Forest dynamics in the Pfyn forest in recent centuries (Valais, Switzerland, Central Alps): interaction of pine (*Pinus sylvestris*) and oak (*Quercus* sp.) under changing land use and fire frequency

Muriel Bendel,* Willy Tinner and Brigitta Ammann

(Institute of Plant Sciences, University of Bern, Altenbergrain 21, CH-3013 Bern, Switzerland)

Received 1 March 2005; revised manuscript accepted 31 July 2005

A HOLOCENE RESEARCH PAPER

Abstract: *Pinus sylvestris* is co-dominant in many areas of eastern and northern Europe. In Switzerland, the Pfyn forest is considered to be the largest natural forest of *Pinus sylvestris*. Its development under changing land use during recent centuries is largely unknown. Of particular interest is the interaction between pine and oak, for it has been suggested that oak has benefited from the strong decline in economic uses of the forest such as pasturing, litter removal and logging. In order to improve understanding of the dynamics in this particular forest type over time, the vegetation and fire history of the Pfyn forest were reconstructed by pollen and charcoal analyses of the sediments of Pfafforetsee. Four phases of decline in *Pinus* pollen percentages are explained by logging events and other anthropogenic activities during recent centuries. During the twentieth century human impact on *Pinus* was probably exacerbated by forest fires. When human influence ceased or declined, *Pinus* was able to regain its former importance within a few decades. Whereas *Pinus* experienced considerable change, *Quercus* species (*Q. pubescens*, *Q. petraea* and *Q. robur*) exhibit constant and low pollen values throughout the record. Under constant climatic conditions, pine should therefore not suffer late-successional replacements by oak in the Pfyn forest. This finding is especially important for nature conservation and forest management, since strong decline in *Pinus sylvestris* in the canton of Valais has also been interpreted as a consequence of successional dynamics towards a more natural vegetation.

Key words: Charcoal analysis, pollen analysis, fire history, forest dynamics, forest history, land use, Switzerland, Central Alps, late Holocene.

Introduction

Pinus sylvestris L. is an extremely widespread species in Eurasia and occurs in a wide range of habitats (Boratynski, 1991; Willis *et al*., 1998). Under cool continental conditions it co-dominates forests in Scandinavia, eastern Europe and northern Asia (Walter, 1974). Forests of *Pinus sylvestris* are an important landscape element in the canton of Valais in the southeast of Switzerland. They cover an area of 12 000 ha, which corresponds to 11% of the total forest area of the canton of Valais (Lock *et al*., 2003). In contrast to the Swiss Plateau and the rest of Central Europe, pine trees are not restricted to extreme habitats such as shallow soils and wetlands. Instead they are characteristic of the continental mountain belt between *c*. 800 and 1800 m a.s.l. (Landolt, 1992).

The largest forest of *Pinus sylvestris* in Switzerland, the Pfyn forest (or Bois de Finges), is located in the valley bottom of the Valais, between Leuk and Sierre (Figure 1) and occupies an area of approximately 700 ha (Werner, 1985). The long-term vegetation and fire development of this forest is largely unknown. The nearest site studied palynologically is Lac du Mont d'Orge (650 m a.s.l.), a small lake near Sion, about 40 km west of the Pfyn forest, the record of which reflects vegetation development since *c*. 16 000 cal. BP (calibrated radiocarbon years before present) (Welten, 1982; Bieri-Steck, 1990). This lake is situated in the middle of intensive vine cultures at the south-exposed slope once covered with forests dominated by *Pinus*, *Quercus*, *Ulmus* and *Fraxinus*

*Author for correspondence. Present address: Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland (e-mail: muriel.bendel@wsl.ch)

 10.1191/0959683606hl906rp

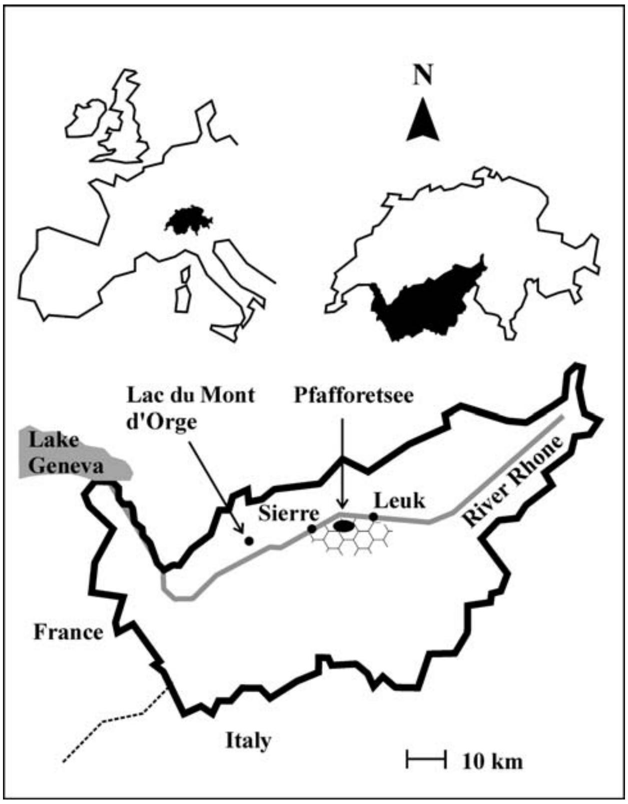

Figure 1 Location of Pfyn Forest (patterned area) and Pfafforetsee in the canton of Valais, Switzerland

(Welten, 1982). It is remarkable that *Pinus*, after having reached its maximal extention of 80% between 13 000 and 11 500 cal. BP in the record, exhibits values around 20–30% from 9500 cal. BP to the present (Welten, 1982). This result contrasts with the development of *Pinus* as a pioneer north and south of the Alps (eg, Lobsigensee, Soppensee, Lago di Origlio, Lago di Muzzano; Ammann, 1989; Lotter, 1999; Tinner *et al*., 1999; Gobet *et al*., 2000), where it was almost entirely replaced by deciduous and coniferous trees. However, the question remains as to whether the tree occurred predominantly in mixed or mono-dominant stands in the Valais.

Human activity in the area connected with agriculture and cattle breeding began about 7800 cal. BP (Welten, 1982). During the Younger Neolithic, Bronze and Iron Ages, *Quercus* and *Pinus* both reached values in pollen diagrams of around 20%. Since the Late Iron Age (2500 cal. BP), oaks sharply decreased because of devastation of montane forests on the southern slopes used for cultivation of cereals and grapes (Welten, 1982). It is likely that during those times, agriculture rarely occurred in the area of the Pfyn forest in the valley bottom, because most of its soils are stony and shallow and thus not suited for husbandry. Nevertheless, forest pasturing and litter collection, both of which were widespread until the 1950s (Werner, 1985), were most probably common in the Pfyn forest. Ott (1972, in Kempf, 1985) reports that at the end of the 1960s pasturing, especially by goats, could still be found in one-fifth of the forests in the Valais. It is reasonable to assume that these various forest uses, combined with others such as fuel collecting and selective logging, have caused shifts in species composition and thus have favoured pine relative to oak.

The history, distribution and interaction of pine and oak in the central Valais have caused intensive discussion (eg, Schmid, 1936; Meyer, 1950; Burnand, 1970, 1976; Stein, 1978; Rigling and Cherubini, 1999; Lock *et al*., 2003; Rebetez and Dobbertin, 2004; Kienast *et al*., 2004). It has been hypothesized that the observed ingrowth of oak in forests previously occupied by pine can be regarded as a succession towards the potential natural vegetation (Rigling and Cherubini, 1999). This conclusion contradicts the 'relict pine-forest hypothesis' of Schmid (1936), which stated that many pine forests in the Alps date from the first pine forests that became established after the last glaciation. In this sense the Pfyn forest was regarded as one of the largest relict pine forests in the Alps (Schmid, 1936).

The aims of this study are (1) to describe the changes in this forest during the last centuries with a particular emphasis on *Pinus* and *Quercus*, and (2) to relate its dynamics to changes in land use and fire frequency.

Methods

Study site

The canton of Valais is an inner-alpine valley in the southeast of Switzerland with low annual precipitation and a continental climate. The Pfyn forest (500–700 m a.s.l.) is located in the upper Rhone valley between Leuk and Sierre in the canton of Valais (Figure 1). Three-quarters of the Pfyn forest are covered with pine (Bille and Werner, 1986), with *Erico-Pinetum caricetosum albae* and *Ononido-Pinetum/Odontito-Pinetum* being the most important associations (Werner, 1985). Previously flooded areas (so-called 'Rottensand') near the River Rhone, which were described as *Hippophaëtum*, where *Hippophaë rhamnoides* was the most abundant species with few *Juniperus communis* intermingled (Meyer, 1950), are increasingly covered by a pioneer pine forest.

With an annual precipitation of 587 mm, the Pfyn forest site is one of the driest in Switzerland (Schürch and Vuataz, 2000). Hills, which exceed the small lakes in the troughs by about 50–80 m in height, make up roughly one-third of the Pfyn forest. The creation of the hills likely dates from the end of the last glaciation, when the steepened slopes of the adjacent mountains became unstable after the glacier retreated. About 10 000 years ago, a rockslide heaped up the hills in the valley bottom (Burri, 1997). Thus, it can be assumed that the onset of sedimentation in these lakes dates from the beginning of the Holocene.

Pfafforetsee (N 46°17′58″/E 7°35′13″, 555 m a.s.l.) has a crater-shaped basin with a maximal depth of 11 m and an open-water area of about 0.38 ha (Schanz *et al*., 1986). It is the deepest of the six lakes in the Pfyn area (Schanz *et al*., 1986) and is fed mainly by groundwater. In 1906, a canal from the River Rhone was built through the Pfyn forest (Werner, 1985; Bille and Werner, 1986), a small branch of which was indirectly connected to the Pfafforetsee via a small pond. Since then, water from the River Rhone has been additionally brought to the lake.

Coring

A Livingstone corer of 4.5 cm diameter was used in February 2001 to obtain 145 cm of sediment from Pfafforetsee at a depth of 7.8 m in a gently sloping part of the basin. The sediment was described according to Troels-Smith (1955). The core was stored at 4°C prior to analysis.

Sample preparation and pollen analysis

Subsamples of 1 cm^3 were retrieved from the core from every second centimetre above 62 cm (with a few exceptions above 12 cm) and from every fifth centimetre below this horizon. Samples (48) were prepared for pollen and charcoal analysis with standard methods according to Moore *et al*. (1991).

Lycopodium tablets were added for the estimation of pollen concentrations (Stockmarr, 1971). Pollen was identified at a magnification of 400× with the aid of pollen keys (eg, Moore *et al*., 1991) and photo atlas (eg, Reille, 1992). The pollen sum employed was 500 unless the content of the complete slide was less than that value. Percentage values were based on the total terrestrial pollen sum.

Groups of taxa within the same genus or family which cannot be further differentiated are referred to as pollen-'types' (Moore *et al*., 1991). Because of the surrounding closed forest and the small size of the lake (*c*. 40 m radius), the pollen record is expected to reflect development mainly of the local vegetation (relevant pollen source area < 300–400 m, see Sugita, 1994).

Charcoal analysis

Charcoal particles (> 10 μm) were identified and counted at a magnification of 400× on the same slides used for pollen analysis (Tinner and Hu, 2003; Finsinger and Tinner, 2005) following the criteria of Swain (1973) and Clark (1988). Charcoal-particle concentration was calculated via the same approach as used for pollen (Stockmarr, 1971). Charcoal particles on pollen slides may be used to estimate the past fire occurrence at a regional scale (*c*. 20–100 km radius, eg, MacDonald *et al*., 1991; Tinner *et al*., 1998; Whitlock and Larsen, 2001).

Loss-on-ignition (LOI)

Analysis of loss-on-ignition was conducted according to Heiri *et al*. (2001) in order to determine the amount of organic, carbonate and minerogenic matter of the sediment. For the analysis, 2 cm^3 were retrieved from the same depths as for pollen analysis.

Presentation of diagrams and zonation

The results for pollen, charcoal and LOI are presented as TILIA-diagrams (Grimm, 1991–1993). Local pollen assemblage zones (LPAZ) were calculated by optimal partitioning using the sum-of-squares criterion (Birks and Gordon, 1985), implemented with the program ZONE (for further details see Ammann *et al*., 2000). The number of significant pollen zones was evaluated by comparison with the broken-stick model (Bennett, 1996).

^{210}Pb dating

A total of 23 freeze-dried sediment samples were ^{210}Pb-dated at the Science Museum of Minnesota (St Croix Watershed Research Station). Dates were calculated according to the constant rate of supply (CRS) model (Appleby and Oldfield, 1978). For the model run, supported ^{210}Pb was estimated from the seven deepest horizons sampled (65–117 cm).

Results

^{210}Pb dating, sedimentology and LOI

Total ^{210}Pb activity declines from surface values of around 4.8 pCi/g to a variable background (supported ^{210}Pb) of 0.2–0.6 pCi/g below 64 cm (Figure 2; D. R. Engstrom, personal communication, 2003). Uncertainty of calculated age rises with sediment depth, peaking at the lowest dated sample at 64 cm (AD 1832±27, Table 1). Because no macrofossils were found in the lower half of the core, radiocarbon dating was not possible. Therefore, the age of this section can only be roughly estimated. If ^{210}Pb-derived sedimentation rates for the section 55–64 cm (9 yr/cm) are extrapolated, the age of the base of the core can be estimated as *c*. AD 1100. The regular presence of *Castanea* and *Juglans* pollen supports a post-Roman age of the lower-most samples (see Discussion).

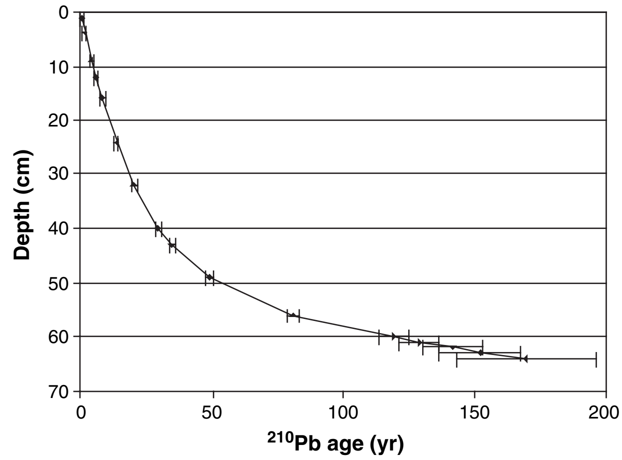

Figure 2 ^{210}Pb age in years (±sd) for the upper part of the core of Pfafforetsee

The core consists of various types of gyttja. Below 65 cm is calcareous gyttja and lake marl, above 65 cm mostly fine detritus gyttja, including a layer of silty gyttia between 51 and 56 cm. Calculated sedimentation rates between 59 and 63 cm exhibit relatively low uniform values, which increase sharply above 59 cm and peak at 15 cm (Figure 3).

Results of LOI analysis give more detailed information about the lithology of the core than visual sediment description. Loss-on-ignition suggests constant sedimentation rates below 60 cm (Figure 4). Between 54 and 36 cm, carbonate as well as organic content reach the lowest values recorded. Above 36 cm, organic content rises to values comparable with those found below 60 cm, whereas carbonate remains low and constant, reaching half the values of the lower part of the core.

Pollen and charcoal

The main pollen and spore types recorded are shown in Figure 5 as percentage values, and charcoal is given in concentrations (particles/cm^3). Records of pollen types associated with human land use are summarized in Figure 6. It must be kept in mind that percentage values are interdependent and that a change in one pollen type influences the percentages of all others. This problem can be assessed by considering pollen concentration and influx values. In general, pollen concentration (data not shown) is in agreement with pollen percentages, suggesting that our diagram is not affected by calculation artefacts (Bendel, 2001).

Six statistically significant local pollen assemblage zones are identified. The lower half of the core (LPAZ 1, 2 and 3) is characterized by three distinct decreases in tree pollen.

Table 1 Results of ^{210}Pb dating of Pfafforetsee. Ages of levels (±sd) were calculated using CRS model (Appleby and Oldfield, 1978). Measured samples were 1 cm thick

cm	Age AD	cm	Age AD
0.5	2001±0.7	42.5	1966±1.4
3.5	2000±0.7	48.5	1952±1.6
8.5	1997±0.8	55.5	1920±2.1
11.5	1995±0.8	59.5	1882±5.6
15.5	1993±0.8	60.5	1873±7.6
23.5	1988±0.9	61.5	1860±11.2
62.5	1849±15.6	62.5	1849±15.6
31.5	1981±1.0	63.5	1832±26.7
39.5	1971±1.2		

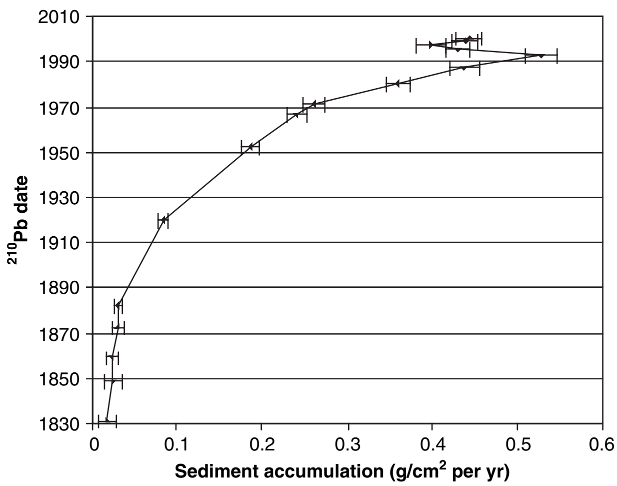

Figure 3 Sediment-accumulation rate (g/cm^2 per yr) for the upper part of the core (64 cm ≈ AD 1832±27) of Pfafforetsee

Percentage values of herbs such as *Odontites*, *Plantago lanceolata*, Rubiaceae and Cerealia increased during these phases. In the upper half of the core, a fourth decline in tree pollen is associated with an increase of pollen indicative of human impact (LPAZ 5). In contrast to the three earlier declines, pollen of the whorled water-milfoil (*Myriophyllum verticillatum*) and bracken (*Pteridium aquilinum*) increase especially during this phase, which may point to an increasing anthropogenic influence through eutrophication (*M. verticillatum*) or understorey disturbance (*P. aquilinum*). In the uppermost zone (LPAZ 6), pollen from *Trifolium repens* t., *Lotus*, *Onobrychis* and *Mercurialis annua* become more common. Simultaneously, those of several shrub and tree taxa such as *Sorbus*, *Frangula alnus*, *Rhamnus*, *Sambucus nigra* t., and *Prunus* also increase.

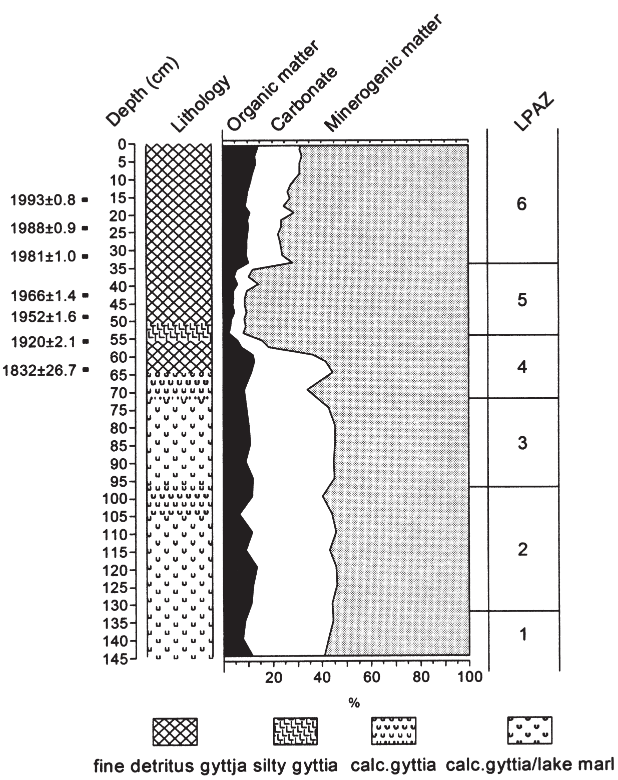

Figure 4 Results of the LOI analysis: organic, carbonate and minerogenic matter of the sediment in percent dry weight of the Pfafforetsee core

Quercus is characterized by low but stable percentage values through the whole core. The *Pinus* curve reflects these four reductions in tree pollen mentioned, and reaches its highest values in the uppermost zone (LPAZ 6). Charcoal concentration remains low and stable in the bottom half of the core and is characterized by a marked increase at the end of LPAZ 4. In the top half, charcoal concentration increases, and considerable fluctuations can be detected in sediments deposited during the last century.

Discussion

Chronology

The break between sediments containing unsupported ^{210}Pb (above 64 cm) and lower sections with only supported (background) ^{210}Pb is ambiguous, as ^{210}Pb values continue gradually to decline below 65 cm. We assume that changes in sediment lithology affect ^{226}Ra concentrations in the minerogenic fraction, and hence also supported ^{210}Pb. This assumption is supported by the calculated sediment-accumulation rates, which are relatively low and uniform prior to 1900 but rise strongly during the first half of the twentieth century. This increase in sediment flux corresponds to a sharp rise in minerogenic matter, indicating major erosional inputs, or perhaps the onset of repeated flooding by the River Rhone.

The large uncertainty for the older dates is typical for ^{210}Pb, which is reliable only for the last 120–150 years (Appleby, 2001). The main dating uncertainty lies with (1) changes in sediment lithology and associated variability in supported ^{210}Pb, and (2) potential increases in ^{210}Pb flux to the lake associated with the onset of river flooding. Because the constant rate of supply model used assumes a constant flux of ^{210}Pb, a systematic increase in ^{210}Pb inputs could cause a substantial dating error.

In addition to measurements of ^{210}Pb, biostratigraphic changes may also be used for chronological purposes. Short cores can be indirectly dated using other radiometrically dated pollen profiles, or historically documented vegetation changes for recent centuries (van der Knaap *et al.*, 2000). Typical changes in pollen spectra, such as the general increase of *Pinus* Subgen. *Pinus* (ie, *Pinus sylvestris* and *P. mugo*) followed by *Fraxinus excelsior* during the second half of the twentieth century are also present at our site. In general, *Pinus* as well as *Fraxinus* pollen would expand as these trees colonized abandoned marginal grassland. The end of pollarding probably also contributed to the increase in *Fraxinus* (Aaby, 1986).

In the Pfafforetsee record, *Populus* increased simultaneously with *Fraxinus*. This expansion can be explained by the presence of a poplar plantation established during the 1950s about 200 m from Pfafforetsee, which is in agreement with the ^{210}Pb-dated increase of *Populus* pollen at around 1970 (35–30 cm). Since poplars are known to be fast-growing, we assume that pollen production began within two decades after plantation. In this region, poplar is often not well represented in pollen diagrams, so that the observed increase at AD 1970 is most likely to be of local origin.

In Lac du Mont d'Orge, the behaviour of *Fagus* is characterized by a pattern very similar to that of our study site (Welten, 1982). The distribution of the tree most probably declined stepwise since Mediaeval times and underwent an increase during the last century. This pattern is not restricted to the Valais, but occurs also at most of the sites in Switzerland analysed by van der Knaap *et al.* (2000). Therefore, we must assume that the lower part of our core most probably dates from Mediaeval times, in agreement with dating based on extrapolation of sediment accumulation rates (see Results).

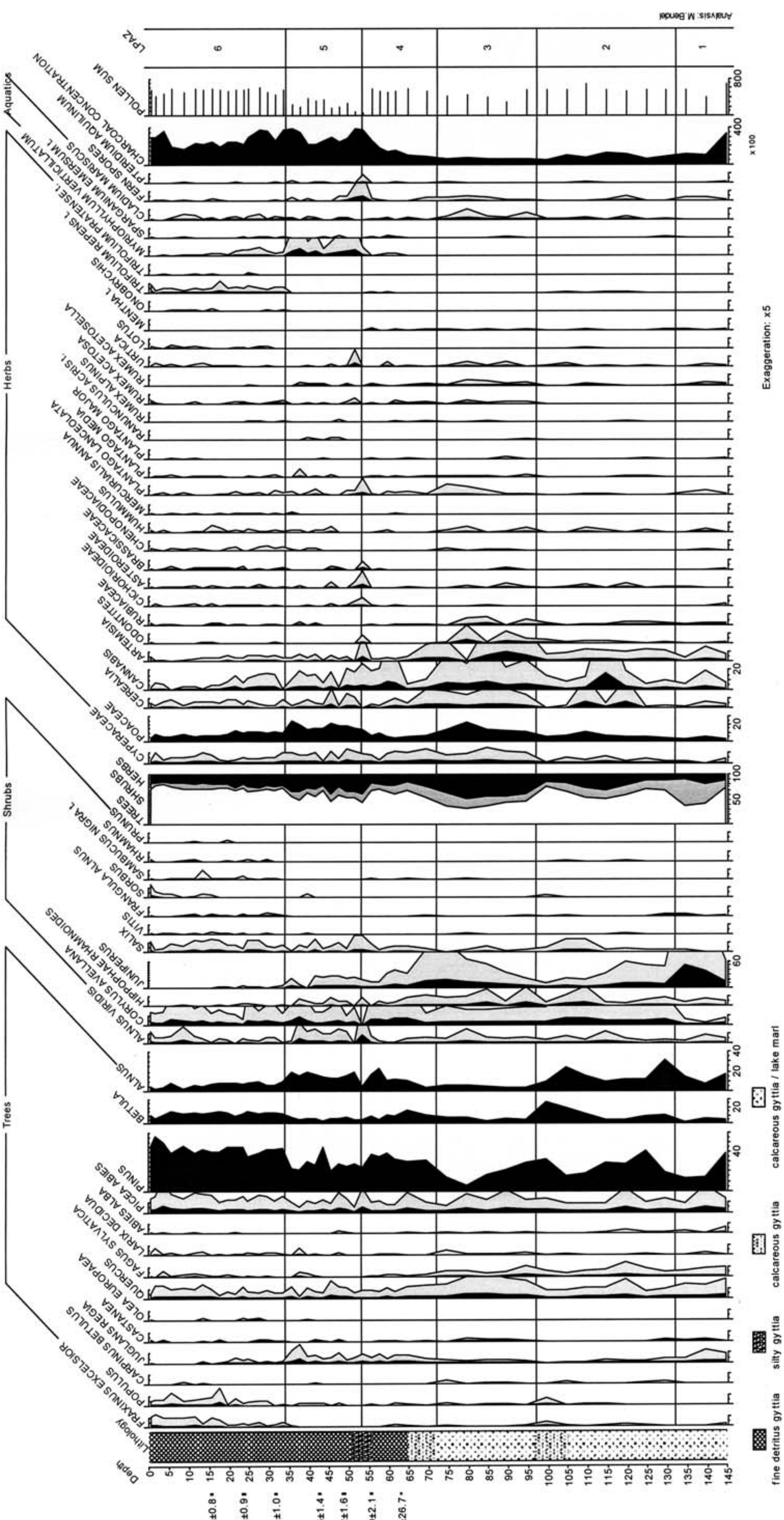

Figure 5 Percentage diagram of Pfafforetsee, showing main types of pollen and spores recorded, the charcoal concentration, and the pollen sum

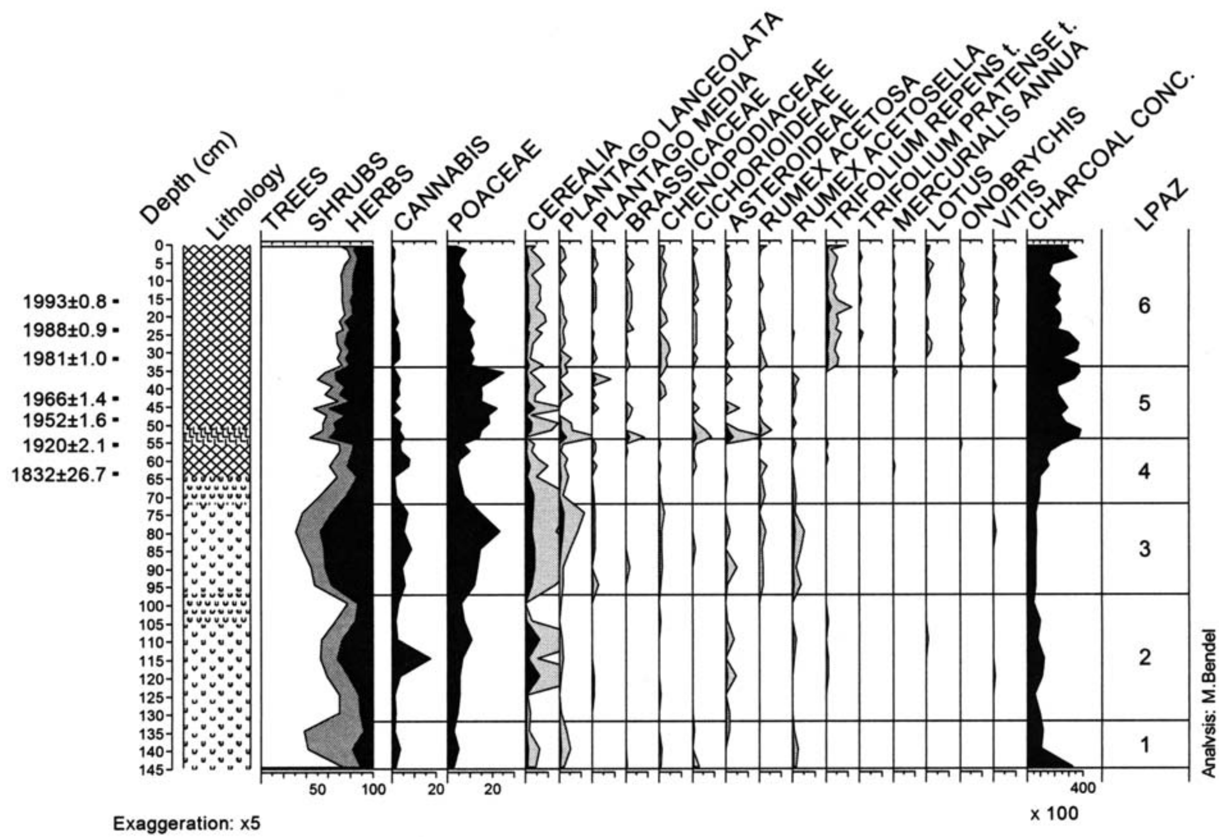

Figure 6 Percentage diagram of selected pollen types associated with land use and charcoal concentration recorded in Pfafforetsee

The decline of *Cannabis sativa* pollen around AD 1900, which is conspicuous north of the Alps (van der Knaap *et al*., 2000), cannot be detected in our core. The gradual decline in values of *Cannabis sativa* during approximately the last two centuries is more similar to results of palynological studies from the southern Pre-Alps (eg, Tinner *et al*., 1998) and Southern Central Swiss Alps south of the River Rhone (eg, Welten, 1982; van der Knaap and Ammann, 1997). The similarity between the Pfafforetsee pollen record and those from further south is underlined by taxa such as *Quercus ilex* (one pollen grain on 109.5 cm, data not shown) and *Olea europaea* found in Pfafforetsee. Such pollen from the Mediterranean region is possibly brought by southern winds across the Alps, although the two trees are also rarely planted for ornamental purposes in the Valais.

LOI and sedimentology

Stable carbonate and organic contents below 60 cm suggest constant sedimentation rates and low disturbance. Flooding of the lake by the River Rhone must have been a rare event. Before the dams were built (mainly during the 1950s and 1960s; Werner, 1985) the natural bed of the river seems to have been wide enough to lessen major flooding events. At 60 cm (*c*. AD 1880 according to the ^{210}Pb chronology), carbonate as well as organic matter decline. This change is most probably caused by changes in water chemistry and the influx of water-transported detritus. Since the water of the River Rhone has lower carbonate content, it probably diluted the high carbonate concentration of the lake water, thus causing the abrupt end of deposition of lake marl and calcareous gyttja.

Long-term forest dynamics

Many different economic activities such as fuel collecting, fodder-gathering (pollarding), logging and forest pasturing still shaped most of the forests in the Valais and in the whole of Switzerland during the early twentieth century (Burnand, 1976; Kempf and Scherrer, 1982; Kempf, 1985; Stuber and Bürgi, 2002). Logging was carried out with varying intensity over time. The last major clear-cuttings, which attained far greater extent than logging activities during the second world war date from the first half of the nineteenth century (Kempf and Scherrer, 1982). Logging also extended to the area of the Pfyn forest (Meyer, 1950). Other uses, such as forest pasturing and litter collecting, were common activities until the 1950s in this area (Werner, 1985). Such activities are expected to have influenced plant-species composition over recent centuries. It is likely that species that are tolerant to browsing and that produce a large amount of well-dispersed seeds which can germinate on barren ground were favoured. In the Valais, extension of pine is often regarded as an indication of past forest use that favoured pines rather than oaks (eg, Burnand, 1976). Today, the spread of *Quercus* at the expense of *Pinus* can be observed in many forests (Rigling and Cherubini, 1999; Lock *et al*., 2003; Kienast *et al*., 2004). This development has been attributed to different causes: cessation of forest pasturing and litter collection, increased drought stress and competition, insects and phytopathogens may have favoured oaks at the expense of pines (Rigling and Cherubini, 1999; Lock *et al*., 2003).

The Pfafforetsee pollen record reflects mainly local and regional vegetation history. Pollen of *Rumex alpinus*, *Alnus viridis*, *Plantago atrata*, *P. alpina*, *Castanea* and *Fagus* must have been brought to the lake from higher-elevations or from the western part of the Valais with its less pronounced continental climate.

Fluctuating tree-, shrub- and herb- values indicate several logging events in the past. In the lower half of the core, tree pollen percentages decrease three times, while those of shrubs and herbs increase. Neither sediment description nor LOI reveal any change during those times. Therefore, the fluctuating pollen values most probably reflect changing vegetation composition in the regional surroundings of the lake. It is known that in addition to forest pasturing and litter collection, logging was common in the area of the Pfyn forest (Meyer, 1950). The last clear-cuts in the Pfyn forest date from the second world war, when 37 ha of forest were cut and drained for agricultural use (Kempf, 1985; Werner, 1985). The first known aerial photographs of the area, taken in 1946 and 1949, show clear-cut areas in the eastern part of the Pfyn forest (where they made up almost one-half of the surface) and around the farm 'Pfyngut' – and thus in close proximity to Pfafforetsee (Werner, 1985). The silty layer between 55 and 50 cm dated at AD 1920–1950 therefore most probably records the time between the beginning of the last century to the end of the second world war, when additional sites were converted to arable land and canals for drainage were built or extended.

In contrast to *Pinus* pollen, *Quercus* exhibits hardly any fluctuation over recent centuries. This result stands in contrast to reports that oaks have suffered under the previously widespread forest uses and, additionally, have been cut on the southern slopes and also in the Pfyn forest for the construction of the railway during the 1860s (Werner, 1985). Historical reports suggest that oaks were intermingled in the Pfyn forest and that some small areas were even pure oak (Meyer, 1950). Since pressure on pine and oak forests in the Valais has decreased (Burnand, 1976; Kempf and Scherrer, 1982), we would expect oaks to become more widespread.

Braun-Blanquet (1961, in Burnand, 1976) already stated, in contradiction to Schmid (1936), that most pine forests at lower elevations in the Valais must be regarded as degradation stages of *Quercus pubescens* woods. This hypothesis cannot be supported with our pollen data for the Pfyn forest, either because young *Quercus* trees are not yet producing pollen, for it takes 30 to 60 (80) years for oaks to reach their reproductive stage (Lang, 1994), or because the area of the Pfyn forest does not belong to the sites naturally occupied by deciduous trees such as oaks. In fact, our data show that in the Pfyn forest anthropogenic activities of the past centuries repeatedly reduced the occurrence of *Pinus sylvestris* (eg, LPAZ 1, 3 and 5). Subsequently, when human activity ceased or became weaker (eg, LPAZ 2, 4 and 6) *Pinus sylvestris* was able to regain its former importance within a few decades.

Our data suggest that Pfyn forest has been rich in pines for at least the past several centuries. Pine abundance was especially great when human activities were low. The long-term role of *Quercus* was marginal. Our findings are supported by the first mention of the forest in 1544 as a 'long pine forest' (Meyer, 1950), as well as other historical reports describing pine as the most abundant tree species (eg, Murith, 1810; Schiner, 1812, in Meyer, 1950). These sources imply that under unchanged climatic conditions, the pines in the Pfyn forest should not suffer successional displacement by oak, as generally suggested for forests of *Pinus sylvestris* in the Valais (Rigling and Cherubini, 1999). The natural potential of *Pinus sylvestris* in the lowlands of the Valais region is underscored by the pollen record of Lac du Mont d'Orge, where the species has been able to maintain high and almost constant pollen values during the past 9500 years.

Oaks were, and still are, scattered within the pine forest and found in relatively limited localities, ie, on hilltops (Meyer, 1950; Burnand, 1976; Werner, 1985). These oak patches closest to Pfafforetsee are located west of the lake at a distance of *c*. 600–700 m. However, it seems that only a small number of individuals are producing pollen, and many saplings do not reach the age for pollen production. The occurrence of small patches of oak on hilltops might be attributed to the location of Pfyn forest in the valley bottom in the shade of high mountains, a situation that may cause more frequent late frost. Since *Quercus pubescens* is known to be very sensitive to late frost (Burnand, 1976), small patches of oak forest are only found on the highest hills (50–80 m above the troughs) in the Pfyn forest – and therefore farthest away from the cold air accumulating between the hills (Burnand, 1976; Werner, 1985). Considering that *Quercus* produces quite a large amount of well-dispersed pollen (Lang, 1994), it is unlikely that large changes during recent centuries would have remained undetected in our study. Although historical reports suggest a larger distribution of oaks in the Pfyn forest in the past (Meyer, 1950), the trees do not seem to have reached a broader extension in the area than today.

Whilst *Pinus* pollen reflects several logging events in the lower part of the core, various herbs and shrubs document land-use changes that took place during the middle of the twentieth century. Intensified local agriculture is reflected by several taxa recorded in the uppermost zone: *Mercurialis annua*, as well as *Lotus*, *Onobrychis*, *Trifolium pratense* t., *Trifolium repens* t., Chenopodiaceae and Brassicaceae expand simultaneously. *Rumex acetosa* t. replaces *Rumex acetosella* after a transitional period during which both types occur. The expansion of vineyards especially on the southern exposed slopes (Kempf and Scherrer, 1982; Kempf, 1985) is reflected in an increase in pollen of *Vitis vinifera*.

Fire history

Kempf and Scherrer (1982) list 23 historically known fires in the Pfyn forest between AD 1775 and 1976. Ten of those occurred after 1950, indicating an increase in fire frequency since the middle of the twentieth century, even assuming that in the past some have not been reported. Three of these fires have left visible scars on the landscape of the Pfyn forest: 1921, 1962 and 1964 (Werner, 1985). Depending on soil properties, after an initial recolonization state characterized by *Betula* and *Populus tremula*, further vegetation development differed among sites. In areas with shallow soil, pioneer trees survived and *Quercus* regrew from the stock, whereas in the driest sites, trees could not persist and herbs typical of open areas became abundant. On deeper soils, *Pinus sylvestris* could establish (Werner, 1985). Therefore, the hypothesis that *Pinus sylvestris* generally regenerates well on burned areas (eg, Burnand, 1976; Sannikov, 1994) cannot be supported for all parts of the Pfyn forest. Taking into account the large extension of Pfyn forest, it seems very improbable that large-scale fires have played an important role in determining the occurrence of *Pinus sylvestris* in the past. This is supported by our charcoal data, which are stable at rather low levels until the beginning of the twentieth century, but sharply increase afterwards.

In general, correlations between *Pinus* pollen and charcoal particles are not pronounced, suggesting that fires were responsible only in part for vegetational dynamics in the Pfyn forest. However, it is likely that fires repeatedly disrupted or destroyed notable areas of pine forest. The most marked fire impact is found at 55–35 cm, corresponding to AD 1920–1980, when charcoal-inferred fire increases and *Pinus* declines (LPAZ 5, Figure 5). Increase of *Pinus* after AD 1970–1980 (above 35 cm) is associated with the pine forest becoming more dense and openings being closed. In part this increase can also be attributed to the ingrowth of pines in the 'Rottensand', which is the area of the Pfyn forest once flooded by the River Rhone. Analysis of aerial photographs suggests an increase of pine coverage of 30–70% between 1946 and 1982 (Werner, 1985). This development can also be detected in the pollen diagram. Taxa from dry, open or irregularly flooded environments such as *Juniperus*, *Odontites* and *Hippophaë* are more often found in the older sediments, reflecting a landscape with more open habitats. A comparison of aerial photographs from 1959 with others from 1982 found comparable results with a decrease from 40 to 7 ha in steppic elements in the previously flooded area (Werner, 1985). In the light of our results, it is not possible to recommend fire-management strategies (eg, controlled burning, reduced fire-fighting) that could help prevent the ongoing reduction of *Pinus sylvestris* in the Valais. Since to our knowledge this is the first attempt to reconstruct the long-term fire ecology of the *Pinus sylvestris* forests in and around the Alps, additional investigations would be needed to reach this goal. However, our results show that high-resolution palaeoecological records are necessary to address the origin and nature of local forest dynamics. In particular, they are essential to assess important management or protection issues such as the degree of landscape and vegetation naturalness (Vale, 2002).

Acknowledgements

We thank J.F.N. van Leeuwen, M. Winter, L. Wick and W.O. van der Knapp for helping with pollen identification, F. Oberli for laboratory help, W. Tanner and W. Finsinger for coring, D. Engstrom for sediment dating and H.E. Wright for English corrections to the manuscript. We are grateful to P.E. O'Sullivan, H.J.B. Birks, J.-N. Haas and anonymous reviewers for helpful comments on earlier drafts of the manuscript.

References

Aaby, B. 1986: Trees as anthropogenic indicators in regional pollen diagrams from eastern Denmark. In Behre, K.-E., editor, *Anthropogenic indicators in pollen diagrams.* Balkema, 73–93.

Ammann, B. 1989: Late-Quaternary palynology at Lobsigensee. Regional vegetation history and local lake development. *Dissertationes Botanicae* 137, 1–157.

Ammann, B., Birks, H.J.B., Brooks, S.J., Eicher, U., von Grafenstein, U., Hofmann, W., Lemdahl, G., Schwander, J., Tobolski, K. and **Wick, L.** 2000: Quantification of biotic responses to rapid climatic changes around the Younger Dryas – a synthesis. *Palaeogeography, Palaeoclimatology and Palaeoecology* 159, 313–47.

Appleby, P.G. 2001: Chronostratigraphic techniques in recent sediments. In Last, W.M. and Smol, J.P., editors, *Tracking environmental change using lake sediments. Volume 1: basin analysis, coring, and chronological techniques.* Kluwer Academic Publishers, 171–203.

Appleby, P.G. and **Oldfield, F.** 1978: The calculation of ^{210}Pb dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment. *Catena* 5, 1–8.

Bendel, M. 2001: Vegetations- und Feuergeschichte der letzten 200 Jahre im Pfynwald (Wallis, Schweiz). Palynologische Untersuchungen des Pfafforetsees. Unpublished diploma thesis, University of Bern.

Bennett, K.D. 1996: Determination of the number of zones in a biostratigraphical sequence. *New Phytologist* 132, 155–70.

Bieri-Steck, K. 1990: Spät- und postglaziale Vegetationsgeschichte des Lac du Mont d'Orge im Wallis. Unpublished diploma thesis, University of Bern.

Bille, R.-P. and **Werner, P.** 1986: *Natur entdecken im Pfynwald.* Schweizerische Verein Für Handarbeit und Schulreform, 144 pp.

Birks, H.J.B. and **Gordon, A.D.** 1985: *Numerical methods in Quarternary pollen analysis.* Academic Press, 317 pp.

Boratynski, A. 1991. Rage of natural distribution. In Giertych, M. and Mátyás, C., editors, *Genetics of Scots pine.* Elsevier, 19–30.

Burnand, J. 1970: Vergleich von Waldgesellschaften im Gebiet der Bergsturzhügel von Siders. Unpublished diploma thesis, Swiss Federal Institute of Technology ETH Zürich.

—— 1976: *Quercus pubescens*-Wälder und ihre ökologischen Grenzen im Wallis (Zentralalpen). *Veröffentlichung des Geobotanischen Institutes ETH,* Heft 59, Rübel.

Burri, M. 1997: Géologie récente de Finges et de ces environs (VS). *Bulletin de la Murithienne* 115, 9–27.

Clark, J.S. 1988: Stratigraphic charcoal analysis on petrographic thin section: application to fire history in northwestern Minnesota. *Quarternary Research* 30, 81–91.

Finsinger, W. and **Tinner, W.** 2005. Minimum count sums for charcoal-concentration estimates in pollen slides: accuracy and potential errors. *The Holocene* 15, 293–97.

Gobet, E., Tinner, W., Hubschmid, P., Jansen, I., Wehrli, M., Ammann, B. and **Wick, L.** 2000: Influence of human impact and bedrock differences on the vegetational history of the Insubrian Southern Alps. *Vegetation History and Archaeobotany* 9, 175–78.

Grimm, E. 1991–1993: *TILIA and TILIA GRAPH*. Illinois State Museum.

Heiri, O., Lotter, A.F. and **Lemcke, G.** 2001: Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology* 25, 101–10.

Kempf, A. 1985: Waldveränderungen als Kulturlandschaftswandel – Walliser Rhonetal: Fallstudien zur Persistenz und Dynamik des Waldes zwischen Brig und Martigny seit 1873. *Basler Beiträge zur Geographie* 31, 1–262.

Kempf, A. and **Scherrer, H.U.** 1982: Forstgeschichtliche Notizen zum Walliser Wald. *Eidgenössische Anstalt für das forstliche Versuchswesen* 243, 1–123.

Kienast, F., Hadorn, S. and **Schütz, M.** 2004: Werden Walliser Föhrenwälder zu Eichenwäldern? Eine pflanzensoziologische Studie mit historischen Aufnahmen. *Informationsblatt Forschungsbereich Landschaft WSL* 59, 1–3.

Landolt, E. 1992: *Unsere Alpenflora*. 6th edition. Schweizer Alpenclub, 318 pp.

Lang, G. 1994: *Quartäre Vegetationsgeschichte Europas. Methoden und Ergebnisse.* Fischer.

Lock, S., Pahlmann, S., Weber, P. and **Rigling, A.** 2003: Nach Stalden kehren die Flaumeichen zurück. *Wald und Holz* 83, 29–33.

Lotter, A.F. 1999: Late-glacial and Holocene vegetation history and dynamics as evidenced by pollen and plant macrofossil analyses in annually laminated sediments from Soppensee (Central Switzerland). *Vegetation History and Archaeobotany* 8, 165–84.

MacDonald, G.M., Larsen, C.P.S., Szeicz, J.M. and **Moser, K.A.** 1991: The reconstruction of boreal forest fire history from lake sediments: a comparison of charcoal, pollen, sedimentological, and geochemical indices. *Quaternary Science Reviews* 10, 53–71.

Meyer, K.A. 1950: Frühere Verbreitung der Holzarten und einstige Waldgrenze im Kanton Wallis, I. Unterwallis. Linkes Rhoneufer. *Mitteilungen der Schweizerischen Anstalt für das forstliche Versuchswesen* 26, 683–750.

Moore, P.D., Webb, J.A. and **Collinson, M.E.** 1991: *Pollen analysis.* 2nd edition, Blackwell.

Murith, L.J. 1810: *Le guide du botaniste qui voyage dans le Valais.* Henri Vincent.

Rebetez, M. and **Dobbertin, M.** 2004: Climate change may already threaten Scots pine stands in the Swiss Alps. *Theoretical and Applied Climatology* 79, 1–9.

Reille, M. 1992: *Pollen et śpores d'Europe et d'Afrique du Nord. Editions du Laboratoire de botanique historique et palynologie.* Laboratoire de Botanique Historique et Palynologie.

Rigling, A. and **Cherubini, P.** 1999: Wieso sterben die Waldföhren im "Telwald" bei Visp? Eine Zusammenfassung bisheriger Studien und eine dendroökologische Untersuchung. *Schweizerische Zeitschrift für Forstwesen* 150, 113–31.

Sannikov, S.N. 1994: Evolutionary pyroecology and pyrogeography of the natural regeneration of scots pine. *Proceedings 2nd international conference on forest fire research.* Coimbra, Vol. II, 961–68.

Schanz, F., Elber, F., Hürlimann, J. and **Niederberger, C.** 1986: Regionallimnologische Untersuchungen an sechs Kleinseen im Pfynwald (Kanton Wallis). *Bulletin de la Murithienne* 104, 45–61.

Schmid, E. 1936: Die Reliktföhrenwälder der Alpen. *Beiträge zur geobotanischen Landesaufnahme der Schweiz* 21, 1–190.

Schürch, M. and **Vuataz, F.-D.** 2000: Groundwater components in the alluvial aquifer of the alpine Rhone River valley, Bois de Finges area, Wallis Canton, Switzerland. *Hydrogeology Journal* 8, 549–63.

Stein, N. 1978: Die standörtliche Verbreitung und klimaökologische Abgrenzung waldbildender submediterraner (*Quercus pubescens*), subborealer (*Pinus sylvestris*) und mitteleuropäisch-montaner Florenelemente (*Abies alba*) am Beispiel des mittleren Wallis (Zentralalpen). *Geographica Helvetica* 33, 93–112.

Stockmarr, J. 1971: Tablets with spores used in absolute pollen analysis. *Pollen and Spores* 13, 615–21.

Stuber, M. and **Bürgi, M.** 2002: Agrarische Waldnutzungen in der Schweiz 1800–1950. Nadel- und Laubstreue. *Schweizerische Zeitschrift für Forstwesen* 153, 397–410.

Sugita, S. 1994: Pollen representation of vegetation in quaternary sediments – theory and method in patchy vegetation. *Journal of Ecology* 82, 881–97.

Swain, A. 1973: A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments. *Quaternary Research* 3, 383–96.

Tinner, W. and **Hu, F.S.** 2003: Size parameters, size-class distribution and area-number relationship of microscopic charcoal: relevance for fire reconstruction. *The Holocene* 13, 499–505.

Tinner, W., Conedera, M., Ammann, B., Gäggeler, H.W., Gedye, S., Jones, R. and **Sägesser, B.** 1998: Pollen and charcoal in lake sediments compared with historically documented forest fires in southern Switzerland since A.D. 1920. *The Holocene* 8, 31–42.

Tinner, W., Hubschmid, P., Wehrli, M., Ammann, B. and **Conedera, M.** 1999: Long-term forest fire ecology and dynamics in southern Switzerland. *Journal of Ecology* 87, 273–89.

Troels-Smith, J. 1955: Karakterisering of løse jordater. *Danmarks Geologiske Undersegelse*, Series IV, 39–73.

Vale, T.R. 2002: *Fire, native peoples, and the natural landscape.* Island Press.

van der Knaap, W.O. and **Ammann, B.** 1997: Depth–age relationships of 25 well-dated Swiss Holocene pollen sequences archived in the Alpine Palynological Data-Base. *Revue de Paléobiologie* 16, 433–80.

van der Knaap, W.O., van Leeuwen, J.F.N., Fankhauser, A. and **Ammann, B.** 2000: Palynostratigraphy of the last centuries in Switzerland based on 23 lake and mire deposits: chronostratigraphic pollen markers, regional pattern, and local histories. *Review of Palaeobotany and Palynology* 108, 85–142.

Walter, H. 1974: *Die Vegetation Osteuropas, Nord- und Zentralasiens.* Gustav Fischer.

Welten, M. 1982: *Vegetationsgeschichtliche Untersuchungen in den westlichen Schweizer Alpen: Bern – Wallis.* Denkschriften der Schweizerischen Naturforschenden Gesellschaft, 95, 1–104.

Werner, P. 1985: La végétation des Finges et de son Rhône sauvage. *Bulletin de la Murithienne* 103, 39–84.

Whitlock, C. and **Larsen, C.** 2001: Charcoal as a fire proxy. In Smol, J.P., Birks, H.J.B. and Last, W.M., editors, *Tracking environmental change using lake sediments. Terrestrial algal, and silicious indicators.* Kluwer, 75–97.

Willis, K.J., Bennet, K.D. and **Birks, H.J.B.** 1998: The late Quaternary dynamics of pines in Europe. In Richardson, D.M., editor, *Ecology and biogeography of Pinus.* Cambridge University Press, 107–21.