changes in farm management practices, which can lead to agricultural intensification or extensification, are common responses to changes in economic integration and supra-national land use policies (Lambin, Geist, & Rindfuss, 2006; Monteiro, Fava, Hiltbrunner, Della Marianna & Bocchi, 2011). As a proxy for farm organization, we measured farm size and livestock density. By using the reduced agricultural area (as defined in Table 1, footnote (d)) to estimate both these variables, we took into account the lower productivity of marginal grasslands and the agricultural yield differentials between grasslands areas. This facilitated comparison of different land use types in terms of intensification or extensification. Livelihoods diversification, especially through non-farm or off-farm activities, has been associated with agricultural abandonment (Mottet, Ladet, Coque, & Gibon, 2006). However, the cost of abandonment is often offset by gains in other activities (Sineiro-García, Vázquez-González, & García, 2014). As a proxy variable for diversification, we included the share of part-time farms in a municipality.

Thirdly, the effect of institutions was tested at the local level by measuring the importance of collective land management. The ‘tragedy of the commons’ (Hardin, 1968) postulates that open access areas are prone to overuse, depletion and eventual abandonment. Accordingly, collectively-owned land, such as municipal grasslands, may be at a higher risk of abandonment. By contrast, under specific conditions, collective property can lead to sustainable agriculture (Ostrom, Walker, & Gardner, 1994; van Gils, Siegl, & Bennett, 2014). We used two variables to test these contentions: grasslands owned by a municipality, and grasslands under collective property and management of farmers groups. Both categories include grasslands, forest, rocky surfaces, water bodies, and other land not used in productive activity. At an intermediate level between the national and the local, we measured land use regulations, particularly through national and regional parks. Natural parks have been conceived for multiple goals, among them to prevent agricultural land conversion into more profitable uses (urbanisation for example) and to reduce land abandonment (Davis & Hansen, 2011; Kramer & Doran, 2010).

The relationships between grassland changes and the factors hypothesised to influence land use decisions were analysed using a Generalized Linear Model (GLM) based on a gamma distribution of the dependent variables and logarithmic link functions (Hardin & Hilbe, 2007). The model was specified as:

$$LUCC_{i,t1-t0}/UAA_{t0} = \alpha + \beta X_{to} + \gamma Z + \varepsilon$$

A, β and γ are parameters

X is a vector of independent variables (covariates only)

Z is a dummy variable that measures the “sub-region” effect

Ɛ is the error term

t_0: 1990

t_1: 2007 in Austria's Tyrol and 2010 in Italy's South Tyrol

The dependent variable ($LUCC_{i,t1\text{-}t0}$/UAA $_{t0}$), estimated at the municipality level, is the share of LUCC in the two grasslands categories of the utilized agricultural area (UAA) at the beginning of the inter-census period. Standardisation of LUCC by the UAA at 1990 is reliable because: (i) it is not prone to the small land use size effect (having a small number in the denominator causes non linearity), (ii) it estimates the proportion of a given LU in the entire municipality and thus identifies the main land use orientation of the municipality, (iii) it standardizes each land use by the same quantity in a given municipality, (iv) it enables better representation of the spatial distribution of LUC, and (v) it reduces the bias introduced by outliers (the small municipalities effect).

LUCCi is equal to the difference in surface areas between two census years (t_1-t_0). i indicates land use categories – i.e., grasslands of high-management intensity and marginal grasslands. A positive difference means more surface area of a particular land category at time t_1 – i.e., grassland expansion. When comparing LUCC between municipalities, a positive difference can reflect either the actual expansion of grasslands or a slowdown in their reduction. A negative difference means less surface area of a particular land category at time t_1 – i.e., grassland abandonment.

After following standard protocols of data cleaning, independent variables were selected based on the above theoretical considerations and prior detection of multicollinearity. Parameters were estimated through generalized linear models with z-transformation of selected independent variables and box-cox transformation of dependent variables, to address skewed distributions and multiple scales of covariates. Models were first applied to the entire set of municipalities in the binational Tyrol region and then separately to each of the sub-regions. Each model was also estimated for each of the two grassland categories.

4. Results

4.1. Trends in grassland changes

Over the 1990–2010 period, municipalities in Austria's Tyrol and Italy's South Tyrol experienced similar levels of grassland changes, but with different dominant trends. Most expansion of high-management intensity grasslands occurred in Austrian Tyrolean municipalities while most conversion to other agricultural uses took place in Italy's South Tyrol (Fig. 2). Grassland conversion in the South Tyrol was due to abandonment and conversion to cropland and permanent crops. Marginal grassland areas decreased more in Austria's than in Italy's Tyrol. We found significant differences between higher and lower altitude municipalities in terms of changes in marginal grasslands and in total UAA. The Kruskal-Wallis test did not identify significant differences in grasslands of high management intensity by sub-region.

4.2. Causes of grassland changes

The models provide robust regression results, with no multicollinearity (VIF between 1.1 and 4.2). Estimation results for both grassland categories are presented in Table 2 for the whole Tyrol region and in Table 3 by sub-regions. In all models, the Likelihood Ratio Chi-Square indicates statistical significance at the 1% level. The scaled deviance in all models is close to 1, suggesting a good fit.

The model for the whole region confirms that grassland changes were more pronounced in Austria's Tyrol, meaning that less abandonment or more land use expansion of grasslands occurred there than in South Tyrol. While the association is positive with grasslands of high management intensity (i.e., expansion or less reduction has occurred in

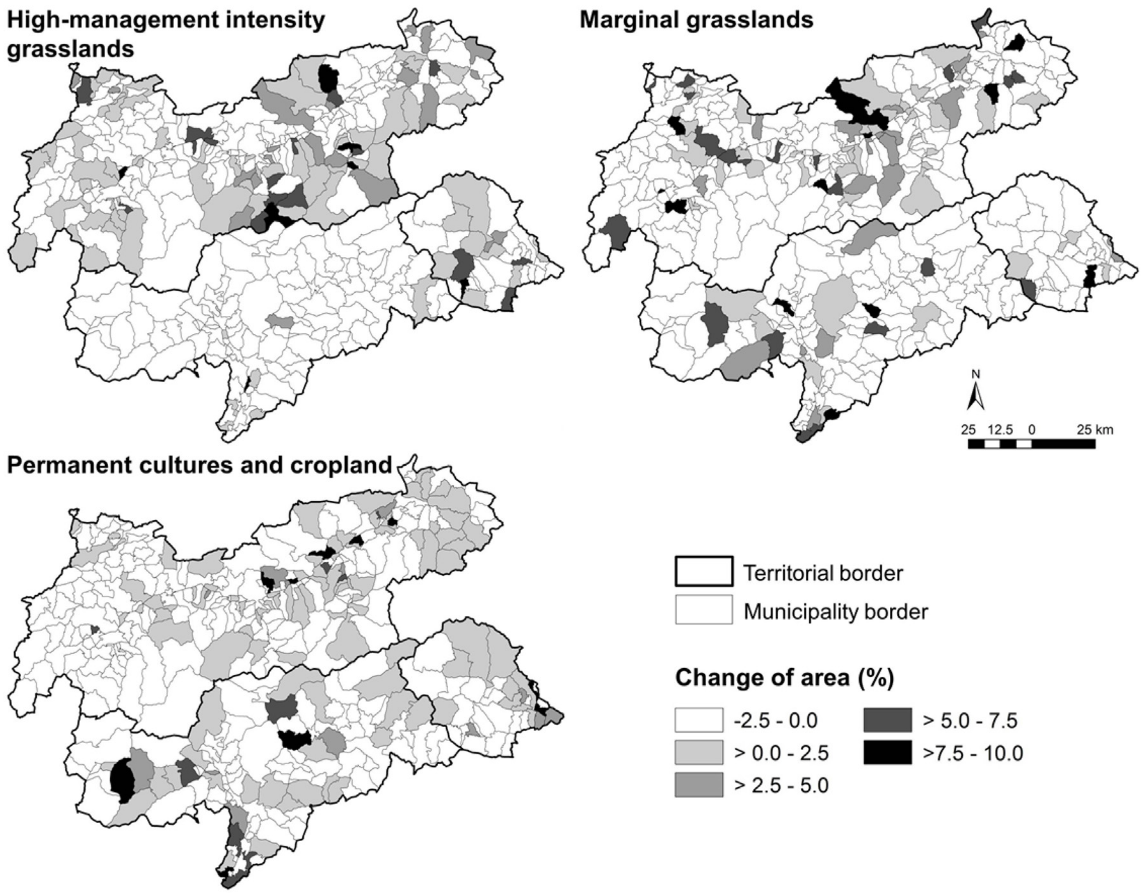

Fig. 2. Area change of high-management intensity grasslands, marginal grasslands and permanent crops or croplands between 1990 and 2010.

Table 2
Estimation results of the association between grassland changes and factors of change in the bi-national Tyrol region.

	Changes in grasslands of high management intensity		Changes in marginal grasslands	
	B	Std. Error	B	Std. Error
(Intercept)	−0.607	0.1098	0.424	0.1235
(Subregion_Austrian Tirol = 1)	0.746***	0.1089	−0.296**	0.1244
Altitude (High mountain = 1)	0.135	0.1172	−0.375**	0.1245
Slope	0.016	0.0743	−0.115*	0.0696
Remoteness	0.121**	0.0482	−0.07	0.0721
Potential forest area	−0.037	0.0552	0.03	0.0747
Population	0.04**	0.0167	−0.096**	0.0382
Farm size	−0.094*	0.0505	0.067	0.0704
Municipal grasslands	−0.108*	0.0614	0.005	0.0571
Communal grasslands	−0.021	0.0559	0.058	0.0606
Park	−0.1**	0.0427	0.009	0.0548
Livestock density	0.208***	0.0454	0.025	0.0537
Part time farms	−0.047	0.0549	0.084	0.0629
Likelihood Ratio Chi-Square	(N = 394, df = 12): 76.738***		(N = 394, df = 12): 33.974***	
Scaled deviance	1.03		1.03	

***, ** and * refer to significance at the levels of 1%, 5% and 10%, respectively.

Austria), the relationship is opposite for marginal grasslands: there was more reduction of marginal grasslands areas in Austria's Tyrol municipalities compared to Italy's South Tyrol. Bio-physical factors (altitude and slope) are significant for changes in marginal grasslands. The negative relationship suggests that, in high mountain municipalities, more land utilized for pasture was abandoned. Remoteness, a factor expected to influence negatively grassland changes, is positively associated with changes in grasslands of high management intensity and has no effect on changes in marginal grasslands.

The positive effect of population on changes in grasslands of high management intensity indicates that more populated municipalities have experienced expansion or less reduction of this category of grasslands. The effect was opposite in the case of marginal grasslands. Our indicators of farm organization (farm size and livestock density) also explain the increase in grasslands of high management intensity, though with opposite effects: municipalities with larger farms observed a reduction (or less expansion) of grasslands of high management intensity, and municipalities with more livestock per utilized agricultural area experienced more expansion (or less reduction). There was no relationship between livestock density and changes in marginal grasslands. Diversification of mountain livelihoods, as measured by the share of part-time farms, did only have a significant effect on changes in grasslands of high management intensity. Similarly, the effect of institutional factors on land use decisions is only significant for changes in grasslands of high management intensity, both in relation to public ownership of grasslands and the establishment of natural parks.

The modelling results by sub-region suggest several differences in explanatory factors of grassland changes between the two sub-regions (Table 3). Regarding grasslands of high management intensity in Austria's Tyrol, municipalities located in high mountains that were more remote and more populated were most affected by an expansion or lower reduction of this grassland category. None of these factors were significant for changes of this nature in Italy's South Tyrol, where farm size and communal access to grasslands had a negative effect instead. In other words, in Italy's South Tyrol, municipalities with larger farms and more communal grasslands (Agrargemeinschaf) experienced more

Table 3
Estimation results of the association between grassland changes and factors of change by sub-regions.

	Changes in grasslands of high management intensity				Changes in marginal grasslands			
	Austria's Tyrol		Italy's South Tyrol		Austria's Tyrol		Italy's South Tyrol	
	B	Std. Error	B	Std. Error	B	Std. Error	B	Std. Error
(Intercept)	0.028	0.1056	−0.613	0.1346	0.097	0.1112	0.642	0.1837
Altitude (High mountain = 1)	0.296**	0.1487	0.085	0.1761	−0.269*	0.1428	−0.643**	0.2931
Slope	−0.081	0.0871	0.134	0.1441	−0.165*	0.0850	0.009	0.1215
Remoteness	0.202***	0.0625	−0.046	0.0718	−0.082	0.0912	0.021	0.1227
Potential forest area	0.008	0.0577	−0.147	0.1212	−0.024	0.0803	0.197	0.1647
Population	0.071**	0.0334	−0.035	0.0236	−0.144***	0.0230	−0.042	0.0404
Farm size	0.030	0.0646	−0.292***	0.0779	−0.039	0.0795	0.201**	0.0687
Municipal grasslands	−0.049	0.0795	−0.092	0.0851	−0.020	0.0656	0.128	0.1401
Communal grasslands	0.045	0.0685	−0.151*	0.0844	0.025	0.0696	0.166	0.1230
Park	−0.066	0.0569	−0.098	0.0666	0.070	0.0748	−0.018	0.0790
Livestock density	0.273***	0.0611	0.108**	0.0508	−0.014	0.0717	0.013	0.0519
Part-time farms	−0.018	0.0650	0.153	0.1421	0.021	0.0723	0.137	0.2095
Likelihood Ratio Chi-Square	(N = 279, df = 11): 29.659**		(N = 116, DF = 11) = 31.889*		(N = 279, df = 11): 24.003**		(N = 116, DF = 11) = 17.674*	
Scaled deviance	1.040		1.115		1.05		1.12	

***, ** and * refer to significance at the levels of 1%, 5% and 10%, respectively.

reduction in grasslands of high management intensity. In addition, there was also less grassland intensification in those rural communities rather than the municipalities with a high share of natural parks. In both sub-regions, higher livestock densities were positively associated with changes of this grassland category.

The case of marginal grasslands is less clear. In Austria's Tyrol, abandonment has been influenced exclusively by bio-physical factors and population. In Italy's South Tyrol, high altitude municipalities were also affected by abandonment. However, municipalities with larger farms had less abandonment.

5. Discussion

5.1. Trends in grassland changes

Our results show that trajectories of grasslands conversion are spatially heterogeneous, as they are influenced by multiple, interacting factors (Munroe et al., 2013). This geographical heterogeneity in land use change is observed across the bi-national territory of the Tyrol region, though with important differences between the Austrian and Italian sub-regions. This spatially heterogeneous reconfiguration of Tyrolean landscapes reflects interactions between various causes of land use change and economic diversification (Mottet et al., 2006; Sineiro-García et al., 2014). National and local institutional factors mediate the impact of biophysical, economic and policy factors on local land use decisions, particularly in marginal agricultural areas (Gorton, Douarin, Davidova & Latruffe, 2008). This leads to multiple co-existing trends that represent the different ways marginal areas cope with regional integration (Keenleyside & Tucker, 2010).

The European Alps are still predominately used for mountain agriculture. However, since mid-19th century, three main trends of land use change have been characteristic: grasslands abandonment in the subalpine region, continuous grasslands farming, and specialization in vine and fruits (Zimmermann et al., 2010; see also Sanjuán et al., 2018 for changes in the Pyrenes). Our analysis shows that, during the study period, grasslands conversion mostly affected the Southern Italian and western Austrian Alps. These changes in Alpine grasslands directly affect key ecosystem services such as forage quantity, soil stability, natural hazards regulation, water provision, soil fertility and carbon storage (Egarter Vigl et al., 2017; Niedertscheider et al., 2017; Schirpke, Tasser, & Tappeiner, 2013). In the high mountains, forested areas are valuable for carbon storage and timber production. In grasslands areas, aesthetic value is negatively correlated with forage quality and quantity. Thus, meadows and pastures of high management intensities have higher forage production but a lower aesthetic value. Nevertheless, the trade-off between ecosystem services and agricultural productivity can be significantly reduced or even avoided by adopting sustainable management practices (Badgley et al., 2007). Grasslands of low management intensity (i.e., extensively used grasslands or marginal grasslands) positively influence regulating and cultural ecosystem services.

Management of the mountain landscape is a central policy issue. Managed grasslands are of high cultural value and their conversion into forested areas is perceived negatively (Bauer, Wallner, & Hunziker, 2009), particularly by farmers. For farmers, the economic function of mountain agriculture is predominant. By contrast, tourists greatly value the preservation of cultural landscapes for recreational purposes (Pecher et al., 2017). For actors from outside the Alps, reforestation is less problematic (Hunziker et al., 2008). A meta-analysis carried out by van Zanten, Verburg, Koetse, & van Beukering (2014) revealed that in general people preferred mosaic-pattern to homogenous agriculturally dominated land cover. Changes in mountain agricultural land use thus influence both key ecosystem services and people's perception of the landscape.

5.2. Causes of grassland changes

In the whole region, difficult environments determined by high altitude and slope have implied abandonment of marginal areas. The need for lowering production costs may result in the reduction of time-consuming traditional practices and in the abandonment of unproductive sites in subalpine zones with steep slopes (Tappeiner et al., 2003). In remote municipalities where commuting is problematic, small farms have to intensify their farming operations to maintain their income level from agricultural activities, though this affected the land use decisions on grasslands of high management intensity as these are likely to be the most productive. Simultaneously, continuous grasslands farming that enables specialization in cattle farming with intensified fodder production emerges on the more productive valleys (Flury, Huber, & Tasser, 2013; Gellrich, Baur, Koch & Zimmermann, 2007). Specialization in higher value land uses such as vine and fruits only occurs in locations with the most suitable bio-climatic conditions, especially in the South-Tyrolean Adige valley, where grasslands have almost completely disappeared.

The positive effect of population on reducing abandonment or even increasing the shares of grasslands in the municipalities agricultural areas suggests that demographic growth can provide direct or indirect demand for grasslands and the output from grasslands. However, in Austria's Tyrol, where there is a strong competition for land between building sites and agriculture, the urban sprawl has taken over valley bottoms where the best soils and intensively utilized agricultural areas are located. This land conversion also occurred elsewhere in the European Alps (Monteiro et al., 2011; Sanjuán et al., 2018). This may explain why, contrary to expectation, grasslands of high management intensity have not experienced a big reduction in low accessibility areas. The most accessible areas tend to be converted to even more intensive land uses or to settlements, thereby pushing grasslands further away. Moreover, large shopping centres and leisure facilities with associated parking lots and enlarged roads have emerged. This can be viewed as the expected trade-off between integration into a national economy and abandonment of traditional activities (Keenleyside & Tucker, 2010; Lieskovský et al., 2015). This suggests that these land use and demographic dynamics need to be regulated. For example, in the Italian South Tyrol, the agricultural suitability of some areas and their associated high value production are counteracting urbanisation trends. Wherever the land is highly productive, such as in fruit trees and vineyard areas, land conversion to settlements and infrastructure has been noticeably slower (Tasser et al., 2012).

Farms with a large useable area tend to abandon primarily areas that are least favourable for agriculture to reduce their workload. The resulting fodder loss is substituted by: (1) the purchase of concentrated feed, (2) intensification of the remaining areas, and (3) a reduction in the number of animals. The higher the livestock density the less land is abandoned.

The right of farmers to use publicly owned grasslands has been practiced since the Early Middle Ages in European mainland, including Tyrol (van Gils et al., 2014). The number of livestock units pastured per farmer on the commons during summer was in most cases strictly regulated. However, with changes in agrarian structures, these areas have become less used over time.

The negative influence of natural parks on intensively used areas is counterintuitive. Intensively used agricultural areas were generally excluded from the designation as protected area and were therefore not subject to use restrictions. Natural parks are predominantly situated in peripheral areas where farmers adopt more extensive and sustainable land uses. Within natural parks, farmers receive higher area subsidies provided that they maintain an extensive management of the land.

5.3. *Differences between Austria's and Italy's Tyrol*

Our results highlight that grassland conversion differed between the Austrian and Italian territories of the Tyrol region. In Austria, while the proportion of marginal grasslands that was abandoned seems to be larger than in Italy, the opposite has happened to grasslands of high management intensity. This difference is explained by the fact that small farms with part-time farmers have been abandoned in Austria's Tyrol over the last 20 years while farms with full time farmers did consolidate (Schermer, 2014). The difference between sub-regions is also the result of a higher conversion of grasslands into permanent crops in South Tyrol (Tasser et al., 2012).

Differences in national agricultural policies could also influence patterns of agricultural change, reflected by grasslands conversion and farm holdings figures. While such influence can be better observed in the long term, availability of comparable data challenges the comparison between countries. Based on the first census data for the whole Tyrol region, carried out with a homogenised methodology in both countries in 1961 (ISTAT, 1962; Österreichisches Statistisches Zentralamt, 1963), our estimation shows that the rate of decline of farm holdings in the two sub-regions between 1961 and 2010 was identical (30.5% in Italy and 31.3% in Austria). Although economic pressures from regional integration have been similar on farms in both sub-regions, policy and governance institutions affecting rural areas could have reinforced agricultural policy. While the major support policy in Austria has been an area-based agri-environmental program, in Italy the focus has been on stabilizing farms by supporting farm investment (Siegl & Schermer, 2012). As an illustration of this difference, in 2010 Austria's CAP, expenses were about € 2040 per farm from the first pillar (i.e., direct payments to farmers) and € 7960 from the second pillar (i.e., rural development policy) (Bundesanstalt für Agrarwirtschaft, 2015). In South Tyrol, a livestock-based farm received only € 1850 on average from the first pillar and € 2041 from the second pillar (Amt für Landwirtschaft, Autonomous Province of South Tyrol 2014). Calculated for all types of farms in South Tyrol (grasslands, arable, viticultural and fruit-growing), the corresponding subsidy per farm was only half of that received in Austria's Tyrol. However, in South Tyrol large public investments go to the construction and maintenance of agricultural infrastructures (e.g., cooperatives, dairies, transport networks). This results in lower ancillary expenses and higher payout prices for agricultural products (de Meyer, 2014).

On the other hand, the effects of urban sprawl on agricultural land conversion was more regulated in Italy's South Tyrol. In this part of the Tyrol region, political support for the protection of agricultural land goes back to the second half of the 20th century, with the regional planning system established by the Provincial Council Alfons Benedikter. This system pursued a conservative approach which attributed a special value to agrarian areas in terms of their ethnic, political and environmental characteristics (Pasquali et al., 2002). Since the 1990s, such strict regulation has been relaxed. Nevertheless, urban sprawl remains much lower than in the rest of the Tyrol region.

6. Conclusion

This study revealed heterogeneous patterns of grasslands conversions in the bi-national Tyrol region. The Tyrol region also demonstrates the influence that agricultural and rural development policies can have on patterns of grasslands conversion. Spatially-targeted land use and agricultural policies can reduce land abandonment trends by enabling the integration of less favoured areas, particularly those located in the mountains, into more resilient forms of agricultural production and, more generally, of rural development.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apgeog.2019.03.006.

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