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Neolithic to Bronze Age (4850–3450 cal. BP) fire management of the Alpine Lower Engadine landscape (Switzerland) to establish pastures and cereal fields

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Abstract

Agro-pastoral activities in the past act as environmental legacy and have shaped the current cultural landscape in the European Alps. This study reports about prehistoric fire incidents and their impact on the flora and vegetation near the village of Ardez in the Lower Engadine Valley (Switzerland) since the Late Neolithic Period. Pollen, charcoal particles and non-pollen palynomorphs preserved in the Saglias and Cutüra peat bog stratigraphies were quantified and the results compared with the regional archaeological evidence. Anthropogenic deforestation using fire started around 4850 cal. BP at Saglias and aimed at establishing first cultivated crop fields (e.g. cereals) and small pastoral areas as implied by the positive correlation coefficients between charcoal particles and cultural and pastoral pollen indicators, as well as spores of coprophilous fungi. Pressure on the natural environment by humans and livestock continued until 3650 cal. BP and was followed by reforestation processes until 3400 cal. BP because of climatic deterioration. Thereafter, a new, continuous cultivation/pastoral phase was recorded for the Middle to Late Bronze Age (3400–2800 cal. BP). After rather minor human impact during the Iron Age and Roman Period, intensive agriculture was recorded for the Medieval Period. The area around Ardez was used for crop cultivation from about 1000 cal. BP until the start of the 'Little Ice Age' (600 cal. BP). Despite a land-use reorganisation, the following gradual decrease in agricultural activities led to the extant mixture of a cultivated, grazed and forested landscape in the Lower Engadine. In addition, this study demonstrates the excellent value of the fungus *Gelasinospora* as a highly local marker of past and today's fire incidents, as well as of the use of micro-charcoals from pollen slides and macro-charcoals (>150 μm) from pollen sample residues for the reconstruction of short- and long-term fire histories.

Keywords

European Alps, Holocene fire ecology, Neolithic to Bronze Age fire management, pollen and non-pollen palynomorphs, prehistoric crop cultivation and pastoral activities, statistical cross-correlations

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Introduction

The present-day landscape of the European Alps is the result of past land-use management (Carcaillet, 1998; Fischer et al., 2008; Maurer et al., 2006; Stern, 1983). Fire has played a major role (Carcaillet et al., 1997; Clark et al., 1989; Colombaroli and Tinner, 2013; Keller et al., 2002) and is regarded as a main trigger for deforestation in the Alps during the Holocene (Tinner et al., 1999). Moreover, slash-and-burn and shifting cultivation seem to have been important prehistoric techniques for the production of cereals since the Neolithic Period (Behre, 1988; Berglund et al., 1991; Birks et al., 1988; Carcaillet et al., 1997; Clark et al., 1989; Rösch et al., 2002). However, it is difficult to assess whether fire events resulted from single lightning events, or if human populations generated them intentionally (Vannière et al., 2008). Fire was used to open the landscape (or to maintain it open) since approximately 7200–5200 cal. BP in the Central Swiss Alps (Tinner et al., 1996; Wick, 1991; Wick and Tinner, 1997), around 5500 cal. BP in the Northern Alpine forelands (Clark et al., 1989; Rey et al., 2013; Schwörer et al., 2015), since 5000 cal. BP in the Southern Swiss Alps (Morales-Molino et al., 2015; Tinner et al., 1999), and from 4250 to 1150 cal. BP on the Swiss Plateau (Tinner et al., 2005). In parallel, slash-and-burn practices were known in the lowlands surrounding the Alps already since 6200 cal. BP

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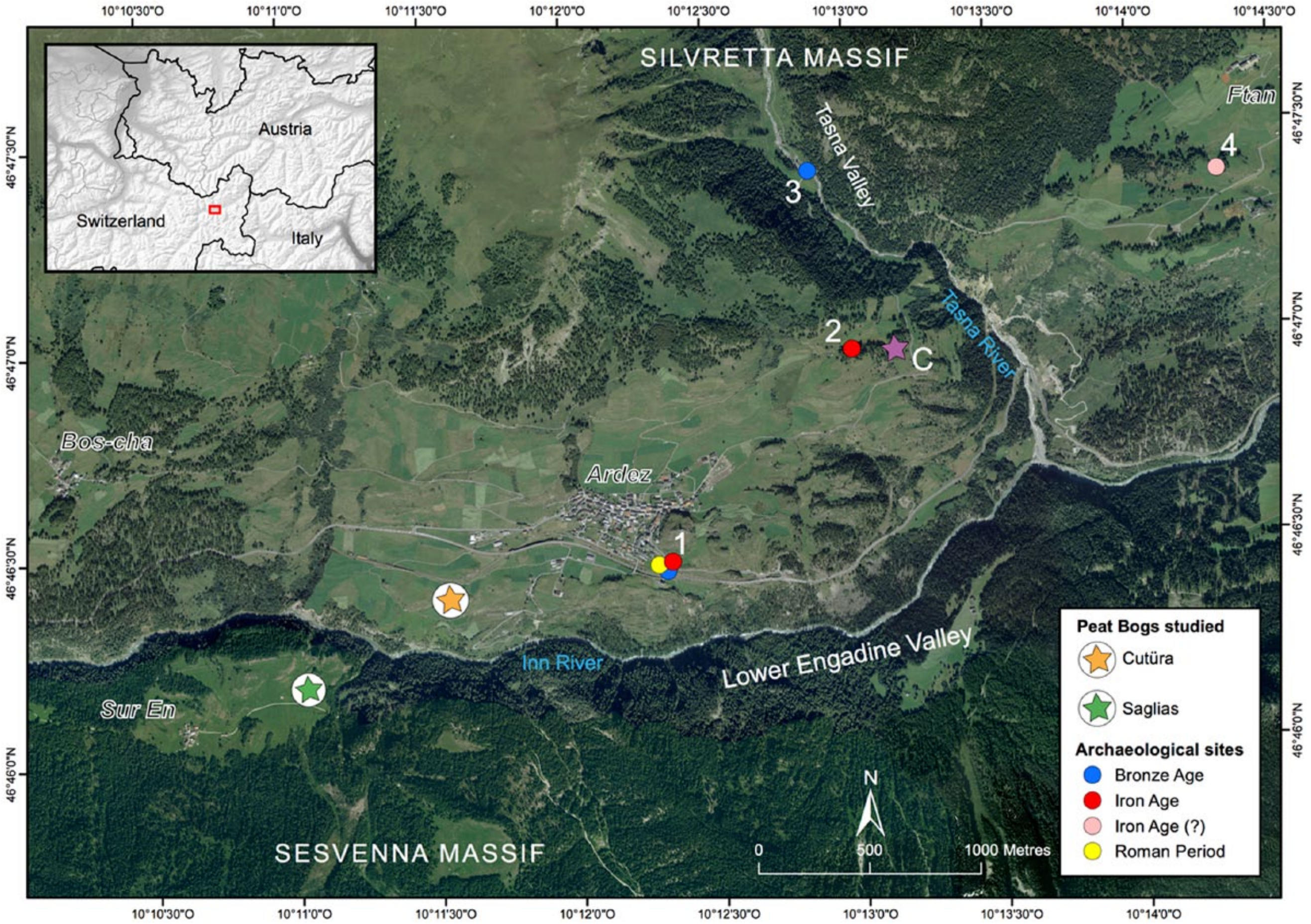

Figure 1. Location of the Saglias and Cutüra peat bogs in the Lower Engadine Valley (Canton of Grisons, Switzerland) with known archaeological sites in the vicinity of the village of Ardez. 1. Suotchastè (Ardez), settlement dating to the Late Bronze Age and Iron Age, few artefacts dating to the Roman Period. 2. Chanoua (Ardez), stray finds dating to the Late Iron Age (Fritzens-Sanzeno Culture). 3. Pra da Punt (Ftan), single find dating to the Bronze Age. 4. Umbrain (Ftan), settlement probably dating to the Iron Age. The locality *C* denominates the site of Chanoua (Zoller et al., 1996).
Orthoimagery © Swisstopo – Bundesamt für Landestopografie; archaeological sites: archive of the Archaeological Service of the Canton of Grisons country borders: http://www.diva-gis.org. Graphic: Walser, April 2015.

(Morales-Molino et al., 2015; Tinner et al., 2005). Smaller fires were mostly intended to control the expansion of sprouting shrubs such as hazel (*Corylus avellana*), which benefited of prior forest clearances. Fire was used as well in the Upper Engadine Valley (Switzerland) during prehistoric times (Gobet et al., 2003). There, larch meadows (*Larix decidua*) were established, as well as pastoral areas, which, in turn, promoted the growth of green alder (*Alnus viridis*; syn. *Alnus alnobetula*) from 3900 cal. BP onwards. Later, the openness of the landscape reached its maximum around 500 cal. BP (AD 1450) in the Upper Engadine Valley.

Here, we present new palaeoecological data retrieved from two peat bogs around the village of Ardez in the Lower Engadine Valley (Switzerland, 1460 m a.s.l.), south of the Silvretta Massif in the central Eastern Alps. The Saglias record documents the evolution of the flora and vegetation since approximately 6000 cal. BP. The micro-charcoal data from this sequence offer the possibility to better define the fire history in the Lower Engadine Valley in the context of the regional establishment of agricultural terraces. The Cutüra record covers the last 1000 years only but offers a consistent reconstruction of the history of cereal cultivation around the village of Ardez during the Medieval Period. These data are particularly interesting in comparison to the archaeological evidence of former human presence and activities (Kothieringer et al., 2015; Reitmaier, 2012). The results are also compared with palaeoecological studies from the nearby Silvretta and Samnaun Massifs (Bauerochse and Katenhusen, 1997; Dietre et al., 2014; Wahlmüller, 2002; Welten, 1982a; Zoller et al., 1996), and the surrounding regions such as the Upper Engadine Valley (Gobet et al., 2003), the Montafon Valley and the Rätikon Massif (Bringemeier et al., 2016; Röpke, 2012; Röpke et al., 2011), the Ötztal Alps (Festi, 2012; Festi et al., 2014; Kofler et al., 2005; Putzer et al., 2016) and the Swiss Alpine forelands (Tinner et al., 2005). All these studies emphasised deforestation and regional human activities, but only few studied the impact of preceding or synchronous prehistoric fire incidents on the former flora and vegetation. The relation of such fires to the establishment of the pastoral and cultural landscape is discussed using classical palynological indicators (Behre, 1981, 1986; Festi, 2012; Oeggl, 1994), as well as spores of coprophilous fungi, which are commonly used to strengthen the interpretation of livestock grazing pressure at local scale (Blackford and Innes, 2006; Carrión et al., 2010; Davis and Shafer, 2006; Ejarque et al., 2011; Miras et al., 2010). The possible impact of changing climatic conditions on the recorded vegetation changes in the past 6000 years is also discussed.

Regional setting

The Lower Engadine Valley (canton of Grisons, Switzerland) follows the Inn River in the Rhaetian Alps until it meets the Austrian border (Figure 1). Pronounced cliffs flanking the Inn River characterise this valley, and today's villages are located on geomorphologically formed terraces at elevations between 1000 and 1500 m a.s.l. The village of Ardez (1460 m a.s.l.) and its vicinity

Figure 2. Photographic overview of the Saglias and Cutüra peat bogs and the coring locations west/south-west of the village of Ardez, Lower Engadine Valley, Switzerland.
Photo: Dietre, July 31, 2012.

harbour archaeological sites from the Bronze Age to the Roman Period (Figure 1). Ardez is listed in the *Swiss Inventory of Cultural Property of National and Regional Significance*. Today, the Ardez terrace is used for cattle grazing and for some cultivated fields (e.g. west of Ardez; Figure 2). Sparse larch trees grow on the lower slopes of the Silvretta Massif (north of Ardez), forming the so-called larch meadows which were used as grazed forests for more than 4000 years (Zoller et al., 1996). Pine forests (Scots pine – *Pinus sylvestris*) grow on steeper slopes and are followed upwards (up to 2100 m a.s.l.) by Arolla pine (*Pinus cembra*), Mountain pine (*Pinus mugo*) and larch, which built up the extant timberline.

The Saglias Bog (a small, 100 × 50 m in dimension, slightly disturbed peatland dominated by *Eriophorum* (cottongrasses) and *Trichophorum* (deergrasses) intercalated with moorland spotted orchids (*Dactylorhiza maculata*)) is located southwest of Ardez (46°46′6.72″N, 10°10′57.22″E, 1420 m a.s.l.), on the southern side of the Inn River (on the northern slopes of the Sesvenna Massif) near the hamlet of Sur-En (Figures 1 and 2). The name *Saglias* probably refers to 'a ditch besides a cultivated field' in the Rhaeto-Romanic language, which describes very well the location of this mire. The small, 50 × 30 m in dimension, heavily grazed Cutüra Bog is located west of Ardez (46°46′19.39″N, 10°11′23.88″E, 1400 m a.s.l.) on a terrace above the Inn River, at the base of the southern slopes of the Silvretta Massif (Figures 1 and 2). The name *Cutüra* relies thereby on the cultivation of food crops in the Rhaeto-Romanic language, which also describes the historical and today's importance of this wetland area formerly surrounded by cereal fields and livestock grazing areas. The mean annual temperature of our research area is 5.5°C as recorded by the weather station of the nearby town of Scuol (1304 m a.s.l.; MeteoSwiss, 2013). It ranges from −8.3°C in January to 22.8°C in July, the mean July temperature being 15.2°C. The mean annual precipitation is 706 mm distributed over 93 days of rain/snow on average, and the annual average relative humidity is 70% (MeteoSwiss, 2013).

Materials and methods

Peat coring

In 2012, peat cores were taken from both the Saglias and the Cutüra Bogs (Figure 2) with a Russian-type peat corer, featuring a 5-cm-wide and 50-cm-long coring chamber. The Saglias core (ASG-2012) is 287 cm long, including various clayey-sandy phases (Figure 3). The coring stopped at −297 cm depth because of the bedrock (the section 297–287 cm was not sampled). The Cutüra core (ACW-2012) is 140 cm long, with a sandy base (140–130 cm). The end of the corer stopped at −150 cm on impenetrable coarse sand (the section 150–140 cm was not sampled). The sedimentary profiles of both cores were described during field work and by macroscopic analyses (Figure 3).

Palynological, carpological and charcoal identification and quantification

A total of 66 sediment samples (of 1 cm^3 each) were extracted for palynological analyses from the 287-cm-long Saglias record, as well as 18 peat samples from the 140-cm-long Cutüra record. The mean sampling resolution was 4 cm for the Saglias stratigraphy (with a resolution of 2 cm between 230 and 161 cm depth) and

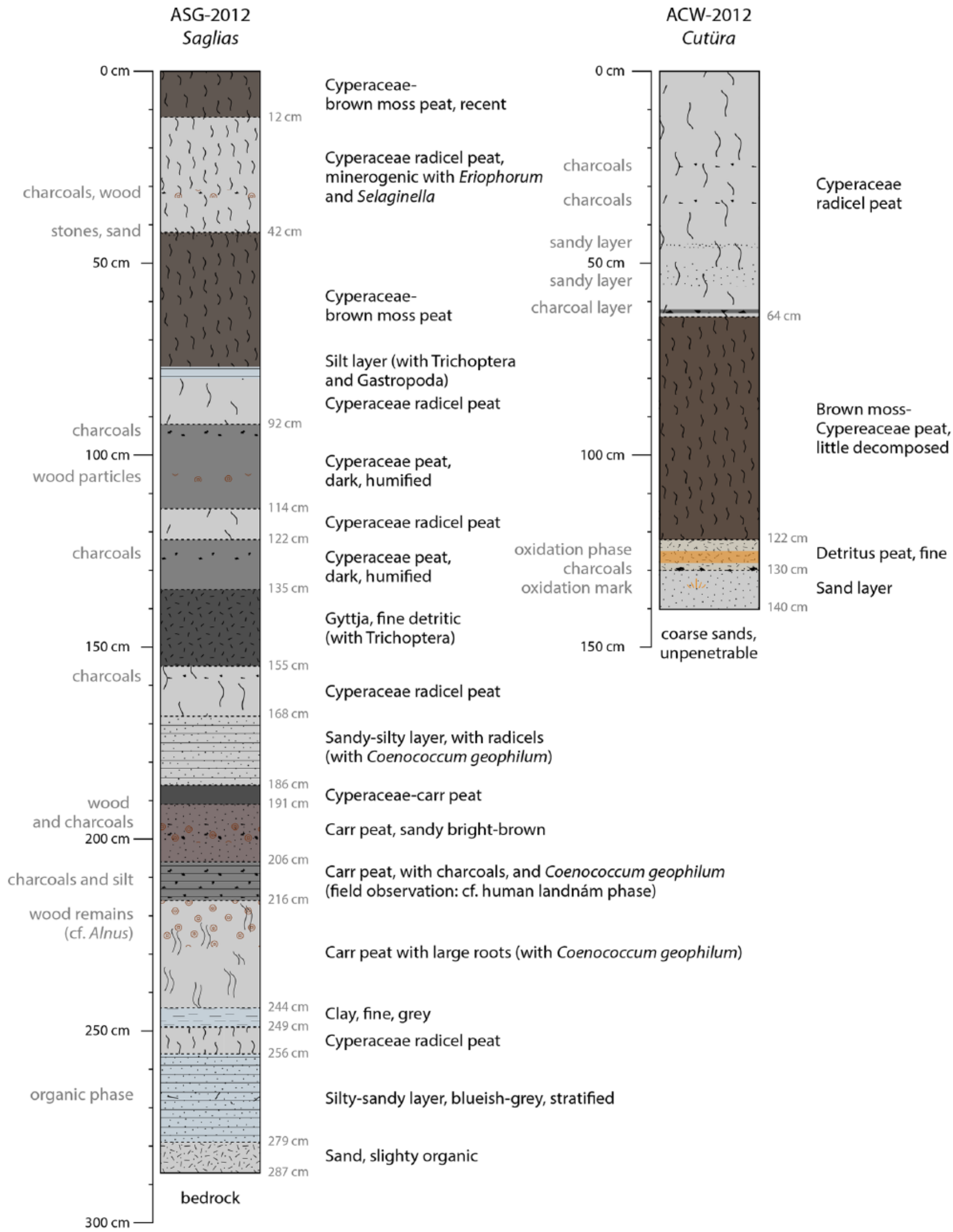

Figure 3. Schematic sketch of the Saglias (ASG-2012 core, 1420 m a.s.l.; left) and Cutüra stratigraphies (ACW-2012 core, 1400 m a.s.l.; right) in the Lower Engadine Valley (Switzerland) as described during field work and confirmed by observations during macro-fossil evaluation. Graphic: Dietre, July 2016.

8 cm for the Cutüra stratigraphy. A defined number of club-moss spores (*Lycopodium clavatum*) was added to each sediment sample to allow the calculation of concentrations (number cm^{-3}) and influx (number cm^{-2} yr^{-1}) values (Maher, 1981; Stockmarr, 1971). After dilution in distilled water, sediment samples were washed through a 150-µm mesh-sieve, and the fractions 7–150 µm were chemically treated using a chlorification step and a 1-min acetolysis at 95°C following standard procedures (Seiwald, 1980). Silty samples were additionally treated with hydrofluoric acid (HF; 10%, 95°C) to remove silt. The obtained residue of each sample was thereafter mounted in glycerine and stained with fuchsine for palynological analysis.

The identification of micro-fossils was done using an Olympus BX50 light microscope with phase-contrast equipment at 400× magnification (and at 1000× magnification for specific micro-fossils). A minimum of 500 arboreal pollen were counted per sample using the software *PolyCounter* (Nakagawa, 2012, version 3.1.4), resulting in total counts for pollen, spores, micro-charcoal particles and non-pollen palynomorphs (NPPs) of generally more than 1200 micro-fossils (1800 on average). Pollen and spores were identified using the modern pollen collection of the Institute of Botany of the University of Innsbruck and using reference literature (Beug, 2004; Fægri et al., 1993; Moe, 1974; Moore et al., 1991; Punt and Blackmore, 1991; Punt and Clarke, 1976–1984; Punt et al., 1988, 1996, 2003; Reille, 1992). Following the methods described by Dietre et al. (2014), Cerealia-type pollen refers to Poaceae (grasses) pollen featuring the characteristics of cereal pollen larger than 40 µm (see Beug, 2004; Colombaroli

Table 1. Details of AMS radiocarbon dates obtained on terrestrial plant macro-fossils from the peat stratigraphies of Saglias (ASG-2012) and Cutüra (ACW-2012) near Ardez, Switzerland. Radiocarbon-AMS analyses were conducted at the ETH Zürich, Switzerland. Calibrated ages are calculated at 95% confidence level (2σ) using the software *clam* (Blaauw, 2010, version 2.2) and the *INTCAL13* calibration curve of Reimer et al. (2013), within the statistical software *R* (R Core Team, 2014, version 3.1.1). One radiocarbon date (in italics) was excluded from the age–depth model.

Lab. no.	Core	Depth (cm)	Material	Dry weight (mg)	Age ^{14}C BP (uncal.)	$\partial^{13}C$ (‰)	Age cal. BP (2σ)
ETH-52240	ASG-2012	93.5–94.5	11 SL + 15 MCP	8	1707 ± 28	−25.1 ± 1.1	1620 ± 74
ETH-52239	ASG-2012	157.5–158.5	9 SL + 18 MCP	3	3164 ± 32	−27.1 ± 1.1	3396 ± 54
ETH-52238	ASG-2012	222.5–223.5	18 SL	10	4208 ± 31	−29.1 ± 1.1	4738 ± 110
ETH-51535	*ASG-2012*	*252.5–253.5*	*3 SL*	*3*	*680 ± 25*	*−25.3 ± 1.1*	*620 ± 56*
ETH-51533	ACW-2012	67.5–68.5	3 SL + 1 Rosaceae spine	3	579 ± 25	−26.5 ± 1.1	590 ± 54
ETH-51534	ACW-2012	118.5–119.5	9 SL	1	1059 ± 26	−26.8 ± 1.1	990 ± 62

SL: substantia lignosa; MCP: macro-charcoal particles (>500 µm).

et al., 2013). The pollen taxon *Pinus* gathers *Pinus sylvestris, Pinus mugo* and undefined pine pollen grains, whereas pollen of *Alnus glutinosa*–type (black alder) were distinguished from pollen of *Alnus viridis*. Cultivated plant taxa (cereals, i.e. Cerealia-type and *Secale cereale* – rye) as well as accompanying taxa (e.g. *Centaurea cyanus* – cornflower, Urticaceae – nettle) were considered as cultural indicators. The definition of pastoral indicators follows Behre (1981, 1986), Oeggl (1994) and Festi (2012); however, family-level taxa (other than Urticaceae) were excluded from the list of cultural and pastoral indicators. NPPs were identified using reference studies (Cugny et al., 2010; Dietre et al., 2012; Gelorini et al., 2011; Van Geel and Andersen, 1988; Van Geel and Aptroot, 2006; Van Geel et al., 2003). The NPP nomenclature follows the guidelines described by Miola (2012) with the laboratory abbreviations IIB (Innsbruck Institute of Botany, Austria) and HdV (Hugo-de-Vries-Laboratory, University of Amsterdam, The Netherlands). On the same palynological slides, sharp, opaque, black elements were identified as micro-charcoal particles (Clark, 1988b; Swain, 1973). Additionally, macro-charcoal particles (>150 µm) as well as the plant and animal macro-fossils were quantified from pollen sample residues (1 cm³).

Data presentation

The diagrams of pollen, cryptogam spores, NPPs as well as micro-/macro-charcoal particles were drawn using the software *Tilia* (Grimm, 2011, version 1.7.16). All biotic taxa are represented as percentage values relatively to the sum of pollen from terrestrial plants (excluding Cyperaceae as well as mire plants). Micro-charcoals are represented as influx values (particles $cm^{-2} yr^{-1}$, i.e. accumulation rate) and macro-charcoals as concentrations (particles cm^{-3}). The zonation in local pollen assemblage zones (LPAZs) was established according to a stratigraphically constrained incremental sum of squares clustering method (CONISS; Grimm, 1987) based on the square-root transformation of the pollen percentage values of taxa included in the pollen sum (upland trees, shrubs and herbs). The number of relevant zones to be considered was ascertained with the help of the broken stick model (Bennett, 1996; MacArthur, 1957) with the same clustering methods and data using the package *rioja* (Juggins, 2012, version 0.8-7) within the software *R* (R Core Team, 2014, version 3.1.1). The palynological data from the Saglias and Cutüra records will be stored in the European Pollen Database (EPD) in due times.

Chronology

Altogether, six radiocarbon dates were obtained at the Laboratory of Ion Beam Physics of the ETH Zürich (Switzerland) on the Saglias and Cutüra peat stratigraphies using terrestrial macro-fossils (Table 1). The ^{14}C ages were transformed into years cal. BP (i.e. calibrated before AD 1950) with a 95% confidence interval (2σ) based on the calibration curve *INTCAL13* by Reimer et al. (2013) and using the software *clam* (Blaauw, 2010, version 2.2), within the software *R* (R Core Team, 2014, version 3.1.1). For each stratigraphy, the age–depth model (Figure 4) was obtained using the same software, by linear interpolation of the calibrated ages and the surface date (AD 2012 coring), and drawn using the package *ggplot2* (Wickham, 2009, version 1.0.0). One

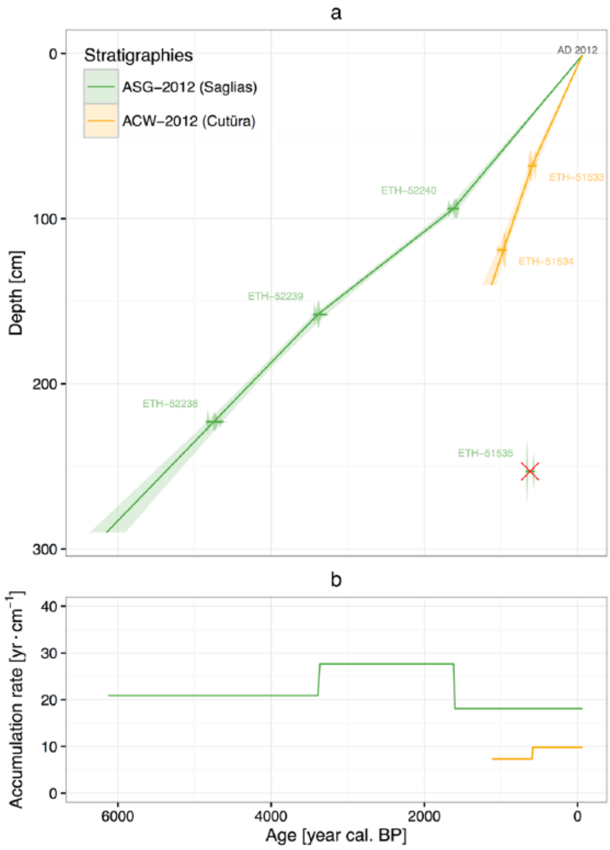

Figure 4. (a) Age–depth model and (b) accumulation rate computed by linear interpolation of AMS radiocarbon dates performed on the Saglias (ASG-2012, 1420 m a.s.l.) and Cutüra (ACW-2012, 1400 m a.s.l.) peat bog stratigraphies (Lower Engadine Valley, Switzerland). The surface value AD 2012 refers to the date of sediment coring. Calibration was performed using the software *clam* (Blaauw, 2010, version 2.2), the *INTCAL13* calibration curve by Reimer et al. (2013) within the software *R* (R Core Team, 2014, version 3.1.1) and the package *ggplot2* for the illustration (Wickham, 2009, version 1.0.0). One excluded radiocarbon date is shown as a red cross. The light colour envelopes show the 95% confidence level. Graphic: Dietre, April 2016.

radiocarbon date (too young) was excluded from the corresponding age–depth model.

Cross-correlations between micro-charcoals and other micro-fossils

Micro-charcoal particles (<150 µm) are known to represent local to regional fire impacts (Clark et al., 1998; Patterson et al., 1987). Charcoal particles from pollen slides (here called micro-charcoal, as opposed to macro-charcoal) were considered suitable to detect individual fire events (Clark, 1988a; Tinner et al., 1998). Cross-correlations were therefore computed for the micro-charcoal record against all the micro-fossil taxa and group sums from the Saglias record to interpret the impact of fire on the former vegetation, using the software *R* (R Core Team, 2014, version 3.1.1). The according results were then illustrated using the package *ggplot2* (Wickham, 2009, version 1.0.0). Such analyses assumed the data to feature two important properties: (1) the absence of a linear gradient among each variable's values and (2) the regular resolution span between samples (Green, 1981). In our study, micro-charcoal influx values and pollen and NPP percentages (relatively to the pollen sum) were used from selected samples distributed at 2 cm resolution along the dated peat core from 223 to 161 cm depth (i.e. 4750–3450 cal. BP). According to the age–depth model of the Saglias stratigraphy, the time resolution of the 32 selected samples shows a mean of 41.74 years (i.e. between sampling points) within the mentioned target period of 1300 years. This represents a period of 600 years before and 700 years after the Neolithic-to-Bronze-Age transition in Central Europe around 4150 cal. BP (i.e. 2200 BC). This period was chosen to investigate the relationship between micro-charcoal particles and taxa showing particular behaviour, for example, shrubs/pioneer species, coprophilous fungi as well as the fire-promoted fungus *Gelasinospora* (Sordariales, Ascomycota; Van Geel, 1978).

The calculation of cross-correlations implies shifting the data series incrementally, from a lower to an upper limit. The temporal shift between two levels in the series (i.e. the samples) is provided by the age–depth model and is called a lag. The duration of one lag is the mean of the time intervals between adjacent samples. When data series are not shifted, the cross-correlation actually corresponds to the direct correlation coefficient (CC) between the two variables. However, when data series are shifted by n lag(s), the calculated CC then informs on the relationships between the two variables given an interval equal to n times the average temporal (rounded) interval between samples. Here, the calculations were restricted to the direct correlation (lag 0) and the first eight positive lags, so as to assess the response of biotic taxa to fire incidents for a maximum time span of 334 years. For simplification, a first selection of cross-correlograms was performed using an automatic extraction of taxa featuring at least one significant coefficient (positively or negatively, with 95% confidence interval) among the lags 0–8. Additionally, erratic cross-correlograms typical for taxa with low counts were considered as mathematical artefacts and excluded. For all these calculations, the use of influx (micro-charcoal) and percentages (other taxa) data was intentionally chosen after running the same analysis on detrended influx and detrended percentage data (using linear regression). This control step provided highly similar results and suggested the absence (or non-significance, at least) of trends among the variable values (i.e. taxa).

Results

Palynological results from the Saglias Bog

According to the radiocarbon dates and the corresponding age–depth model (Table 1; Figure 4) the Saglias Bog started to grow and accumulate peat shortly before 6000 cal. BP. The accumulation rate varied between 17.9 and 27.7 yr cm^{-1}. The first layers of the Saglias stratigraphy (287–256 cm depth) were mostly composed of sand and silt (Figure 3), with a small organic content. From 256 cm depth (about 5450 cal. BP), the sediment was mostly built up by sedge peat (Cyperaceae) as well as carr and brown-moss peat. A layer of fine clay was found at 249–244 cm depth (5300–5200 cal. BP), a sand and silt layer at 186–168 cm depth (4000–3600 cal. BP) and a silt layer at 80–77 cm depth (1350–1300 cal. BP). Several wood layers (probably from *Alnus*) were found at 229–216 cm depth (4850–4600 cal. BP) and 106 cm (1950 cal. BP). A combination of wood and charcoal particles was detected at 201–198 cm depth (4300–4250 cal. BP) and 32 cm depth (500 cal. BP; AD 1450). In addition, a charcoal layer was recorded at 126 cm (2500 cal. BP). Most notably is a layer of carr peat between 216 and 206 cm (4600–4400 cal. BP) containing macro-charcoals and silt, which was hypothesised already during field work to originate from a first human *landnám* phase (which turned out to be correct after the detailed palaeoecological analyses, see below). In total, the palynological content of 66 samples from the Saglias stratigraphy was analysed. The four LPAZs and sub-zones can be described as follows.

LPAZ-S1 (283–198 cm, 6150–4225 cal. BP). The first zone is characterised by a high amount of arboreal pollen (Figure 5). The main tree taxa were *Picea abies* (spruce) together with *Pinus* and *Larix decidua*, the latter reaching high percentage values, such as around 5000 cal. BP (33.7%). Before this larch peak, *Tilia* (lime), *Corylus avellana* and *Ulmus* (elm) exhibited consistently high values (2–14%). During the second half of the LPAZ-S1, these taxa were replaced by alder species (*Alnus glutinosa*–type and *Alnus viridis*), which reached up to 10%. In parallel, the amount of coniferous tree pollen decreased, while *Fagus sylvatica* (beech), *Betula* (birch) and *Juniperus*-type (juniper) appeared with up to 0.9%, 1.6% and 2.7% (Figure 5). During the same period, Poaceae and Cichorioideae (composite family) reached higher values (up to 9.2% and 10.3%, respectively) together with *Senecio*-type (groundsel), *Artemisia* (mugwort) and *Campanula*/*Phyteuma*-type (campanula/rampion). This second part of LPAZ-S1 also revealed high amounts of micro-charcoals (with 811 and 1113 particles cm^{-2} yr^{-1} at 4700 and 4450 cal. BP, respectively) and high amounts of macro-charcoals (up to 51 particles cm^{-3}) as well as *Coenococcum geophilum* fruit bodies. Constantly high values of *Selaginella selaginoides* (club spikemoss), *Lycopodium annotinum* (club-moss) and *Equisetum* (horsetail) were present during the final phase of this zone (Figure 6). While the first part of LPAZ-S1 contained very few NPPs, the second part starting around 5000 cal. BP showed high amounts of mire taxa such as from Neorhabdocoela worms (*Microdalyellia, Gyratrix*), micro-algae (*Zygnema*, Zygnemataceae), the soil fungus *Glomus* and an unknown micro-fossil (IIB-1407). During the final phase of this zone, high values of spores of coprophilous fungi (such as from Sordariaceae) were predominant, as well as from the fungus *Gelasinospora* (up to 2.4% compared with the terrestrial pollen sum) and an abundant unknown micro-fossil (IIB-1205).

LPAZ-S2 (198–168 cm, 4225–3600 cal. BP). The first centuries of this zone (LPAZ-S2a, 4225–3900 cal. BP) confirmed the trend revealed at the end of LPAZ-S1. The amounts of coniferous trees strongly decreased (down to 35%), while micro-charcoal particles showed their maximum values (1490 particles cm^{-2} yr^{-1} at 3950 cal. BP), and *Alnus viridis* increased up to 13.9% (Figure 5). Macro-charcoals were also very abundant during this zone and reached up to 93 particles cm^{-3} at 4200 cal. BP. *Ulmus, Tilia* and *Juniperus*-type were heavily reduced compared with LPAZ-S1, whereas *Betula, Fagus sylvatica* and Ericaceae (heather family) showed slight increases. After 4150 cal. BP, that is, the start of the Bronze Age, cereals (Cerealia-type), Urticaceae, *Polygonum* *aviculare*–type (knotweed), Apiaceae (umbellifers), Caryophyllaceae (pink family), Chenopodiaceae (chenopods), *Epilobium* (fireweed, data not shown), *Pteridium aquilinum* (bracken) and ferns in general (monolete spores) all increased to higher quantities (Figures 5 and 6). Coprophilous fungi (*Cercophora, Sporormiella, Podospora*/*Zopfiella*-type, *Sordaria*-type and other Sordariaceae) also peaked, as well as the fungus *Gelasinospora*. In addition, some seeds of *Sambucus racemosa* (red elderberry) and *Rubus idaeus* (raspberry), as well as fruit bodies of *Coenococcum geophilum* and Trichoptera remains were found as macro-fossils.

During the sub-zone LPAZ-S2b (3900–3600 cal. BP), *Alnus viridis, Alnus glutinosa*–type, *Corylus avellana, Senecio*-type, Cichorioideae, *Calluna vulgaris* (common heather) as well as all other Ericaceae reached their highest values recorded throughout the entire stratigraphy (Figure 5). A massive, temporary decline in micro-charcoal (down to 166 particles $cm^{-2} yr^{-1}$) was paralleled by the near-disappearance of *Larix decidua*, Poaceae, *Equisetum, Lycopodium annotinum* as well as by the absence of nearly all NPPs locally present before (Figure 6).

LPAZ-S3 (168–90 cm, 3600–1550 cal. BP). After 3600 cal. BP, a massive reforestation took place, and the amounts of coniferous trees increased to 80–90%, mainly because of increasing *Picea abies, Pinus, Larix decidua* and *Abies alba* (fir) values (Figure 5). During LPAZ-S3a, *Alnus glutinosa*–type, *Alnus viridis*, Cichorioideae and Poaceae decreased to values below 10%. However, several cultural and pastoral indicators were still present in significant amounts (Cerealia-type, *Centaurea jacea*–type (brown knapweed), *Achillea*-type, *Artemisia, Cirsium* (thistle), *Plantago* (plantain), *Polygonum aviculare*–type) during this phase. From the macro-fossil side, some seeds of *Tilia, Rubus idaeus, R. fruticosus* (blackberry) and Trichoptera remains were found. In addition, high amounts of wetland taxa such as *Parnassia palustris* (bog-star) and *Microdalyellia*, as well as erosion indicators such as *Glomus* were present (Figure 6). The next subzone LPAZ-S3b (starting 2850 cal. BP) shows a similar plant and NPP composition as in LPAZ-S3a, but was first characterised by a massive rise of *Larix decidua* (2700 cal. BP), followed by a major peak of micro- (1085 particles $cm^{-2} yr^{-1}$) and macro-charcoals (700 particles cm^{-3}) around 2500 cal. BP (Figure 5). This peak was subsequently followed by *Pinus* values above 30% (2300–1700 cal. BP). Cultural and pastoral indicators and spores of coprophilous fungi were less present compared with LPAZ-S3a, except for *Artemisia* and *Senecio*-type (Figure 6). However, mire and wetland taxa remained present between 2850 and 1550 cal. BP (*Parnassia palustris*, ferns, Zygnemataceae, *Centropyxis, Microdalyellia*).

LPAZ-S4 (90–14 cm, 1550–190 cal. BP). The youngest pollen assemblage zone of the Saglias record (LPAZ-S4) encompasses 1360 years. It is generally characterised by lower amounts or arboreal pollen, which were balanced by rising values of taxa from cultural indicators such as pollen from cereals (Cerealia-type, up to 4.6%), Apiaceae (up to 6.9%), Cichorioideae (20.9–27.7%) and Poaceae (10.1–30.2%; Figure 5). *Castanea sativa* (chestnut) pollen is present throughout this zone together with some *Juglans regia* (walnut) pollen, probably as a result of the cultivation of these fruit trees in nearby regions south of the Engadine region (mid-distance transport). However, between 1400 and 1200 cal. BP (AD 550–750), the pollen values of coniferous trees, deciduous trees and shrubs reached for a short time similar values as at the end of LPAZ-S3 before dramatically declining again. Thereafter, the arboreal species slowly re-established in the area, parallel to the onset of the cultivation of rye (*Secale cereale*) around 1100 cal. BP. This corresponds to the time of the foundation of Ardez according to written sources (called Ardezis ca. AD 840 (1110 cal. BP); Grimm, 2009). Abundant pollen of Fabaceae (legume family), Rubiaceae (bedstraw family), Apiaceae, Cichorioideae and Poaceae throughout LPAZ-S4 point to pastoral environments during the Medieval Period, but are possibly also the result of crop plant cultivation (Apiaceae, Fabaceae) around the village of Ardez. Micro-charcoal particles were found in important proportions (615–866 particles $cm^{-2} yr^{-1}$) and spores of coprophilous fungi (all types), *Gaeumannomyces, Glomus, Valsaria variospora*–type and the unknown types HdV-551 (fungi) and IIB-1404 reached their maximal values (1000–600 cal. BP; AD 950–1350), but rapidly decreased thereafter (Figure 6). At the end of LPAZ-S4 (400–200 cal. BP; AD 1550–1750), spores of coprophilous fungi, *Glomus, Gaeumannomyces* as well as microfossil remains of *Centropyxis, Arcella* and Neorhabdocoela were prominent again (Figure 6). Finally, the zone LPAZ-S4 revealed macro-fossils from wetland animals such as Trichoptera and Gastropoda remains, as well as some seeds of *Rubus idaeus* and one cereal spiklet (600 cal. BP).

Palynological results from the Cutüra Bog

According to the radiocarbon dates and the corresponding age–depth model (Table 1; Figure 4), the Cutüra Bog started to grow and accumulate peat around 1000 cal. BP, and the overall pollen deposition matches well the youngest pollen zone at Saglias Bog (i.e. LPAZ-S4). The accumulation rate of the Cutüra record varied from 7.4 to 10.0 $yr\,cm^{-1}$. The bottom layers of the core were mostly sandy, with oxidation marks and some organic content at 130 cm (Figure 3). From 122 to 64 cm depth (1000-550 cal. BP; AD 950–1400), the sediment was composed of brown-moss and Cyperaceae peat, and from 64 cm upwards of Cyperaceae radicel peat. A massive charcoal layer (250 particles cm^{-3}) was recorded at 130 cm (1050 cal. BP; AD 900), and several other charcoal layers at 63, 34 and 25 cm depth (550, 250 and 170 cal. BP; AD 1400, 1700 and 1780). Finally, sandy layers were found at 56–50 and 45 cm depth (about 475–420 cal. BP/ AD 1475–1530 and 370 cal. BP/ 1580, respectively). The palynological contents of 18 samples from the Cutüra peat were analysed, and the two LPAZs can be described as follows.

LPAZ-C1 (124–48 cm, 1130–390 cal. BP). Judging from the presence of several wetland taxa (e.g. *Parnassia palustris, Selaginella selaginoides*, Zygnemataceae), the start of the local peat accumulation happened under mire conditions. The maximum values of up to 92% of all tree and shrub taxa were registered at the very beginning of this zone, pointing to a local, closed-canopy forest around 1000 cal. BP (AD 950; Figure 5). A high concentration of macro-charcoals (250 particles cm^{-3}) was found at the base of the stratigraphy dated to 1050 cal. BP (AD 900). During the following five centuries, the total of arboreal pollen steadily decreased to 37.4%, while rising and high amounts of micro-charcoal particles were found (up to 2179 particles $cm^{-2} yr^{-1}$). In parallel, the amounts of cultural and pastoral plant indicators increased sharply, mainly related to the presence of higher pollen values of Cerealia-type, *Artemisia*, Poaceae and Cichorioideae. Synchronously, spores of coprophilous fungi also appeared together with the rising values of *Glomus, Clasterosporium* and *Valsaria variospora*–type (Figure 6). In parallel to the important increase in Poaceae (up to 36%) around 750 cal. BP (AD 1200), a ca. 350-year-long-phase of *Secale cereale* (up to 3%) and other cereals occurred (up to 9.3%; Figure 5). The optimum of this cultivation phase was radiocarbon dated to 590 cal. BP (i.e. AD 1360; Table 1).

LPAZ-C2 (48–8 cm, since 390 cal. BP). During LPAZ-C2, the total of arboreal pollen remained below 40% and Poaceae values fluctuated around 10–29%, indicating a generally open cultural

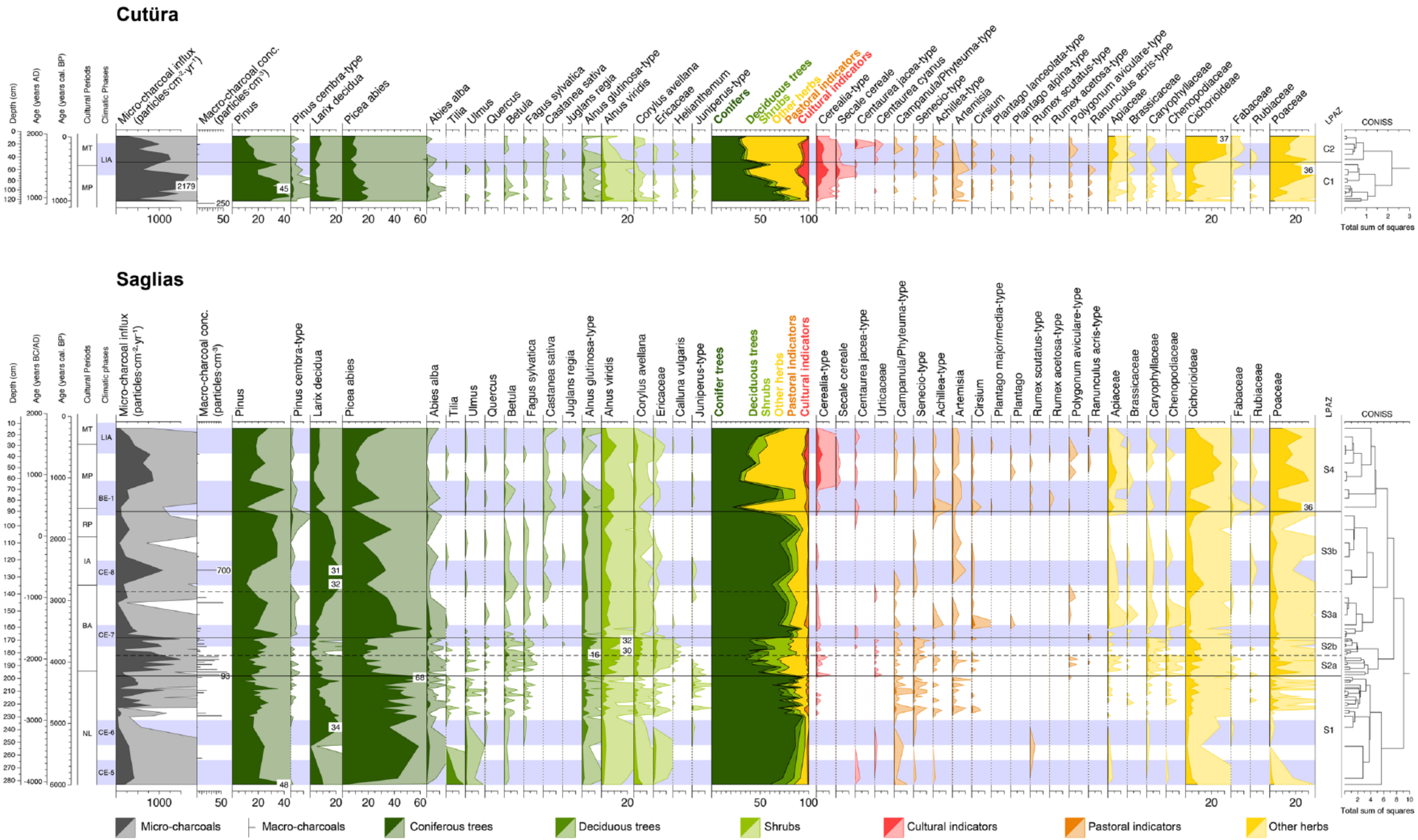

Figure 5. Combined palynological diagram showing selected plant taxa as well as micro- and macro-charcoal particles from the Saglias Bog (bottom) and Cutüra Bog (top) near Ardez, Switzerland, drawn using *Tilia* software (Grimm, 2011, version 1.7.16). Micro-charcoals are expressed as influx values (particles $cm^{-2}yr^{-1}$), macro-charcoals (>150 μm) as concentration (particles cm^{-3}), and all other taxa as percentages relatively to the pollen sum, calculated by including all upland (terrestrial) plants (excluding Cyperaceae). Unless otherwise noted, main tick marks represent 10% relatively to the pollen sum. Light colour curves result from a 10-fold exaggeration of the original curves. The main diagram summarises the different plant taxa groups included in the 100% pollen sum. Blue bands represent cold/wet phases (Bond et al., 2001; Haas et al., 1998) with the abbreviations and enumerations of the cold phases: CE: Central European; BE: Bond-Event; LIA: 'Little Ice Age'. Cultural periods stand for NL: Neolithic; BA: Bronze Age; IA: Iron Age; RP: Roman Period; MP: Medieval Period; MT: Modern Times. With some few exceptions, the top and bottom panels share the same taxa.
Graphic: Dietre, April 2016.

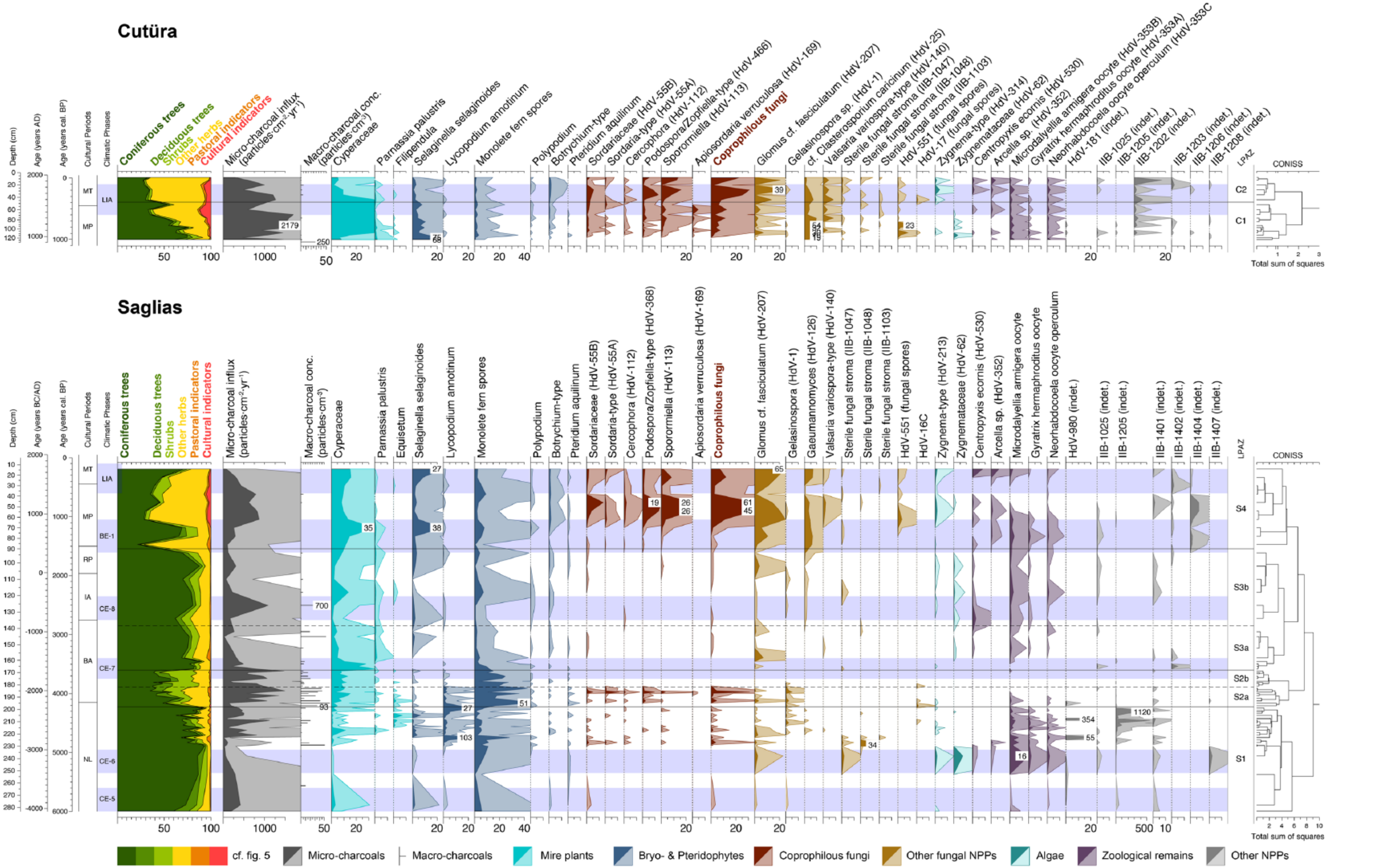

Figure 6. Combined palynological diagram showing selected taxa of mire plants, cryptogams, non-pollen palynomorphs (e.g. coprophilous fungi, algae, and animals) and micro- and macro-charcoal particles from the Saglias (bottom) and Cutüra records (top) near Ardez (Switzerland) drawn using *Tilia* software (Grimm, 2011, version 1.7.16). Micro-charcoals are expressed as influx values (particles $cm^{-2}yr^{-1}$), macro-charcoals (>150 µm) as concentration (particles cm^{-3}) and all other taxa are expressed as percentages relatively to the pollen sum, calculated by including all upland (terrestrial) plants (excluding Cyperaceae). For further explanations and abbreviations, see Figure 5.
Graphic: Dietre, April 2016.

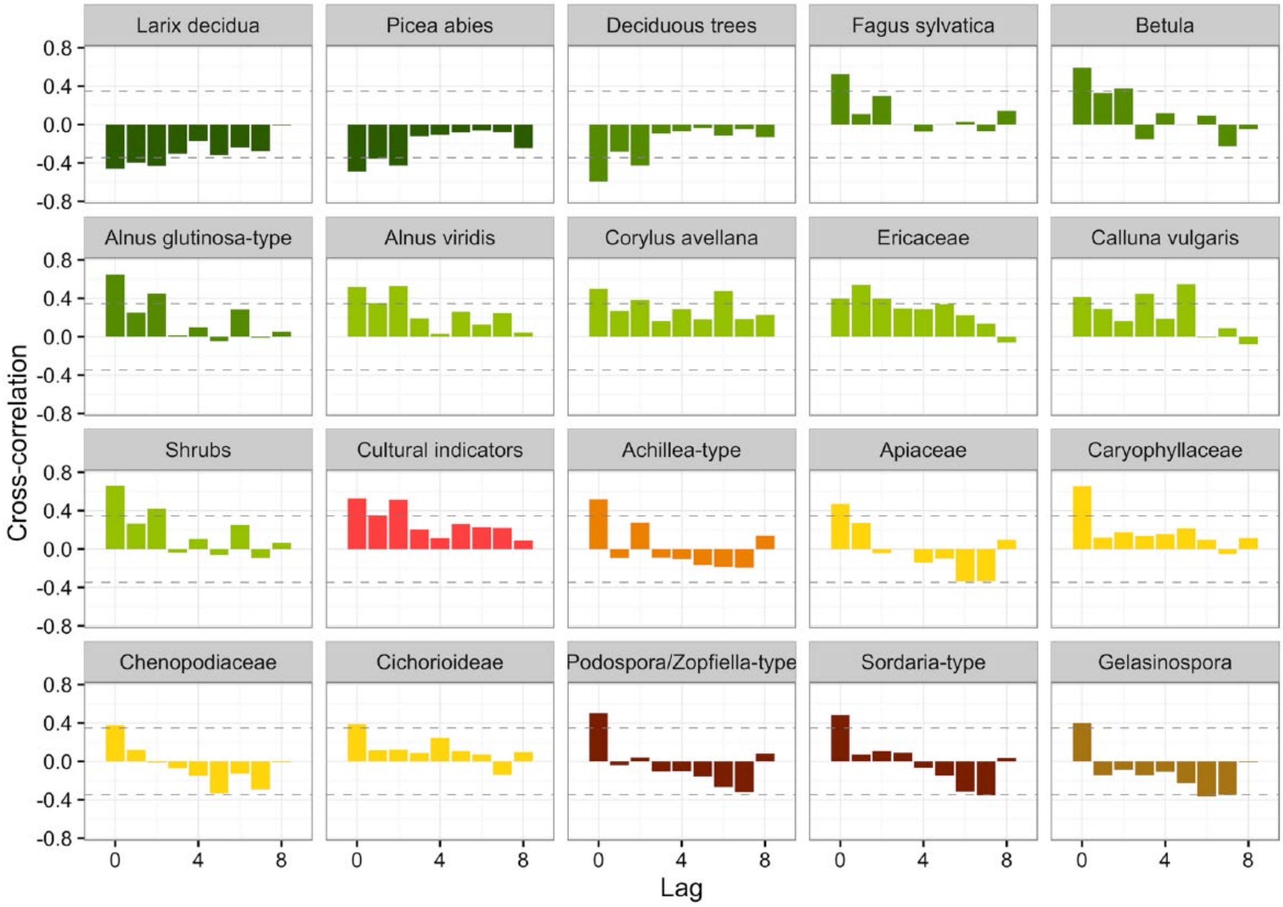

Figure 7. Cross-correlograms for selected taxa against the micro-charcoal record of 32 palynological samples (between 161 and 223 cm depth) from the Saglias bog near Ardez, Switzerland, with a ca. 42 years resolution for the time span 4750–3450 cal. BP, drawn with *R* (R Core Team, 2014, version 3.1.1) and the software package *ggplot2* (Wickham, 2009, version 1.0.0). Micro-charcoal influx values (particles $cm^{-2} yr^{-1}$) are used against percentage values of other taxa, relatively to the pollen sum. Only direct correlation (lag 0) and the correlation for the first eight positive lags are shown. Correlation coefficients outside the range of grey dashed lines are statistically significant.
Graphic: Dietre, April 2016.

landscape similar to the today's mixture of pastoral areas and small cultivated fields around the village of Ardez (Figure 2). Rye and cereal pollen showed a steady presence together with typical crop weeds such as *Centaurea cyanus* (typical for rye and cereal fields, especially winter crops) and *Centaurea jacea*–type. However, during the last two centuries, the total of cereal pollen values sunk towards 1.0%, corresponding well to the reduced interest of historical and extant farmers in crop production, partly because of increasing interest in tourism-related activities. In parallel to the long-term reduction in cultural plant indicators during Modern Times, the presence of Apiaceae and Cichorioideae increased together with *Polygonum aviculare-type, Achillea*-type, Rubiaceae and Fabaceae. Spores of coprophilous fungi were also found in important amounts (up to 30.7%, relatively to the pollen sum), especially spores of *Podospora*/*Zopfiella*-type, *Sporormiella* and Sordariaceae (Figure 6). In addition, high amounts of *Glomus* and *Valsaria variospora*–type point to local disturbances during the peat development processes. Important values of *Zygnema*-type and the unknown micro-fossils IIB-1202 and IIB-1203 may additionally point to wetter bog conditions for this phase possibly related to the 'Little Ice Age' (LIA; Figure 6).

Cross-correlations from the Saglias Bog record

Cross-correlations of palynological finds from the Saglias record encountered between 4750 and 3450 cal. BP were calculated for each taxon against the influx of micro-charcoals (particles $cm^{-2} yr^{-1}$). These calculations used the percentage values of all palynological taxa (pollen and NPPs), relatively to the pollen sum. A total of 17 taxa and 3 group-taxa showing significant correlations were finally selected (Figure 7).

Correlations at lag 0. Significant and negative correlations with the micro-charcoal particles were found at lag 0 (direct correlation) for two of the most important taxa throughout the Saglias record: *Larix decidua* and *Picea abies*. Their CCs were −0.46 and −0.49, respectively. Negative correlations were also found for the total of deciduous trees at lag 0 (CC: −0.59). All the other taxa selected showed a positive direct correlation with micro-charcoal particles. The highest coefficients were found for the total of shrub taxa (CC: 0.66), Caryophyllaceae (CC: 0.65), *Fagus sylvatica* (CC: 0.53), Cultural indicators (CC: 0.53); Achillea-type (CC: 0.52), *Podospora*/*Zopfiella*-type (CC: 0.50), *Sordaria*-type (CC: 0.48), Apiaceae (CC: 047), *Gelasinospora* (CC: 0.40), Cichoriodeae (CC: 0.39) and Chenopodiaceae (CC: 0.38).

Correlations at lags 1–2 (–3) (from 42 to 83 (to 125) years after fire incidents). Most of the arboreal taxa (*Betula, Alnus glutinosa, A. viridis, Corylus avellana*) showed significant correlation also at lag 1 and/or at lag 2 except for *Fagus sylvatica. Larix decidua* and *Picea abies* were negatively correlated with micro-charcoal particles at both lags 1 (CC: −0.40 and −0.36, respectively) and 2 (CC: −0.43 both). The total of deciduous trees was also negatively correlated at lag 2 (CC: −0.43). Except for Ericaceae (which showed the highest correlation at lag 1; CC: 0.54), all significant coefficients at lag 2 were higher than at lag 1. At lag 3 (125 years after fire incidents), only *Calluna vulgaris* was found significantly and positively correlated with micro-charcoal particles (CC: 0.45).

Correlations at lag 4 (167 years after fire incidents). No taxon was found significantly correlated with micro-charcoal particles at lag 4, neither positively nor negatively.

Correlations at lags 5–7 only (from 209 to 292 years after fire incidents). Calluna vulgaris was positively correlated with micro-charcoal particles at lag 5 (CC: 0.55) and *Corylus avellana* at lag 6 (CC: 0.47). *Gelasinospora* was negatively correlated at lag 6 (CC: −0.37), and *Sordaria*-type at lag 7 (CC: −0.35).

Correlations at lag 8 (334 years after fire incidents). As for lag 4, no taxon was found significantly correlated with micro-charcoal particles at lag 8, neither positively nor negatively.

Discussion

Establishment of the Saglias and Cutüra Bogs

The age–depth model calculated for the Saglias record (Figure 4) revealed peat accumulation to have started ca. 6000 years ago, in the Middle Neolithic Period. The climatic or anthropogenic origin of peat bogs in mountainous areas is often discussed but hardly convincingly demonstrated (Blackford, 2000; Cubizolle et al., 2013). However, the establishment of the Saglias Bog prior to the first evidence of human presence in the vicinity (archaeologically and palynologically, see below) suggests that it originated from geomorphological alterations eventually because of changing climatic conditions. In this respect, the Central European climatic deterioration phase CE-5 dated to 6100–5600 cal. BP (Haas et al., 1998; phase which equals the Rotmoos-1 climatic deterioration sensu Bortenschlager, 1970) may have provided the necessary conditions. In contrast, the Cutüra Bog established more recently, around 1000 cal. BP (AD 950), in relation to forest clearances by fire and the establishment of agricultural field terraces and/or livestock grazing areas during the High Medieval Period.

Opening of the Lower Engadine landscape by fire during the Late Neolithic and Middle Bronze Age Periods (4850–3450 cal. BP)

The first major fire phase at Saglias started between 4850 and 4750 cal. BP as revealed by high concentration of macro-charcoals followed by high micro-charcoal influx values. The subsequent maximum fire opening occurred at 3950 cal. BP, which is concomitant with a sandy erosional layer (Figure 3). It overlaps with the transition between LPAZ-S1 and -S2 which correlates with the Neolithic-to-Bronze-Age transition as well. A strong decrease in the three main tree taxa (i.e. *Pinus, Picea abies* and *Larix decidua*) occurred at the same time, in addition to an increase in *Corylus avellana* and Ericaceae (including *Calluna vulgaris*). Findings of spores from *Gelasinospora* corroborate the proximity of these fire-proned clearings (Figure 6), as this fungus is known for its growth after local fires (Van Geel, 1978). In addition, ferns found very suitable conditions to grow after the burnings. The sporulation of bracken (*Pteridium aquilinum*) was favoured by forest fires with highest values recorded at 4150 cal. BP (LPAZ-S2a), which is comparable to their presence at other sites after fire events (Clark et al., 1989). *Ulmus* and *Tilia* were regularly present until 3600 cal. BP, and the role of fire in their later extinction is likely, similarly to the evidence found in the Northern Swiss Alps (Thöle et al. 2016). Pollen and spore evidence therefore points to a fast and massive opening of the landscape around Saglias Bog during the Late Neolithic Period and Early Bronze Age, which was appropriate to the growth of herbs, pioneer shrubs and understorey species typical of post-fire vegetation.

The cross-correlation analyses for the time period 4750–3450 cal. BP support the above-mentioned evidence and first revealed negative impact of fire incidents on the main tree taxa, as well as positive impact on open land taxa (Apiaceae, Caryophyllaceae, Chenopodiaceae, Chicorioideae) of the Lower Engadine Valley, immediately and up to 80 years later (Figure 7). Second, they showed a medium-delayed (about 80 years) response of pioneer shrubs (positive) and deciduous trees (negative). Similar to its reaction on the Swiss Plateau (Tinner et al., 2005), *Corylus avellana* was strongly promoted by fire around Ardez as evidenced by the cross-correlation analysis and the according hazel maximum during the Middle Bronze Age (5–6%).

Installation of first prehistoric cultivated fields and livestock pastures

The Neolithic-to-Bronze-Age transition implied major social and economic changes (Bezinge and Curdy, 1994) and it is interesting to see that the statistical pollen data clustering and subsequent zonation does independently corroborate these major ecological changes at Saglias (i.e. LPAZ-S1/-S2 transition). In the Alps, these changes coincided with a general altitudinal lowering of the treeline (Nicolussi et al., 2005; Pott et al., 1995; Tinner et al., 1996; Wick and Tinner, 1997). Vegetation and landscape openings related to pastoralism and other human activities since 4300 cal. BP were also revealed north of our research area in the subalpine Silvretta Massif based on archaeological, palaeoecological and pedological data (Dietre et al., 2014; Kothieringer et al., 2015; Reitmaier et al., 2013). There, the major changes were dated to the Neolithic-to-Bronze-Age transition (i.e. 4150 cal. BP) and to the Late Bronze Age (3200–2800 cal. BP). Around Ardez, however, the first evidence of crop production and livestock grazing activities dates back to 4850 cal. BP, but remained rather weak (Figures 5 and 6). The cereal cultivation and grazing was thereafter intensified from 4200 cal. BP onwards (Early Bronze Age) as shown by higher amounts of coprophilous fungi and regular findings of Cerealia-type and Urticaceae pollen. The cultivated fields and settlements were probably in the very vicinity of the Saglias Bog or in the Ardez area, but this hypothesis is not yet supported by archaeological findings. Nevertheless, the cultivation of cereals was also attested for the Late Neolithic and Bronze Age Period around Chanoua (east of Ardez; Figure 1), on agricultural terraces above Ramosch (Zoller and Erny-Rodmann, 1994; Zoller et al., 1996), as well as for neighbouring areas (Festi, 2012; Festi et al., 2014; Röpke et al., 2011; Welten, 1982a).

Around Ardez, crop cultivation must have been strong according to the high cereal and nettle values, but the livestock pressure may have remained subtle during the Early Bronze Age if we consider the discrete occurrence of pastoral pollen indicators (Figure 5) and the recovery of *Alnus viridis* comparable to evidences from Northern Italy (Wick, 1994). Moreover, *Sporormiella* was sparsely retrieved during the Late Neolithic Period and Early Bronze Age (i.e. the period of interest for the cross-correlation analyses; Figure 6). At other study sites, this most-encountered coprophilous taxon has nourished a rich discussion about its indicator value for livestock grazing (Burney et al., 2003; Davis, 1987; Davis and Shafer, 2006; Etienne and Jouffroy-Bapicot, 2014; López-Sáez and López-Merino, 2007; Van Geel et al., 2007; Wood and Wilmshurst, 2013; Wood et al., 2011). As some authors related high *Sporormiella* values directly to high cattle density (Davis and Shafer, 2006; Etienne et al., 2013; Feranec et al., 2011; Gill et al., 2013; Parker and Williams, 2012; Raper and Bush, 2009; Wood and Wilmshurst, 2012, 2013), the reason why *Sporormiella* was not more abundant during the Early Bronze Age at

Saglias may have been a shift towards more sheep- and goat-dominated livestock husbandry and dairy production (Carrer et al., 2016; Würgler, 1962).

Another discussion point is the regional evolution of larch. Several studies attested the presence of larch meadows for 5600 cal. BP on the southern-exposed slopes at Chanoua (east of Ardez; Figure 1), Ramosch (ca. 1600 m a.s.l.) and adjacent regions, and related their development to grazing activities after man-made fire openings (Gobet et al., 2003; Zoller and Erny-Rodmann, 1994; Zoller et al., 1996). At the northern-exposed slopes above the Saglias Bog, however, larch was still an important taxon around 5000 cal. BP, but later declined because of burning pressure (Figures 5 and 7) – except of a brief recovery around 4300 cal. BP.

Fire management and cycles of forest regeneration

Cycles of landscape openings, exploitations and abandonments were running over long periods (up to 4000 years) from the Neolithic to the Iron Age in the French Alps prior to the perennial establishment of agricultural practices (Carcaillet, 1998). The palynological data from the Saglias record suggest similar cycles. The regenerative potential of forest taxa can be identified in the AP/NAP ratio (Figure 5). During the opening phases (4850–4350 and 4200–3450 cal. BP, respectively), peaks of arboreal pollen are still regularly recorded, for instance, at 4400, 4250, 4100, 4000, 3800 and 3550 cal. BP. This represents one peak every 170 years, on average, and so would be relevant for the regeneration of major tree species (*Pinus mugo, Pinus sylvestris, Larix decidua, Picea abies*) from seedlings.

For the first 80 years after the fire incidents, the cross-correlation analyses indicate negative impact on two major tree taxa (*Larix decidua* and *Picea abies*) and indirectly revealed these reforestation episodes by the absence of any significant impact on plant taxa at lag 4 (167 years after fire incidents; Figure 7). Indeed, among taxa significantly correlated (positively or negatively) to fire incidents within approximately a hundred years (lag 0–3), the lag 4 often featured a non-significant minimum correlation value. This is particularly noticeable for *Larix decidua* (CC: −0.17), *Alnus viridis* (CC: 0.03) and the group of cultural indicators (CC: 0.12), and to some extent for Ericaceae (CC: 0.29) and *Calluna vulgaris* (CC: 0.19). This time span of 167 years for reforestation after fire incidents represented by the lag 4 corresponds rather well with the past 170-year cycle of reforestation shown above for the Ardez area and compares with the 262-year cycle calculated for the Southern Swiss Alps (Morales-Molino et al., 2015), with the 140-year cycle in the Eastern Italian Alps (Leys et al., 2014), and with the 250 years of fire return intervals in the Central Alps (Stähli et al., 2006).

Considering the presence of pollen indicators for cultural and pastoral activities among taxa positively responding to fire incidents (i.e. total of cultural indicators, and *Achillea*-type), as well as major coprophilous taxa such as *Podospora*/*Zopfiella*-type and *Sordaria*-type, it becomes highly probable that these Neolithic and Early Bronze Age fire incidents were of anthropogenic origin. This is in agreement with Röpke et al. (2011) who related forest clearings during the Bronze Age in the adjacent St Antönien Valley to food demands rather than to other activities, and is also in line with Gobet et al. (2003) who concluded that the beginnings of human activities in the Upper Engadine Valley dated back to the Early Bronze Age. The use of fire was to open the pine/spruce/larch forests for first cereal cultivation activities, as shown for other Alpine areas (Gobet et al., 2003; Morales-Molino et al., 2015).

An additional clue to the anthropogenic origin of the reduction in conifer forests during the Neolithic-to-Bronze-Age transition around Ardez is given by *Alnus viridis*. Several authors suggested that its prehistoric expansion might result from a combination of both anthropogenic impact and changes in climatic conditions (e.g. Wick and Tinner, 1997), but other studies explained the expansion of green alder solely (or at least mainly) by human impact (Rey et al., 2013; Tinner et al., 1996; Welten, 1982b). In the Swiss Valais, *Alnus viridis* is reported for having possibly been promoted to provide fodder since the Late Neolithic Period/Early Bronze Age (Haas and Rasmussen, 1993; Welten, 1982b). At Saglias, *Alnus viridis* most strongly reacted about 80 years after fire incidents (Figure 7) and may have become regionally important between 3800 and 3650 cal. BP (Figure 5). This is in particular accordance with Gobet et al. (2003) and Bringemeier et al. (2016), who concluded that fire gave advantage to the growth of *Alnus viridis* in the close-by Upper Engadine and St Antönien Valleys (Switzerland). Therefore, it is likely that fire was used regularly from the Late Neolithic Period to the Early Bronze Age around Saglias as a management tool after initial forest clearings.

Abandonment of prehistoric agro-pastoral fields

The most opened landscape was probably found during the Early Bronze Age, with coniferous trees representing only about 35% of the pollen assemblages (at 3950 cal. BP; Figure 5). This was followed by the disappearance of spores of *Gelasinospora* between 3800 and 3500 cal. BP, the reduction in pastoral indicators as well as the complete disappearance of all coprophilous taxa (Figure 6). These synchronous events give evidence of the reduced use of fire and the end of livestock grazing activities, followed by an increase in *Alnus viridis*, which may also point to a wetter/colder climate related to the climatic deterioration phase CE-7 between 3750 and 3400 cal. BP (Haas et al., 1998). Such a climatic deterioration during which the Austrian glaciers of Pasterze and Gepatschferner advanced (Nicolussi and Patzelt, 2000) is likely to have lowered the interest of agro-pastoral communities on the northern-exposed slopes of the Sur-En agricultural area near Saglias. This might have led local farmers to move their agricultural activities towards the climatically more favourable southern-exposed lands in the immediate vicinity of the settlement of Ardez. This is consistent with other regional palynological evidence (Welten, 1982a; Zoller et al., 1996) and with several archaeologically dated settlements from the Middle Bronze Age (ca. 3500 cal. BP) in the Lower Engadine Valley (Reitmaier, 2012), as well as with rising amounts of pioneer shrubs colonising abandoned lands (e.g. *Betula, Corylus avellana, Alnus glutinosa*). In consequence, the forest regeneration (up to 85% arboreal pollen) since 3600 cal. BP as evidenced at Saglias by arboreal pollen data might have been restricted to the less valuable northern-exposed slopes.

After that, a late Middle to Late Bronze Age period (3400–2800 cal. BP) of agricultural recovery happened at Saglias, which correlates well with the regionally known archaeological evidence (Kothieringer et al., 2015; Reitmaier, 2012; Reitmaier et al., 2013). During the Iron Age and Roman Period, the use of the northerly exposed area south of Ardez (i.e. around Saglias; Figures 1 and 2) seems to have been completely disrupted, even if one local and massive fire event occurred at 2500 cal. BP.

Medieval agriculture and possible climatic constraints

The local forests were massively cleared again during the Medieval Period, and newly opened areas were used for both pastoral and cultivation activities (e.g. cereals, pulses) until habits changed during Modern Times. The strongest decrease in arboreal pollen amounts recorded at Saglias at 1450 cal. BP (AD 500) was not accompanied by evidences for fire incidents. This important loss of forested cover might therefore have been related to unfavourable climatic conditions during the so-called Migration Period/Bond-Event-1 (BE-1; dated to 1600-1050 cal. BP/ AD 350–900; Figures 5 and 6) resulting in glacier readvances in Central Europe, as well as temperature lows on the Northern Hemisphere (Bond et al., 2001; Moberg et al., 2005; Nicolussi and Patzelt, 2000). After a forest regeneration phase (1350-1150 cal. BP/ AD

600–800), important forest clearings by fire happened at AD 900 onwards at Saglias, as well as at Cutüra, as recorded by high macro-charcoal concentration for the latter. This resulted in a strong reduction in major tree and shrub taxa between 1050 cal. BP (AD 900) and 350 cal. BP (AD 1600), accompanied by an important increase in anthropogenic indicators. The reopening of the forests compares chronologically well with the High Medieval foundation of the village of Ardez at AD 840 (1110 cal. BP, Grimm, 2009) followed by intensive crop cultivation (wheat, rye, pulses (Fabaceae), crucifers (Brassicaceae), umbellifers (Apiaceae)). Similar cultivation practices took place in the nearby St Antönien Valley (canton of Grisons, Switzerland), where the strongest deforestation happened from 650 cal. BP (AD 1300) to 450 cal. BP (AD 1500) after the establishment of Walser settlers (Röpke et al., 2011), and also correlates well with the maximal landscape openings in the nearby Upper Engadine Valley at 500 cal. BP (AD 1450) (Gobet et al., 2003).

As recorded at Cutüra, the amounts of cereal pollen decreased steadily after 500 cal. BP (AD 1450) (Figure 5) as did the total amounts of coprophilous fungi as well, especially at Saglias (Figure 6). An abandonment of pastoral and cultivated fields around Ardez during the end of the Late Medieval Period and the early Modern Times is likely and may be related to the climatic deterioration of the LIA (600–100 cal. BP/ AD 1350–1850). Before the LIA, the surroundings of the Saglias Bog were probably rather used for pastoral activities, while those around the Cutüra Bog were most likely devoted to the cultivation of cereals and other crops. During the LIA, less pastoral activities were recorded around Saglias and less cultivation of cereals around Cutüra/Ardez. In addition, high amounts of fungal spores of *Glomus* and *Valsaria variospora*–type as well as sandy layers in the youngest parts of the Cutüra record (Figure 3) point to local disturbances and erosional processes during the peat development. Important values of *Zygnema*-type may additionally point to a wetter bog and unfavourable climatic conditions for this LIA phase, which may represent increasing cultivation difficulties and losses in cereal yields. The post-LIA near-abandonment of cereal cultivation in the Lower Engadine Valley might be explained by shifts towards new economical fields such as tourism.

Conclusions

The palynological analyses conducted on the Saglias and Cutüra records provided a detailed history of the regional use of fire in the Lower Engadine Valley since the Late Neolithic Period, as well as of the cultivation of crops such as cereals and pastoral practices. Our results confirmed that the current landscapes of the Lower Engadine Valley inherited from millennia of land-use history. Human-induced disturbances and landscape openings such as during the Late Neolithic obviously led to more diversified ecosystems and resulted in more nutrient adapted pastoral grassland taxa, which is in agreement with the same phenomenon at other sites (Colombaroli and Tinner, 2013; Colombaroli et al., 2013) and which may be highly relevant to today's ecosystem management and nature conservation issues (e.g. Isbell, 2010). Fire was thereby used to clear the larch–spruce forests and gain open land for pastoral activities, and potentially for early attempts of cereal cultivation. The valley floors were preferred for terrace-managed agriculture, and the higher subalpine areas were used for pastoral purposes, at least seasonally between spring and autumn. Palynological data from Cutüra enabled a refined vision of the land-use around the village of Ardez since the High Medieval Period. The cultivation of cereals was pursued since 1050 cal. BP (AD 900), in addition to large surrounding areas used for pastoral activities. The cultivation of rye (*Secale cereale*) reached an optimum around 600 cal. BP (AD 1350). Then, the LIA cooling event may have been responsible for limited food production, which subsequently led to large-scale forest recovery. During Late Medieval and Modern Times, pastoral activities and crop cultivation increased again around Ardez and continued up to the present day.

Finally, according to their strong relation with micro-charcoal particles, this study showed the high potential of fungal spores for palaeoecological reconstructions of past human activities. In this regard, the legitimacy of using spores of the fungus *Gelasinospora* (HdV-1) as an excellent indicator for local fire incidents during the Holocene was emphasised. However, our non-contiguous sampling design might prevent our data from revealing the full fire history around Ardez, as hinted by Clark (1988a) for similar studies, although his simulated sampling was much more sparse than ours. More precisely, our analytical resolution of about 42 years prevented us from identifying individual fire events, and thus from reconstructing fire frequency (Conedera et al., 2009; Tinner et al., 1998). Still, cross-correlation analyses for the Neolithic-to-Bronze-Age transition at Saglias revealed the important potential of this archive, also as charcoal layers were already visible during sediment coring. Moreover, macro-charcoal particles extracted from the pollen sample residues add to the reconstruction and understanding of past fire incidents.

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