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Reconstructing Anthropogenic Disturbance Regimes in Forest Ecosystems: A Case Study from the Swiss Rhone Valley

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Abstract

Anthropogenic disturbances of forest ecosystems are increasingly recognized as fundamental ecological processes with important long-term implications for biogeochemical cycles and vegetation patterns. This article aims at reconstructing the extent and intensity of the two most common types of traditional forest uses—forest litter collecting and wood pasture—in the Swiss Rhone valley (Valais) by (i) identifying the spatiotemporal patterns, and (ii) modeling the biomass removal through these practices. Detailed information on agricultural practices and socio-economic context were essential to develop reliable estimates of anthropogenic disturbance regimes. In the Valais, predominately goats and sheep grazed in the forests. The intensity of grazing was a function of the number of grazing animals and the available grazing area. Forest litter was used as bedding for farm animals during the winter. Key factors determining the intensity of litter collecting were the number of animal units, the amount of available substitute products (straw), and the area where litter raking could be practiced. The results show that wood pasture and forest litter collecting were practiced on a significant proportion of the forested landscape in the Valais up to the second half of the 20th century. Until the implementation of forest management plans in the 1930s, almost half of the forests in the study area were affected by wood pasture and/or forest litter collecting. The regulations in the management plans led to an essential reduction of the area available for these traditional practices but likewise to an increased pressure on the remaining areas. The results suggest that the notion of a slow but steady disappearance of traditional non-timber forest uses and the associated effects on forest ecosystems is oversimplified. Quantitative reconstructions of biomass output resulting from these practices confirm the importance of traditional non-timber forest uses for ecosystem development in this region. Furthermore, it is very likely that similar effects have been widespread throughout regions with similar natural and socio-economic context, for example, throughout a significant proportion of the European Alps. This study underlines the importance of environmental history for ecological sciences as well as for forest management and conservation planning.

Key words: historical ecology; disturbance; ecosystem change; woodland pasture; forest litter collecting; Switzerland.

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Introduction

Knowing the site history of an ecosystem is often crucial for understanding current ecological processes. In view of the widespread prevalence of land use and the ubiquity of land-use legacies, Foster and others (2003) recommend addressing human activity as a fundamental ecological process and applying lessons from land-use history to landscape conservation and management.

For instance, long-term impacts of land-use change are frequently discussed in the context of biogeochemical cycling (for example, carbon and nitrogen cycles). Previous agricultural land use (Compton and others 1998; Koerner and others 1999; Jussy and others 2002) and logging activities (Goodale and Aber 2001; Latty and others 2004; Fraterrigo and others 2005) have been shown to strongly influence forest carbon and nitrogen cycles and nutrient pools.

Historical land use has also been increasingly recognized as an important factor determining modern vegetation patterns. Vegetation response to the type and intensity of previous agricultural land use (Koerner and others 1997; Prévosto and others 2004; Wulf 2004), the timing of agricultural abandonment (Graae and others 2003; Chauchard and others 2007), logging history (McCay 2000), and combined effects of different land-use types (Foster 1992; Eberhard and others 2003) have been found on varying temporal and spatial scales. Consequently, interpretations of regional differences in forest composition have to be based on information on regional differences in relevant human activities (Bürgi and others 2000). Foster and others (1998) concluded that historical land use has altered vegetation–environment relationships across broader geographic regions and should be considered in studies of global change.

In recent times, time-lag effects of land use, that is, land-use legacies, have gained special attention. Various studies highlighted the long-term impacts of former land use on the current state of ecosystems (for example Koerner and others 1997, 1999; Compton and Boone 2000; Goodale and Aber 2001; Foster and others 2003). Dupouey and others (2002) for example, showed that two centuries of farming during Roman times induced gradients in soil nutrient availability and plant diversity that are still measurable almost 2000 years later and suggested that effects of past agricultural land use on forest biodiversity may be irreversible on an historical time scale.

Facing the diverse and partly long-lasting impacts of land use on pattern and processes in ecosystems, several studies asked for a better implementation of land use history in ecosystem management (for example Dale and others 2000; Cronon 2000; Foster and others 2003). Eberhardt and others (2003) concluded that the understanding of past land use should be integrated into ecological models used to advise the management of biological reserves. For central European forests, Wohlgemuth and others (2002) proposed management principles integrating information on natural as well as anthropogenic disturbances, their regimes, and historical range within.

To assess the impact of anthropogenic disturbances, detailed information on forest use and management is needed. In the past, the forests of central Europe were not only sources of timber and fuel wood but also directly and indirectly supplied nutrients to sustain the human population. Agrarian societies, which were largely based on self-sufficiency, depended heavily on traditional non-timber forest uses, such as wood pasture and forest litter collecting (Bürgi 1999, Stuber and Bürgi 2001, 2002; Bürgi and Stuber 2003). Different studies have shown that the practice of traditional non-timber forest uses has a significant impact on forest ecosystems. In his pioneer work, Ebermayer (1876) described the effects of continuous forest litter removal such as nutrient depletion, mechanical damage to tree recruitment, and reduced tree growth. Litter plays two principal roles in forest ecosystems: (i) it forms an inherent part of the nutrient cycle of the forests, buffers microclimatic fluctuations (Ginter and others 1979), and (ii) acts as protection against erosion and soil compaction (Benkobi and others 1993; Geddes and Dunkerley 1999).

Dzwonko and Gawronski (2002) showed that current vegetation composition in mixed oak-pine woodland in Poland is associated with past material removal by man. In a 16-year litter removal experiment, they found that continuous litter removal resulted in substantial soil impoverishment and changed the composition of ground vegetation. Glatzel (1990, 1991) pointed at nutrient depletion and reduced acid neutralizing capacity as the most severe effects of biomass removal. The recovery of forest ecosystems from such practices is an extremely long-lasting process and therefore the impact of past forest uses is evident long after the abandonment of the respective land use (Kreutzer 1972; Hüttl and Schaaf 1995). Perruchod and others (1999) included time series of anthropogenic litter removal in a model for 20th century carbon budget of forest soils in the Alps. However, the authors mentioned the lack of reliable quantitative data on historical forest litter harvesting.

Particularly in remote regions, such traditional non-timber forest uses were practiced until only a few decades ago. This also holds true for the upper Swiss Rhone valley, the Valais (Gimmi and Bürgi 2007). In the same area, more specifically in the pine forest belt of the Valais, increased mortality of Scots pine (*Pinus sylvestris* L.) and significant shifts in tree species composition from the sub-boreal Scots pine to the sub-Mediterranean downy oak (*Quercus pubescens* Willd.) have recently been observed (Rigling and others 1999; Rigling and Cherubini 1999; Rigling and others 2004). Complex interactions between different factors were suspected to contribute to these effects. Besides climate change (Rebetez and Dobbertin 2004; Dobbertin and others 2005; Bigler and others 2006), insects (Dobbertin and others 2007), fungal decay and phytopathogenes (Schönfeld and others 2004), changes in forest use also were considered as potentially relevant. Therefore, Gimmi and Bürgi (2007) analyzed the history of wood pasture and forest litter collecting in the Valais in the late 19th and the 20th centuries based on the information from forest management plans and interviews with contemporary witnesses. The results illustrate how traditional non-timber forest uses were widespread, and in addition to forest fires (Gimmi and others 2004), significantly shaped the disturbance regime in forest ecosystems of this region.

To increase the ecological relevance of historical information, it is important to go beyond qualitative information and quantify human impacts on ecosystems—as far as permitted by the historical sources available (Bürgi and Gimmi 2007). Therefore, this article aims at quantifying the impact of non-timber forest uses on forest ecosystems by (a) reconstructing spatiotemporal patterns of forest litter collecting and wood pasture in the pine forest belt of the upper Swiss Rhone valley and (b) estimating the biomass removal through these practices. Reliable quantitative estimates of biomass output due to traditional forest uses provides the potential to incorporate these practices into ecological models and assess the impact on biogeochemical cycles and vegetation changes.

Study Region

"Valais" is the French name of a Swiss canton situated in the southwestern part of the country bordering Haute-Savoie in France to the West, and the Val d'Aosta in Italy to the south (Figure 1). The Valais contains the main part of the catchment area of the upper Rhone to its mouth in the Lake Geneva. The mountains surrounding the valley (highest top 4618 masl) shield the inner part of the valley from the moist oceanic air masses transported by western winds. This inner-Alpine situation causes a rain shadow, making the central Valais the driest region of Switzerland (annual precipitation 500–600 mm) (Rebetez and Dobbertin 2004).

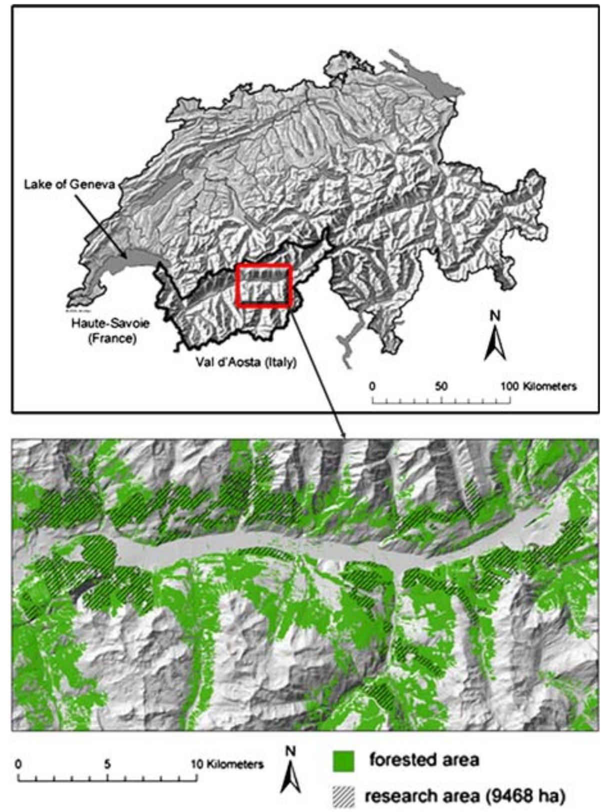

Figure 1. The study area (Canton of Valais) in the southwestern part of Switzerland and the location of the forested area under investigation (9468 ha).

The area under investigation covers 9468 ha of public forests in 22 municipalities in the upper central Valais (Figure 1). The forests were chosen due to the excellent source availability (esp. forest management plans). The forests range in elevation from 540 masl to the upper tree line at about 2390 masl.

Forests dominated by Scots pine (*P. sylvestris* L.) are an important forest type in the Valais, covering about 11% (12,000 ha) of the total forested area (Werlen 1994). Most forests in the study area—particularly pine forests—have been established after clearcutting during the late 18th and the 19th century (Rigling and others 2004). The region was an important timber source for the fast growing cities in the basin of Lake Geneva and further down in the French Rhone valley. These pine forests are located primarily in the main Rhone valley, ranging from the valley bottom up to altitudes around 1600 masl. About 40% of the forests included in the analyses consist of such pine-dominated stands (more than 50% pine in the modern tree species composition). Mixed pine stands contain downy oak (*Q. pubescens* Willd.) and other deciduous trees in lower elevations and in higher areas spruce (*Picea abies*) and larch (*Larix decidua*). Above 1500 masl, forests in the study area are mainly dominated by spruce and/or larch. In addition, fir (*Abies alba*) and Swiss stone pine (*Pinus cembra*) occur in smaller quantities.

Data and Methods

Sources

The collection of quantitative information about traditional non-timber forest uses is mainly based on forest management plans (MPs) from 22 municipalities in the upper Swiss Rhone valley, complemented by oral history interviews with 12 contemporary witnesses from the same region and additional written sources. In the study area (and in the Valais in general), forests are predominately owned by the municipalities (Burgergemeinden) and only small areas are private holdings. For the private forests, no management plans were written but oral history interviews suggest that wood pasture and litter raking were hardly executed on private lands (Gimmi and Bürgi 2007). MPs are the main planning tool in forestry. For the study area, a series of MPs were written in the mid-1920s and the mid-1930s. These plans include a report on the previous use, a description of the current state of the forests (for example tree species composition) and guidelines for future management. This characteristic is especially valuable for our study as the MPs contain information on non-timber forest uses conducted before and after the implementation of the plans. On a regional scale, forest management plans provide good quality information on the spatial extent of the practices. Forest management plans largely represent the view of the forest administration whereas oral history interviews provide first-hand information from people who had personally practiced the traditional non-timber forest uses. Oral history interviews provide particularly rich information on the practical aspects and socio-economic background of traditional forest uses. The combination of the two source types led to a comprehensive picture of the history and significance of traditional non-timber forest uses. Detailed source critical information on the two main source types, that is, management plans and oral history interviews, is given in Gimmi and Bürgi (2007).

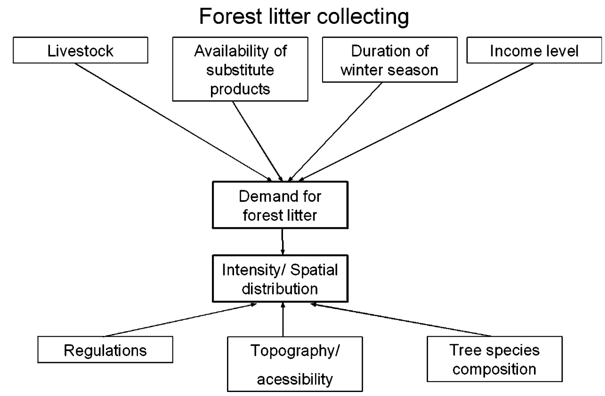

Figure 2. Conceptual graph of factors determining the demand for forest litter as well as the intensity and the spatial distribution of forest litter collecting.

Information taken from the MPs and oral history interviews was complemented by additional written sources such as documents from the forest administration, recent and contemporary literature, and statistical sources. Livestock statistics at the municipality level were available from the second half of the 19th century onwards, whereas the earliest statistics for grain production and litter meadows dates from 1917 (Schweizerische Statistik, Schweizerische Statistische Mitteilungen, Statistische Quellenwerke der Schweiz/a list of statistical sources is added separately in the references).

The spatial distribution of traditional forest uses was reconstructed for two time steps (before and after 1930, that is when MPs have been issued). The amount of biomass removal due to wood pasture was quantified for the period 1900–1960. Due to lack of source availability, the reconstruction of biomass removal from forest litter collecting was possible only for the period 1917–1960. The results for biomass removal are given in total biomass output per surface and time unit [kg/m^2 per y].

Reconstruction Techniques

Forest Litter Collecting. The development of a reliable model for biomass removal by forest litter collecting has to be based on basic considerations about the agricultural and socio-economic context of these forest uses (Figure 2). In Alpine regions, forest litter was mainly used in the stables to bind the livestock dung and to produce farmyard manure. Therefore, the demand for litter depends on the number of local livestock and the length of the winter season, during which the livestock were kept in the stables. Additionally, the demand for forest litter was driven by several socio-economic factors. Available substitute products, such as straw from the cultivation of grain and litter from wet meadows reduced the demand for forest litter. Furthermore, the local income level determined whether people could afford to buy additional straw or not. The local intensity and spatial distribution of forest litter collecting also depended on legislative regulations concerning forest litter collecting (spatial, temporal, and quantitative limitation) as well as on geographic parameters such as the local topography and the accessibility of the forests. In addition, the spatial distribution of tree species composition determined where litter collecting was preferably practiced. According to oral history interviews in the region, litter from spruce, pine and birch were preferred whereas the needles of the larch were not collected because they were regarded as unfavorable (Gimmi and Bürgi 2007).

The local intensity of forest litter collecting ($Intens_{flc}$) is expressed by the ratio of the local demand for forest litter ($LitDem_{forest}$) and the area where this practice was performed ($Area_{flce}$):

$$Intens_{flc} = \frac{LitDem_{forest}}{Area_{flce}} \quad (1)$$

Forest management plans and oral history interviews provide detailed information about the spatial extension of forest litter collecting in the upper Swiss Rhone valley. Based on these sources, we consider that forest litter collecting was actually practiced ($Area_{flce}$) only on half of the area, where it was legally allowed ($Area_{flcl}$):

$$Area_{flce} = \frac{Area_{flcl}}{2} \quad (2)$$

The local demand for forest litter is calculated by subtracting the amount of locally available substitute products (SubstProd) from the total demand for litter ($LitDem_{tot}$) in a specific municipality. Additionally, it has to be taken into account that with a quantum of forest litter a farmer could only replace about 50% of a quantum of straw from grain production (Rebel 1920), as straw was more efficient for binding the dung to manure.

$$LitDem_{forest} = LitDem_{tot} - Subst\,Prod * 2 \quad (3)$$

Straw from the cultivation of grain was by far the most important substitute product for forest litter in the Valais—litter from wet meadows was relevant only in a few cases. The crop yield of straw essentially depends on which type of grain is cultivated (Table 1). In the Valais, predominately winter rye was cultivated. To avoid overestimating the straw production based on modern data, we use historical crop yield data (Becker-Dillingen 1927). As the environmental conditions for grain production in the Valais are rather unfavorable (mountainous/dry), we applied three straw yield scenarios (straw1–3) ranging from the lower to medium yields given in the literature.

The total demand for litter in a specific municipality is calculated by multiplying the total number of large animal units (LUs) of the municipality (tot_{LU}) by the litter demand per LU ($LitDem_{LU}$—calculations see below). As litter was mainly used during wintertime, the demand for litter depended on the length of the winter season, which differed depending mainly on the altitude. A weighted index ($Index_{alt}$) is implemented to account for the altitudinal differences of the municipalities.

$$LitDem_{tot} = LitDem_{LU} * tot_{LU} * Index_{alt} \quad (4)$$

The LUs are calculated based on the so-called ‘‘Stosszahlen'' for Alps in the upper Valais (Imboden 1972), which reflect the relative demand for fodder for the different types of livestock, that is, horse = 1.5LU; cattle = 1LU; donkey and mule = 0.83LU; sheep and goat = 0.17LU. The sources containing data about the $LitDem_{LU}$ show a certain range of variability (Table 2). Some sources give data on the $LitDem_{LU}$ in volumes (for example, bags or litter piles), which first have to be converted to weight. For this purpose, 12 litter samples have been collected at different pine-dominated sites in the Valais. From this sample a conversion factor from volume to weight of 0.15 kg/l has been determined. This factor has been applied to information indicating litter demand in terms of volume per LU. Based on the sources given in Table 2, we applied three

Table 1. Range of Variability for Straw Yield for Different Types of Grain (Data from Becker-Dillingen 1927) and Straw Yield Scenarios used for Reconstruction

	Range of variability given in Becker-Dillingen (1927)		
Type of grain	Low yield	Medium yield	High yield
Winter rye	3.2 t/ha	3.7 t/ha	4.2 t/ha
Spring rye	1.4 t/ha	2.3 t/ha	3.2 t/ha
Winter wheat	3.2 t/ha	4.6 t/ha	6.0t/ha
Spring wheat	2.0 t/ha	3.5 t/ha	5.0 t/ha
Winter barley	2.0 t/ha	2.8 t/ha	3.6 t/ha
Spring barley	1.6 t/ha	2.4 t/ha	3.2 t/ha
Oat	0.9t/ha	1.45 t/ha	2.0 t/ha
Model scenarios	**straw1**	**straw2**	**straw3**

Table 2. Range of Variability in Information from Different Sources about Litter Demand per Large Animal Unit (LU). Where the Volumes/LU have Been Given in the Sources the Conversion Factor of 15 kg/hl has Been Applied to Calculate Weight/LU (Details Given in the Text)

Source	Information	Volume/LU	Weight/LU
OHI Eyholz	At least 10 bags of forest litter to overwinter a cow	6.67–10 hl/LU	100–150 kg/LU
Stebler (1921)	1 litter pile per cow and winter	8.2 hl/LU	123 kg/LU
Johann (2004)			260–378 kg/LU
Mean			189 kg/LU

scenarios for litter demand per LU (150, 200 and 250 kg/LU) to the model.

Evidence from forest management plans and oral history interviews, both indicate that, after the Second World War forest litter was successively replaced by imported grain straw. Improved transport facilities and alternative income opportunities in the rising hydroelectric, chemical and tourism industries made straw import possible and affordable (Gimmi and Bürgi 2007). For the 1960s, forest litter collecting is only reported for a small number of extremely remote municipalities. Therefore, we introduced a yearly decrease of the demand for forest litter of 10% after 1945 for all municipalities.

Wood Pasture. In comparison to forest litter collecting, the reconstruction of wood pasture is relatively simple. Nevertheless, it is again necessary to consider the agricultural context of this traditional form of forest use. In the pine forest belt of the Valais, grazing was almost exclusively done by goats and sheep. Whereas the sheep together with the cattle were driven to the alpine pastures during the summer, and grazed in the forests for only about 2 months per year, most of the goats stayed in the villages and provided the local population with milk. For this purpose, the goats were kept grazing in the nearby forests during the whole year except for a few days with high snow cover in winter and some extremely hot days in summer. Therefore, the duration of the grazing season (Dur_{graz}) is determined as 330 days for goats and 60 days for sheep.

The basic data to calculate the local intensity of wood pasture ($Intens_{graz}$) are livestock statistics on the municipality level, the same as used in the model for forest litter collecting. The fodder requirement (Fodreq) is estimated by 1.25 kg/d (dry substance) for goats and 1.5 kg/d for sheep (Landwirtschaftliche Beratungsstelle Lindau 2002). In contrast to the reconstruction of forest litter collecting, we make the assumption that wood pasture was uniformly practiced on the whole area where it was legally allowed ($Area_{graz}$).

$$Intens_{graz} = \frac{Livestock * Fodreq * Dur_{graz}}{Area_{graz}} \quad (5)$$

Results

Spatiotemporal Extent of Non-timber Forest Uses

The spatiotemporal distribution of forest litter raking and wood pasture for almost 9500 ha of public forests in the upper Swiss Rhone valley is shown in Figure 3. The first time step represents the spatial distribution of the forest uses for the period 1900–1930 (Figure 3A), and the second time step shows the distribution for the period 1930–1960 (Figure 3B).

The area where forest litter collecting was practiced decreased from 1606 ha (17% of the total area) in the first period to 605 ha (5%) in the second period (Figure 4). In pine-dominated forests (≥80% pine proportion in 1930), the respective decrease was even stronger from 471 ha (20%) initially to 113 ha (5%). Goats grazed on 3612 ha (38%) in the first period and on 1990 ha (21%) in the second period. Here, for pine stands only a slight decrease from 829 ha (34%) to 756 ha (31%) can be observed. Sheep grazing decreased moderately from 1284 ha (14%) to 957 ha (10%) for the total forest area, whereas for pine forest the respective proportion even increased from 104 ha (4%) to 165 ha (7%). Before 1930, wood pasture and forest litter collecting were practiced in combination on 1050 ha (11%) of all forests. This area essentially dropped to 440 ha (5%) after 1930. In pine forests, the decline was even more pronounced from 306 ha (13%) to 100 ha (4%). Consequently, the total area where no traditional non-timber forest uses were practiced, increased on the total area from 5300 ha (56%) to 7312 ha (77%). In comparison, this proportion only slightly increased in pine forest from 1419 ha (59%) to 1644 ha (68%) after 1930.

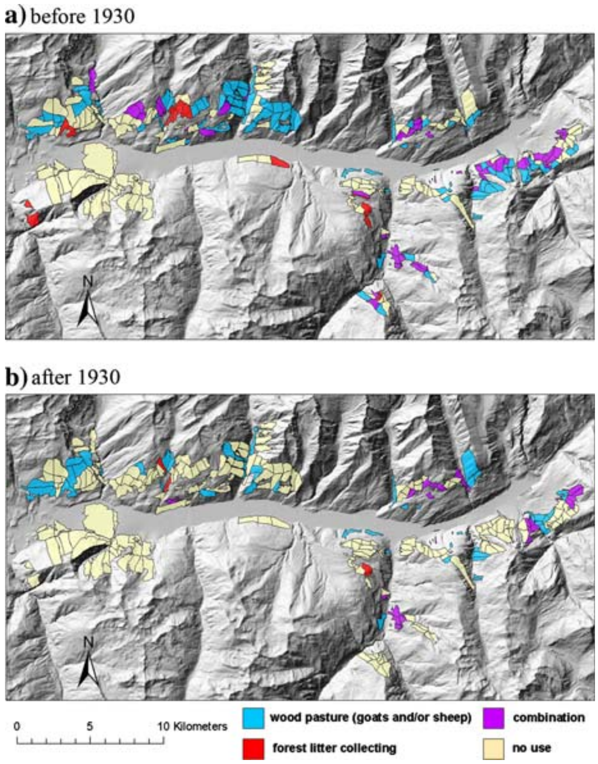

Figure 3. Spatiotemporal distribution of wood pasture and forest litter collecting in the upper central Valais before and after 1930.

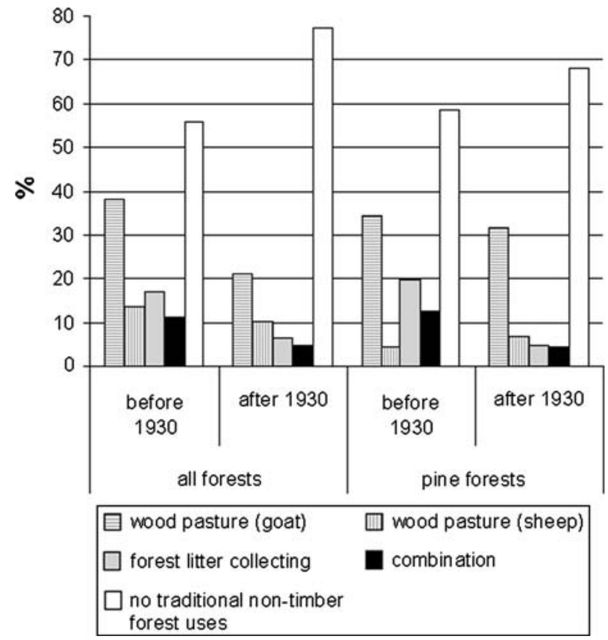

Figure 4. Comparison of the spatiotemporal extent of non-timber forest uses between the total forest area and pine forest stands.

Intensity of Non-timber Forest Uses

Forest Litter Collecting. The reconstruction of biomass output due to forest litter raking is based on different assumptions with specific uncertainties. To show the range of variability of the model output, we analyzed nine models with three different estimates for litter demand per LU (250/200/150 kg) and three scenarios for straw yield (see Table 1). Figure 5 shows the results of all nine models. We present here the values for the most reliable reconstruction with medium litter demand per LU (200 kg/LU) and medium straw yield scenario and will discuss the impact of different estimates on the model output later.

The average biomass removal increased from 0.15 kg/m^2 per y in 1917 to almost 0.25 kg/m^2 per y in the early 1930s. This is a result of increasing LU until the mid-1920s and the limitation of the area where litter raking was allowed in the MPs around 1930. During the Second World War, grain production increased (Figure 6), making more straw locally available which lowered the demand for forest litter. Therefore the average biomass removal decreased to 0.16 kg/m^2 per y until 1946. After the Second World War, improved transport facilities and economic revival made straw import easier. This led to a successive decrease in demand for forest litter and consequently to the decline in biomass removal.

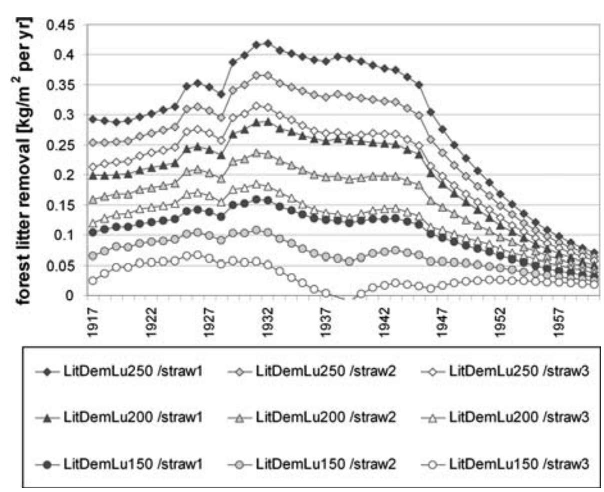

Figure 5. Reconstruction of biomass removal due to forest litter collecting for the period 1917–1960 for different estimates of litter demand per large animal unit and straw production rates. Rectangles indicate the highest estimate for litter demand (250 kg/LU), triangles intermediate demand (200 kg/LU), and circles the lowest demand (150 kg/LU). Black filling shows the lowest range of straw production rate, gray filling intermediate straw production, and no filling indicates the highest estimate for straw production.

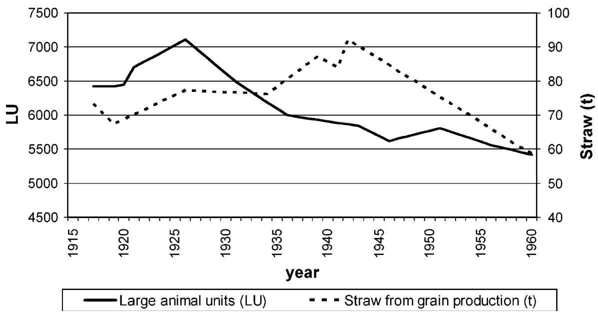

Figure 6. Changes in large animal units (LU) and straw production for 22 municipalities in the upper central Valais in the period 1917–1960.

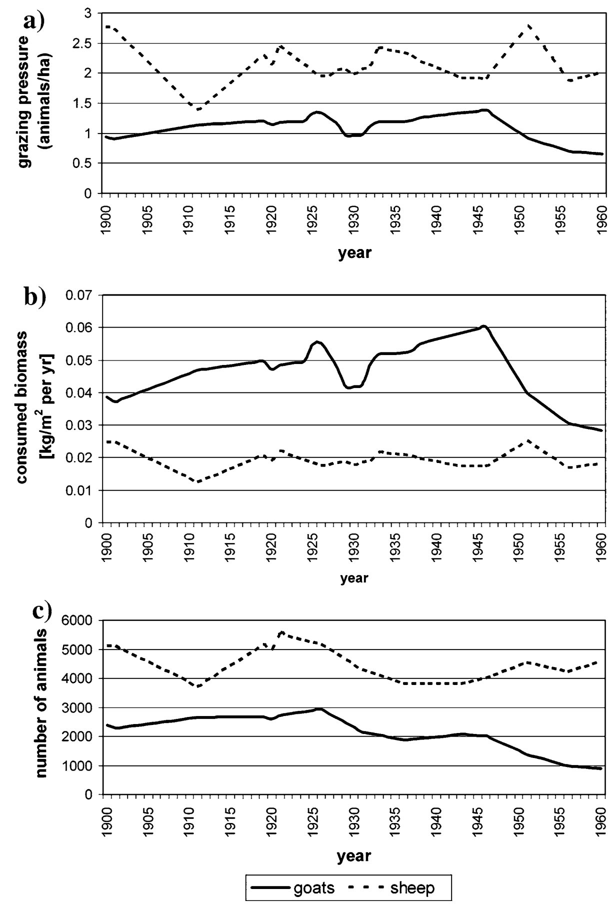

Figure 7. (**A**) Animal density on grazed areas in the period 1900–1960 and (**B**) biomass output due to wood pasture by goats and sheep for the same period. (**C**) Changes in goat and sheep numbers for 22 municipalities in the upper central Valais.

Wood Pasture. The intensity of goat grazing increased slightly, but continuously during the first quarter of the 20th century (Figure 7 A, B), as a consequence of rising numbers of goats (Figure 7C). The grazing pressure increased in this period from 0.95 to 1.35 goats/ha which resulted in an increase of the consumed biomass by goats from 0.38 to 0.55 kg/m^2 per y. After a short phase of decline around 1930, grazing pressure peaked in the mid-1940s with 1.4 goats/ha or a biomass removal of 0.6 kg/m^2 per y. Two reasons contributed to this effect. First, the area where grazing by goats was practiced, was significantly reduced by the regulations of the management plans. And secondly, the initial decrease of goat livestock in the late 1920s was decelerated by the crisis of the Second World War. In the post war period, numbers of goats and grazing pressure decreased rapidly.

Grazing by sheep was generally restricted to a much smaller area than grazing by goats (Figure 3), but the number of sheep was always considerably higher (Figure 7C). In contrast to the goats, the sheep only grazed in the forests for a short period in spring and autumn. As a result, the grazing pressure by sheep is generally higher in terms of animals per area but lower in respect to the amount of annually consumed biomass. Changes in the intensity of grazing by sheep reflects mostly fluctuation in sheep livestock, because the area where grazing by sheep was practiced changed slightly over the study period. A peak in intensity is observed in the beginning of the 1950s with 2.8 sheep/ha or 0.25 kg biomass/m^2 per y. A minimum in intensity occurred around 1910 with 1.4 sheep/ha or 0.125 kg biomass/m^2 per y.

Discussion

Our results show that forest litter collecting and wood pasture were practiced on a substantial portion of the forested area in the upper Swiss Rhone valley during the first half of the 20th century. Around 1930, the area where these forest uses could be practiced was essentially reduced by regulations in the forest management plans. Local case studies give evidence that the violation of the rules given in the MPs was punished (Gimmi and Bürgi 2007). At the same time, the demand for forest litter and wood pasturing remained stable. The result was an increasing pressure on the remaining areas. It was the intention of the forest administration to exclude non-timber forest uses particularly from forests which were important for timber production. Consequently, forests with lower productivity, such as pine forests, were disproportionately affected relative to non-timber forest uses.

The intensity of wood pasture is a simple function of the number of grazing animals and the amount of grazing area. In contrast, the modeling of the biomass output due to forest litter collecting was much more complex and was based on a number of assumptions which have a certain range of inherent variability. A sensitivity analysis was conducted to assess the impact of different estimates for the most important variables (litter demand per LU and straw production) on the model. Figure 5 shows that changes in the estimate for litter demand per LU has a considerable impact on the model output. In contrast, different scenarios for straw productivity have only a minor influence on the reconstruction results. The range of variability seems to be quite high but we assume limited reliability from the models providing the highest and lowest values because they result from the combination of the extreme estimates. However, the range of uncertainty in the estimated removal rates should be considered when applying the values to ecological models. Due to the limitations of the available sources, some aspects of the socio-economic context of forest litter collecting could not be appropriately integrated into the model. In particular, historical data on the local income level and the accessibility of a municipality would provide important information to assess how much substitute product (straw) could be imported. With the availability of such information it would, for example, be possible to assess if and how during the First and Second World War reduced import and transport facilities led to an increased demand for forest litter.

To check the plausibility of our results, we compared the model output with values given in other studies. An excellent overview of litter manipulation studies over the past 150 years providing rich material for such comparison was recently published (Sayer 2006). Measurements of annual litter production in pine forests ranged from 0.14 to 0.38 kg/m^2 (Ebermayer 1876; Schwappach 1887). Values for litter removal from experiments range from 0.6 kg/m^2 in the first raking to 0.14 kg/m^2 in subsequent harvests (Ebermayer 1876; Ramann 1883; Ganter 1927; Kreutzer 1972). Our modeled estimates for litter removal seem to fit very well in the range of experimental values of litter removal. Further, the comparison shows that an essential portion of the annual litter fall was continuously removed. Consumed biomass amounts by goats reconstructed in this study are comparable with biomass consumption by red deer recently found in the Swiss National Park (Schütz and others 2006). But goats seem to have a much higher proportion of browsing on woody species (up to 50%) than ungulates such as red deer (Stuber and Bürgi 2001; Suter and others 2004). Additionally, reconstructed historic goat densities are much higher than modern average ungulate density in temperate forests (for example, Reimoser and Gossow 1996; Côté and others 2004; Fankhauser and Enggist 2004). Therefore, the impact of woodland pasture on tree species composition might have been even more pronounced compared to browsing by ungulates.

What is the significance of these findings in the context of the recently observed mortality of pine and shifts in tree species composition from pine to downy oak and other deciduous trees in the pine forest belt of the Valais (Rigling and others 2004)? The continuous biomass and nutrient output caused by forest litter collecting led to ideal conditions for the regeneration of pine as a pioneer species on raw soils. In contrast, acorns were mechanically removed in great quantities, hindering regeneration of oak. The removal of the litter cover made soils directly exposed to climatic influences. We therefore assume that drought effects were amplified in stands where litter collecting was practiced. Wood pasture also has highly species-specific consequences, as damage to pine regeneration resulting from browsing is negligible in comparison to that to deciduous trees (Weber and others 2007). Timber harvesting played a minor role in forests used for wood pasture and/or forest litter collecting. Only in the most easily accessible forests near the settlements dead wood, branches, and cones were collected in significant quantities for fire-wood (details are given in Gimmi and Bürgi 2007). Thus, it seems highly plausible that the abandonment of wood pasture and forest litter collecting initiated the shift in species composition from pine to oak as pine was subjected to increased competition.

Conclusion

The results from this study confirm that forest litter collecting and wood pasture are important factors in the anthropogenic disturbance regime in the region. Both practices affected a significant proportion of the forested landscape in the upper central Valais up to the second half of the 20th century. Quantitative reconstruction of biomass output underpins the importance of traditional non-timber forest uses for ecosystem development in this region, and it is very likely that similar effects have been widespread throughout the regions with a similar natural and socio-economic context, for example, throughout a significant proportion of the European Alps.

In the Valais, the area where wood pasture and forest litter collecting could be practiced, was reduced as a result of the implementation of forest management plans around 1930. In combination with times of crisis during the Second World War, this led to an increased pressure on the remaining areas. Thus, the notion of a slow but steady disappearance of traditional non-timber forest uses and the associated effects on forest ecosystems is oversimplified. The effects of these uses on specific forests or forest types might even increase temporally due to changes in regulation or demand. Detailed information on agricultural practices and socio-economic context is needed to develop sound estimates of anthropogenic disturbance regimes.

Further, our results suggest that forest litter collecting and wood pasture may contribute to the recently observed changes in tree species composition from pine to deciduous trees. The practice of wood pasture and litter raking led to specific environmental conditions which favored pine as a pioneer species. After abandonment of these practices, pine was again subjected to increased competition.

Reconstructing anthropogenic disturbance regimes requires detailed historical information on a set of parameters which characterize the society-nature interaction in a given region. This underlines the importance of environmental history for ecological sciences as well as forest management and conservation planning as stated by Foster and others (2003).

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