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Combining classification tree analyses with interviews to study why sub-alpine grasslands sometimes revert to forest: A case study from the Swiss Alps

Mario Gellrich [a,b,*], Priska Baur [b], Brett Harvey Robinson [a], Peter Bebi [b]

[a] Institute of Terrestrial Ecosystems, Swiss Federal Institute of Technology (ETH), Universitaetstrasse 16, CH-8092 Zurich, Switzerland
[b] Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Zuercherstrasse 111, CH-8903 Birmensdorf, Switzerland

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Abstract

Natural reforestation reflects a decline in traditional agricultural practices. In the last decades, natural forest re-growth has replaced much of the grasslands in the Swiss mountains. This is an area where traditional cultivation has preserved unique landscapes and habitats of high ecological value. We investigated the patterns and determinants of natural reforestation of sub-alpine grasslands at the sub-parcel level using raster cells as the units of the analysis, and at the municipality-level. The study encompassed four municipalities in the Swiss Alps. Land-use data were derived from aerial photographs taken between the 1950s and 2000. We derived the research design for field-work (interviews in this study) from spatial statistical models (classification trees in this study). This method is known as the "finding answers in the errors" approach. This allowed us to relate the behaviour of landowners and operators to changes in land-use/land-cover types, which is one of the main challenges in land-use/land-cover change research.

Three of four classification trees accurately described the locations where natural reforestation occurred, which was mostly on steep and north-facing slopes. However, additional information from interviews was necessary to understand the patterns and determinants of reforestation. Interviews revealed that policy factors (e.g. delayed land consolidations) enhanced forest re-growth. Some sites remained under cultivation despite model predictions of reforestation. Socio-economic factors, not incorporated into the models, explained these discrepancies. These factors included the opportunity costs of farm labour (e.g. aged farmers retaining traditional practices), a conversion to low-cost cultivation practices (e.g. deer and horse pasturing), agri-environmental requirements (e.g. land required to avoid exceeding the prescribed number of livestock per hectare) or other benefits (e.g. hobby farming). Many farms were abandoned during the 50-year study period. The remaining farms often increased in size, whereas farm labour remained stable or decreased. Farm labour costs increased faster than incomes, leading to undergrazing and the cessation of tree and shrub clearance. Although our discussion references specific case study areas, our methods are applicable to the study of other areas undergoing land-use change.

Keywords: Agriculture; Alpine pastures; Land abandonment; Finding answers in the errors; LULCC; Reforestation; Switzerland

1. Introduction

Increasingly, policymakers and researchers confront problems resulting from land-use/land-cover changes (LULCC) from local to regional scales. Soil degradation, environmental pollution and decreasing biodiversity are worldwide problems resulting from LULCC (Meyer and Turner, 1994; DLG, 2005). LULCC can also be beneficial. For example, natural reforestation of agricultural land, as investigated in this study, can contribute to the stabilisation of soils (Tasser et al., 2003), carbon sequestration (Houghton et al., 1999) and a temporary increase of biodiversity (Laiolo et al., 2004).

* Corresponding author. Present address: Institute of Terrestrial Ecosystems, Swiss Federal Institute of Technology (ETH), Universitaetstrasse 16, CH-8092 Zurich, Switzerland. Tel.: +41 44 632 45 90.
E-mail address: mario.gellrich@env.ethz.ch (M. Gellrich).

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Scholars have used various approaches to reveal the determinants of LULCC. One of the most common is spatial statistical modelling (Lesschen et al., 2005), which can reveal the factors determining LULCC and/or characterise the locations where changes have occurred. A common problem for LULCC modellers is that adequate socio-economic data are not available for use in spatial statistical models. Socio-economic data should be collected at the plot or parcel level, i.e. the level at which landowners make their land-use decisions (Irwin and Geoghegan, 2001). However, socio-economic data are often only available for administrative units such as municipalities or settlements.

This lack of socio-economic data has led LULCC modellers to focus on large administrative units. Allen and Barnes (1985) investigated the causes of deforestation using a sample of 39 developing countries. Wood and Skole (1998) merged satellite images with census data for *municipios*, an administrative unit in the Brazilian Amazon, to examine determinants of deforestation. Other approaches use aggregate socio-economic variables to model LULCC at disaggregated levels. Müller and Zeller (2002) linked village-level information to the pixels from satellite images within municipalities. This revealed the influence of village-level factors on the land-use dynamics in the central highlands of Vietnam. Rudel et al. (2000) linked census data at the municipality-level to inventory plots within municipalities to examine the causes of reforestation of agricultural land in Puerto Rico. Models that use aggregate socio-economic data may provide useful information about the determinants of land-use/land-cover changes. However, they are inadequate for the examination of processes at decision relevant levels, i.e. at the plot, parcel or sub-parcel level, and are thus ineffective for the study of LULCC processes.

Unravelling the detailed-scale mechanisms of LULCC requires a link between the land and information from land operators and households. However, this approach is challenging. Farmhouses are often distant from their fields, making it difficult to link farm-level data to the land-use changes observed from aerial photographs or satellite images (e.g. Entwisle et al., 1998). Few studies integrate spatial statistical modelling and interviews. McCracken et al. (1999) successfully predicted land-cover changes at the property level in the Brazilian Amazon. Here, the households lived on well-defined plots and had little impact on adjacent land. Thompson et al. (2002) interviewed pastoralists in Kenya to classify land-use strategies, and then developed statistical models to explain these strategies. A shortcoming of approaches that integrate data from interviews into statistical models is that the collection and geo-referencing of interview data is expensive.

Here, we investigate the natural reforestation of sub-alpine grasslands caused by agricultural land abandonment. Land abandonment and reforestation is a worldwide phenomenon (Rudel et al., 2000; DLG, 2005). In western European countries, it often occurs in areas with unfavourable production conditions (Baldock et al., 1996; MacDonald et al., 2000). For example, in the Baltic countries, Estonia, Latvia and Lithuania, between 10% and 21% of the agricultural land was categorised as abandoned in 1999 and 2002, respectively (DLG, 2005). Valuable semi-natural grassland may also become reforested. Swiss forestlands increased by 17,000 ha (1.4%) between the 1980s and 1990s. Natural reforestation was responsible for 87% of the newly wooded land (SFSO, 2001).

Usually, patterns and causes of land abandonment and reforestation are investigated using census and other aggregated data (e.g. Baldock et al., 1996; Rudel et al., 2000; Gellrich and Zimmermann, 2007). Although individuals make land-use decisions, there is a lacuna of knowledge about the individual motivation to abandon marginal land and allow natural reforestation. Land abandonment and reforestation are important political issues because of their environmental and social consequences (Baldock et al., 1996; MacDonald et al., 2000; DLG, 2005). Any forthcoming policy on land abandonment and reforestation relies upon a sound understanding of the processes involved.

We investigated the patterns of natural reforestation of sub-alpine grasslands in four municipalities in the Swiss Alps between the 1950s and 2000. Our objectives were to (i) characterise the agricultural land where cultivation persisted and abandoned land overgrown by trees and shrubs, (ii) investigate individuals' motives to abandon or maintain cultivation, and (iii) examine the determinants of reforestation in case study municipalities. The central hypothesis was that land operators balanced costs and benefits while deciding to maintain or abandon the cultivation and that land abandonment and natural reforestation relates to indicators of the increasing opportunity costs (i.e. the value of the alternative use) of agricultural labour.

2. Methods

2.1. Study areas

We selected four municipalities, Tujetsch, Eggiwil, Soazza and Blitzingen (Fig. 1), which gave a cross-section of the agro-climatic, topographic and socio-economic conditions in the Swiss Alps. Natural reforestation of sub-alpine grasslands has occurred at all sites, as indicated by the recent Swiss land-use statistics (SFSO, 2001). Table 1 summarises the land-use/land-cover and socio-economic characteristics of each municipality.

Tujetsch (134 km^2), consists of several small villages with an average altitude of 1450 m. The mean annual temperature of agricultural areas (including alpine areas) ranges from −2.5 °C to 5.2 °C (from 5.2 °C to 13.8 °C in July) and the mean annual precipitation ranges from 1194 mm to 1702 mm. As in the other three municipalities, livestock farming (cattle, sheep and goats) is the most common form of agriculture and managed pasture is the dominant land-use. Tujetsch is characterised by a relatively high proportion of alpine pastures (22%), which occur at

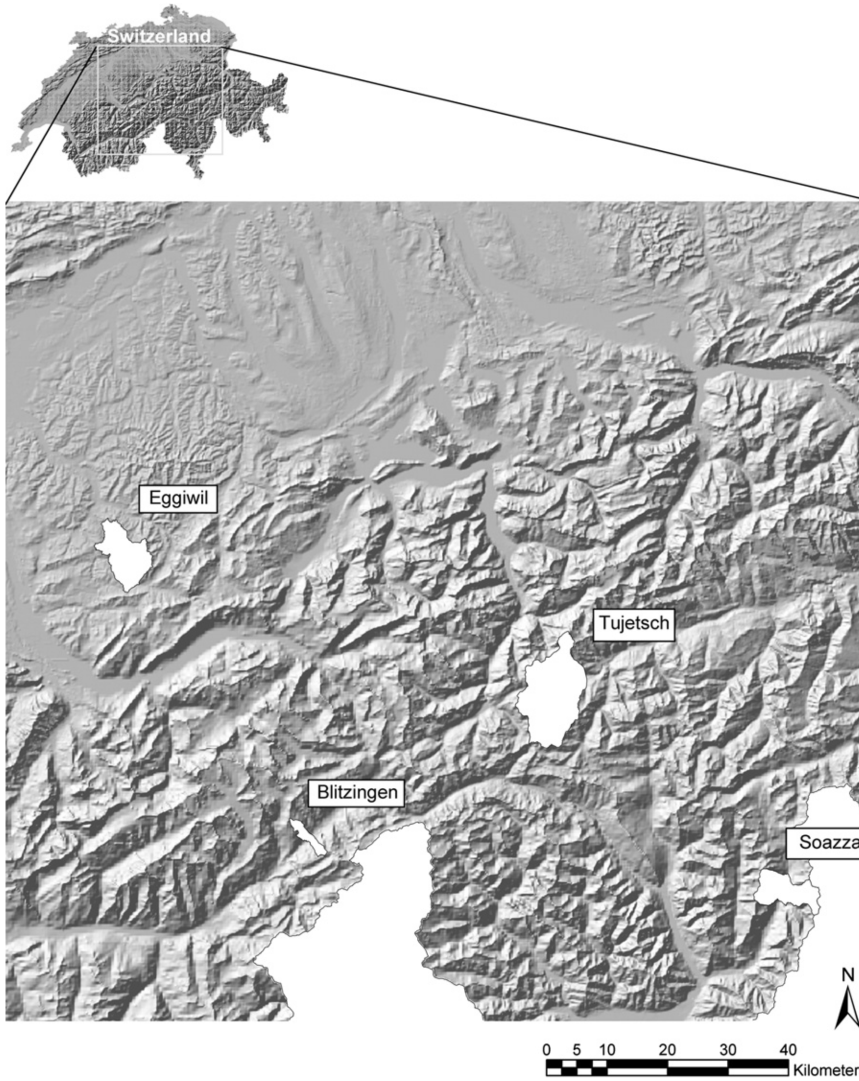

Fig. 1. Locations of the case study municipalities Tujetsch, Eggiwil, Soazza and Blitzingen in the Swiss Alps.

Table 1
Characteristics[a] of the case study municipalities compared to Switzerland (CH)

	CH	Tujetsch	Eggiwil	Soazza	Blitzingen
Land-use/land-cover[b]					
Shrubs (%)	1.5	4.5	0.0	2.6	2.9
Closed forest (%)	26.7	5.5	36.8	47.3	19.8
Agriculture without alpine pastures (%)	23.9	3.7	41.5	1.0	8.4
Alpine pastures (%)	13.0	22.0	13.0	6.2	28.3
Unproductive area/other (%)	34.9	64.2	8.7	42.8	40.6
Socio-economic conditions					
Population change 1950–2000 (%)	54.6	35.9	−6.6	3.2	−45.0
Employees in the primary sector 2000 (%)	3.3	4.0	25.5	5.5	4.1
Proportion of fulltime farms 2000 (%)	69.8	65.7	71.3	27.3	100.0
Number of farms 1939	238,481	183	335	65	35
Number of farms 1990	108,296	62	288	18	4
Decrease of farms 1939–1990 (%)	54.6	66.1	14.0	72.3	88.6
Average farm size 2001 (ha)	15.6	13.1	13.5	6.7	22.0

[a] Data were taken from a digital elevation model provided by the Swiss Federal Office of Topography, Swiss climate station data (Normals 1961–1990), Swiss land-use statistics (1992/1997), and population and agricultural censuses provided by the Swiss Federal Statistical Office.
[b] In % of the total area.

and above the treeline (ca. 2200 m). Grazing occurs during summer. While the number of farms has decreased from 183 to 62 during the past half century, the population has increased by 36%. Tourism and the construction site of the New Alpine Transversal (NEAT, currently the world's largest railway tunnel) are the largest employers.

Eggiwil (size 60 km^2) lies at an altitude of 729 m. The mean annual temperature of agricultural areas ranges from 4.4 °C to 7.8 °C (from 13.1 °C to 17.0 °C in July), the mean annual precipitation ranges from 1360 mm to 1961 mm. The topography is characterised by flat valley bottoms with steep flanks. Eggiwil is the only selected municipality that lies entirely below the treeline. Compared to the other municipalities, the Eggiwil's agricultural land (54% including alpine pastures) has more favourable agro-climatic and topographic conditions. The population decreased (by 6% between 1950 and 2000), as did the number of farms (from 335 to 288 between 1939 and 1990). Agriculture is still an important employer as indicated by the 25% employees working in the primary sector (Table 1).

Soazza (46 km^2) lies at an altitude of 626 m. The mean annual temperature of agricultural areas ranges from 1.0 °C to 10.6 °C (from 9.3 °C to 19.9 °C in July), the mean annual precipitation ranges from 1496 mm to 1747 mm. While parts of the municipality above the treeline have unfavourable agro-climatic conditions, the valley floor has a Mediterranean-type climate. This results in vegetation that is distinct from the other municipalities. Chestnut-trees (*Castanea sativa*) are ubiquitous in Soazza but are absent in the other municipalities where Norway spruce (*Picea abies*) and birch (*Betula pendula*) predominate. The low proportion of agricultural land (7%) and high proportion of forest and shrubs (50%) reflect unfavourable topographic conditions. The population remained approximately stable during the study period, while the number of farms decreased from 65 to 18 between 1939 and 1990. Many people in Soazza work in the nearby cities of Bellinzona and Lugano, which are tourism and industry hubs in southern Switzerland.

Blitzingen (12 km^2) lies at an altitude of 1290 m. The mean annual temperature of the agricultural areas ranges from −2.0 °C to 5.5 °C (from 6.2 °C to 14.6 °C in July), the mean annual precipitation ranges from 1393 mm to 2258 mm. Blitzingen has the highest proportion of alpine pastures (28%) of the three municipalities. The population decreased by 45% between 1950 and 2000. In addition, the decrease of the number of farms was higher than in the other three municipalities (from 35 to 4 between 1939 and 1990). Due to its location at the end of a mountain pass, the job supply varies with season. The locals only receive reasonable incomes from the traffic and weekend tourism in the summer, when the pass is open.

2.2. Data preparation

The binary response variable used in the classification trees refers to the presence/absence of natural reforestation of agricultural land. It was derived from black and white (BW) aerial photographs taken between in the 1950s and 1960s and true colour (RGB) aerial photographs taken between 1998 and 2000 (Table 2). Aerial photographs were ortho-rectified to allow for overlay and comparison. The geometric accuracy between the BW and RGB images was determined by the root-mean-square error (RMSE). To calculate the RMSE, we compared the location of 10 checkpoints placed on each BW image with the location of the same checkpoints on the respective RGB image. The RMSEs were between 3.02 m and 5.12 m (Table 2), which was appropriate for the analyses because the raster cells used for land-use classifications and spatial modelling were 25 m.

Irwin and Geoghegan (2001) suggested that land-use/land-cover changes and its determinants should be investigated at the parcel level, where properties are clearly distinguishable. Other authors point out that land-cover changes are often not restricted to parcel boundaries and sub-parcel representation of land-cover is preferable (e.g. Brown et al., 2000). In this study, data on the parcel level were incomplete or not available for the 50-year study period, and we were primarily interested in land-use/land-cover changes at the sub-parcel level. Thus, we followed the suggestions by Brown et al. (2000) and used raster cells as the units of observation. Using sub-parcel representations of land-use/land-use changes minimises problems related to the parcel–pixel mismatch, which occur if the size of raster cells/pixels exceeds the size of parcels (Sherbinin et al., 2002).

For land-use classifications, ortho-images were overlaid with a raster with 25 m cell size. Raster cell size corresponds to the resolution of the digital elevation model that provided the basis for the calculation of most of the explanatory variables (see Table 3). To reduce spatial dependence in the presence/absence data, we followed suggestions by Munroe et al. (2002) and classified a regular sample of raster cells for model building. We sampled every fifth raster cell in *x*- and *y*-direction from the raster. To facilitate comparisons of model results, the distance between raster cells was equal in all municipalities. This distance should be as large as possible to minimise spatial dependence (see Munroe et al., 2002). At the same time, the smallest sample should enclose an adequate number

Table 2
Evaluation years of the black and white (BW) and true colour (RGB) aerial photographs

	Tujetsch	Eggiwil	Soazza	Blitzingen
Evaluation years of BW aerial photos	1959	1953/1954	1961/1962	1960/1961
Evaluation years of RGB aerial photos	2000	1998	1999	1999/2000
RMSE between BW and RGB images (m)	3.02	3.39	5.12	3.87

The root-mean-square error (RMSE) measures the geometric accuracy between the BW and RGB images.

Table 3
Explanatory variables used in the classification trees with abbreviations as used in the text, variable units, spatial resolutions and data sources

Variable	Abbrev.	Unit	Resol.	Source[a]
Annual degree days[c]	DDEG	(day °C)	25 m	CSD/ DEM25
Precipitation sum[b,c]	PREC	(1/10 mm/ month)	25 m	CSD/ DEM25
Potential direct shortwave radiation[b,c]	SDIR	(kJ/day)	25 m	CSD/ DEM25
Soil depth	SOILDEP	(cm)	25 m	BEK200
Slope	SLOPE	(°)	25 m	DEM25

The following data sources were used.
[a] DEM25: digital elevation model available as raster with 25 m cell size (source: Swiss Federal Office of Topography); CSD: Swiss climate station data (Normals) evaluated between 1961 and 1990; BEK200: soil suitability map at 1: 200,000 (“Bodeneignungskarte der Schweiz”).
[b] The values were calculated as average of the growing season (May–September).
[c] For details of variable calculation see Zimmermann and Kienast (1999).

of raster cells for classification tree building. In Soazza, i.e. the municipality with the smallest number of presence/absence observations, we had 148 raster cells available after sampling and classification, which is an adequate sample size to fit a classification tree (see Therneau and Atkinson, 2006).

For each raster cell, we visually estimated the amount of land under agriculture and forest. A raster cell was classified as ‘agriculture’ if it showed ⩾50% agricultural land-use. Likewise a raster cell was classified as ‘forest’ if it was >50% covered by trees and shrubs. The definitions of ‘agriculture’ and ‘forest’ are subjective; although the Swiss land-use statistics use similar thresholds to delineate agricultural land and forest (see BFS, 1992). Changes in land-use were determined by comparing classifications made for raster cells. Raster cells that changed from ‘agriculture’ to ‘forest’ are labelled ‘presence’ observations in this study. Likewise, raster cells that remained ‘agriculture’ are labelled ‘absence’ observations. Since reforestation does not occur above the treeline, we excluded these areas from the analysis. We estimated the treeline by determining the highest altitude in each municipality where trees and shrubs occurred on aerial photographs. Planned reforestation, which was distinguished from natural reforestation by means of interviews with the local foresters, afforestation maps and field work and land that could not clearly be classified as ‘agriculture’ and ‘forest’ were also excluded from the analysis.

The explanatory variables used in the classification tree analyses (Table 3) were selected to prove the study hypothesis and are proxies for the cultivation costs and yield potential of agricultural land. To make the model results communicable to landowners and operators, we only used easily interpretable variables. Reforestation was considered to have occurred where the conditions were unfavourable for agricultural production, which was mostly on steep land with shallow soils, low temperature and shortage of precipitation. From a previous study conducted over the entire Swiss Alps (Gellrich et al., 2007), we also know that reforestation is limited near the treeline.

We hypothesised that the distance to roads and farmhouses would influence land abandonment and reforestation because they affect transportation costs. However, investigating such effects in the classification trees was difficult because tenancies have changed. Many parcels have merged or were split, new roads and farmhouses were constructed, and means of transport have changed over the 50-year study period. We could not construct adequate distance related variables that consider all these different cases. Whether the accessibility is considered as ‘good’ or not also depends on the type of land-use (e.g. mowing or pasturing) and individual preferences. Some authors (e.g. Chomitz and Gray, 1996) report endogeneity problems with the distance to roads in statistical models. This is because the conditions of agricultural production often influence road location. To avoid incorrect inferences from distance related variables, only time invariant geo-physical explanatory variables were used to develop the classification trees. Possible effects of the accessibility of the land on the individuals’ land-use decisions were examined by interviews.

2.3. Classification trees

We used classification tree (CT) analysis to characterise the agro-climatic, topographic and soil characteristics of the sample of observations classified as ‘presence’ or ‘absence’. In a CT, a dataset is recursively partitioned into increasingly homogenous subsets called terminal nodes (Breiman et al., 1984). Each terminal node is assigned the label of the majority class (presence or absence of reforestation in this study). Splits defining how to partition the data were selected based on information statistics that measure how well the split decreases the heterogeneity of training data. The classification process starts at the root node (which encompasses the entire dataset) and ends at the terminal nodes. A developed CT encodes a set of decision rules in form of if–then-statements, which are analogous to the decisions made by individuals while managing their land.

CTs are usually pruned to avoid over-fitting, i.e. making it too sensitive to variation peculiar to the datasets used for model building. Pruning entails reducing the number of nodes to determine how the misclassification error rate changes as a function of tree size (Breiman et al., 1984). We used 10-fold cross-validation to find an optimal level of complexity for each CT (Venables and Ripley, 2002). We tested other forms of cross-validation, and found that the final form of our CTs was insensitive to the form of cross-validation. CTs were built and pruned using the library section *rpart* (Therneau and Atkinson, 2006) available in the R statistics software (R Development Core Team, 2006).

CT model predictions are based on the proportion of observations of presence and absence at a terminal node (Miller and Franklin, 2002). The proportion of 'presence' indicates a probability that is analogous to the probability of presence in logistic regression models (see Hosmer and Lemeshow, 2000). Here, we translated the encoded decision rules of each tree into Arc-Macro-Language (AML) code and ran the code using ArcInfo© procedures to obtain raster maps containing the probability that agriculture land reverts to forest in each raster cell.

Prediction accuracy was measured by the AUC = "area under the receiver operating characteristic (ROC) curve" (Metz, 1978) based on an independent dataset. An ROC plot is obtained by plotting sensitivity values (=fraction of observed 'present' correctly predicted) on the y-axis against 1 – specificity values (specificity = fraction of observed 'absent' correctly predicted) on the x-axis for a range of probability thresholds (Miller and Franklin, 2002). The AUC provides a measure of overall model accuracy based on different probability thresholds. AUC values close to 0.5 indicate low similarity between the observed and predicted values, whereas values close to 1.0 indicate high similarities between the observed and predicted values. According to Hosmer and Lemeshow (2000), AUC values from >0.8 are excellent and those >0.9 are outstanding.

2.4. Preparation of interviews

Following the "finding answers in the errors" approach proposed by Wood and Skole (1998), fitted CTs provided the basis for interviews. Conceptually, this approach comprises of three steps. Firstly, a spatial statistical model is calibrated to replicate the actual pattern of land-use/land-use change. Secondly, model predictions are compared with the actual land-use/land-use changes and variations between the predicted and the actual land-use/land-use changes are identified. Thirdly, additional data are surveyed in the field to identify possible causes of model misspecifications and spurious associations. The latter occur if the relationships between variables found in the model indicate 'true' causality, although unmeasured factors – which are not included into the model, but related to the variables in the model – are the true causes of the observed land-use/land-cover changes (Wood and Skole, 1998).

Wood and Skole (1998) proposed the use of regression residuals to select some observations representing "outliers" and which fall "along (or close to) the regression line" and collect additional information for these observations in the field. In the CTs, the probability of a particular observation becoming abandoned and overgrown was estimated, while in the actual event, either an observation was abandoned and overgrown or not. Thus, there is no clear way of calculating residuals to compare predicted value versus actual value. In addition, as the prediction results in a probability that ranges from 0 to 1.0 (in theory) we needed to determine the critical value of the probability that an observation 'counts' as an abandoned or unabandoned observation.

Often researchers take 0.5 as the threshold to consider a predicted probability value to be a 'correctly' or 'incorrectly' predicted observation. However, Geoghegan et al. (2001) criticised this ad hoc choice of a threshold. We make no absolute assumptions about correctly or incorrectly predicted observations. Instead, we were interested in similarities and deviations between the actual land-use/land-use changes and corresponding CT predictions. Model deviations are not regarded as "errors" per se, but as indicators of local peculiarities related to the cultivations costs and benefits of land-use. To identify similarities and deviations between the actual land-use/land-use changes and model predictions, we systematically selected sites in the field (henceforth 'interview sites') by visually comparing the actual 'presence' and 'absence' with the corresponding CT predictions. The minimum size of one interview site corresponded to the size of the raster cells used for model building (i.e. 625 m^2). One interview site could also include multiple cells, provided that they were of the same type (for site types see Table 4), adjacent, and belonged to the common parcel and owner, respectively. We selected interview sites based on the 2×2 classification matrix shown in Table 4.

Whether the predicted probability was 'low' or 'high' (Table 4), depended on the range of probability values of each model and the availability of observations. In Tujetsch, for example, the predicted probabilities ranged from 0 to 0.91. We selected interview sites for (II) and (III) where the probability was 0.91. Where we could not find sites for (II) and (III) at predicted probabilities of 0.91 (e.g. because all sites showing these probabilities were forest in the 1950s/1960s), we took the next lowest predicted probability to select interview sites (in this example 0.83). We repeated this procedure until we found appropriate sites for (II) and (III). Likewise, sites for (I) and (IV) were selected where the probability was close to 0. This approach is similar to the selection of "outliers" and observations that "fall along (or close to) the regression line" as proposed by Wood and Skole (1998) as it takes well-modelled sites (here I and II) and potential model misspecifications (here III and IV) into account.

Within each municipality we selected at least two sites for (I), (II), (III) and (IV). Some respondents had more than one interview site according to the classification

Table 4
Classification matrix used to select interview sites

Model predictions	Observed from aerial photographs	
	Cultivation maintained (absence)	Reforested (presence)
Probability of reforestation low	I	IV
Probability of reforestation high	III	II

matrix in Table 4. This is because we obtained a total of 48 interview sites. After selection, we obtained the landowners' addresses from the local surveying and mapping office. We contacted landowners by mail, and then telephoned to arrange a meeting. We interviewed 31 landowners (18 full-time farmers, 1 part-time farmer, 2 hobby farmers, 2 retired farmers and 8 non-farmers). For reforested sites and those under cultivation, we interviewed the landowners and farmers, respectively. Cases were a farmer had a plot that was partially reforested were considered if they were consistent with the classification scheme in Table 4. Such cases, however, were not interpreted separately. Interviews occurred between August 2004 and July 2005. We used semi-structured interviews based on pre-set topics that related to the personal information of respondents, characteristics of the interview sites, the motivation to abandon or maintain the cultivation, and the underlying causes of reforestation.

3. Results

3.1. Model results

Fitted CTs encode a set of decision rules describing the geo-physical characteristics of the model sample of presence/absence observations. For example, the left most decision rule of the CT of Tujetsch (Fig. 2) can be translated: "if steepness (SLOPE) is <28.53 (°) and radiation (SDIR) is $\geqslant$19,270 (kJ/day) and precipitation (PREC) is $\geqslant$1110 (1/10 mm/month), then 588 observations occurred at this terminal node and 19 were presence". As the majority of observations at this node are absences, an absence ('abs') was assigned to this node. For predictive purposes, where the same geo-physical conditions exist throughout the unsampled parts of the study area, there is a 0.032 (19/588) probability of reforestation.

The explanatory variables in CTs were selected to create splits that maximise the resulting node homogeneity. Thus, the variables used in early splits (i.e. close to the root node) were considered more important for the explanations of reforestation than variables in later splits, i.e. those close to the terminal nodes (see Miller and Franklin, 2002). The CTs for Tujetsch, Eggiwil and Soazza used steepness (SLOPE) for the first split. This indicated that the steepness of slopes is the factor with the largest influence on the land-use decisions of land operators. The CT for Blitzingen used radiation (SDIR) for the first split, which indicated an influence of the slope aspect on the land-use decisions of landowners in Blitzingen.

The AUC value provided in the head of each CT (Fig. 2) measures the prediction accuracy based on an independent dataset. The CTs of Soazza (AUC = 0.887), Blitzingen (AUC = 0.872) and Tujetsch (AUC = 0.793) predict the corresponding independent datasets well. This indicates that the explanatory variables included in these models represent the most important geo-physical factors influencing land-use decisions. The prediction accuracy of the CT of Eggiwil is comparably weak (0.596).

The ratio of the presence/absence observations was used to estimate the quantity of reforestation in each municipality. In Tujetsch, 794 observations representing absence and 137 observations representing presence of reforestation were available (Fig. 2), indicating 15% of the sample of observations altered from agriculture to forest. Soazza and Blitzingen had the highest reforestation rates (53% and 28%, respectively) of the four municipalities, while Tujetsch had a moderate reforestation rate (15%). In Eggiwil, reforestation occurred only sporadically (1%).

Visual comparisons of CT predictions (Fig. 3) with aerial photographs showed that the predicted probability of reforestation was higher on steep slopes and lower on gentle slopes and land close to the valley floor. With increasing altitude, the probability of reforestation decreased, irrespective of the topographic conditions, which showed that the CTs correctly predicted the decrease in forest re-growth in areas approaching the treeline. In Blitzingen, reforestation occurred mostly on the north-facing part of the municipality, which underlined the importance of radiation in the corresponding CT.

3.2. Linking individuals and models

Site-characteristics as stated by respondents are summarised in Table 5 and described below.

For sites on which cultivation has been maintained, and the predicted probability of reforestation was low (category I in Table 4), models accurately predicted the agro-climatic, soil and topographic conditions as suitable for agricultural production (Table 5). Most of these sites (10 out of 13) are mowed meadows; 12 sites were characterised as less steep; 10 sites were characterised as easily accessible in the past. Two sites were under pasture. The herdsmen of one site stated that there was no road and that the pasture is only accessible by a 2 h walk. However, he considered the land favourable for pasturing because it was less steep. In Soazza and Tujetsch, some of the sites suitable for mechanised mowing were used as pastures for Highland cattle.

For reforested sites with a high predicted probability of reforestation (category II in Table 4), models accurately predicted the agro-climatic, soil and topographic conditions as less suitable for agricultural production (Table 5). All of these sites (12) were characterised as steep; 10 sites were characterised as difficult to access in the past. Some of these sites were additionally characterised as shady because north-exposed and/or close to forest edges or respondents mentioned that the soils are shallow, wet or stony. Seven sites were formerly used as meadows, whereas respondents stated that, in the past, this land had to be mowed by hand due to the steepness of slopes; five sites were formerly under pasture.

Sites where the cultivation has been maintained and the predicted probability of reforestation was high (category III in Table 4) indicate model misspecifications. Most of

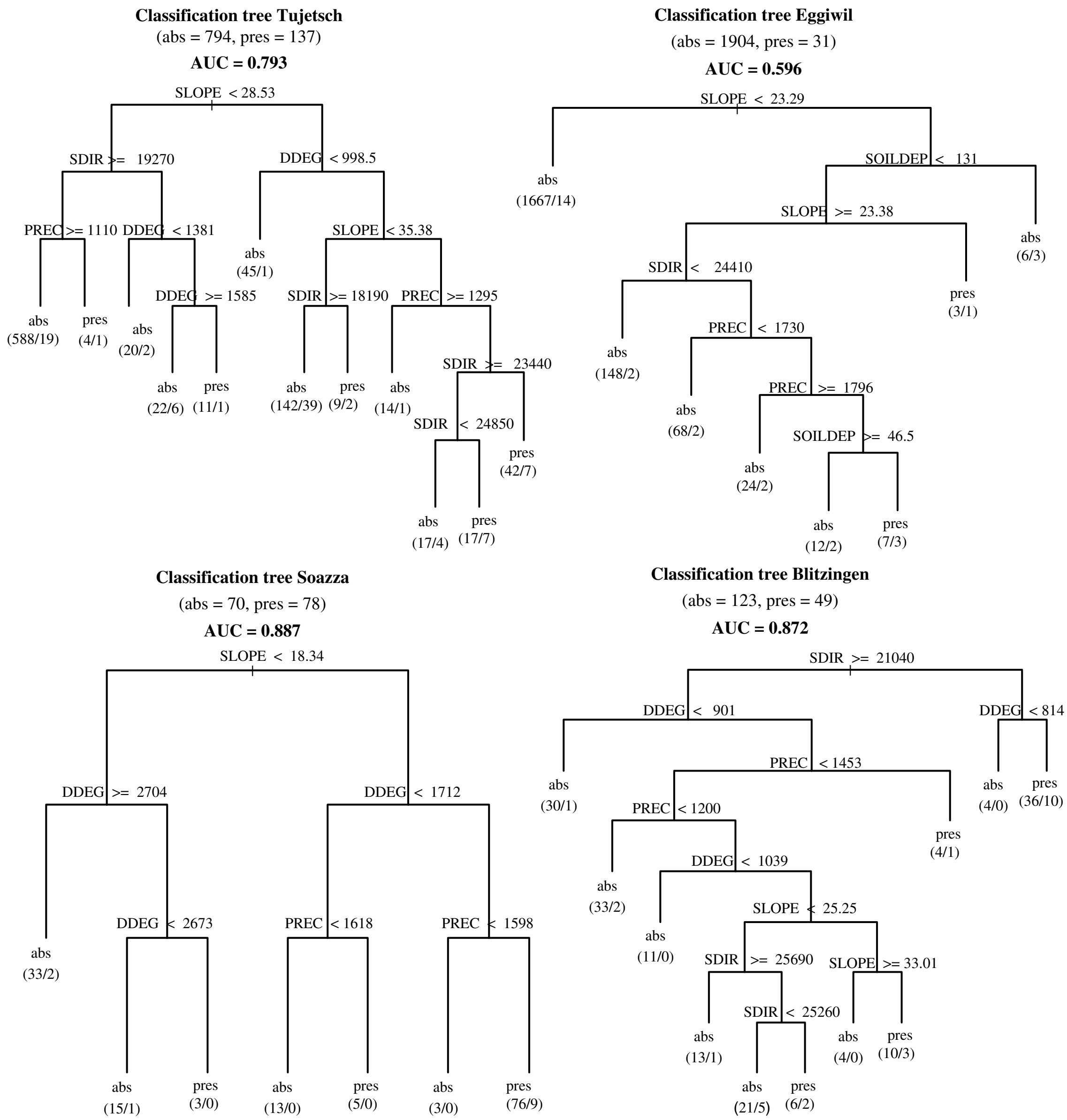

Fig. 2. Fitted classification trees (CT). The 'pres' and 'abs' in the head of each CT refer to the number of 'presence' and 'absence' observations used for model building. The AUC measures the prediction accuracy based on an independent dataset (see text). For variable units and abbreviations, see Table 3. For details of the values at terminal nodes, see text.

these sites (8 out of 11) were under pasture. At four of these sites, farmers stated no specific causes for the maintenance of cultivation, but pointed out that the land was relatively steep. For seven sites, we found explanations for the maintenance of cultivation. One of these sites (in Tujetsch) is an agricultural compensation area for which the owner is obliged to maintain cultivation. The farmer stated that he had brought the land into production after it lay fallow for several years and that he obtained additional payments from the owner – otherwise he would not cultivate this land. One site in Eggiwil, was mowed by a small winch-drawn mower. The farmer stated that this was common practice in the past but that only a few farmers use this technique today. A farmer in Soazza stated that he cultivates the land because agricultural politics regulates the maximum number of cattle per hectare and he did not have enough favourable land to keep as much cattle as he wanted. He also mentioned that he paid no rent for this land and the owner helped to make hay – otherwise he would not have cultivated it. Another landowner in Soazza stated that he mowed the land for many years just to prevent reforestation and keep the old stable from ruin. Farmers brought two sites in Blitzingen into production after they lay fallow for many years. These farmers stated that they experimented with alternative agriculture such as deer and horse pasturing. They invested much time to clear the land from trees and shrubs and stated that the professional farmers had no interest in cultivating this land. A former

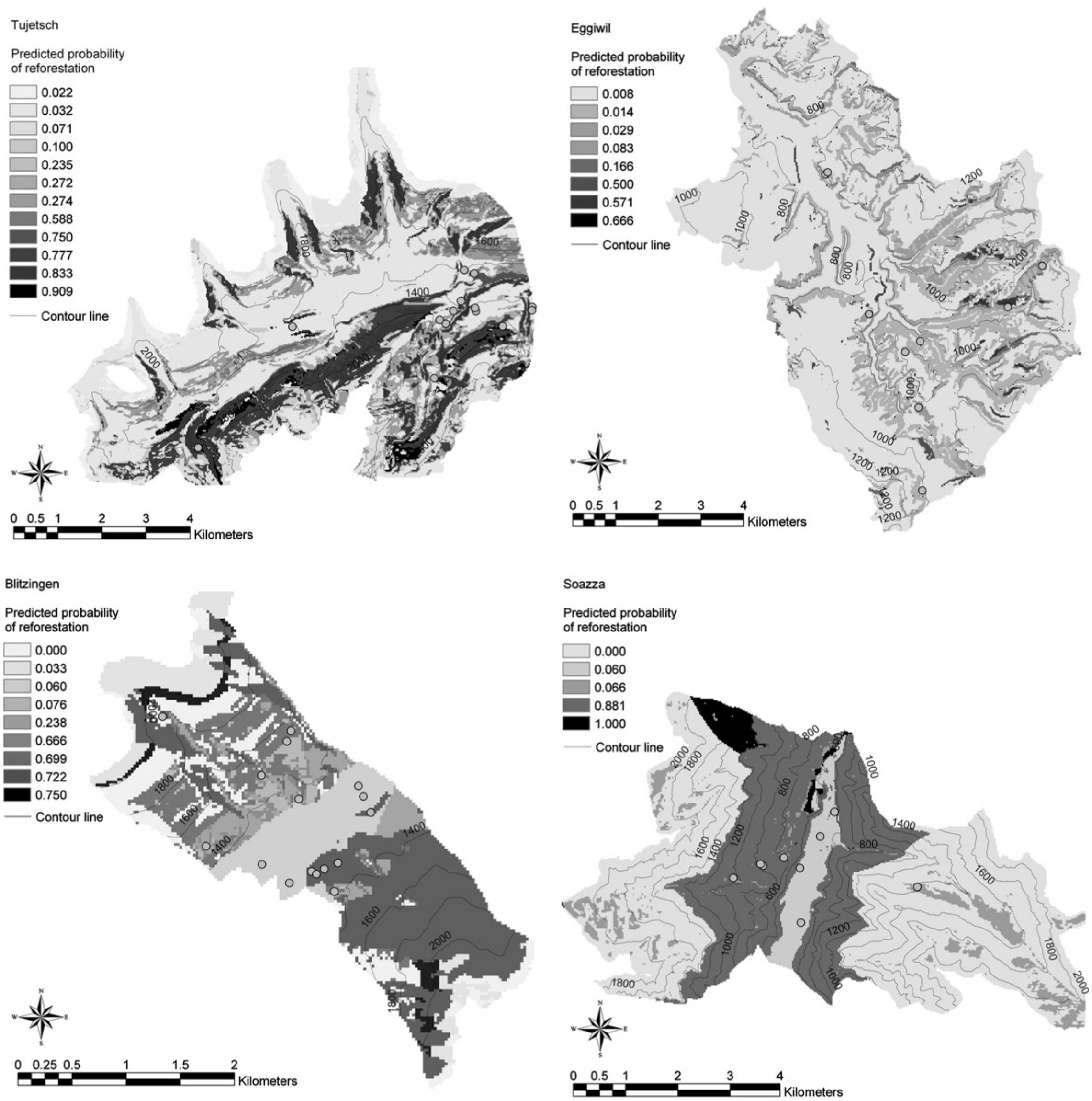

Fig. 3. Predicted probabilities of reforestation. The corresponding classification trees are illustrated in Fig. 2. Interview sites are marked by points. For better illustration of the topographic conditions, contour lines showing altitudinal gradients in 200 m steps were added to each map.

agricultural site in Blitzingen is now part of a summer residence. The owner stated that he mowed the land to prevent reforestation.

Reforested sites showing low predicted probabilities of reforestation (category IV in Table 4) also indicate model misspecifications. Most of these sites (8 out of 12) were under pasture and characterised as less steep. We obtained explanations for the abandonment of cultivation for all sites. Respondents stated that the sites were abandoned because there were no roads in the past making accessibility difficult (5 sites) or the access was difficult due to the wetness of soils (2 sites). One respondent stated that land abandonment occurred because the grass was of low quality due to soil wetness. Two sites were abandoned because small trenches, holes in the ground and old stonewalls made mechanisation difficult. At one site, the respondent stated that cultivation was abandoned because the land was too dry due to shallow soils and that this dryness resulted in low hay yields.

3.3. Determinants of reforestation

The interviews revealed similarities and differences between the four municipalities regarding the determinants of reforestation. For all four municipalities, farm structures changed as the result of the economic development during the study period. Of the 21 farmers, 14 stated that the farm size had increased, one stated that the farm size had decreased and six stated that the farm size remained unchanged. The number of livestock increased in 16 farms, decreased in one farm and remained unchanged in four farms. In two of the latter farms, farmers stated that only the composition of livestock has changed. The number of employees decreased in 10 farms, increased in 1 farm and

Table 5
Summary characteristics of interview sites as stated by respondents

Site-type[a]	Mun.[b]	# sites[c]	Site-characteristics as stated by respondents								
			Land-use[d]		Steepness[e]		Accessibility[f]		Intensity[g]	Changed[h]	Other
			Past.	Mead.	Less steep	Steep	Easily accessible	Access difficult	Hay-crop/ year	# sites	
(I)	T	4	1	3	3	1	2	2	n.s.	0 from 4	Meadows are often additionally grazed in spring and/or autumn (all municipalities); alpine pastures are grazed during approx. 80–100 days per year (all municipalities), remoteness of the land is of minor importance if mechanised mowing is possible (Tujetsch), pasture only reachable by 2 h foot walk but considered as favourable because less steep (Soazza), former meadows used as pastures from spring to autumn for Highland cattle (Tujetsch, Soazza)
	E	2	0	2	2	0	2	0	3	1 from 2	
	S	3	2	1	3	0	2	1	2	0 from 3	
	B	4	0	4	4	0	4	0	1–2	1 from 4	
	# total	13	3	10	12	1	10	3	1–3	2 from 13	
(II)	T	4	1	3	0	4	2	2	1–2	All	Reforested land was shady due to is location on north-exposed slopes or its closeness to forest edges (Blitzingen, Soazza); land has wet, stony and/or shallow soils (Tujetsch, Soazza); steep land which has formerly been used as meadows was totally or partially mowed by hand (all municipalities); the slope aspect of the hillside and the wetness of soils make the land particularly vulnerable for the germination of tree seeds (Soazza)
	E	2	2	0	0	2	0	2	n.s.	All	
	S	2	0	2	0	2	0	2	1–2	All	
	B	4	2	2	0	4	0	4	1	All	
	# total	12	5	7	0	12	2	10	1–2	All	
(III)	T	2	2	0	0	2	1	1	n.s.	1 from 2	Steep meadows completely or partially mowed by hand (all municipalities); alpine pastures grazed during approx. 80–100 days per year (all municipalities), additional payments from the owner to maintain cultivation (Tujetsch), use of the land as summer residence (Blitzingen), owner helps the farmer to make hay and farmer pays no lease (Soazza); steep meadow mowed by means of a motorwinch (Blitzingen), site grazed to conserve the value of the land and prevent the old stable from ruin (Soazza), already overgrown land brought into cultivation because suitable for deer and horse pasturing (Blitzingen)
	E	2	1	1	0	2	2	0	1–2	0 from 2	
	S	2	1	1	0	2	0	2	1	1 from 2	
	B	5	4	1	0	5	1	4	1	4 from 5	
	# total	11	8	3	0	11	4	7	1–2	6 from 11	
(IV)	T	4	0	4	3	1	2	2	1–2	All	Reforested land has small-scaled topographic idiosyncrasies such as wet and stony soils and holes in the ground (Tujetsch, Soazza), old stonewalls (Soazza), soil damages by cattle (Blitzingen) and small streams (Eggiwil), making mechanisation difficult; grass was of poor quality due to the wetness of soils (Tujetsch)
	E	3	3	0	0	3	1	2	n.s.	All	
	S	2	0	2	2	0	2	0	2	All	
	B	3	1	2	3	0	0	3	1–2	All	
	# total	12	4	8	8	4	5	7	1–2	All	

[a] Site-type according to Table 4: (I) cultivation maintained and predicted probability of reforestation low, (II) reforested and predicted probability of reforestation high, (III) cultivation maintained and predicted probability of reforestation high, (IV) reforested and predicted probability of reforestation low.
[b] Municipality: T = Tujetsch, S = Soazza, E = Eggiwil, B = Blitzingen.
[c] # sites = number of interview sites.
[d] Land-use: pasture, meadows.
[e] Steepness: 'less steep' can be translated as "mechanised mowing is easily possible, if only steepness is taken into account"; 'steep' can be translated as "mechanised mowing would be difficult, if only steepness is taken into account".
[f] Accessibility: the accessibility of the land in the period prior reforestation (site types II and IV), and at the beginning and end of the 50-year study period (site types I and III); most sites characterised as 'easily accessible' were within a distance of approximately 100 m from roads.
[g] Intensity: land-use intensity measured in hay crops per year (n.s. = not specified).
[h] Changed: the number of sites at which the land-use has changed during the study period.

remained stable in 10 farms. Farm sizes ranged from 22 ha to 40 ha in Tujetsch, from 5 ha to 77 ha in Eggiwil, from 3 ha to 44 ha in Soazza and from 7 ha to 44 ha in Blitzingen. In all four municipalities, respondents perceived the main determinants of reforestation were undergrazing and the cessation of the manual clearing of pastures from trees and shrubs, caused by farm labour shortages. Here, we summarise the perceptions of respondents regarding the determinants of reforestation.

In Tujetsch, the construction of hydroelectric power stations, roads and railways, and the growing importance of the tourism from the 1960s on, brought many new jobs and led to considerable migration of farm labour. This led to farm abandonment. At the end of the study, many farms had reached their maximum size and farmers stated that labour, rather than land was limiting. Thus, where agro-climatic and topographic conditions were unfavourable, trees and shrubs colonised the land. Free grazing, a common practice up to the 1960s, was subsequently forbidden. This forced farmers to fence in their livestock. Interviewees reported that fencing, in combination with a decreased number of goats that formerly cleaned pastures from trees and shrubs, was another important determinant of reforestation. Some new farmers joined the local farming community. We distinguished two cases: Firstly, children of former farmers who left their jobs and returned to take over their parents' farm and, secondly, career changers from urban areas who took over the farm of retired farmers without a successor.

In Eggiwil, agriculture is still an important employer and respondents stated that land is scarce. Land from farms without successors was distributed among the remaining farms. This explains the low quantity of reforested land. Reforestation was mainly the result of the undergrazing of alpine pastures. Dairy cattle often grazed on farm pastures and were not brought to the alpine pastures, as was common practice in the past. Although reforestation occurred only sporadically, many respondents were sensitive about this topic. This is because the Federal Office for Agriculture recently updated the delineation of agricultural land to prevent the subsidisation of already reforested land. In the past, such cases of abuse provoked public criticism. The subsequent decrease of farm areas had led to a significant loss of income for some of the interviewed farmers.

Soazza lies near the cities of Bellinzona and Lugano, which are centres of industry and tourism in Southern Switzerland. This proximity allows people reside in Soazza and commute to the larger cities, taking advantage of lower taxes. The lack of well-paid farm jobs and unfavourable conditions for agriculture (steep slopes, fragmented ownership structure due to hereditary customs), led to farm labour migration and farm abandonment. Another important determinant of reforestation that respondents reported was the delay of land consolidation. This process, which originally aimed to improve the fragmented structure of agricultural land, took more than 30 years (from the 1960s to the 1990s). As the result of the uncertain land tenure during this period, many agricultural areas (mostly on the Mont Grand, a mountain side of 50 ha size close to the village) were abandoned. Only occasionally, when landowners used old stables and surrounding land as summer residences, was reforestation prevented on Mont Grand. The reconstruction of old stables for summer residences is forbidden because old stables in this region, contrary to other regions in the Swiss mountains, have traditionally no space for farmers to stay overnight. According to one respondent, this regulation has depressed land prices and has led to the reforestation of much of the land. Some respondents linked farm abandonment to regulations concerning animal welfare discouraging farmers to invest in new stables. At the end of the study, many hobby farmers were cultivating land that was unattractive for professional farmers. Some of the owners raise no lease and may even pay to make hay to prevent the land from reforestation.

Blitzingen had limited employment opportunities. Respondents stated that many young people migrated to the larger cities due to the lack of apprenticeship training positions, and winter avalanches that often make roads impassable. Three of the remaining four farms are professional farms that cultivate almost all the agricultural land. Farmers stated that farm size had reached its maximum and that they do not have enough time to keep the pastures clear of stones from avalanches and regenerating trees and shrubs. Recently, non-mainstream farmers have established who preserve traditional farming practices and simultaneously experiment with low-cost cultivation forms such as deer and horse pasturing. These farmers have started to re-use reforested land. Contrary to Tujetsch and Soazza, where land consolidations where carried out to improve the fragmented structure of parcels, the fragmented structure of parcels still exists. One of the professional farmers stated that he cultivates more than 750 single parcels (farm size 40 ha), and that he needs additional labour to overcome the disadvantages imposed by the fragmented farm structure, but that this has little influence on his decision to cultivate the land.

4. Discussion

4.1. General findings

In three of the four case study municipalities, selected geo-physical variables could accurately model the pattern of reforestation/maintenance of cultivation. This indicates that landowners follow simple cues when deciding to abandon or maintain the cultivation. Such cues relate to the decision to abandon land where slopes are steep and north-facing. That reforestation occurred on steep and north-exposed land is consistent with findings from other European case studies (e.g. Didier, 2001; Poyatos et al., 2003). That reforestation was less frequent on agricultural land close to the treeline is consistent with findings from a previous Swiss study conducted over the whole mountain area (Gellrich et al., 2007).

Specific local characteristics such as small trenches, wet soils, soil degradation by cattle or the lack of roads in the past explained cases where our models gave a high probability of agricultural maintenance, while in the field, reforestation occurred (case IV, Table 4). These factors make mechanisation or pasturing difficult. In contrast, socio-economic factors, not included in the models, explained an erroneously high probability of reforestation, when in the field, cultivation was maintained (category III in Table 4). These socio-economic factors include low opportunity costs of farm labour, e.g. aged farmers, that maintained traditional labour-intensive farming practices, a conversion to extensive pasturing, financial and other support from landowners, or changing the intended land-use (e.g. hobby farming; use of the land as summer residence; extra payments from owners). These factors either reduce management costs, enhance benefits or relate to non-profit-oriented behaviour.

We investigated sites where the models accurately predicted the LULCC to identify potential spurious associations. Three of four models indicated that steepness was the key factor determining the land-use decisions of landowners. Interestingly, this finding is contrary to the perception of some of the interviewed farmers, who stated that the steepness of slopes was unproblematic because steep land was suitable as pastureland. Was it a spurious relationship, found in the models, between the slope steepness and reforestation? The steepness of slopes was used as proxy variable for labour costs. Most respondents stated that farm labour became scarcer in the last decades. If farm labour becomes scarcer, we would expect that farmers abandon labour-intensive work. The manual clearing of trees and shrubs from pastures is such labour intensive and unprofitable work. Abandoning this work has led to reforestation. Hence, the influence of the steepness of slopes on the land-use decision found in the models is not a spurious association, but confirms the expected influence of changing labour costs on reforestation.

The possible influence of the distance of the land from roads and farmhouses on reforestation was investigated via interviews. Interviews confirmed the expectation that land remote from roads and farmhouses was more frequently reforested (Table 5). The direct accessibility of the land by roads was more important for the land-use decisions than the distance of the land from farmhouses. This is consistent with findings by Pezzatti (2001), who showed that the land-use intensity decreases with increasing distance to roads. In contrast, alpine pastures often require no road access as herdsmen stay with the livestock over summer and milk is processed on site (Netting, 1972). Extensively grazed sheep pastures, as in Blitzingen, do not even require herdsmen. This explains why respondents considered alpine pastures as favourable, even if they are not accessible by roads.

4.2. Particularities in the case study municipalities

The comparative analysis of the structural change in agriculture showed that in Tujetsch, Soazza and Blitzingen most farmers had no successor. In contrast, in Eggiwil most farms were taken over by a successor. In Tujetsch, Soazza and Blitzingen much of the farmland was abandoned. While the remaining farmers took over the favourable land, unfavourable parcels remained unused. Therefore, the remaining farms increased in size, while farm labour remained stable or decreased. Since farm labour costs increased faster than returns, labour extensive cultivation practices spread out leading to an undergrazing of pastures and the cessation of the manually clearing of trees and shrubs from pastures.

What caused the poor prediction accuracy of the model of Eggiwil? In Eggiwil, reforestation occurred only sporadically and, as showed by the model (Fig. 2), much of the cultivated land has similar agro-climatic and topographic conditions as the reforested land. In other words, farmers in Eggiwil cultivate almost all available land. This is due to the high demand for agricultural land since the number of farms is still high and farm areas are comparatively small. Many farmers had no other professional education than farming. These farmers had few opportunities to work off the farm, which may explain why they maintain the cultivation of marginal land. Another explanation for the maintenance of cultivation is that dairy farming (which is common in Eggiwil as in other parts of the Pre-Alps) is financially attractive for farmers because milk quotas secure regular income.

Further differences between the four municipalities relate to the employment opportunities concerning commuting distance. In Tujetsch and Soazza, off-farm job opportunities are better than in Eggiwil and Blitzingen due to the tourism and the vicinity to the cities of Bellinzona and Lugano. This is a further incentive to reduce investing labour in the cultivation of marginal land. In Soazza, additional local factors, such the delayed land consolidation and the prohibition on modifying old stables for use as summer residences enhanced reforestation. Conversely, part-time, hobby and non-mainstream farmers' interests in marginal land increased in recent years and (as in Blitzingen, Tujetsch and Soazza) this has slowed down reforestation. One reason is that the low-cost cultivation methods used by these farmers, such as deer and horse pasturing, may make cultivation of marginal land profitable.

The situation in the cases study municipalities exemplifies what mountain farming in the Swiss Alps means today. Traditional mountain farms, such as Eggiwil, in the sense that farms are handed down from one generation of farmers to the next, are scarce. In Tujetsch, Soazza and Blitzingen the picture is different. Recently, part-time and hobby farmers as well as career changers have started to cultivate land that is economically unviable for professional farmers.

Some of them do not rely on farm income for their living. As shown in this study, this mixture of traditional and modern farming partially explains why sub-alpine grasslands sometimes revert to forest.

4.3. General interpretation of results and the role of agricultural policies

Taken together, deviations of model predictions from the actual land-use/land-cover changes, and the different extent of reforestation found in the case study municipalities, can be explained by: (i) local idiosyncrasies related to the costs and benefits of land-use, (ii) local political factors, and (iii) economic processes occurring at higher levels, which have different local impacts. The influence of these factors confirms the economic hypothesis guiding our research in that they show that land managers balanced costs and benefits while deciding to maintain or abandon the cultivation and that land-use changes relate to indicators of the increasing opportunity costs of farm labour. The influence of these factors is also consistent with findings in other European case studies. Baldock et al. (1996) concluded from their studies on the determinants of land abandonment in parts of Finland, Spain, the Netherlands, Italy and France that agricultural land with unfavourable cultivation conditions are the most vulnerable to become abandoned. From their study in different European mountain areas, MacDonald et al. (2000) identified specific local socio-economic factors such as off-farm employment and the time required for pluriactivity, which enhanced land abandonment. Strijker (2005) concludes from his empirical work in the Netherlands that the increase of the opportunity costs of farm labour is one of the main determinants of agricultural land-use changes including intensification, extensification and land abandonment.

Further important factors influencing reforestation concern agricultural policies. Politicians recognise that policy measures may help preventing land abandonment. The overarching objective declared in the EU Sustainable Development Strategy and Gothenburg Council conclusions is halting the loss of biodiversity in the EU by 2010 (DLG, 2005). The EUs Common Agricultural Policy (CAP) provides a means, such as direct payments and the support of rural development, to prevent the abandonment of marginal land with high biodiversity (DLG, 2005). Swiss policy also includes measures for the maintenance of cultivation in areas with high biodiversity, although the focus is on the support of agricultural production and income. Swiss farmers obtain, for example, fewer subsidies for the cultivation of alpine pastures than for the cultivation of meadows and cropland (BLW, 2005). At the same time, alpine pastures are the most vulnerable to become abandoned and overgrown by trees and bushes (SFSO, 2001). As the financial incentives to maintain the cultivation of alpine pastures is low, we expect reforestation to continue.

4.4. Methodological considerations

This study is the first field application of the "finding answers in the errors" approach that was hitherto untested (pers. comm. Prof. Charles Wood). In their original publication Wood and Skole not only propose the systematic analysis of model misspecifications and potential 'spurious associations', but further suggest the use of the information from fieldwork to improve model fit. In this study, we did not include the information from fieldwork into the statistical models. This is because (except for the model of Eggiwil) our models fitted very well and we were primarily interested in the results from fieldwork, i.e. the motivations of landowners to abandon or maintain cultivation.

An advantage of the "finding answer in the errors" approach compared to pure statistical modelling approaches (e.g. Munroe et al., 2002) is that we obtained further insights into the processes of land-use/land-use change. It is in particular the small-scaled topographic and soil characteristics and political and economic processes at local and higher levels, which are difficult to identify using aerial photograph interpretation and statistical models. Only the combination of statistical models with qualitative in-depth interviews, as applied in this study, can reveal such factors, i.e. provide "answers to the errors" in the models.

An advantage of the "finding answers in the errors" approach compared to pure interview approaches (e.g. Hoffmann et al., 2001) is that models provide information about the importance of single factors influencing land-use/land-use changes. An advantage compared to approaches in which data from interviews are included into statistical models, in particular when interviews are conducted over large areas (e.g. Entwisle et al., 1998; McCracken et al., 1999; Thompson et al., 2002), is that it is less expensive and time consuming. A disadvantage of the "finding answers in the errors" approach is that it requires suitable models for the selection of interviews sites. Thus, it may be problematic in regions showing heterogeneous land-uses and small-scaled patterns of land-use/land-cover change. Aggregation of data as used by Wood and Skole (1998) may deal with the heterogeneity in data but would not allow examining detailed-scale patterns and processes of land-use/land-cover changes as this study provides.

5. Conclusions

A few general factors, such as the steepness and aspect of slopes, and a variety of specific local factors were found to influence reforestation. Specific local topographic and soil conditions as well as policy factors enhanced forest re-growth. Local factors that retarded reforestation relate to the opportunity costs of farm labour, low-cost cultivation practices, agri-environmental requirements and other benefits. Our findings indicate that the present policy measures are not suitable to prevent reforestation because they do not consider these specific local determinants of reforestation and rather focus on the support of agricultural production and income than on the maintenance of the cultivation of marginal land. If the prevention of reforestation is the goal of agricultural policy, then legislation should provide financial incentives to maintain marginal land with high biodiversity. Further, from the perspective of environmental economics and fiscal federalism, regulators should consider the regional demand for maintaining alpine pasturing in addition to local determinants of land-use/land-use change. Although our discussion refers to specific case study areas, this approach may be useful for others who aim to study land-use/land-cover changes based on spatial statistical models and qualitative interviews.

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